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Tokenizing Green Energy

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Policy Parameters for Blockchain Applications in the Energy Sector

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Abstract

This paper explores the sustainability and implementability of blockchain solutions in the energy sector. Sustainability is related to the choice of consensus algorithm and to energy tokenization. Implementability of blockchains is shown to depend on the regulatory environment and the development of the physical power grid. It is argued that blockchains are well-suited for enabling peer-to-peer energy trading and green energy investments. In regards to policy, the creation of an institutionally sponsored energy token, as a trial run for blockchain-based green energy investments, is recommended.

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1 Introduction

When it comes to blockchain technology's impact on the environment, public attention is largely focused on Bitcoin mining farms (Jiang et al. 2021, The Economist 2021). With the largest miners located in developing countries to capitalize on low energy prices, running the Bitcoin blockchain consumes vast amounts of energy and is, environmentally speaking, devastating. However, many blockchain applications that are conducive to the climate should not go unnoticed.

This paper aims to show how blockchain-based incentive structures for renewable energies work and to highlight the challenges that arise in their implementation. In particular, some parameters for policy-making in the energy sector are presented. To this end, section 2 briefly introduces the blockchain technology and accounts for applications in climate-related fields. Subsequently, section 3 looks at how blockchain solutions are integrated into energy markets and outlines potential benefits. Section 4 continues with a more detailed discussion of tokenization, before section 5 compares and contrasts different consensus algorithms. Section 6 highlights the technical challenges facing blockchain applications and relates their future success in the energy sector to improvements in the physical grid. In section 7, the insights of the preceding parts are synthesized and some policy parameters for integrating blockchains into the energy industry are submitted. Lastly, section 8 summarizes and concludes the paper.

2 Blockchain Technology and Climate Applications

Fundamentally, the blockchain is a technology which enables a community to maintain trust by making and preserving truths (Agung et al. 2020). It "offers a way for people who do not know or trust each other to create a record of who owns what that will compel the assent of everyone concerned" (The Economist 2015). Its mathematical and cryptographic foundations were laid out by the pseudonymous Satoshi Nakamoto (2008) in the paper "Bitcoin: A Peer-to-Peer Electronic Cash System". Blockchain technology was initially implemented in Bitcoin, the first and still most well-known cryptocurrency, before branching out to different fields (Narayanan 2016).

The blockchain consists of an open, distributed ledger that can record transactions between parties efficiently and in a verifiable and permanent way. Each party on a blockchain has access to the entire distributed database while no single party controls the data or information. Communication occurs directly between peers instead of through a central node and every transaction and its associated value is visible to anyone with access to the system. Once a transaction is entered in the database and the accounts are updated, the content of the data or the timestamps cannot be altered or tempered with without detection. (Catalini and Gans 2020, Lansiti and Lakhani 2017, Pierro 2017).

The digital nature of the ledger allows users to set up algorithms and rules that automatically trigger transactions. These “smart contracts” encode the terms of a traditional contract into a computer program and executes them automatically if specific predefined requirements are met. Thereby, smart contracts consistently enforce regulations and methodologies to ensure transparency and accountability while removing intermediaries such as verifiers and auditors (Baumann 2018, IMF 2016: 23).

Since its inception, blockchain technology has found various fields of application, including in climate-related areas (Schletz et al. 2021). As part of climate finance, it can facilitate climate-friendly investments through a higher traceability of financial flows and reduced management and transaction costs (Blockchain Climate Institute 2018, Lau et al. 2020). In carbon markets, the blockchain can be used to improve carbon asset transactions by guaranteeing transparency and the validity of transactions (cf. Franke et al. 2020, Blockchain for Climate Foundation 2021). For emissions tracking, blockchain solutions enhance supply chain visibility and make it easier to track emission reductions, thereby addressing double counting issues (Cholteeva 2021, UNFCC 2021). Lastly, for clean energy trading, blockchain-based platforms can allow consumers to directly buy, sell or exchange renewable energy with each other, using tokens or tradable digital assets representing quantities of energy production (UNFCC 2017). This integration of blockchains into energy markets and electrical grids is the focus of the next section.

3 Energy Markets and Smart Grids

Over the last decades, energy generation has significantly changed. Conventional energy sources such as coal, oil and gas (as well as nuclear) have been supplemented and partially superseded by renewables, in particular wind and solar. At the same time, the underlying structure of energy markets has remained remarkably unaffected. A limited number of effectively monopolistic corporations still hold sway over many countries’ energy grids. In Germany, for instance, the four power companies E.On, RWE, EnBW and Vattenfall control roughly 80 percent of the electricity supply (Berkel 2013).

Still, centralized power plant construction is gradually being replaced by a decentralized, decarbonized and digitized system with numerous small-scale providers (Andoni et al. 2019). For one, the declining costs of rooftop solar panels and batteries has made local energy production more affordable. A decentralized energy grid allows communities greater control over the energy sources they consume and enables them to sell power back to the grid, offering revenue opportunities and providing back-up power for the system as a whole (Gagan 2019). In developing countries with energy access limitations, “decentralization based on solar or wind is often the easiest way to electrify remote parts of the country, because it is cheaper, more flexible and faster than centralised power plant construction and grid extensions” (Schletz et al. 2020: p. 4). Combined with advanced metering infrastructure and other technical advancements, a “smart grid” can store the energy derived from renewables and distribute according to times of peak demand, when power outages occur, or as a means of reducing dependency on fossil fuels. Thereby, electrical consumption is more efficiently matched with supply and the system as a whole becomes more robust (FERC 2008).

The integration of energy storage devices, the intermittent nature of renewable energy sources and the appearance of a new type of grid user called the prosumer, who produces and consumes energy in a local area, adds complexity to the energy system. Managing this decentralized energy system in a centralized manner would be costly and require complex communication infrastructure (Musleh et al. 2019). Accordingly, due to its inherent nature, the blockchain could offer a promising solution to control and manage increasingly complex energy systems and microgrids (Pilkington 2016).

Blockchain technology can provide dispatching agencies with full, real-time knowledge about the operation status of a power grid. This allows producers to develop dispatching plans that maximize profits. Grid users, in turn, can specify their price preferences in the form of their willingness to pay or sell energy. Blockchain platforms can then display location-specific and real-time energy prices (Andoni et al. 2019, Musleh et al. 2019).

With this real-time infrastructure in place, blockchain technology can be employed to manage peer-to-peer transactions. Using smart contracts, electricity is delivered to the consumer once the the previously agreed price is paid to the producer. Buyers and sellers can be automatically paired. By cutting out the middleman, peer-to-peer trading reduces the electricity trading transaction costs among prosumers. Moreover, the interactive nature of a peer-to-peer grid leads to higher efficiency, as it incentivizes prosumers to adjust their behavior rather than being charged an average price (Schletz et al. 2020). An interesting way of setting up energy transactions on the Ethereum blockchain is outlined by Agung and Handayani (2020). First, a producer produces electricity and a token with the corresponding value is generated. If the producer wishes to sell, a sell order of the corresponding token is placed in the network. The system checks if sufficient electricity is available and locks it before the sell order is published. A consumer who needs electricity can then purchase a token with the corresponding value. The system checks the consumer's balance and locks it before the buy order is published. When sell and buy order meet on the market, a smart contract is created to generate the transaction. As the electricity is consumed, the token with the corresponding value is "burned" and exits circulation. Once miners verify the transaction, the block candidate is added to the blockchain and the smart contract is executed (cf. Sabounchi and Wei 2017).

Another proposal for peer-to-peer energy trading are market auctions. Mengelkamp et al. (2018) construct an auction mechanism where the demand and production capacity of each user is automatically measured and predicted by smart meters and subsequently broadcasted. Based on this information, excess demand or supply is calculated and sent to the corresponding blockchain account of the agent. Hahn et al. (2017) present a distributed auction system where a seller with excess power can launch a new auction and publish his available power in the blockchain. Bidders in need of electricity can bid after receiving the new auction. The auction and payment processes are automated by smart contracts and smart meters detect and report the flow of electricity during the transaction, verifying that the transaction is completed.

Another advantage of blockchain technology is that it offers increased security and resiliency to the power grid. The cryptographic securitization combined with the consensus mechanism provides immutability to the data which is added to the blockchain. In addition, there is no single point of failure compared to centralized data architectures since the computational capacity is fragmented instead of concentrated in one single computer. And since every participant in the network has access to the ledger, the vulnerability of the network as a whole to attacks is mitigated (Musleh et al. 2019, Zhuang et al. 2021). This is especially pertinent since cyber attacks have often been directed at critical infrastructure systems. Blockchains could also improve network resilience and supply security by facilitating Internet of things applications and creating more efficient flexibility markets (Mylrea and Gourisetti 2017).

Blockchains also have some positive ramifications for renewable energy transition efforts. Peer-to-peer trading creates new incentive structures for prosumers to invest in renewable energy sources and purchase locally generated green energy (Schletz et al. 2020). For one, blockchain's immutable transaction history can be adopted for the monitoring and certification of renewable energy certificates (Schletz et al. 2020, 2021). Green certificates are a commodity product that proves that the electricity has been generated from renewable energy sources. Standardized trading of certificates supports the market integration of renewable energies and makes energy markets more transparent and liquid. (Imbault et al. 2017). Certificates that provide info on sourcing could in turn be worked into smart contracts. Buyers who prefer clean or locally produced energy in order to minimize carbon footprints and transmission losses, can structure contracts so as to preferentially buy those types. Lastly, as will be shown next, tokenization facilitates the addition of renewable energy generation incentives (Schletz et al. 2021).

4 Tokenizing Energy

Tokens are integral to many blockchain-based energy trading mechanisms and conducive to renewable energy incentive schemes. Generally, tokens are a cryptocurrency built on top of a pre-existing blockchain. A token represents a tradable asset or utility that resides on its own blockchain and allows the holder to use it for trading, to hold and store value or to use as a form of currency. Tokenization creates new markets or novel business models based on co-ownership and asset sharing. Ethereum, for instance, with its native cryptocurrency Ether, is the underlying blockchain for a multitude of tokens that are using the platform to develop services and products.

In the energy sector, cryptocurrencies can be used to “tokenize” a number of things: energy itself, its means of production, such as solar panels or photovoltaic systems, or even carbon-dioxide saved or captured. Through Initial Coin Offerings, or ICOs, tokens are employed to attract investment and crowdfunding. New cryptocurrencies can also reward desired behaviors and facilitate green energy investments. For example, cryptocurrency can be assigned to those with the highest stake in the system or providing the most socially useful service. In a renewable energy context, generators are rewarded with more currency if they generate the least carbon-intensive energy (Andoni et al. 2019: 158). In the remainder of this section, an overview of different tokens is provided.

Types of Energy Tokenization

Energy Investment and Asset Co-ownership	Energy Generation, Energy Savings and Carbon Capture	Energy Trading
SUNEX (Sun Exchange)	SolarCoin (SolarChange)	NRG (Enervalis)
Sun-E (Local-e)	ETK (EnergiToken)	WPR (WePower)
MPQ (ImpactPPA)	NRT (Nori)	POWR (Power Ledger)

Some companies aim to facilitate green energy investments and asset co-ownership. The startup Sun Exchange (2021) has developed a sharing economy platform that crowd-sales photovoltaic projects to investors. Distributed ledgers keep track of ownership and revenues in immutable records and provide the transparency required for regulatory compliance. Investors buy solar assets, which are then leased to consumers in the developing world, typically local schools and smaller enterprises. Smart contracts are used to automatically execute payments from solar producers to investors. In addition to the regular payments from supported projects, investors collect one SolarCoin token for every MWh of electricity produced. Local-e (2021), a Seattle-based startup, has launched the cryptocurrency Sun-e aiming to financially support local and renewable energy investments. Investors can support their community members with solar installations by purchasing Sun-e coins that are granted to solar producers for 100 kWh of verified energy produced. ImpactPPA (2018) uses a token model for financing projects that deploy clean energy solutions. Token holders will get to vote on and approve which projects to fund, giving the community a voice on investment decisions.

Other cryptocurrencies are used to reward low-carbon energy generation. SolarCoin, launched by SolarChange (2021), is a cryptocurrency whose creation is tied to solar energy production. Solar energy producers can file a claim to register their solar installation via a monitoring system. The monitoring system sends generation to the SolarCoin Foundation, which then pays out SolarCoins at a rate of one SolarCoin per one MWh of verified electricity production. By design, the total SolarCoin supply is set to last for 40 years, delivering incentives for the generation of 97,500 TWh of solar-powered electricity. SolarCoin's valuation took off in 2017, hitting $2.4 in early 2018, before plummeting later the same year. In July 2021, it is prized at only $0.0039 per coin. The Ethereum-based EnergiToken (2021), on the other hand, was designed to incentivize consumers for energy savings. Tokens are granted to anyone who can certify energy saving actions, such as taking low-carbon transport or buying energy-efficient appliances. However, current valuation is at zero. EcoCoin (2021) is a similar cryptocurrency that rewards users for a sustainable lifestyle, such as buying vegetarian lunch or taking the bike to work. Actions are verified through smart sensors, inspectors and or certified vendors. Next to energy subsidies and savings, there is also the option of carbon capture. Nori (2021) is a carbon removal marketplace that sells Nori Carbon Removal Tonnes (NRTs), representing a ton of CO2 that has been removed from the atmosphere for a minimum of 10 years. Nori aims to commoditize the removal of CO2 and remove the costly matching process of traditional carbon offset markets.

Tokens can further be designed to enhance decentralized smart grid solutions and peer-to-peer energy trading. NRG Coin (2021), issued by Enervalis, enables household consumers, system operators and energy suppliers to conduct energy transactions via smart contracts. The currency is generated by injecting energy into the grid. The rate of coins produced depends on the supply-demand conditions on the time of injection, so real cost of energy is reflected in the price. In this way, Energi effectively operates as an incentive and reward mechanism for more efficient use of renewable energy at a local level (cf. Mihaylov et al. 2014). In 2018, the blockchain startup WePower (2021), in collaboration with the energy provider Elering AS, tested the large-scale tokenization of energy data in Estonia. WePower's WPR token represents one KWh of energy produced and is tradable. Using smart contracts, users were able to buy and sell electricity based off of real-time power generation and prices. Renewable energy projects are funded through the sale and trading of the produced tokenized energy (Schiller 2017). The Australian startup Power Ledger (2019) has developed a blockchain-based platform that enables energy tracking and peer-to-peer trading. Its POWR token has both access and incentive features. Ownership of POWR tokens gives users access to the platform's trading system. At the same time, all prosumers generating and consumers purchasing energy are rewarded with POWR tokens under an incentive formula weighted towards renewable energy producers. Currently, 60% of POWR tokens are held by the top three holders, with 90% held by the top hundred. After its IPO in late 2017, valuation was very high in 2018, reaching $1.75. The price subsequently dropped to the IPO price of $0.09 in 2019. Beginning in February 2021, there was another spike up to $0.6 with the price subsequently returning to $0.16 (Etherscan 2021).

5 Consensus Algorithms

Every blockchain has a consensus algorithm which ensures that the rules of the protocol are followed and that all transactions take place reliably. There currently exist many types of distributed consensus algorithms, each with distinctive features that determine performance characteristics such as scalability, transaction speed, security and spending of resources such as electricity. Still, all consensus algorithms require a procedure for generating and subsequently accepting a block. A block can be generated or proposed by some node in the network, and it encodes a number of transactions. In a cryptocurrency system, for example, these are monetary transactions between different accounts. Subsequently, the proposed block has to be accepted by network members, a process called "reaching consensus". Since open blockchains are built as distributed systems that do not depend on a central authority, distributed nodes have to somehow agree on the validity of transactions. Once a block is accepted, it becomes part of the blockchain, and it is cryptographically linked to the blocks preceding it. After a time, depending on the consensus algorithm used, the block becomes a permanent part of the blockchain, i.e. it reaches "finality" (Andoni et al. 2019).

The first blockchain consensus mechanism, which is used by Bitcoin, is proof-of-work (PoW). Under PoW, miners are presented with a difficult computational problem or puzzle. It consists of finding a numeric value, called a "nonce", which is used to generate a "hash value". By inserting the nonce into the algorithm, miners seek to change the hash value, which ensures that the block of data has not changed. The miner who finds the correct nonces and hashes gets to add the next block and receives a reward for doing so. Once the problem is solved and a valid hash is identified, other users can validate the solution immediately without having to go through the resource-intensive computation process. Once the majority of the community validates and confirms the block, the next block can be added to the chain (CRS 2019: 24).

Two key features of PoW protocols are their asymmetry and built-in incentive structures. The work of adding to the blockchain must be moderately hard, yet feasible, for the requester but easy to check for the verifier. Finding the right hash is difficult but confirming its validity is simple. Subsequently, the investment of computational capacity to the network is rewarded with value in the form of cryptocurrency. In the case of Bitcoin, the miners who create and publish new blocks to the blockchain are rewarded with Bitcoin.

Overall, PoW algorithms are very secure, but also slow and energy intensive. Solving complex mathematical puzzles necessitates very high computational power which is limited by current energy capacities (Hassan et al. 2021). These energy requirements make PoW protocols undesirable for environmental reasons. As a result, developers have increasingly migrated towards proof-of-stake (PoS) algorithms that are energy efficient, faster and more scalable. However, they are introduced at the expense of some security and decentralization (Andoni et al. 2019). Ethereum, the currently most actively used blockchain, transitioned to PoS in 2020 (Fairley 2019).

Instead of a race to be the first to solve computations, PoS depends on the community's stake in the currency. The more currency a "validator", the PoS equivalent to the PoW's miner, holds, the more transactions can be validated. Among other advantages, this method skips the energy-intense hashing race since all of the currency is already created and the amount is stagnant. Validators are instead chosen at random and earn currency through transaction fees for building new blocks. However, they also put their own cryptocurrency investment at risk when they propose or attest to a new block. If a validator adds a malicious block to the blockchain based on an invalid transaction, he risks losing his stake and being ejected from the network (CRS 2019: 24, Muzzy 2020).

With PoW and PoS being the most well-known protocols, there are many more available mechanisms such as the Federated Byzantine agreement, proof-of-authority, proof-of-elapsed-time, proof-of-activity, proof-of-burn and proof-of-capacity (cf. Andoni et al. 2019: 150). Additionally, there are also consensus algorithms that have been specifically designed for energy trading, such as the proof-of-energy protocol proposed by Siano et al. (2019), which is an adjusted version of PoS for greater energy efficiency and sustainability. Another interesting suggestion is Hassan et al.'s (2021) design for blockchain-based smart grid auctions.

Energy efficiency targets will almost certainly initiate a movement away from traditional PoW algorithms. Since the PoW mining process entails high energy costs, less energy-intensive consensus algorithms such as PoS, and adapted mechanisms designed for energy trading, are likely candidates for future implementations. A leading competitor in this field is Cardano, the most well known of the green cryptocurrencies and currently the fifth-largest cryptocurrency (Lacey 2021). Cardano (2021) is a PoS blockchain platform that saves significant amounts of energy through "a combination of novel approaches, including multi-ledger, side chains, and parallel transaction processing through multi-party state channels". Still, there remains a lot of potential for improvement in green consensus algorithms in areas such as security and decentralization.

6 Technical Constraints and Physical Infrastructure

With all of blockchain's potential advantages, there comes a number of challenges. A study conducted by PwC pointed to three critical aspects to the blockchain's future success in the energy sector: (1) user-friendly, easy to use and effective applications, (2) cost efficiency of the verification process, and (3) value-added offered by the blockchain over centralized client-server solutions (PwC Global Power & Utilities, 2016). Many important problems, such as scalability, data privacy and energy efficiency of the network are currently being addressed by blockchain developers (Mire 2019).

Network scalability, for one, is enhanced through the use of layer-2 solutions, such as sidechains. Layer-2 is a secondary framework that is built on top of an existing blockchain system, the layer-1, in order to improve the transaction speed and scalability of blockchain networks. By running a parallel sidechain, the speed of transactions is optimized while the parent chain stays largely unchanged and retains its high security (Back et al. 2014, Injective Protocol 2021).

Data privacy is another issue. If public blockchains are used for monitoring the power consumption of users, their electricity consumption would be accessible. Add to this smart metering technology and one could not only discover consumers' daily activity patterns but even the types of devices that are currently in use. Hence, blockchain-based energy platforms will almost certainly require signature and encryption schemes designed to improve privacy protection (Bao et al. 2020).

Another potential roadblock to blockchain's adoption in the energy industry is the fact that there is a physical commodity and a physical infrastructure underneath each transaction (Eurelectric 2017). Blockchain-based energy platforms and peer-to-peer trading depend on a physical grid that relays energy from point A to point B. In contrast to blockchain applications in the finance sector, energy must still be "delivered through the physical grid, demand and supply need to carefully be managed and controlled to comply with real technical constraints and power system stability" (Andoni et al. 2019: 151). Widespread smart meter coverage is necessary for measuring energy in- and outflows. Distribution boards and circuit breakers are needed for demand response, and batteries for energy storage. For local and renewable energy production, solar panels and wind parks have to be constructed and connected to the power grid.

Because of blockchain's dependency on the physical grid, its success in the energy industry will be contingent on the market forces, government investments and regulatory standards that drive infrastructure development. The next section dives into the latter two aspects and sets out some parameters for state investment into, and regulation of, blockchain solutions.

7 Policy Parameters

Many experts working in blockchain startups view the current regulatory environment as a significant impediment to blockchain implementations. By their account, the "global energy sector is one of the most highly regulated industries in the world" with "centralised market legislations and monopolies". This leads to "uncertainties associated with rolling out new technologies operating in highly regulated markets and industries, particularly technologies that many associate with speculative cryptocurrencies" (Mire 2019). A survey by the Electric Power Research Institute (2019) found that 77% of respondents had concerns that the energy industry "lacks appropriate standards" for blockchain applications in utilities. These views suggest that companies face high levels of regulatory risk as well as regulatory complexity which are costly to manage (Bürer et al. 2019). Another key problem is the lack of standardization in blockchain solutions. At the moment, no standards are established and interoperability between protocols is low. Moreover, once a blockchain system is instituted, subsequent changes are difficult to realize since they have to be approved by the system nodes. For blockchains in the energy sector, such discussions may engender mistrust and fragmentation (Andoni et al. 2019).

For these reasons, institutional action, especially in the form of market design and green energy investment, appears appropriate. A tentative approach would be to create a more amiable regulatory environment. This involves tackling the above-mentioned issues, namely the energy industry's monopoly problem, regulatory uncertainties and the lack of standardization. However, none of these have immediate or obvious solutions. Breaking up natural monopolies over energy supply will bring energy costs up. Accordingly, elected governments will likely prefer to wait for monopolies to incrementally weaken as market structures change, in particular as local energy production becomes more widespread. Moreover, since blockchain is a new technology that is still being developed, regulation is highly complex and needs to be adaptable. For the same reason, stipulating concrete standards may backfire as it is not yet clear which blockchain protocols will prove successful. Overall, many of the current impediments to blockchain implementation are structural and do not appear immediately fixable.

In contrast to this regulatory approach, a very ambitious plan would be the creation of a blockchain-based energy platform. The system could subsequently be employed for government or investment schemes. This future peer-to-peer energy trading platform could then emerge as a cousin to existing cap and trade programs such as the EU ETS. While the EU ETS creates a carbon market for firms, a European peer-to-peer trading network could create an energy market for consumer, producers and prosumers.

Since the realization of such a project is still a long way off (and its construction much too elaborate to attempt here), a more feasible proposal is here put forward: a state- or institutionally-sponsored token that subsidizes renewable energy production (and possibly industry energy savings). This token could function as an interesting trial run for blockchain-based public green energy investments.

From a technical standpoint, creating such a token would not be uncharted territory. As was shown in section 4, many types of energy tokens already exist and the concept has been variously tested (albeit with varying success) by private companies. Also, setting up a token does not require creating a novel blockchain platform. A new token can simply be tethered to an existing network, for instance Ethereum, that guarantees intervention-free investment and trading for users.

An institutionally-issued token has a number of benefits over traditional ways of subsidizing (such as tax-breaks). Tokens are generally traded on markets and accessible to private investment. In principal, a limited amount of public funding can draw additional private investment and thereby achieve a greater total effect. However, tokens are thereby also open to speculation and market manipulation which introduces instability and the possibility of price crashes. To mitigate price volatility, regulation and oversight could be employed. This would in turn attract institutional investment to the token market, further enhancing stability.

Token-based investment has the additional advantage of being highly incentive compatible. Using tokens, energy providers can be subsidized according to actual energy outputs instead of potential energy generation (as would be the case under subsidies for the installation of solar or photovoltaic systems). Combined with blockchain-enabled tracking of energy sources, smart contracts and auction designs for peer-to-peer trading, tokenization enables incentive structures that integrate price signals and market mechanisms. Users can be automatically rewarded for the efficient energy usage of their appliances and be encouraged to adept their consumption to current energy prices. In this way, blockchains can provide much more fine-grained incentives than traditional subsidies.

Another potential benefit is that tokens give token-holders a stake (and sometimes vote) in the project or network. Tokens are built around communities whose members have multiple roles beyond being an investor, such as early adopters, users, miners or validators. Producers, consumers and traders of renewable energy may be encouraged to look beyond short-term financial performance. Community-mindedness could engender long-term investment in and commitment to the members' shared goals.

Lastly, the institution that sets up a token is also bound by the blockchain's algorithms and protocols. From a viewpoint of political commitment, a public institution cannot unilaterally change how the consensus algorithm functions (presuming a wide distribution of stake). Users do not need to trust governments or other institutions in the way that might otherwise be required for political promises. Withdrawals of already given (financial) commitments are simply not possible in a blockchain infrastructure.

An important question is which institution is best equipped to introduce (and fund) such a token. Possible candidates are nation states, supranational organizations such as the European Union and international institutions such as the World Bank or IMF. Choosing between them will involve trade-offs in regards to market depth, potential for manipulation and policy intervention. For one, since energy moves across national borders, energy trade is also required to function between countries. However, if there are different token-based systems in two countries, interoperability may be lower, and consequently markets thinner and prices more heterogeneous. Additionally, if every state uses its own energy token, there may be a potential for "manipulation" in order to boost at-home energy production or trade. On the other hand, if a token-based system is designed for proactive policy intervention, a world-bank issued token would conceivably allow for less effective regulation in a specific country or region than a state-issued token. Interestingly, many of these trade-offs are reminiscent of the debates surrounding the introduction of international currencies, such as the euro. Overall, deciding on an appropriate issuer will depend on what a token-based energy system is designed to do as well as which institution has the knowledge, public trust and independence to keep the platform running in concordance with its prospective institutional mission.

Lastly, what type of token is employed is consequential. Tokens can assign ownership rights, they can represent an amount of electricity, or a quantity of carbon dioxide that has not been emitted due to conservation practices. For trading, using tokens that directly represent electricity is reasonable. For green investment, on the other hand, allocating ownership, for example over solar panels, can be advantageous. Tokens can be generated through the "mining" or "validating" of new blocks, through energy production and savings, or via the trading process itself. This implies that tokens could potentially be earned by consumers as well as suppliers. Additionally, it is possible to take tokens out of circulation via "burning" if the energy represented by a token is consumed. Setting up some incentive (in the form of token earnings) for adding to the blockchain is an absolute prerequisite. Beyond that, different tokens can be made to emerge in different ways. Multi-token systems, where multiple tokens are used for distinct purposes, allow for flexibility and complexity in trading and subsidy schemes. Or, alternatively, the same token can be made to emerge in different amounts. For instance, renewables can be subsidized by allocating a greater share of tokens to sustainable power generation compared to conventional energy sources. Overall, introducing a sophisticated multi-token system will require ongoing tweaking and improvement. In the case of blockchains, experimenting with trial runs is particularly advisable since, once a token is set up, the initial protocols are very difficult to subsequently modify.

8 Conclusion

The ongoing automatization, decentralization and digitalization of the energy sector will eventually require a distributed system of some kind to manage the ever-increasing complexity. Blockchains are currently the leading contender and should partake in this transformation. While peer-to-peer trading platforms are still in the early stages of development and their scale of adoption is limited, they "have the potential to radically change established roles of incumbent energy companies, such as energy suppliers or grid operators, who are in most countries are regulated monopolies and own the physical infrastructure" (Andoni et al. 2019: 167).

This paper aimed to show how blockchains can be employed to further renewable energy proliferation. First, the purpose and rudiments of the blockchain technology were presented. A distributed ledger that contains tamperproof information was shown to enable people who would not usually trust each other to agree on a state of affairs. While blockchains were developed to fit various areas, the paper's main focus was on how blockchains can be integrated into energy systems. To this end, the changes in the energy sector's market structure and the development of smart grids were related. Blockchains were then shown to enable peer-to-peer trading mechanisms that generate location-specific and real-time energy prices. Next, a number of cryptocurrencies were introduced in order to exemplify different types of tokens, distinguished by what they represent and how they are generated. Thereafter, the relative advantages and drawbacks of the proof-of-power and proof-of-stake algorithms where explained, with the former being very secure and decentralized and the latter energy efficient and scalable. Subsequently, the technical challenges facing blockchains were highlighted and the future success of energy sector implementations was related to developments in the underlying, physical grid. Finally, some policy parameters for blockchain applications in the energy industry were suggested. In particular, the challenges of the regulatory environment were accounted for and some outlines for the institutional issuance of energy tokens were suggested.

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