Blockchain as a Technology Backbone for an Open Energy Market

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1 Introduction

Energy systems are evolving rapidly to adjust to the increasing volume of renewable energy generation, such as wind, solar, geothermal, biomass, and hydropower. Supported by the privatization of the energy sector and encouraged by financial incentives, renewable energy sources (RES) have undergone a massive expansion in recent years. In 2017, 17.5% of the EU gross electricity consumption was generated by RES, mainly from wind power, hydropower, solar, geothermal, and biomass, representing a total worth of 226.5 million tons of oil equivalent (EC 2019). Ultimately, the EU seeks to have a 20% share of its gross final energy consumption from renewable sources by 2020. To achieve this objective, member states are required to find innovative ways to manage the energy grid, redefine the cap-and-trade programs, or ensure a steady reduction in the carbon footprint of the transportation industry. Amidst the different technological innovations in the sector, one such technological innovation that is rapidly influencing the industry is the distributed ledger network, or blockchain technology. Blockchains are progressively entering the energy industry to help address the challenges faced by inefficient energy systems. The blockchain technology, primarily characterized by its ability to circumvent intermediaries or a central authority, offers important advantages over

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the traditional energy management in the form of flexibility, security, transparency, and speed.

Despite its increasing importance in the energy industry, a better understanding of this new technology is required to improve our comprehension of its potential for the energy industry. We therefore provide in this chapter a review of the technology underlying blockchain in the energy sector. We discuss how blockchain can benefit energy system operations, markets, and consumers in achieving the ambitious goals set by the EU. We present several cases, such as cap and trades, energy grids, and electric vehicles. These cases clearly illustrate the initiatives of the United Nations in the creation of Climate Chain Coalition in January 2018, which is incorporating blockchain technology to support accurate information recording and sharing (United Nations 2018). We also complement our analyses with first-hand empirical investigation on the proliferation of blockchain technology in the green-energy sector. We identify six prominent categories of blockchain-based green-energy projects from a dataset of ventures that opted to use initial coin offerings (ICOs) to finance their projects. Finally, we analyze their success rates in reaching their funding objectives and their return volatility and compare them to traditional non-green cryptocurrencies.

2 What Is the Blockchain Technology?

One is likely to have encountered the word blockchain in relation to Bitcoins. The widespread attention on Bitcoins is primarily due to the substantial price volatility it has witnessed in recent years. In 2017 alone, Bitcoin's value exponentially increased by approximately 2000%, before it dropped to 50% of its peak value. The stories of overnight riches left most to wonder how they seemingly missed out on the opportunity to stake a claim in the $300 billion worth of Internet money market. However, apart from the market opportunities, Bitcoins caught the attention of many because it exhibited that facilitating transactions and record keeping can be conducted without an oversight of a central authority. The underlying technology behind Bitcoins that enabled the disintermediation is the blockchain technology.

Blockchains are open network protocols that decentralize the storage of data, making it independent of authority, tamper-proof, and transparent (IBM Think Academy 2016). Primarily, the technology is based on peer-to-peer network and cryptography. It entails a decentralized network of computers or "miners," who compete to record and verify specified transactions. The recording and verification processes are based on a consensus mechanism based on complex cryptography. For instance, on the Bitcoin blockchain, when a Bitcoin owner spends a coin, the network of computers or "miners" time-stamps the transaction and groups it with other recent transactions in a block of data. Blockchain then uses algorithms in order for the network participants to come to a consensus and eliminate ambiguity or any conflicting information between the different nodes. The transactions are then permanently recorded on the blockchain using cryptography. One of the key features of the technology is the consensus mechanism. The consensus algorithm divides the right to update the blockchain to a set of network members with exhibited interest. For instance, Bitcoin blockchain uses a proof of work (PoW) consensus mechanism, i.e., requiring miners to compete to be the first to solve a mathematical puzzle. Whoever solves the problem first gets to create the next block and is rewarded with a Bitcoin. In this manner, the blockchain ensures incentive for miners to participate, while making sure that the cost of manipulation exceeds the benefits. What is also crucial is that the network members are widely distributed, such that no single member or cartel can overtake the majority, even if they had the means and the incentive to do so (Tapscott and Tapscott 2016).

The core innovation of blockchain is that it gives the opportunity to have a trusted and decentralized direct exchange between two parties without requiring an intermediary. Blockchain technology offers a way for untrusted parties to reach an agreement on a common digital record that might otherwise be easily faked or duplicated. The recorded transactions are simultaneously kept across all the servers in the blockchain network, and therefore, it circumvents the need for a single point of control. The data on the blockchain are public, easily verifiable by all parties, consistent, and always available. Furthermore, due to their decentralized nature and lack of a central point of failure, blockchains are very resilient to fraud and are immutable, meaning that once inserted in the blockchain, they cannot be changed. In addition, the blockchain contains a verifiable record of every single transaction ever made, allowing traceability and transparency. Once entered, the record is theoretically tamper-proof. No single party can shut the system down, and any attempt by the majority to undermine the network would be visible to the whole network. Moreover, the cost of a majoritarian move to overwhelm the network is designed to be high enough to outweigh the consequent benefits, preventing any such efforts. Furthermore, these functions are executed completely autonomously, independent of any single authority or ownership.

In addition to allowing disintermediation, immutability, and transparency, the wide scope of applications of blockchain stems from its ability to incorporate “smart contracts.” Smart contracts are simply digital protocols that automatically execute predefined processes, without an involvement of a centralized intermediary. The ability to make instantaneous and built-in settlements allows blockchain to support such smart contracts. It is the use of these smart contracts that allows us to develop versatile blockchain-based systems that facilitate exchanges and interactions suited to specific contexts. For instance, using such smart contracts, some blockchain-based energy companies have developed automated energy grids that allow exchange of excess energy among the neighboring houses without relying on a central utility provider.

Due to these advantages, blockchain is progressively making its way to the energy industry. The German Energy Agency conducted a survey based on the opinion of 70 managers working in the energy sector (Burger et al. 2016). The results provide evidence that nearly 20% of the managers think that blockchain technology is pioneering for energy suppliers, while the majority of survey participants plans or has already started initiatives for blockchain innovation. In fact, several energy firms have already taken interest in exploring the potential benefits of distributed ledger technology as a catalyst for low-carbon transition and sustainability.

A typical example of a company applying blockchain in the energy sector is Pylon Network. The company produced a smart meter, called Klenergy Metron, which integrates blockchain technologies that can trace and automatically record energy produced and consumed. The technology allows localized electricity market to exist, which leads to greater efficiency in the use of renewable energy. Similarly, a venture called M-PAYG is exploring the use of blockchains to provide pay-as-you-go solar services in the developing world, in order to make access to energy more feasible. M-PAYG allows off-grid low-income households and businesses to access solar energy through small-scale mobile repayments until full ownership transfer. This service relies on blockchain-based solution implementation that offers transparency, real-time monitoring, and control of solar assets. We further discuss prominent applications of blockchain in the energy sector in the following section.

3 Blockchain in the Energy Industry

Blockchain technology is expected to be most useful in industries where there is no physical exchange, such as in the financial sector (Luke et al. 2018). In such industries, blockchains can provide trustworthy records of transactions without a verification of physical exchange in a decentralized fashion. The energy sector is an obvious example of an industry with the potential to integrate the blockchain technology. Electricity is conducted at the speed of light and is impossible to track between two points in an electricity network (Luke et al. 2018). As a result, electricity markets are centralized on trading platforms similar to stock exchanges. Although the centralization of electricity production enables economies of scale in energy generation, it also leads to inefficiencies in transporting the electricity to the consumers, the inability for the consumer to choose between consuming green and fossil energy, and, most importantly, a limited access of electricity-generating prosumers to the energy market to sell their surplus of energy, which remains a privileged playing field for the institutionalized energy suppliers (Kounelis et al. 2017).

There is an increasing interest in academia on the blockchain's potential for the energy industry. Mihaylov et al. (2014)'s paper is one of the first on this topic by considering the use of cryptocurrencies for P2P energy trading. Their paper discusses the use of the technology underlying blockchain in the energy sector. Blockchain presents a new virtual currency that allows the generation and consumption of renewable energy to be directly transformed into virtual coins. Sikorski et al. (2017) further develop a small-scale blockchain-based machine-to-machine electricity market. They find that blockchain technology can successfully support the electricity sector. In addition, Al Kawasmi et al. (2015) develop a local blockchain market model to exchange carbon emissions. The approach in their paper simplifies the anonymous trading between the market participants. This type of anonymous trading is also considered by Aitzhan and Svetinovic (2016). They define a decentralized energy-trading platform based on tokens. They find that blockchains allow for implementing decentralized energy trading and that the reachable degree of privacy is significantly higher than in more traditional centralized trading platforms.

Recognizing blockchain technology's potential value in the energy sector, many companies are investing and are actively involved in blockchain-related projects. As Stefan Jessenberger at Siemens Digital Grid explains: "In our view, the blockchain technology might revolutionize the way DERs [distributed energy resources], grid operators and marketplaces will interact in a secure, efficient and transparent way while also enabling new business models. Especially in combination with artificial intelligence, advanced forecasting algorithms and the usage of geographical information of the assets, the technology offers promising capabilities in order to enable the autonomous trading of energy and flexibility, while incorporating the locational value of DER's and loads." In the following section, we illustrate these new business models by discussing three prominent applications of the blockchain technology in the clean energy sector, along with descriptions of some prominent projects.

3.1 Projects and Applications

3.1.1 Blockchain and Prosumers' Access to the (Micro)grid

The key feature of the blockchain technology in the electricity sector is that they can provide innovative trading platforms where prosumers and consumers can trade interchangeably their energy surplus or flexible demand on a P2P basis. This, in turn, will inform consumers about the real cost of electricity generation, which might lead to a more rational energy consumption (Uddin et al. 2017). Usually, the energy companies would purchase the energy surplus at a discount and sell it to consumers at a standard price. However, if prosumers who have invested in RES facilities, such as small wind turbines or PVs, are allowed to sell their energy without any intermediary, this could potentially lead to energy savings for all stakeholders.

Blockchain technology therefore encourages the development of P2P markets, where both energy producers and consumers can exchange electricity in a local grid. The approach to trading electricity based on blockchain requires fitting communication hardware or a blockchain-connected computer to a smart electricity meter. The smart meter acts as a point of contact and validation between the electricity system and the blockchain. The meter processes electricity generation. This information is converted into tokens, which are then allocated to the market participants as trades take place, by appending transaction to the blockchain. Coins can be stored in "e-wallets" with the meter and can be exchanged using fiat money or cryptocurrencies.

Another key innovation is that blockchain technology provides full transparency on the origin of the electricity consumed. The traceability of energy flows is currently limited (Andoni et al. 2019). Current intermediaries act as market access points for the transmission of energy, but there is no assurance on the origin of the electricity purchased. In fact, there is a high chance that the energy used by the end consumer is provided by the closest fossil-fuel power plant (Andoni et al. 2019). Community energy microgrids based on blockchains essentially allow local energy trading between consumers, while providing information on the origins of the energy and maintaining secure and tamper-proof records.

However, this does not mean that transmission and distribution system operators will become obsolete. These operators still occupy a central place in the electricity market, as they own the physical infrastructure of electricity grids and are responsible for their stability. In addition, they are liable for ensuring that the decentralized energy trades can actually occur. The P2P transactions can only work if the distribution infrastructure is maintained. This means that the pricing scheme needs to be adjusted. Besides helping solve different system vulnerabilities, the operators will need to adjust the pricing structure to charge the consumer separately for their energy usage and for their grid connection (Serpell 2018). Therefore, one could envision a network where a share of every blockchain transaction is given to the transmission operators.

By allowing local market microgrids, blockchains decrease the pressure on transmission networks, improve economics of small-scale renewables, and enrich customers with greater choice and transparency in energy supply. Large corporations such as Ikea have been supporting this new vision of an electric market. Several projects focus on local marketplaces and P2P trading in community projects or microgrids. For instance, LO3 Energy aims at activating German neighborhoods with a new approach to the way renewable energy is bought and sold by testing the German market with an effort to run ahead of a planned nationwide rollout of microgrid technology for renewables (LO3 Energy 2019). Millions of homes and businesses across Germany currently benefit from solar panels fitted to their roofs but must sell the excess power back to the grid at a set price determined by the major utility firms. Solar users will have the opportunity to become prosumers and sell their excess power to their closest neighbors by use of Ethereum-based smart contracts. Tokens specify that a certain amount of energy was produced from the solar panels and can be transferred from a prosumer's smart meter wallet to end consumers by use of blockchain technology. Tokens are deleted by the consumer's smart metering device, as purchased energy is used in the house. Microgrid users interact with the platform by defining their price preferences in the form of willingness to pay or sell electricity. According to Lawrence Osini, LO3 Energy's CEO, this technology will offer "[. . .] many of Germany's early adopters of PV technology, who are reaching the expiration of the feed-in tariff, [. . .] a new way to receive the full benefit from their investment in renewables, while allowing energy consumers the choice to buy energy directly from their neighbors and community. We think many participants will recognize that buying energy locally strengthens their community and the local economy" (LO3 Energy 2019). This project follows the successful development of a US-based microgrid in Brooklyn, New York, and will be set up in Lazarettgarten in Landau and in the Allgau region of Southern Germany.

Ikea is also aiming at supporting green-energy innovation through the Lab Space10, a prototype for how solar energy could be installed in local communities and then shared on a small microgrid. The microgrid will allow people to sell their surplus of energy to others on a blockchain-powered platform. The project is called SolarVille, and it pledges to bring cheaper solar technology to homes in all of these markets by 2025. Ikea has also been selling solar panels in the UK since 2013 and launched a solar panel kit in 2017 (Schwab 2019).

3.1.2 Cap and Trade

There are other domains in the energy sector where the blockchain technology is readily applicable. The purpose of cap and trade is to push companies to reduce their greenhouse gas emissions by limiting (cap) the amount they can emit and allowing them to "trade" excess credits. This is done by a centralized body agreeing to the total quantity of industrial carbon that can be emitted within the jurisdiction. These allowances are distributed to companies that emit carbon, usually by free allocation and auctions. The funds received by the central authority are usually reinvested later in clean energy initiatives. According to the European Commission, in 2010 greenhouse gas emissions from big emitters covered by the EU Emission Trading System (EU ETS) had decreased by an average of more than 17,000 tons per installation from 2005, a decrease of more than 8% since 2005 (EC 2019).

To support the EU ETS, a secondary market has been created, where a company that needs more carbon emission rights than its existing credits allow is required to buy them from another facility. This method is however not free of shortcomings. The major argument against this organization is that the cap-and-trade method is more complicated and opaque than a direct tax on carbon emission. For instance, the lack of carbon labelling standards and a single globally recognized methodology to calculate the carbon footprint is a significant challenge. Calculating the carbon label of a product requires tracing each ingredient or component from the beginning of production to the end product, along with various skills, methods, and personnel. This process is complex, costly, and time-consuming. According to 3M, the cost of calculating the carbon footprint of a single product can be as high as $30,000 (The Economist 2011). In addition, each country has its own set of rules and pricing mechanism. This means that firms are not able to reliably compare the footprint of similar products across countries, creating further challenges when reporting on their carbon credits. Consequently, small energy producers are, in practice, excluded from claiming carbon credits due to the high costs associated with the procedure. In addition, audit processes are often performed manually by a central authority; therefore they are prone to errors and even fraud (Banerjee 2018). This can make cap-and-trade systems more debatable for the public and more difficult to monitor by the authorities. A standardized method to measure the carbon footprint and an internationally accepted pricing become critical to achieve reasonable results with the cap-and-trade system.

Blockchain technology can help companies meet the demand for accurate, reliable, standardized, and accessible information for carbon emission calculation. The instant authentication, uncorrupted data, and smart contracts make it an optimal solution to integrate suppliers, manufacturers, logistics service providers, and stock locations into a single network for rule-based interactions and value generation. Blockchain will therefore provide a standardized and accepted "carbon currency" to calculate carbon emissions, which is the key feature of this integrated network. The authorities, journalists, and analysts would then be able to accurately assess carbon emissions without relying on quarterly reports published by a centralized authority. This means that the purchase and trade of carbon credits between businesses and the state would be transparently and accurately accessible to anyone with an Internet access.

Another limitation to the cap-and-trade system is the inherent possibility of market manipulation (Serpell 2018). In the absence of regulation to limit such opportunistic behavior, business can time the purchase of carbon credits, by purchasing more credits than required when the price is low and sell when the price is high. In the USA, these opportunistic incentives are generally dealt with by limiting the amount of allowances a business can bank for later use. However by using a blockchain technology to maintain the cap-and-trade system, it is conceivable for each token to carry with it unique features, such as an expiration date. The token could then be followed and traded until the expiration date. As the token expires, an equivalent number of tokens could be distributed to carbon neutral or negative businesses, maintaining consistency with the market supply of tokens with no necessary governmental control. Several entrepreneurs are developing blockchain technologies for renewable or carbon certificates and their automatic issuance and trading. For instance, *Volts Markets* uses smart contracts to automatically issue and track renewable energy certificates via an energy assets exchange platform. Similarly, *Veridium* created an Ethereum-based platform to trade carbon credits and natural capital assets through their cryptocurrency *TRG*.

Blockchains, therefore, provide a platform where all stakeholders across the supply chain can work together in a transparent and accountable manner by unifying the cap-and-trade system with accurate and standardized measurements and credits. The World Economic Forum is in favor of the development of such cryptocurrencies and has already lobbied for the use of blockchain technology, arguing that carbon credits are the ideal contenders for cryptocurrency as these are data-driven, depend on multiple approval steps, and are independent from the physical impact to which they correlate (Vanclay et al. 2011).

An example of such platform is the Energy Blockchain Lab, which is collaborating with IBM to develop a blockchain platform for trading carbon assets in China (Coindesk 2016). The platform aims to reduce the costs of China's national carbon market by 30%. The cryptocurrency not only aims at enhancing carbon reporting by standardizing and recording all relevant emission data but also by ensuring that all value-based transactions are valid and settled automatically. This approach has also been adopted by the Russian startup CarbonX, which aims to incentivize a sustainable consumer behavior by the use of blockchain technology in a P2P carbon trading between consumers. CarbonX is assessing a variety of products and services in terms of their carbon footprint to inform a rational energy behavior.

3.1.3 Electric Vehicle Charging

Over a quarter of greenhouse gases produced in the EU are a result of transportation and contribute to overall pollution levels (EC 2019). On the contrary, electric cars have no emissions and make less noise so their increased use will mean cleaner and quieter cities and towns and improved quality of life. The use of electric cars has significantly increased over the last decade. So much that electric cars are becoming the norm in Norway. In Norway, 60% of the cars sold are electric, bringing the country a step closer to the government's ambitious goal to have all new cars with zero emissions by 2025 (NPR 2019). This marks the first time in history when electric cars outsold gas and diesel in the European country. It also means that electric vehicles are no longer the exception. It however means that we need a widespread and seamless charging infrastructure, which supports seamless charging and billing.

Chapter 13 of this book discusses the increasing predominance of electric vehicles in the Netherlands. The authors develop an optimization model that applies unobtrusive charging strategies (i.e., postponing, on-off charging, and two charging speed levels) for an electric vehicle (EV) charging aggregator. Their results show that applying such a model can significantly reduce energy costs for EV users. However, one aspect of such a technology that is not discussed in the book chapter relates to how consumers often cite range anxiety as a factor in not buying an electric vehicle. The worry is that the vehicle will run out of battery power on a long drive before one can find a charging station. Without the proper critical infrastructure widely available, potential buyers may remain hesitant to purchase an electric vehicle. In fact, more than 80% of vehicle charging occurs at home (The Fuse 2018). Given that electric vehicles have a range of around 250 miles, drivers need to access charging stations frequently, which is where the P2P network may play a major role in the development of electric cars.

Blockchain technology could relieve the uncertainty over refueling and enhance EV charging coordination by facilitating anonymous energy payments at participating homes and allow drivers to make charging decisions based on a map and real-time pricing data. The distributed ledger capability allows for new providers who can sell an access to charging stations for a small amount, which reduces the limitation on where one can buy electricity and from whom they buy. Via a peer-to-peer network, the amount of time and energy used to charge the vehicle is tracked by a proprietary service, and then a ledger transaction takes place with a digital payment from the driver to the owner of the charger. Blockchain would also minimize fraud.

If the user is overcharged, he has the power of challenging against the seller by looking back at the log of transactions.

For instance, Emotors uses *Share&Charge*, which is the first e-mobility transaction platform that uses blockchain. *Share&Charge* is a P2P network that allows EV and charging point owners to rent their charging infrastructure to each other autonomously, securely, and without the need for an intermediary. *Share&Charge* relies on the Ethereum blockchain to track the charging transaction. By May 2017, *Share&Charge* allowed EV owners to charge their vehicles by making digital payments using a mobile app. Charging point owners used the app to notify they have a station available, set the price, and collect fees. Until April 2018, the service was available to about 1000 EV owners with 1250 private and public charging points in Germany. The system used an e-wallet and smart contracts on the public Ethereum blockchain as P2P transaction layer. Based on this experience, *Share&Charge* is now also being tested in the USA, allowing drivers to pay each other for the use of their home chargers.

3.2 Empirical Evidence on Green ICOs

In order to highlight the scope and nature of adoption of blockchain in the clean energy sector, we provide some empirical evidence relating to financing efforts of clean energy projects via initial coin offerings (ICOs). Unlike other traditional modes of financing, ICOs are a financing mechanism particularly catered to blockchain-based ventures. In order to raise funds, ICOs require entrepreneurs to sell virtual tokens (cryptocurrencies) that are managed by a blockchain (Willett 2012). Therefore, ICOs allow ventures and projects to raise funds without an intermediary, such as banks, venture capital firms, and crowdfunding platforms. Using one of the prominent ICO-listing websites, ICOBench.com, we compile a list of 40 clean energy-related ICOs identified from a total ICO dataset of 2509 observations launched between April 2015 and September 2018.[1,2] Furthermore, we use the website coinmarketcap.com to obtain the data on post-ICO prices of the issued tokens (Amsden and Schweizer 2018; Howell et al. 2019).

[1]To identify ICOs by projects focusing on clean energy, we use dictionary-based approach complimented with manual verification. We search for the words "green energy," "cleantech," "recycle," "wind," "power," "solar power," "biomass," "renewable energy," "hydro-electric," "photovoltaic," "geothermal," "sustainable," "biofuel," "green transport," "environmental footprint," "greywater," and "electric motor" in the project's description provided in its ICOBench profile. The words were derived from the definition of cleantech available on Wikipedia and other web pages such as www.cleantech.com. After we identify the list of ICOs with the aforementioned words in the description, we manually checked the shortlisted ICO's profiles to make sure the identified projects are directly related to clean energy. After the procedure, we remain with 40 ICOs focusing on clean energy.

[2]The Appendix provides the list of green ICOs.

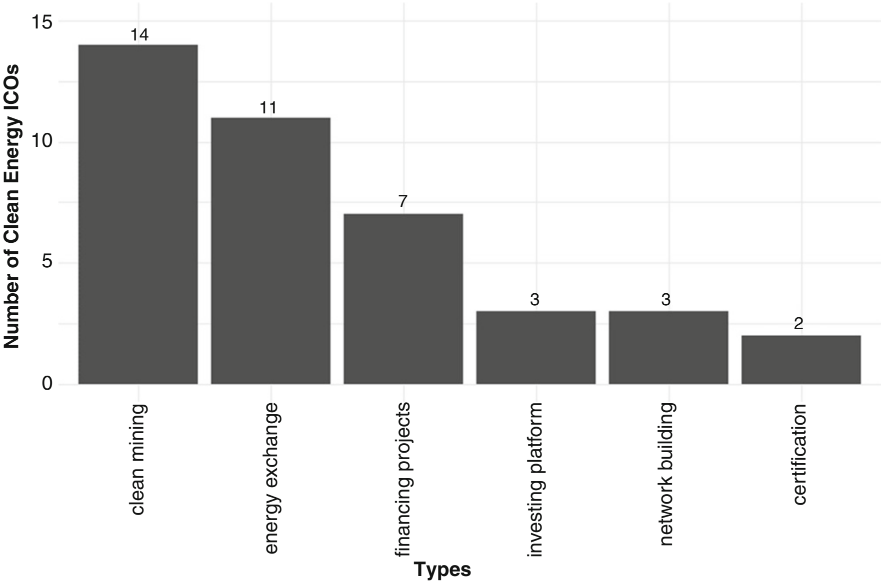

Fig. 1 Number of clean energy ICOs by type

3.3 Types of Clean Energy-Related ICOs

We identify six distinct themes of clean energy-related ICO projects, namely, (1) energy exchange platform, (2) clean mining, (3) financing renewable projects, (4) renewable investment funds, (5) certification/incentive programs, and (6) network building.[3] Figures 1 and 2 provide overviews of the six categories in our sample of clean energy ICOs in terms of the number of projects and success. We find ICOs focusing on clean mining are the most prevalent ones, whereas the ICOs pitching an energy exchange platform witnessed the highest rate of success.

In the following, we provide brief descriptions for each of the six project types:

1. *Clean Mining*: One of the major criticisms of crypto-mining is the high energy requirement. In order to tackle this drawback, various ICOs have emerged proposing to build sustainable mining centers that rely on renewable energy. The incentive to adopt renewables is not solely driven by the desire to mitigate environmental impact, but also to improve the profit margin by incorporating cheaper sources of energy, which constitutes a substantial portion of the mining costs.

[3]The categories are not mutually exclusive, as the underlying tokens from the ICOs may incorporate more than one type of service. The categories are assigned based on the most salient feature of the ICOs. Due to the flexibility of smart contracts, which are able to incorporate different functionalities and attributes, the issued tokens after a successful ICO can incorporate a combination of the mentioned themes, potentially in different variations.

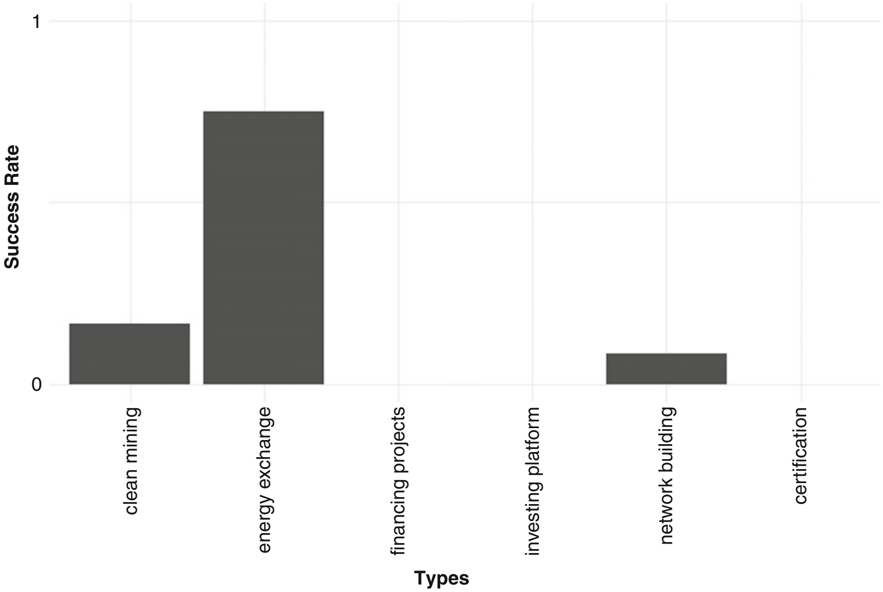

Fig. 2 Success rates by type of clean energy ICOs

2. *Energy Exchange*: We observe that a substantial number of ICOs were related to facilitate electricity exchange, as described in Sect. 3.1. These platforms utilize the blockchain technology to create a decentralized exchange to facilitate energy trade among participants within a network. These systems are mainly focused on improving distribution efficiency, which reduces the waste of produced renewable energy while generating revenue for producers and cheaper energy for consumers.
3. *Financing Renewable Projects*: There are also several projects in our sample that use ICOs simply as a funding mechanism to finance their clean energy-focused projects, offering various forms of returns for funders using smart contracts. These projects may involve different forms of business function, from product manufacturing to expanding an existing business function.
4. *Investing Platform*: Another way that projects use ICOs and blockchain technology to help promote renewable energy sector is by connecting renewable producers in need of funds with consumers or investors by means of pre-purchase of the energy or investment in ownership. For instance, Optonium Coin allows renewable energy developers to sell, in advance, part of the energy to be produced in the future to the consumers.
5. *Certification/Incentive Programs*: Several ventures also introduce tokens as certification or reward for production or adoption of renewable energy. The immutable certifications can be used by firms to fulfill their green reporting requirements and exhibit their commitment to clean energy production to stakeholders. The tokens can also be issued to consumers as a form of reward for using

clean energy. Furthermore, the certification programs help to create immutable time-stamped databases of production of renewable energy.

6. *Network Building*: Another function that blockchain-based clean energy projects seek to provide is to build a network between disparate stakeholders in renewable energy industry based on a common cryptocurrency. The main purpose of the network is to facilitate rapid mutual settlements, helping make communications and transactions between these industry members more efficient.

3.4 Relative Performance of Clean ICOs

In Tables 1 and 2, we provide the descriptive statistics of clean energy-related ICOs and the remaining non-clean ICOs. We report three comparative performance attributes of the ICOs: (1) ICO success, (2) the amount raised, and (3) its impact on the price volatility of the issued tokens. As all ICOs look to issue tradeable tokens, we identify an ICO as a success (*SUCCESS*) if the issued tokens are eventually traded on an exchange (coinmarketcap.com) (Amsden and Schweizer 2018; Howell et al. 2019; Adhami et al. 2018; Fisch 2019). In addition, in order to distinguish the magnitude of success, we also look at the amount raised (*AMOUNT RAISED*) by the projects during the ICO. However, all projects do not disclose the amount raised; therefore the variable only indicates the details of the projects that opted to provide the information. In addition, we measure the token price volatility (*VOLATILITY*) by using the standard deviation of the daily returns (measured by taking the log differences in daily token price series), a method commonly used in measuring volatility of commodity prices (Slade 1991; Fleming and Ostdiek 1999; Regnier 2007). In order to mitigate estimation bias, we only include tokens with more than 90 days of daily price data.

In addition, we compare the clean ICOs with the rest of the ICOs based on various prominent ICO attributes. We report some of the more salient attributes of the ICOs, such as the listing website's (ICOBench.com) assessment of the project (*RATINGS)*, whether a pre-sale of tokens (*PRE_ICO*) or bonuses *(BONUS)* were offered, whether a minimum or a maximum target amount was stated in the ICO (*CAPS_PRESENT*), if the project's blockchain is based on the widely used Ethereum platform (*ETHEREUM*), if the buyers of ICO tokens are verified *(WHITELIST_KYC)*, the number of types of currencies accepted by the ICO (*NUM,_OF_CURR*), whether a fiat currency is accepted (*FIAT*), and the number of members in the team (*TEAM_COUNT*).

3.4.1 ICO Performance

We observe in Table 1 that clean energy-related ICOs are more likely to be successful and raise a higher amount of capital. Moreover, the issued tokens of successful ICOs display lower price volatility in comparison to remaining ICOs. We

Table 1 Summary statistics (clean ICOs)

Statistic	N	Mean	St. Dev.	Min	Median	Max
Performance measures						
SUCCESS	40	0.300	0.464	0	0	1
AMOUNT	19	19,284,899	26,180,655	420	10,000,000	100,012,279
SD _ RET	12	0.137	0.082	0.079	0.114	0.379
Project attributes						
RATINGS	40	3.015	0.676	1.800	3.000	4.600
PRE _ ICO	40	0.600	0.496	0	1	1
BONUS	40	0.475	0.506	0	0	1
CAPS _ PRESENT	40	0.625	0.490	0	1	1
ETHEREUM	40	0.900	0.304	0	1	1
WHITELIST_KYC	40	0.425	0.501	0	0	1
NUM _ OF _ CURR	40	2.125	1.652	1	1	9
FIAT	40	0.025	0.158	0	0	1
TEAM _ COUNT	37	14.568	7.175	4.000	13.000	34.000

Table 2 Summary statistics (other ICOs)

Statistic	N	Mean	St. Dev.	Min	Median	Max
Performance measures						
SUCCESS	2469	0.243	0.429	0	0	1
AMOUNT	1230	16,075,458	122,542,727	26.000	5,100,049.000	4,197,956,135
SD _ RET	601	0.147	0.098	0.046	0.114	1.245
Project attributes						
RATINGS	2469	2.953	0.767	0.700	2.900	4.800
PRE _ ICO	2469	0.438	0.496	0	0	1
BONUS	2469	0.433	0.496	0	0	1
CAPS _ PRESENT	2469	0.663	0.473	0	1	1
ETHEREUM	2469	0.873	0.333	0	1	1
WHITELIST_KYC	2469	0.352	0.478	0	0	1
NUM _ OF _ CURR	2469	1.857	1.472	1	1	13
FIAT	2469	0.018	0.132	0	0	1
TEAM _ COUNT	2261	12.262	7.691	1.000	11.000	67.000

find that 30% of the clean energy-related ICOs eventually issue tokens, which are traded in coinmarket.com. In comparison, other non-clean-related ICOs have a success rate of 24.3%. Furthermore, we observe that on average clean energy-related ICOs raise more than USD 19 million. Among the projects that did disclose the amount raised, the minimum amount raised was USD 420, and the maximum was USD 100 million. The median is USD ten million, which is substantially lower than the mean. This indicates that the distribution of the amount raised is positively skewed, i.e., a few projects raise a substantially greater amount than average projects. The average amount raised among projects that are not characterized as clean energy-related ICOs is lower by USD three million. Among the 40 clean energy-related ICOs, we find that 12 lead to issuance of tokens and had been trading coinmarketcap.com for more than 90 days. We observe that the standard deviation of the price returns of these tokens is on average 0.082, which is lower than the standard deviation observed among other issued tokens 0.098.

3.4.2 ICO Attributes

In this section, we compare the clean energy ICOs with the remaining of the sample with respect to various ICO attributes. First, we find that ICOBench ratings for clean energy projects are on average marginally higher for clean ICOs compared to the ratings for other ICOs [clean ICOs = 3.01, remaining = 2.95]. With respect to launching a pre-ICO sale before the main ICO, the proportion of clean ICOs with pre-sale is substantially higher [clean ICOs = 60%, remaining ICOs = 43.8%]. The greater use of pre-sale among clean energy-related ICOs could be that these projects are generally more likely to lack the resources needed to launch and market an ICO. A greater proportion of clean energy ICOs offers bonus schemes during the ICO [clean ICOs = 47.5%, remaining ICOs = 43.8%]. However, with respect to specifying a soft or a hard cap, the proportion is lower for clean ICOs [clean ICOs = 62.5%, remaining ICOs = 66.3%]. Strikingly, 87.3% of the nongreen sample were based on the Ethereum blockchain, and the proportion was even higher for clean ICOs [90%]. We find that 42.5% of the clean energy ICOs have complied with either or both whitelist and KYC [clean ICOs = 42.5%, remaining ICOs = 35.2%], which indicates that greater proportion of clean ICOs exhibit regulatory compliance. The average number of currency alternatives offered by clean energy ICOs is 2.125, which is greater than the average of 1.85 currencies offered by other projects. The greater number of currency indicates that clean ICOs offer greater purchasing alternatives for investors. We find similarly higher figures with respect to offering fiat currencies as purchasing currency option [clean ICOs = 2.5%, remaining ICOs = 1.8%]. Furthermore, we find that clean energy-related ICOs on average have almost 15 team members and advisors onboard, compared to 12 team members in other projects, suggesting that clean energy projects are generally larger in scale with respect to the number of people involved than most ICO projects.

3.5 Risks and Uncertainties Related to the Blockchain Technology

In spite of its value, the future of the blockchain technology for energy purposes is not set in stone. The technology is new and still involves substantial costs and slow transaction speed, among other technical challenges (Luke et al. 2018). In addition, political issues with grid operators or public perceptions of the technology are potential obstacles for its expansion. Several risks, threats, and challenges await. Here, we discuss two of the technical challenges relating to adoption of blockchain technology.

3.5.1 High Energy Demand

The innovation of blockchain technology is revolutionary because every transaction is verified by using very complex algorithms. This benefits users with a high level of security. However, this security leads to a substantial energy cost. The energy that is required by the Bitcoin network is difficult to assess with certainty because of a very volatile demand and increasing verification complexity. Yet, the usage is estimated to be between 32 and 34 TWh or 250 KWh per block verification (Serpell 2018). This is similar to 1 week of electricity consumption by the average American household. It is estimated that during the recent price spike of Bitcoin in 2017, energy demand increased by 450 GWh every day. This is about 250,000 barrels of oil a day.

While the energy cost of mining Bitcoins is very high, it is not as high as printing physical currency. One must also take into account of the fact that far more physical currency is printed than Bitcoins and that the majority of US dollars in circulation today are digital. As long as blockchains experience a modest growth, this energy consumption should not be an issue. However, if Bitcoin's value continues to rise, the reward a miner receives also increases in value, and therefore he can afford more energy to solve the block algorithm. This could lead to scalability issues for the blockchain technology in the energy industry.

3.5.2 Scalability Issues

Blockchains were defined with a focus on decentralization and security. Yet, this has come at the cost of scalability. Blockchains such as Bitcoin and Ethereum can have extremely slow transaction processing times. The reason is that all full nodes on these blockchains must reach a consensus before the transaction can be processed. Bitcoin can process about nine transactions per second (BitInfoCharts 2019). This is substantially lower than the VISA payment service, which can handle up to 24,000 transactions per second. This has implications on the scalability of the Bitcoin technology.

In fact, the scalability of the blockchain technology is bound to the scalability trilemma. This trilemma, described by Ethereum's Vitalik Buterin, refers to the tradeoffs that blockchain-based projects must make when deciding how to optimize the underlying architecture of their own blockchain. The trilemma involves three components, decentralization, security, and scalability, and states that you can only have two out of the three. Tradeoffs are therefore inevitable and require one to find a balance, without compromising too much on one of the components.

To address this scalability issue, cryptographic strategies for block verification such as the "proof-of-stake" and "directed-acyclic-graph" protocols have been developed (Tapscott and Tapscott 2016). The "proof-of-stake" network participants are able to check transactions based on their ownership of the network's cryptocurrency, rather than by competing with each other to solve a block algorithm (Luke et al. 2018). This protocol, in theory, should substantially diminish the energy consumption of the network and allow more users to take part to the mining process. Directed-acyclic-graph protocols are designed so that it is not possible that a transaction completes until the participants in that transaction verify at least two previously completed transactions. As a result, previously executed transactions are independently verified by a number of following transactions, using less power, compared to other verification methods. However, this protocol may not provide the network security that "proof-of-work" networks like Bitcoin can offer (Luke et al. 2018).

4 Conclusions

In our pursuit for global solutions for the common challenge of climate change, the coordination of actions and the facilitation of cooperation between actors in the green-energy sector is an increasing concern. Blockchain provides the technological basis to achieve such types of interactions. For instance, blockchain allows actors in the green-energy sector to continually update greenhouse emission data from a multitude of sources and share this information in an open and transparent way. Blockchain's potential applications extend to numerous other domains, both private and public, tackling challenges such as monitoring environment treaties compliance, efficient supply-chain management of vital resources, and improving recycling efficiency.

Nonetheless, the blockchain technology and the realization of its potential applications are still in its early phase, and the uncertainties surrounding how its adoption will evolve in the coming years are still profuse. As with the introduction of any new promising technology, the rational assessment around its potential has been marred with speculative exuberance, blurring the line between progress and fad. Furthermore, despite the technology's potential to deinstitutionalize the cumbersome and vulnerable institution-dependent interactions, the process of learning to optimize the technology to create the most value for the wider population still requires much experience. After all, the adoption of a technology is not only based on the merit of the technology itself but also the time-specific social conditions supporting it (Davis 1989). Furthermore, the technology itself is in the process of developing as it still tries to overcome the issues of scalability and efficiency. Nonetheless, despite these tales of caution, its scope to enhance transparency, flexibility, and security is still distinctly relevant for the context of energy industry and, therefore, promises to play an important role in shaping the industry for the future.

Appendix

Table 3 List of ICO clean energy firms based on service category

Clean mining	Energy exchange	Financing renewable projects	Investment platform	Certification/ incentive program	Network building
Airforce Mining	SunContract	Wind Energy Mining	Optonium	Swytch	BioCoin
Minery	PowerLedger	Platio Solar Paving	HydroCoin	Czero	Oilsc
GreenHashes	Pylon Network	Indigo Racing	Bitproperty		EnLedger
Zeus	WePower	NiqBix			
Environ	Universal Brand	Smart City Enterprise			
Cointed	KWHCoin	Reborn Bloc			
Moonlite	Robotina	Sun Money			
EthernityMining	EarthToken	Optonium			
Nauticus	Restart Energy				
CrowdShareMining	Electrify Asia				
BaltiCrypto	Torus				
H2Sol					
OphirCoin					
CryptoSolarTech					

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