Regulating for blockchain technology in the electricity sector: Sharing electricity – and opening *Pandora's Box*?

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Abstract

This paper argues that the regulatory framework of the electricity sector needs profound revision in order to enable the efficient integration of renewable energy sources. This is exemplified by the innovation of blockchain technology which is gaining relevance in the electricity sector. Blockchain technology is more than a technical innovation as it facilitates the interaction of peers and thereby changes roles and responsibilities of existing actors. This poses the urgent regulatory question how to organise dispersed responsibilities.

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Introduction

Merely increasing the amount of generation of electricity from renewable energy sources (RES) will not lead to the desired low-carbon electricity society. Equally important is using the available capacity of RES and the grid infrastructure efficiently. The International Energy Agency highlights this by urging a shift for energy efficiency as a 'hidden fuel' to a 'first fuel' (International Energy Agency 2014). This quest is well established in the idea of smart grids (Clastres 2011; Moura et al. 2013). Smart grids cannot be captured by an exhaustive definition (Beaulieu 2016). Instead, extracting from various definitions, the idea of smart grids can be identified as facilitating the efficient integration of intermittent RES by harnessing flexibility in generation and consumption on basis of shared data on capacities. Even though smart grids are not yet implemented beyond pilot projects, first findings indicate that smart grids will necessarily include a variety of actors who are not yet existent in the electricity sector (Joint Research Centre 2014). Those new actors are not compatible with existing actor categories in the regulatory framework (generator, supplier, system operators, and consumer) (Friedrichsen, Brandstätt & Brunekreeft 2014). One of the most prominent changing actor categories are consumers who have so far been passively consuming electricity and now start engaging with electricity generation (Schleicher-Tappeser 2012). Not only could consumers start selling generated electricity, but they could also offer flexibilities in demand and thereby provide balancing services for maintaining system operation (Dupont et al. 2014; SmartNet project 2016). Smart grids enable their efficient integration in the system technically; however, reaping this potential requires that the legal framework accommodates those 'prosumers' in the electricity market with a focus on efficiency gains.

In this context of changing rationales and technologies, the idea of peer-to-peer transactions in the electricity sector is gaining spirit. Recently, this idea is further accelerated by blockchain technology which enables peer-to-peer (P2P) transactions (Murkin, Chitchyan & Byrne 2016). Arguably, "blockchain technology represents the next step in the peer-to-peer economy" (Wright & De Filippi 2015 4). Blockchain technology is considered to be the epitome of decentral organisation as all information about transactions is dispersed and shared among all users. Trust in transactions is thus inherent in the design of the technology and thereby dissolves the need for verifying central middlemen. In the current electricity sector, the central middlemen are the electricity supply companies and system operators. The relations between consumers and the intermediate entities, suppliers and system operators, are clearly established by regulation. The consumer contracts supply services and the responsibility to communicate load profiles to the system operator with a supply company (Commission of the European Union 2009, art 3(4)). In a P2P based electricity sector, those responsibilities would need to be transferred to the 'peers' and therefore cannot be established anymore on existing clear-cut actor typologies. The implementation of blockchain technology would constitute a radical change in the current organisation of the electricity sector as established by regulation. Regulation needs to establish mechanisms guaranteeing the quantity and the quality of the supply of electricity under a blockchain scenario.

The task of ensuring quantity and quality of electricity supply can be defined as information based responsibilities; compiling and communicating demand patterns and requesting extra generation or load. Both are currently under the responsibility of the supply companies and the system operators. Blockchain technology allows distributing and coordinating this information among peers which essentially weakens the role of supply companies and system operators. This paper explores the potential application of blockchain technology in the electricity sector and seeks to analyse the research question *'how can regulation define and allocate dispersed responsibilities for electricity supply and system operation under a blockchain-scenario?'* As the application of blockchain technology is only emerging in the electricity sector and regulatory questions have been barely touched upon, this paper provides an explorative approach on prospective regulatory challenges regarding 'shared responsibilities' under a blockchain scenario in the electricity sector.

This paper unfolds in three main sections. Section 1 introduces the idea of smart grids and identifies the quest for P2P transactions in the electricity system of the future. Section 2 firstly describes blockchain technology in its origins and emerging applications and secondly explores possible use cases and implementation in the electricity sector. Section 3 then analyses implications of blockchain technology in the electricity sector for the current regulatory regime of responsibilities in quantity and quality of electricity supply.

1. Smart electricity grids

The idea of smart grids is to incorporate efficiency gains as core maxim for electricity grid design and operation and thereby constitutes an alternative to heavy grid capacity extensions facilitating the integration of decentral RES (Poudineh & Jamasb 2014). The key to improve efficiency is to harness flexibility in electricity generation and consumption and thereby turn the current demand-driven system also in a supply-driven system (Papaefthymiou & Dragoon 2016). This section firstly describes smart grids along their main rationale that is the efficient integration of decentral RES and related obstacles in the existing regulatory framework. Secondly, this section identifies the idea of P2P transactions in smart grids as potential way to improve efficiency gains in the electricity system. This section sketches the baseline situation for the main topic of this paper by outlining why P2P transactions in the electricity system are a relevant development for prospective smart grids.

1.1 Rationale: efficient integration of renewable energy sources

One of the main challenges of accomplishing a low-carbon electricity society is the intermittency of RES. Intermittency entails that the availability of energy sources generation depends on seasons, the time of the day, and weather conditions. As those factors do not necessarily coincide with the demand for electricity, idle peaks of high generation and peak demands at times of low generation cause large inefficiencies. Therefore, the potential of RES can only be exploited to its full extent by coupling it with energy efficiency measures. This issue becomes increasingly severe at distribution grid level where decentral generation of RES is connected to the grid (Ecofys 2013). The distribution grid, which was technically designed to merely distribute electricity for final consumption, gradually needs to accommodate bidirectional flows of electricity as consumers connected to the distribution grid are installing small-scale RES generation. ‘Prosumer’ is the widely applied term to describe former consumers who start generating electricity. They are not merely consuming but also producing electricity, thus the artificial name ‘prosumer’. Not only is the current operational design of the distribution grid insufficient for efficiently coping with growing amounts of bidirectional electricity flows, but also the regulatory framework does not enable the efficient use of the electricity generated by prosumers.

One often applied regulatory approach entails that excess electricity generated by prosumers is fed back in the grid and usually sold to, or rather netted with, the contracting electricity supplier (net-metering) (Hughes & Bell 2004). This way of organisation implies two main cascading problems. Firstly, as the price for electricity and the use of the grid (network tariff) is not varying according to the time of use depending on available capacities, producers and consumers are not incentivised to adjust their behaviour accordingly. Consequently, decentral renewable electricity is not harnessed efficiently and prosumers are not charged accurately according to their grid usage (Knops & Hakvoort 2014). This leads to idle peaks of generation and at other times peak demands, which cause a waste of renewable electricity and essentially reinforce the need for electricity of conventional sources and require the extension of the grid to accommodate peaks. Those peaks are even exacerbated by increasing amounts of decentral generation of RES. The second issue is much related to this and concerns the role of prosumers in the electricity market. Currently, regulation does not enable prosumers attaining an independent role in the electricity market as they are usually bound by the contracting conditions of their supplier. If instead prosumers could sell their generated electricity as an independent actor (individually or in aggregated organisational forms) directly on the market they could offer their excess capacity for the real-time value rather than a fixed contracted price for kilowatt hours (Eisen & Morman 2017). Additionally, in order to increase the efficient use of the grid also the network tariffs should represent the use of the grid in terms of capacities rather than volumes. This would place a price on the actual use of the grid and ideally mitigate the need to increase grid capacity. At the core of those two issues is the need to incorporate the maxim of efficiency in electricity supply and system operation through regulation. Only if efficiency is incentivised can decentral RES generation contribute to the overall goal of achieving a low-carbon electricity system.

The idea of smart grids provides a technical solution to this problem by matching generation and demand of electricity close to real-time. Producers and consumers (and prosumers) are connected not only by the electricity grid but additionally exchange data through communication networks on available and required capacities. One example of a definition of smart grids is provided by the European Standardisation Organisations:

> "A Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety." (CENELEC)

An integrated pricing mechanism provides incentives to consume or not consume, to use or not use the grid extensively (Verbong, Beemsterboer & Sengers 2013). In that sense, smart grids are not defined by specific technologies, but follow a different rationale than existing grid operation by incentivising the efficient usage of electricity and the grid.

1.2 'Sharing' electricity: peer-to-peer transactions in smart grids

The preceding section clarified that prosumers are not a significant development if not facilitated technically and economically by regulation. Yet, the idea to 'share' electricity is becoming increasingly popular in the context of persons who start generating their own electricity (Crosby 2014). As this typically entails generation of electricity by means of intermittent RES, unavoidably, excess amounts of electricity are generated. This leads to the quest to efficiently use this idle capacity, possibly by means of 'sharing'.

The term 'sharing' requires some further explanation. One recent scholarly definition suggests the following understanding of 'sharing economy': "consumers granting each other temporary access to under-utilised physical assets ("idle capacity"), possibly for money." (Frenken et al. 2015). Three key elements are subsequently identified: sharing includes “consumer-to-consumer transactions”, “temporary access to a good”, and “physical goods”. Moreover, sharing does not mean that no remuneration is involved. One important recent development is that sharing experiences a novel revival in the context of the online world and digital platforms.

> “Historically, although there are some exceptions, people tended not to share with strangers or those outside their social networks. Sharing was confined to trusted individuals such as family, friends and neighbours. Today’s sharing platforms facilitate sharing among people who do not know each other, and who lack friends or connections in common.” (Frenken & Schor 2017 4).

Partly, this development can also be observed in the electricity sector. One often cited example of this is the Dutch company “Vandebron” (translated as “from the source”) which enables direct transactions between electricity producers and consumers (Vandebron). Usually, in the electricity sector this is not referred to as ‘sharing’ but as P2P supply. The concept of P2P originates in computer science. “In its simplest form, a P2P network is created when two or more PCs are connected and share resources without going through a separate server computer.” (Cope 2002). Simply, a P2P network “is a decentralized model whereby two individuals interact to buy or sell goods and services directly with each other, without intermediation by a third-party, or without the use of a company of business. The buyer and the seller transact directly with each other.” (Investopedia). In that sense, the company “Vandebron” is not enabling fully P2P transactions as the company itself is the middlemen between producer and consumer and remains the responsible electricity supply company. The difference between conventional electricity supply companies and “Vandebron” is that the latter one offers an online market platform for smaller scale RES and consumers who consciously chose to support local RES generation. Both, generator and consumer, pay a flat subscription fee. The idea behind “Vandebron” potentially changes the current business model of incumbent electricity suppliers. As “Vandebron” itself does not possess any assets apart from the software, the online P2P platform, their business model might increase the competitive pressure on traditional large supply companies (Bellekom, Arentsen & van Gorkum 2016). This is only a first step towards an electricity sector which will need to incorporate ways of more efficient integration of decentral small-scale RES generation, inter alia by means of ‘sharing/peer-to-peer mechanisms’.

The resulting question from first developments and ambitions to establish P2P supply is how regulation can organise respective responsibilities of electricity supply. Currently, those responsibilities are clearly defined and assigned to well-established actors, the supply companies. EU regulation defines electricity supply as “the sale, including resale, of electricity to customers” (Commission of the European Union 2009 art 2(9)). Under the title of public service obligations and consumer protection Directive (EC) 2009/72 establishes that "Member States shall ensure that all customers are entitled to have their electricity provided by a supplier, subject to the supplier's agreement, regardless of the Member State in which the supplier is registered, as long as the supplier follows the applicable trading and balancing rules.[…]" (Directive (EC) No 2009/72 art 3(4)). This provision clarifies the rationale behind the necessity to define and assign the task of electricity supply. Firstly, consumers are considered to be the weaker part in the market, and therefore need have the right to be provided by a supply company. Secondly, suppliers are not only contracting the provision of electricity supply with consumers, but also take responsibility to communicate load profiles of their contracted consumers to the system operator. Accurate information on load profiles is essential for balancing the grid and therefore crucial for the quality of electricity supply.

Further below, this paper explores whether blockchain technology could render the need for a provision requiring the responsibility of electricity supply assigned to a specific entity (supplier) nugatory. Instead, by means of blockchain technology any system user could contribute to supply. True P2P transactions however are by definition not enabled by intermediating entities, but need to be facilitated by technology. Arguably, blockchain technology constitutes "the next step in peer-to-peer economies" (Wright & De Filippi 2015 4).

2. Enabling peer-to-peer transactions – blockchain in the electricity sector

Centrally organised business models are challenged by new forms such as 'Airbnb' and 'Uber' which offer decentral, shared services (Fraiberger & Sundararajan 2015). Yet, the conclusion and payment of the transaction remains at centrally organised platforms of those providers. Blockchain technology offers not only decentral service provision, but also enables handling the related transactions decentral. The name 'blockchain' refers to the core of the technology, which entails digital information 'blocks' organised in a chronological 'chain'. "The trust machine" titled an article of 'The Economist' boldly, pinpointing the idea of blockchain technology that is cutting out the middleman and enabling true P2P transactions in various sectors (The Economist 2015). This section firstly outlines blockchain technology in its origins and different forms of applications and secondly, explores the possible use of those applications in the electricity sector.

2.1 Blockchain technology

The above section on P2P transactions in electricity outlined that sharing has a tradition closely connected to trust (Frenken & Schor 2017). Recently, trust in transactions can also be built by digital platforms connecting strangers and mitigating risks. Blockchain technology goes beyond the possibility of a central digital platform by sharing the information of all transactions between all system users.

> "The blockchain turns the entire network into its source of truth. It's a mechanism […] to collectively confer legitimacy on one another. That's why it appeals to the same people who fell in love with the Internet and the Web 20 years ago: No individual or company owns it, and anyone can participate in it." (Rosenberg).

Essentially, blockchain technology can be described as a digital, decentralised, and transparent ledger, which is shared among all users and is not in control of a single central actor (Nakamoto 2008). Trust in transactions is thus inherent in the design of the technology and abolishes the need for a middleman to act as verifying institution.

The origins of blockchain technology are rooted in the financial sector. "Bitcoin" is the most widely known application of blockchain technology which enables financial transactions without central banks as facilitator. Instead, transactions are recorded on 'blocks' which each refer back to the previous 'blocks' and thereby create a 'chain' which cannot be altered as all users act as verifiers (Nakamoto 2008). Thereby "Bitcoin" establishes an independent financial system with an independent currency of the same name. This bears the potential for the participating peers to create the market instead of being integrated in an existing market setting. This connects to the idea that blockchain technology is more than a technological innovation but constitutes an alternative to existing markets and organisations, and therefore is also referred to as "new institutional technology" (Davidson, De Filippi & Potts 2016).

Explaining the origins of blockchain applications requires exploring the question why transactions would rather be carried out on a blockchain than via an intermediate entity. Answers to this question are investigated in research relating to the economics of blockchain (Hasberg 2016). Essentially, it is argued that decentral organised systems reduce transactions costs (Hopf & Picot 2016). Additionally, the shift from central to decentral organised systems accelerates decreasing transactions costs:

> "Systems begin with centralization because this is the most efficient structure to create, establish and enforce rules, i.e. to create knowledge structures. This minimizes duplication and establishes clear hierarchy, and can adjudicate disputes. But those very features mean that centralization has costs that begin to accumulate as these powers become vulnerable to exploitation. […] Eventually, […] the costs of centralization rise along the path of exploitation while at the same time the costs of decentralization fall, often due to technological progress (e.g. cryptography and computers, in the case of blockchain). Centralization brings order, but this order can

> be brittle, and adaptation toward decentralization begins to make the system more robust, flexible, secure and efficient.” (Davidson, De Filippi & Potts 2016 5).

The process of decentralisation has already begun in the electricity sector with increasing amounts of small scale generation which are connected to the distribution grid. However, the decentralisation at the organisational level of the electricity sector is not facilitated yet by regulation. The development of blockchain and its application in the electricity sector require thinking about regulation which enables the decentralisation of organisational forms.

Blockchain itself is merely a technology which can take different forms and functions in its application. One of the earliest applications was “Bitcoin” establishing an independent financial system including its own currency. However, various use cases for the application of blockchain exist. Beyond digital currencies examples include self-executing smart contracts, decentralised organisations, cryptographic tokens, and digital voting platforms (Wright & De Filippi 2015). This only constitutes a non-exhaustive list of possible applications, which will rapidly expand in the future. Those applications could be applied in various contexts, as the application in the electricity sector proves. Two existing applications of blockchain technology which enable new forms of organisation are ‘smart contracts’ and, building on this, what is referred to as Decentralised Organisations.

The idea of smart contracts is that the conclusion of transactions can be fully automated and does not require any human interaction (Szabo 1997). Smart contracts could therefore be understood as “a piece of software code, implemented on a blockchain platform, which ensures self-performance and the autonomous nature of its terms, triggered by conditions defined in advance and applied to blockchain-titled assets” (Savelyev 2017 12). The rationale of smart contracts is economically motivated as “this technology [smart contracts] decreases the marginal costs of contracting, much like the Internet did to the transmission of data and information” (Wright & De Filippi 2015 16). However, beyond the economic dimension, smart contracts also raise fundamental legal questions as they create their own operational realm, from conclusion to enforcement. The characteristic which renders smart contracts a novel phenomenon is that “it allows automation of the process of contractual performance of both parties” (Savelyev 2017 6). So, offer, acceptance, and conclusion are fully automated and out of direct human control. Yet, underlying the smart contract are parties which wilfully agreed on criteria for concluding contracts and also agreed to transfer the trust of the anticipated transactions to the algorithm behind the smart contract. Applying the idea of smart contracts to the electricity sector opens the possibility of P2P transactions close to real-time. This could fundamentally change the role of current actors. The availability and transparency of data on energy and system capacities in combination with smart contracts allows peers to interact directly in a dispersed market. Consequently, this would weaken the key positions of suppliers and system operators in the sector.

Decentralised Organisations build on the application of smart contracts by accumulating smart contracts and thereby enabling new forms of governance. The idea can be summarised as follows: "using a blockchain-based decentralized organization, people and machines (or a combination of both) can coordinate through a set of codified smart contracts, without the need to incorporate into traditional business entities" (Wright & De Filippi 2015 24). As such, blockchain technology allows abolishing the need for large hierarchical organisations, as all data is shared and smart contracts determine interactions. This profoundly changes the existing understanding of organisations in any form as Decentralised Organisations possess no defined legal nature and are not dependent on executive decisions in any hierarchical way. Instead, the whole organisation is dispersed among its participants (Buterin 2014). In the context of a decentralised electricity sector, Decentralised Organisations could provide the opportunity to pool resources and load profiles and manage them according to predefined criteria.

2.2 Blockchain in the electricity sector

In the electricity sector the middlemen are the supply companies and system operators by connecting producer and consumer, contracting supply and delivery services. First reports explore the potential of blockchain technology for the electricity sector and, despite merely observing an initial phase of emergence, overall conclude that blockchain technology could facilitate P2P transactions (Verbraucherzentrale NRW 2016; European School of Management and Technology 2016). All information of transactions is thus shared among all system users and everyone acts as verifier for any transaction. This promises to coordinate dispersed persons offering or demanding electricity supply and services, thus a fully decentralised market setting (Scholtka & Martin 2017). In that sense, the question is not how the incumbent electricity industry will implement blockchain technology, but how blockchain technology will compete and contest with existing companies and markets (Davidson, De Filippi & Potts 2016). Blockchain technology could enable P2P supply, dispersed organisation of system operation, and consumer empowerment.

P2P electricity supply is the direct transaction between a generator and a consumer in the electricity sector. Currently, surpluses of electricity generated by decentral RES installations have to be sold through electricity supply companies for a fixed rate of return. Blockchain technology can enable the connection of 'peers' (system users, either generator or consumer at any moment) and facilitate them as direct trading partners. This is already tested in pilot projects, for example in Australia by the company “Power Ledger” (Powerledger). The company indicates that the future businesses in the electricity sector will not be based on assets, but increasingly on software. This is also the case for the above mentioned Dutch company “Vandebron”, by providing a platform for trade between generators and consumers. The application of blockchain technology goes further by automating the market trading and coordinating various system users. “They [blockchains] coordinate a distributed group of people, making them actually closer to being an economy” (Davidson, De Filippi & Potts 2016 11). Essentially, this would extend the market realm to the current consumer level and facilitate the efficient exploitation of decentral RES sources which are currently rather perceived as burdensome and not integrated in the electricity market (Scholtka & Martin 2017). However, under the current legal framework the direct interaction of peers is not possible, not even do ‘peers’ exist under the current framework. The supply of electricity is solely preserved for supply undertakings. The purpose is to provide consumers with protection, as they are considered to possess the weaker position in the market. Yet, this might change if consumers are truly ‘empowered’ by means of blockchain technology. Instead of being merely consumers, they would take responsibility for their actions. However, the process of empowering needs to be facilitated by technology and regulation equally.

Next to P2P supply of electricity blockchain technology could also enable various system users to directly contribute to maintaining grid stability (system operation). With increasing amounts of RES generation, system operation will increasingly need to rely on measures harnessing flexibility in the system (Kondziella & Bruckner 2016). Only then can the potential of RES be exploited and distribution losses can be reduced. Flexibility can be enhanced by a larger number and variety of system users offering flexibilities. Blockchain technology (possibly in form of smart contracts and Decentral Organisations) could provide the necessary software for system users to offer their flexibilities for system operation. This would assign every system user a balancing responsibility which is currently contracted with the electricity supply companies (Verbraucherzentrale NRW 2016). Moreover, system users would take direct responsibility for their system use. The idea of Decentralised Organisations might be a way of pooling and coordinating various flexibilities without a central entity acting as agent. However, the rewarding mechanism is less straightforward as for the sale of electricity as the timing in combination with the ability and willingness to use or not use the grid infrastructure is decisive.

Ideally (or rather consequently of the preceding two points), blockchain technology in the electricity sector would not only contribute to the efficient integration of RES and efficient grid usage, but also facilitate consumer empowerment. 'Consumer' might in a fully decentralised sector not even be the right term anymore, as every system user could switch between being generator, consumer, and possibly contribute to system operation. 'Empowerment' will then necessarily lead to responsibilities too, which need to be allocated by regulation. This clarifies that regulation for blockchain in the electricity sector would need to reconsider current definitions of actors (or even refrain from focusing on actors, as explained below). Even though the current legal framework on the electricity sector is far from enabling anything from the above outlined emerging ideas on blockchain applications in the electricity sector, the Commission of the European Union ventured a first step adjusting existing definitions in a legislative proposal (Commission of the European Union 2016). The amendment of the Directive includes a new category of consumers:

> "'Active customer' means a customer or a group of jointly acting customers who consume, store or sell electricity generated on their premises, including through aggregators, or participate in demand response or energy efficiency schemes provided that these activities do not constitute their primary commercial or professional activity" (Commission of the European Union 2016 art 2 (6)).

The suggested definition indicates a regulatory shift towards a new role of the electricity consumer (Lavrijssen 2017). Yet, true empowerment necessarily needs to include responsibilities; the definition alone can thus not enable the empowerment as envisaged by the legislative proposal.

3. Regulating for blockchain technology in the electricity sector

The previous section on possible blockchain application in the electricity sector outlined that existing actor typologies will be overhauled, as consumers will not remain consumers according to the current legal definition and understanding. Rather, every system user could contribute to the quantity and the quality of supply and thereby weaken the need for intermediate entities. This disperses the responsibilities electricity supply and not one single actor can be held accountable. Inevitably, this undermines the well-established logic of existing electricity sector regulation. Consequently, regulating for blockchain technology in the electricity sector requires fundamentally rethinking and designing regulation as even basic definitions of actors will not be valid under a blockchain scenario. Due to the fact that blockchain technology dilutes current roles of actors, regulation cannot be based on the definition of clear-cut actors anymore. Instead, regulation for blockchain technology in the electricity sector should focus on functions and tasks. Electricity supply entails two basic functions, namely the generation and supply of electricity and the transport of electricity. Currently, the responsibilities for generation, supply, and transport are allocated to the incumbent intermediate actors (generators, suppliers, and system operators). This institutionalisation is rooted in the central setting of the electricity sector, tailored to a system with large remote generation and passive consumption. However, this setting is changing and the increasing amounts of intermittent decentral RES require new forms of governance. This paper argues that regulating dispersed responsibilities requires focusing on two main functions, namely the quantity and the quality of electricity supply.

3.1 Quantity of electricity supply

Regulating the quantity of electricity supply in a setting of dispersed responsibilities requires establishing an automated dynamic pricing mechanism for electricity. The system users form the market and therefore reap the benefits of directly traded electricity. The example of the Australian company "Power Ledger" provides some practical insights in how the trade of electricity is implemented:

> "To trade electricity utilizing the blockchain, communication hardware must be fitted to a standard digital electricity meter that will keep track of electricity being generated, imported or exported. This is then converted into blockchain tokens, which are allocated to various accounts within the network – consumers, producers, and prosumers – as trading takes place between the parties. The blockchain tokens can then be monetized, either into a standard currency like Australian dollars, or Bitcoins themselves." (Gifford 2016).

This outlines the technical setting, yet one of the regulatory questions regarding the quantity of electricity supply is whether and how to ensure security of supply in a fully distributed setting. Currently, regulation establishes a clear regime protecting consumers in case a supplier fails. On the one hand, in a distributed setting in which system users could even change roles, it is highly complex to enforce a measure of clear accountability in case of failure. On the other hand, the system might also become more robust as the network is not built on one-to-one relations (consumer – supplier), but all system users are interconnected. Even stronger, the idea behind the inclusion of a large number of system users through blockchain technology would improve resilience to the extent that failure of single users would not harm the stability of the system.

3.2 Quality of electricity supply

As already indicated above, regulating the quality of electricity supply is less straightforward than a pricing mechanism for kilowatt-hours. Timing and capacity, and a combination of both are crucial for maintaining the quality of electricity supply. Blockchain technology could enable system users to contribute to system operation by specifying and communicating timing and capacity close to real-time. Possibly, a rewarding mechanism similar to the one mentioned above of the "Power Ledger" company could be installed. Yet, the pivotal regulatory question is analogous to the previous subsection, namely, which organisational entity can be held responsible if the system fails or is possibly hedged? Currently, the system operators are the responsible entities for secure and continuous operation of the grid. Again, dispersed responsibilities could increase technical resilience of the grid; however, it is nearly impossible to establish accountability. In order to develop a regulatory system which is capable of capturing a decentralised organisation of the electricity sector it is necessary to fully retreat from the current idea of well-defined actors. Instead, regulation would need to find mechanisms of pooled responsibilities.

Conclusion

Blockchain technology application in the electricity sector appears a promising innovation to further develop the transition towards an efficient low-carbon electricity sector. In future electricity systems (smart grids) P2P transactions will become increasingly relevant for efficiency gains. This paper points out that the idea to 'share' electricity necessarily also includes responsibilities which need to be allocated by regulation. Truly sharing electricity in form of P2P transactions, cutting out the incumbent electricity supplier and possibly system operator, also requires taking and complying with related responsibilities which are currently contracted with suppliers and system operators.

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