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Blockchain and the future of energy

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ABSTRACT

This paper discusses the emergence of blockchain technology in the energy sector in the light of ongoing energy market transformation. The study builds on literature research and expert interviews, and provides insights into the future energy landscape in the context of the blockchain advent. While the interviewees acknowledge the great, though disruptive, potential of blockchain technology for the primary activities in the electricity sector, there is agreement that inflexible regulatory frameworks impose the biggest challenge. The widest impact which blockchain technology will have in the short-term will be in electric vehicle integration, while in the long-term blockchain will enable peer-to-peer microgrids. The role that the blockchain will play, though, relies mainly on the business model innovation in energy. While a growing body of literature discusses specific blockchain applications and solutions in an advanced technological set-up, this paper presents a holistic picture of the blockchain applicability in the energy sector and thematises this very powerful and versatile technology against the background of two emerging economies: South Africa and Russia.

1. Introduction

Digitalisation of all economic activities is happening at a fast pace. According to an estimate by Accenture [1], digital economy which accounted for 22,5% of the global GDP in 2015 is expected to contribute 25,5% by 2020. In certain developed economies, the share of the digital segment will reach beyond 30% (e.g. the US — 38%, the UK — 33%, Australia — 32%). Moreover, the energy industry is undergoing a far-reaching shift to a decarbonised, decentralised and digitised energy production and distribution.

In order to facilitate the transition of the energy sector from conventional production to new principles and practices, *distributed energy* markets need to emerge. These markets are created through *distributed energy* systems which build on complex interconnected hardware systems and require novel solutions that support the exchange of energy and related data. In the context of the bidirectional electricity flow,[1] the existing centralised and hierarchical information and communication technology solutions soon reach their limits in satisfying the needs of decentralised energy systems [2]. New infrastructure (smart grids) now provides an interface for integrating small renewable energy producers while balancing energy supply and demand [3]. These new markets, which promise higher energy efficiency and lower carbon emission, require a technology that supports peer-to-peer exchange. This functionality can be found in a nascent distributed ledger technology (DLT), called blockchain.

The blockchain acts as a protocol enabling parties to transfer value or assets without a trusted third-party. Transfers are publicly recorded and validated by the network, allowing for a variety of assets to be traded. In order to build trust without an intermediary, all transactions are bundled and locally stored in verified blocks on numerous devices that belong to different participants (nodes) of the network. The blocks are equipped with *hash codes* that contain numbers and letters created with regard to information stored in this block. The hash codes serve for coupling the blocks, where each next block references the previous block's hash. This continuous verification process is conducted by certain members of the blockchain network (*miners*) and requires large computational power to solve complex mathematical problems. Such verification procedure guarantees that each of the network members might add an encrypted block to the chain of blocks; however, the previously chained blocks are not subject to revision. Yet, the exact procedure depends on the consensus mechanism applied in the blockchain.

Three developmental stages of blockchain application can be distinguished. The stage Blockchain 1.0 implies virtual (crypto)currencies (e.g. Bitcoin) that are used as an alternative to real currencies. Blockchain 2.0 enables smart contracts, i.e. digital protocols that

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[1] Standard perspective on the electricity flow in the centralised energy system: generation → transportation → distribution → usage.

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automatically execute predefined transaction processes without intermediaries (e.g. energy supply and relevant payment) in an autonomous and secure manner. The next generation of Blockchain 3.0 reaches a higher degree of autonomy with a decentralised autonomous organisation based on smart contracts with transaction record and program rules maintained on the blockchain [4,5].

In essence, the blockchain possesses a unique set of inherent features that adds value to a number of traditional and emerging applications in the energy sector. Due to these specificities, the [6] Digital Economy Outlook 2017 ranks blockchain as one of the pivotal technologies alongside AI, IoT and Big Data [6]. In the middle of 2017, energy-related use cases already accounted for 3% of the total applications of distributed ledger technologies [7]. Despite the fast changing energy landscape, the scope of the potential applications of the blockchain in the energy sector is, to this day, hardly researched at all. The existing research in the field concentrates on technicalities of particular blockchain solutions. This paper fills a gap in the literature by studying how industry insiders see the role of blockchain technology in the energy sector of the future. We start with a systematic classification of blockchain applications in the energy sector and identify products and services in the sector in which blockchain will be applied, both in the short- and long-term future.

Recent papers discuss the connection between energy trading and blockchain from a very general point of view. For example, Wu and Tran [8] identify four difficulties related to the economy-wide use of blockchain: (1) bottlenecks, (2) reliability and security issues, (3) standardisation and supervision mechanisms, and (4) a shortage of talent. While these difficulties are true for the majority of technological innovations, our paper aims to identify opportunities and difficulties against the background of a specific economy. Previously published studies with a similar focus analysed the potential of the blockchain mainly for advanced economies, particularly Germany (see, for example, [9,10]. This paper, in contrast, discusses how blockchain affects the energy sector in different emerging economies, namely Russia and South Africa. The innovation activities in such a setting face very different challenges, such as a general lack of funding opportunities, under-investment by the private sector, a scarcity of well-trained engineers and a low level of entrepreneurial activities. Examples are Russia [11] and South Africa [12].

While the first specifically blockchain-related publications were published in 2012 and discussed technical issues with respect to bitcoin [13], in 2015 the first blockchain applications appeared for the real sector [14]. Blockchain technologies might serve such purposes as asset registry, inventory and exchange of financial, physical and intangible assets (e.g. votes, reputation, health data, etc.) [15]. Hence, distributed ledgers are to be employed across multiple use cases for static information storage as well as for dynamic data (registry of tradable information) [16]. In the case of static data, the blockchain can be deployed for static registry and identity management. For transactions, the blockchain might be useful for data verification, payment processing infrastructure and smart contracts.

Most papers on the blockchain role in energy discuss distributed energy markets or energy trading for the local microgrid energy/peer-to-peer energy markets with smart contracts deployment. Here, electric vehicle charging is of special importance. Kang et al. [17] propose a vehicle-to-vehicle trading mechanism among e-vehicles built on a consortium blockchain that is based on local aggregators (as authorised nodes). Wang et al. [18,19] combine the consortium blockchain with a polycentric structure, including transaction and billing nodes, for establishing a unified payment channel for electric vehicle charging. Their suggestions aim to integrate different charging pile operators (charges and payment methods), which can solve the persistent problem of cumbersome and varying charging conditions in public places. Kim et al. [20] raise the problem of imposing a charge on the actual user while charging e-vehicles in the public places. They propose a billing system based on the lightweight blockchain for e-vehicle charging, which creates evidence of the time sequence of transactions without third party engagement. Another article shows how the blockchain may be suitable for implementing a sharing system. The blockchain ecosystem is proposed to include blockchain, a lightning network and smart contracts. The payment is executed through the lightning network, and smart contracts are transacted via the hash key verification [21]. Knirsch et al. [22] introduce a blockchain protocol for privacy-preserving electric vehicle charging. Electric vehicles send a request with the desired amount of energy, time interval and geographic region. Charging stations bid and the outcome is recorded on the blockchain. In the next step, the vehicle evaluates the bid recorded on the blockchain and matches it with the initial request. In the charging phase, the vehicle interacts directly with the charging station. Authors consider Bitcoin, Ethereum and Opencoin suitable blockchains and conclude that they are suitable in case of a small number of vehicles; however, scaling and the payment handling phase on the blockchain remain an issue.

Another energy-related topic with great application for blockchain is the trading of carbon emissions and green certificates. The blockchain is used for registration and storage of emission credits [23] and serves as a distributed database of carbon emission transactions, and thereby authenticates renewable energy crypto-credits [24]. Khaqqi et al. [25] created a framework in which the blockchain underlies the monitoring, verification and reporting procedures within emission trading by providing unforgeable and transparent records of permits. Research on Clean Development Mechanisms showed that the centralised registration process formed the biggest bottleneck [26].

For green certificates, an idea close to carbon emission trading, Imbault et al. [27] designed a blockchain system for managing environmental certificates, emission permits, etc. An implementation of consensus blockchain into an industrial operating system allows for traceable and secure transactions of energy assets. The blockchain tracks how the certificates are used and at which threshold they are granted. Castellanos et al. [28] simulate such market transactions based on Ethereum blockchain and smart contracts. The tokenised guarantees of origin (GoOs) are transacted between producers and consumers willing to pay for renewable energy. With blockchain technology, such tokenised GoOs, which are already in place in the European energy market, are transferred directly from consumers to renewable energy producers.

The blockchain technology also plays a major role in integrating energy production, transmission, utilisation and storage [29]. Zhang et al. [30] describe scenarios illustrating the carbon emission rights authentication, preserving the cyber-physical system security, virtual power resources trading and coordinating a multi-energy system. An established central operator might still be needed to ensure trust in direct prosumer-to-prosumer trading models [31]. The blockchain stores data collected from smart meters and transactions, while payments are executed automatically using smart contracts. Wu et al. [32] introduced a hybrid blockchain for a more efficient energy internet, decentralised supervision, as well as credible and safe data storage. Others consider a blockchain-based energy trading architecture with a less-centralised management system [33]. Zeng et al. [34] designed the multi-module cooperative autonomous mode and control flow and use blockchain for decentralised decision making and cooperative activity in the Internet of Energy.

The consortium blockchain is particularly suitable for unified and secure peer-to-peer energy trading in microgrids, energy harvesting networks and vehicle-to-grids with pre-selected energy aggregators, on which the blockchain performs the consensus process and credit-based payment scheme [17,35]. In this trading system, the energy nodes (entities which either sell or buy energy) are interconnected with the help of energy aggregators, i.e. the energy brokers that manage trading-related events and provide wireless communication between nodes.

Blockchain-based technologies can further be coupled with virtual power-plant (VPP) operations for the monitoring and balancing of

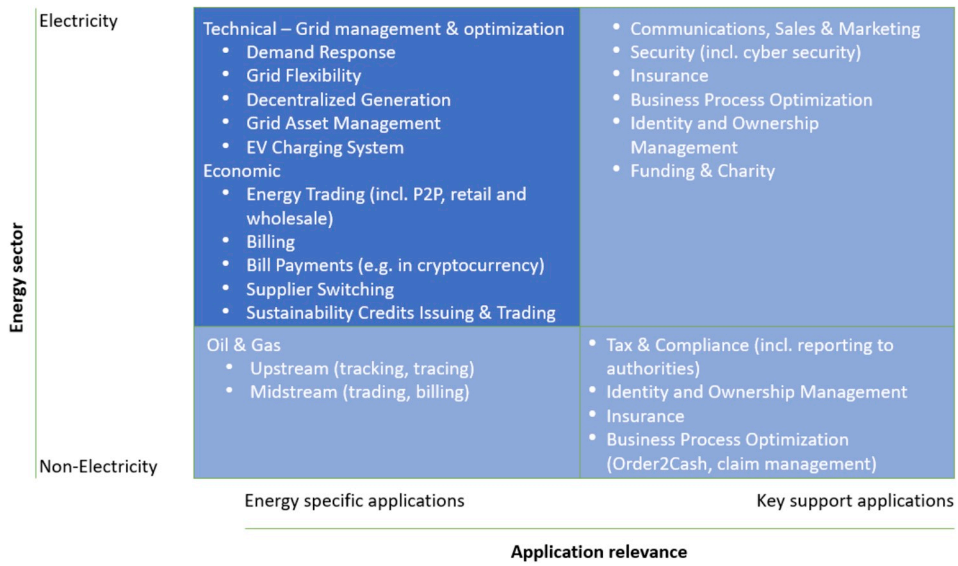

Fig. 1. Systematized overview of the blockchain applications in the energy sector.

demand and supply in real time [36]. Smart contracts based on blockchain encode automated negotiation, settlement and payment for the energy supply, while rewarding grid users for their role in balancing system [37]. Especially the unstable load dynamics of renewable energy sources and an expanding demand by e-vehicles will require Virtual Distribution Grids that provide demand-side grid management services [38,39]. In such an architecture, utilities, aggregators and prosumers are able to redistribute their excess/lack of energy supply and flexibility. In contrast with the wide-spread consideration of peer-to-peer energy trading in micrograds, Ouyang et al. [40] discuss peer-to-peer trading and its technical implementation through smart contracts for direct energy trading among large consumers.

2. Methodology and approach

In a first step, we reviewed the available literature, both energy industry reports and academic papers, through scientific databases. In a second step, we conducted expert interviews with academicians and practitioners to gather knowledge which is not systematically reflected in existing research or other available sources. We identified and approached industry experts and academicians either through their positions in their company or their publication activities, as well as through co-nominations. As the majority of blockchain activities in energy are driven by start-ups [3], we also included management personnel and founders of existing start-ups.

The expert interviews were aimed towards gaining an understanding of such aspects as the applicability of blockchain technology in the energy sector, the prerequisites of blockchain applications, the value which the blockchain can add to the energy industry, as well as the major limitations and issues concerning blockchain implementation. Since blockchain technology in the energy sector is a novel topic, and thus requires an explorative approach, we conducted semi-structured interviews based on a prepared interview guide. The interview questions were adjusted for each interviewee according to individual parameters (experience, attitude, etc.). After the first set of interviews, we asked our interviewees to suggest other experts. Each interview lasted between 45 and 60 min. We attach a list of interviewees to the appendix. We then analysed the interview transcripts with regard to the technologies, products and services that the experts had identified and the preconditions necessary for the scenarios to materialise. Both categorisation and conclusions were reviewed by sociologists to ensure consistency.

In the following chapter, we first present the new reality of the novel electricity market set-up, we introduce the definition and characteristics of blockchain and the energy internet in detail. In a second step, we present our findings based on the expert interviews and identify the challenges that exist when applying the current blockchain technology to the energy internet. Thereafter, we discuss blockchain in regard to its potential implications, issues and a vision for the future of energy in the light of the blockchain adoption.

3. Findings: blockchain in the energy sector

We noted a significantly lower number of businesses involved in blockchain-related activities in the oil-and-gas sector compared with the electricity sector. This can be attributed to the specificity of the industry, such as higher entry barriers compared to the electricity sector, lower potential for the decentralisation of primary activities, etc. [41–43]. In essence, in the oil-and-gas industry we identified existing blockchain projects related to supporting activities (the deployment of blockchain aimed at optimising established business processes), rather than at primary ones.

Regarding cases of blockchain-related activities in the electricity industry, we consider the blockchain to have the highest potential applied to primary activities, both for grid needs and trading. Hence, in the following chapter we discuss in detail those applications located in the quadrant « Energy specific application» in «Electricity» (Fig. 1).

Companies involved in blockchain development for the energy sector combine various applications, so that they do not directly fall into one of the presented classifications.

The discussed blockchain functionality is rarely deployed by companies as stand-alone blockchain projects, but the energy industry tends to combine these functionalities that facilitate a smart environment.

Unlike centralised energy systems, decentralised systems build on large numbers of actors who generate bidirectional electricity flows. In decentralised systems, consumers might also produce energy and create surpluses at certain times of the day, store energy, and thereby actively participate in the grid flexibility through demand-response programs, etc. These opportunities, though, bring about increased operational complexity in transfer of value and information, as well as an effective interface with the physical infrastructure [5].

> *What you actually need [in a decentralised energy system] is: you need a way to have consensus about what has happened in the past and what might happen in the future over the vast number of people that are involved and have to trust each other in order to make sure that the energy*

supply is safeguarded. And this is exactly the pin point where the blockchain is perfectly suited. (Expert 4)

In particular, the demand for the blockchain in distributed energy systems stems from the complex interaction of myriads of users who are acting in real-time in a peer-to-peer environment, relying on consensus in order to facilitate interaction. The increased amount of data and digital value generated in the power sector requires reliable, safe and transparent storage and direct transfer between actors without costly and time-consuming third-party involvement. Besides, the expansion of renewable energy generators facilitated by decreasing equipment costs (Shahan, 2018) denotes an ongoing increase in self-generated energy which, on a mass scale, cannot become self-sufficient without proper exchange mechanisms (Expert 2). Hence, easy market access to absorb the excess electricity requires a new market communication design for such energy producers.

If you want to integrate a small-scale power plant — let's say, the 5-kilowatt PV panel on top of your roof — into the market you still connect to the exact market infrastructure and IT infrastructure. For me [owner of a PV panel] it will cost X and for the big plant it will cost X too … As soon as you are trying to do it in the current market communication design, there's just no way you can compete. (Expert 4)

One of the major implications of the blockchain adoption is the crowding-out of intermediaries between electricity generation and consumption. In particular, blockchain adoption is likely to reduce the role of utilities, retailers and the wholesale energy markets.

I think that, if there is a peer-to-peer trading in place, then the role of utilities is diminished, because people are producing and distributing on their own. (Start-up 3)

You effectively do the job that the billing systems of the retailers do and the job that the trading systems of the retailers and the generators do — all collapsed into one system that operates in a non-hierarchical, very flat manner, where the actual transactions are all enabled by the distributed ledger technology, which sorts out things like trust, the costs of highly distributed transactions and so on.… I think it could effectively do away with the energy retailer in the long term … We can get rid of the differentiation between bulk energy and consumer-level energy by having a large number of small transactions enabled by a combination of much cheaper processing power. (Start-up 3)

The energy exchange without intermediaries results in lower energy costs for a final consumer, since retailers ("middlemen") take an estimated 20% above the value of energy (Expert 3). Besides, the blockchain integration would impact incumbent pricing models in the energy markets. Hence, the blockchain adoption might result in lower energy prices.

That is a societal choice: do we want energy to become something priced the same for everybody, or do we want to use energy prices as one of the factors that people take into account when they decide where to buy a house? (Expert 3)

The integration of the blockchain technology might indirectly impact some other markets, such as real-estate (as stated in the quote above), but it can also provide the basis for new business model developments in other sectors.

For example, automotive producers can actually vertically integrate blockchain for the first time ever … let's just imagine that in a few years from now you will get a car, and they will give it to you for free as soon as you leave them an opportunity to balance, to load and reload the car at night between 2 a.m. and 5 a.m. And for that storage purpose you will get a car for free. So, it is all about new business models. (Expert 4)

The major issue with regard to the blockchain adoption stems not from the technology itself, but rather from the yet unresolved questions of how the industry itself is evolving.

A highly decentralised energy system is nowadays facing problems related to electrical engineering, rather than those regarded as IT ones, especially when it comes to the stability of the grid in the light of injecting electricity produced by individuals. So, while everybody concentrates on blockchain's opportunities for trading, few realise that in the decentralised systems themselves many technical problems remain unsolved. (Expert 7)

In summary, the experts highlighted the following issues:

o Distribution of the blockchain running costs in a decentralised energy market
o Absence of digital identity management standards
o Lack of anonymity
o Data deletion
o Poor performance
o Integration challenges
o Skill requirements and unintuitive interface
o High running costs
o Absence of regulatory treatment in general

Experts agree that the applicability of blockchain technology will gain momentum alongside an increase of renewable energy in the energy mix (e.g. Expert 5). With regard to the decentralised energy system, the blockchain will be of relevance for such applications as peer-to-peer energy exchange in microgrids, which is currently gaining momentum in Europe (Expert 5). However, in the short term the upcoming prospects of the blockchain in the energy sector are associated with electric vehicles, namely e-vehicle charging (Expert 5, Expert 6) and vehicle-to-grid solutions (Expert 3), which, first of all, require a supportive regulatory environment.

In addition, experts claim that some energy applications do not necessitate the implementation of the blockchain yet. For instance, billing can be handled even in a distributed manner on an already existing cloud-based platform. Here, the blockchain corresponds with other technological solutions (Expert 7).

There is a widespread agreement among our interviewees that the blockchain is increasing in importance for geographic areas, where the electricity grid has to be built up from scratch or has to be operated in an isolated manner. Basically, blockchain technologies might follow the landline diffusion path in Africa, where people switched to mobile telecommunication instead. In other words, the blockchain might enable ways to electrify emerging economies without the need to develop traditional centralised grids (e.g. Expert 3).

The expert vision of the future electricity market varies between a genuine peer-to-peer market and a more decentralised market with trusted third parties in place. Furthermore, a peer-to-peer energy system might be technically feasible in the coming years, but the lack/absence of a regulatory framework defers it for much longer (Expert 3).

One scenario, and I am not saying that this one will come to pass, but one scenario is that we get genuine peer-to-peer trading where we do not need aggregators anymore. But, another scenario is that we do get aggregators, which do bundle up generation and demand response, and then sell these either in a traditional market or in the DLT-enabled market, where they sell directly to consumers rather than via retailers. The multiple scenarios could come to pass. … I think, technically it could be done in the next decade. But the regulatory and societal challenges of making that work put it at least twice as far away. I think, we are looking to probably 25 years for something like that at international level. (Expert 3)

In a similar manner, the role of the blockchain in the future market is arguable. While some treat it as a possibly ubiquitous technology, others believe the blockchain will be relevant "*for some tiny applications, but not as a big game changer*" (Expert 5). Still, all experts agree that the blockchain will play a role in the future energy sector.

The true role of the blockchain will depend on the business model innovation in energy.

It requires a thorough applicability analysis for each particular need. This refers to the type of consensus mechanism and other features of the blockchain, but what is more important — the value that can be added with the blockchain with regard to each need … So, if one tells me that he is going to use blockchain for the energy sector, I would ask two questions: for what exactly and what is the business model? (Expert 7)

The opportunities for blockchain in the energy markets of South Africa and Russia

Today, South Africa's electricity generation capacity stands at 44.2 GW; 92.6% of its 44.2 GW of energy production uses coal, 5.7% is nuclear energy, and the rest is produced through gas turbines and renewables. By 2030, the country plans to cover 20% of its demand from renewable energy sources [44]. Although the share of alternative energy is still very low, the way to open up the national grid to small scale energy providers was difficult. It was the very successful Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) that produced the first utility-scale renewable energy initiative. It introduced an open competitive bidding process, which saw the Department of Energy as the procurer and Eskom as the energy buyer. Before a bid could be placed, the independent power producers had to secure 'energy off-take agreements' with Eskom. Through REIPPPP, five bidding rounds took place between 2012 and 2016, providing cost-efficient energy generation [45]. Also in 2011, the National Energy Regulator of South Africa (NERSA) allowed municipalities to connect small-scale embedded generation of under 100 kW [46]. Eskom's Integrated Demand Management programme tested pilot off-grid and grid-tied small-scale renewable energy solutions for industrial and agricultural electricity consumers.

In 2013, NERSA awarded Amatola Green Power (PowerX) an energy trader licence to buy electricity from independent power producers and to sell this on to consumers. In the same year, the updated IRP 2013 predicted an increasingly uncertain energy future ahead and stressed the need for adaptive energy investments. Especially rooftop solar PV was identified as a viable alternative as the argument that renewables could not provide energy security was off the table. During 2018, 27 renewable energy independent power producer projects were signed.

What has great impact in South Africa, though, is the fact that 3.5 million households are not connected to the grid. Hence, there are more and more experts calling for decentralised grid solutions, especially for remote communities.

I think that in countries like South Africa you can get real grid independence and could have peer-to-peer trading in a very loosely coupled way, which is just not possible in the UK or Europe as a whole. I think actually for countries like that — apart from social implications — it potentially opens up a completely new avenue and a completely different model where you could have pretty much grid-wise isolated communities, and you can get rid of the whole transmission network completely. The combination of proper storage, and the amount of sunshine they get, should easily be able to generate the energy that they need, especially for domestic use. (Expert 3)

The blockchain has a tremendous potential for countries in Africa, where not every community is connected to a grid, but there are a lot of microgrid communities, so to say, the blockchain is offering potential to leapfrog the development of centralised grid systems as it happened with the land line phones and the smartphones. As far as I know, Africa had never had the land line phones. (Expert 4)

In addition, the shared ownership of energy equipment is the only affordable form in some regions of South Africa, and voluntary adherence to sharing economic principles (shared use of solar PVs, cars) in more developed regions requires accurately designed solutions for ownership that can be registered and transferred in a transparent and timely manner on the blockchain [47].

Installed capacity in Russia amounts to 240 GW, and almost two thirds of all produced electricity comes from heat power plants mostly running on natural gas (over 60%). However, coal still accounts for almost 15% of generated energy. Russia's energy sector hosts the major stake of installed cogeneration capacity in Europe, which, in turn, accounts for almost 40% of cogeneration capacity all over the globe. Nowadays, the governmental modernisation program revolves around cogeneration practices, which, in the case of Russia, and opposed to the global trend, implies large-scale generation instead of small-scale coproduction from renewables. Furthermore, technological advances in energy generating industries are concentrated largely in the nuclear power sector [48].

Nevertheless, for Russia the development and deployment of blockchain technology ranks as a national priority (e.g. at the Economic Forum in Davos, 2018). So far, blockchain-related discussions have lacked specific resolutions and decisions — though this technology is believed to hold great potential, according to the strategic plans of Russian energy companies and the state (e.g. within the framework of the state programme Digital Economy) [49].

So far, there is little information available, but the publication of action plans for the Digital Economy programme continues. It seems that Russia will not be an exception, and the electric power industry — first of all, the power grid complex — will become the main direction of the implementation of the blockchain technology. Blockchain can support intellectualisation of the power sector. There are certain prospects for its implementation in decentralised power systems and in electric vehicles, but they are associated with uncertainty about these industries per se in Russia. (Expert 6)

At the end of the 20th century Russia's centralised energy system was the world's largest. The chaotic process of decentralisation started already in the 1990s; however, the distributed generators in Russia initially emerged solely at the production sites and did not take root at the residential level. By the early 2010s, electricity tariffs increased significantly and grid connection costs triggered enterprises to establish their own energy supply points — now accounting for 9–9.5% of operating capacities [50]. While cases of industrial use of distributed generation may number in the hundreds, households continue to be supplied by the centralised grid.

The reasons for the differences between Russia's energy sector and current practices on global scale lie in the current structure of the Russian energy sector based on centralisation and traditional sources of energy. … A decentralised energy system with distributed generation, especially with a large share of renewables, where the blockchain is expected to be in great demand, receives less attention in Russia than in any developed country and even in a number of developing countries. Here, decentralised energy supply and the blockchain are an option for isolated and inaccessible territories, although discussions on their potential for the entire Russian market continue. A pilot initiative was launched in July 2017 to support the renewable-based microgeneration, but it is unlikely to have a lasting effect on the Russian energy system. The same can be said about electric vehicles. (Expert 6)

Besides the bias of Russia's energy sector towards fossil fuels, the badly defined regulatory framework of Russia is another difficulty. In particular, the generation of electricity is not strictly defined and codified by law, which makes the estimates of distributed generation in Russia a challenging task (Expert 6). Moreover, a strategic input for the sector development is needed, since "*at the state level, priorities have not yet been set — neither strategy, nor the general scheme: nothing yet*" (Expert 6).

Nevertheless, certain business opportunities in the energy sector may emerge even under the current conditions. The Russian payment service provider QIWI is planning to integrate blockchain technology by 2021 and — at the time of this research — considered collaboration with the Crimean energy company «Tavrida Electric». The energy company plans to record all its transactions on the blockchain [51]. However, one should not expect a wide acceptance of the blockchain until the regulatory framework is in place, especially when it comes to large companies (Expert 1).

Large oil-and-gas players in Russia's energy field show interest in digital technologies, and the blockchain in particular. However, the perspective of digital technologies implementation relates to support activities [52].

The blockchain is most likely to be implemented by the largest companies in the processes of document circulation or contractual activities. Thereby, they can reduce operational costs by 5-10% annually. (Expert 1)

At the current stage, energy companies might implement blockchain in the trading activities, but this will not imply any sector specificity. Nearly any commodity can be traded on the blockchain. (Expert 6)

To conclude, as long as the energy sector in Russia is dominated by conventional fuels and large vertically integrated companies, the energy sector will not — on a large scale — adopt the blockchain technology for energy-specific applications. One of the reasons for that is the threat which the blockchain poses to the function of an intermediary, which concerns some established companies. Furthermore, the blockchain facilitates interaction between dispersed multiple players of the energy system. Thus, the current inflexible structure of Russia's energy system is opposed to the general principles of blockchain technology. As long as power is generated by centralised power plants, the technology might be deployed only as a niche solution.

I believe that by the year 2030 there will be a lot of pilot blockchain projects in Russia's energy sector, and then everything will depend on their results, but I do not think that it will be widely accepted … rather: blockchain will come in as niche application. (Expert 1)

Decentralised energy might gain momentum in remote areas, where decentralised generation is the only viable solution from an economic perspective. This might bring about a window of opportunity for the blockchain. However, a positive scenario of the blockchain adoption might occur for power systems intellectualisation and payment infrastructure development.

Russia is most likely to take on such blockchain dimensions as the intelligence elements of power systems (accounting, control, data exchange, etc.), and, if pilot projects should demonstrate the feasibility, the development initiative for the blockchain-based payments for energy resources. (Expert 6)

4. Conclusion

This research systematises the opinions of industry experts and leading academics regarding the possibilities of blockchain technology for the energy markets. Since most companies are running pilot projects, the application of the technology is mainly dependant on its functionality and features. Our findings show that the electricity sector is testing blockchain technology in an attempt to support the decentralisation of energy production. This focus on trial and error runs is not unusual and was actually suggested by industry reports (e.g. Ref. [9]. The adoption of blockchain technology is consistent with the emerging needs of transforming electricity markets, i.e. is driven by both demand pull and technology push. The application of blockchain in oil-and-gas, on the other hand, is mainly connected to business process optimisation.

Based on our expert interviews we confirmed that the potential of blockchain technology goes far beyond peer-to-peer energy trading. While the latter is widely discussed, the short-term outlook is mainly associated with the blockchain-enabled electric vehicle integration. Although there is disagreement on the exact impact of blockchain technology in energy markets in the mid- and long-term future, our interviewees agree that blockchain will play a significant role in one way or another. Regarding blockchain adoption, the major concerns relate to technology maturity and the role of the regulatory frameworks. While the infant technology will undergo improvements, the regulatory frameworks might pose serious barriers to the technology adoption. Our findings are in line with Burger et al. [10] who reported industry experts' very critical view of the current regulatory framework in Germany. Although the blockchain could help overcome many energy-related issues in countries, such as South Africa, their regulatory frameworks are even more rigid and focused on central energy provision.

Most likely those applications that are connected to less decentralised systems will play a wider role for energy markets across the globe. For blockchain technology to play a bigger role in the energy field, more business model innovations for the energy sector are needed.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techsoc.2018.11.001.

Appendix

Passports of Interviewed Experts & Start-ups

1. Expert 1

Position	SKOLKOVO Energy Centre, Senior Analyst
Geography	Russia

2. Expert 2

Position	Senior industry expert and part-time professor
Geography	The Netherlands

3. Expert 3

Position	Executive of international technology corporation
Geography	United Kingdom

4. Expert 4

Position	Professor and start-up co-founder
Geography	Germany

5. Expert 5

Position	Senior Associate Consulting EU Electricity Market
Geography	Germany

6. Expert 6

Position	Energy policy analyst
Geography	Russia

7. Expert 7

Position	Professor and Managing Director of research institute
Geography	Germany

8. Expert 8

Position	Professor
Geography	South Africa

9. Start-up 1

Position	Founder & CEO
Geography	Israel

10. Start-up 2

Position	CEO
Geography	South Africa

11. Start-up 3

Position	Business Development Manager
Geography	China

References

[1] Accenture, Digital Disruption: the Growth Multiplier. Optimizing Digital Investments to Realize Higher Productivity and Growth, (2016).
[2] M. Mourshed, S. Robert, A. Ranalli, T. Messervey, D. Reforgiato, R. Contreau, et al., Smart Grid Futures: Perspectives on the Integration of Energy and ICT Services, (2015).
[3] International Energy Agency, Digitalization & Energy, IEA PUBLICATIONS, 2017, October.
[4] K. Panetta, Top Trends in the Gartner Hype Cycle for Emerging Technologies, 2017, (2017, August) Retrieved from www.gartner.com/smarterwithgartner/top-trends-

in-the-gartner-hype-cycle-for-emerging-technologies-2017/.
[5] PwC, Blockchain – an Opportunity for Energy Producers and Consumers? (2016).
[6] OECD, OECD Digital Economy Outlook 2017, OECD Publishing, Paris, 2017.
[7] G. Hileman, M. Rauchs, Global Blockchain Benchmarking Study, Cambridge Centre for Alternative Finance with the support of VISA and EY, 2017.
[8] J. Wu, N. Tran, Application of blockchain technology in sustainable energy systems: an overview, Sustainability 10 (9) (2018) 3067.
[9] BDEW, Blockchain in der Energiewirtschaft, Potenziale für Energieversorger, 2017, October.
[10] Ch Burger, A. Kuhlmann, P. Richard, J. Weinmann, Blockchain in the Energy Transition. *A Survey Among Decision-makers in the German Energy Industry*. Berlin, November 2016, (2016).
[11] T.W. Thurner, M. Gershman, V. Roud, Partnerships as internationalization strategy: Russian entrepreneurs between local restrictions and global opportunities, J. Int. Enterpren. 13 (2) (2015) 118–137.
[12] I.H. Petersen, G. Kruss, Promoting Alignment between Innovation Policy and Inclusive Development in South Africa, Development Southern Africa, 2018, pp. 1–25.
[13] M. Holub, J. Johnson, Mapping Bitcoin's Influence on Academic Research, (2017, August).
[14] M. Pilkington, 11 Blockchain technology: principles and applications, Res. Handb. Digit. Transform. 225 (2016).
[15] M. Swan, Blockchain: Blueprint for a New Economy, O'Reilly Media, Inc., 2015.
[16] I. Zikratov, A. Kuzmin, V. Akimenko, V. Niculichev, L. Yalansky, Ensuring data integrity using blockchain technology, Open Innovations Association (FRUCT), 2017 20th Conference of, IEEE, 2017, April, pp. 534–539.
[17] J. Kang, R. Yu, X. Huang, S. Maharjan, Y. Zhang, E. Hossain, Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains, IEEE Transact. Indus. Inform. 13 (6) (2017) 3154–3164.
[18] J. Wang, Q. He, Y. Xu, Q. Han, Z. Zhou, An unified payment method of charging piles based on blockchain, Proceedings of the 2017 the 7th International Conference on Computer Engineering and Networks, 2017, pp. 22–23 July, 2017 Shanghai, China (CENet2017) Online at href=" https://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=299,id.85.
[19] J. Wang, Q. Wang, N. Zhou, Y. Chi, A novel electricity transaction mode of microgrids based on blockchain and continuous double auction, Energies 10 (12) (2017) 1971.
[20] N.H. Kim, S.M. Kang, C.S. Hong, Mobile charger billing system using lightweight Blockchain, Network Operations and Management Symposium (APNOMS), 2017 19th Asia-Pacific, IEEE, 2017, pp. 374–377.
[21] L. Ql, X. Li, B. Qi, H. Wang, Shared economy model of charging pile based on block chain ecosystem, Dianli Jianshe/Electric Power Construction 38 (9) (2017) 1–7 1 September 2017.
[22] F. Knirsch, A. Unterweger, D. Engel, Privacy-preserving blockchain-based electric vehicle charging with dynamic tariff decisions, Comput. Sci. Res. Dev. 33 (1–2) (2018) 71–79.
[23] E. Al Kawasmi, E. Arnautovic, D. Svetinovic, Bitcoin-based decentralized carbon emissions trading infrastructure model, Syst. Eng. 18 (2) (2015) 115–130.
[24] R.D. Leonhard, Developing Renewable Energy Credits as Cryptocurrency on Ethereum's Blockchain, (2016).
[25] K.N. Khaqqi, J.J. Sikorski, K. Hadinoto, M. Kraft, Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application, Appl. Energy 209 (2018) 8–19.
[26] T.W. Thurner, A. Varughese, Experiences of project developers around CDM projects in South Africa, Energy Pol. 61 (2013) 1271–1275.
[27] F. Imbault, M. Swiatek, R. De Beaufort, R. Plana, The green blockchain: managing decentralized energy production and consumption, Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), 2017 IEEE International Conference, IEEE, 2017, June, pp. 1–5.
[28] A. Castellanos, D. Coll-Mayor, A. Notholt, Cryptocurrency as guarantees of origin: simulating a green certificate market with the ethereum blockchain, 5th IEEE International Conference on Smart Energy Grid Engineering (SEGE) : August 14-17, 2017, UOIT Oshawa, Canada, 2017.
[29] T. Yang, Q. Guo, X. Tai, H. Sun, B. Zhang, W. Zhao, C. Lin, Applying blockchain technology to decentralized operation in future energy internet, Energy Internet and Energy System Integration (EI2), 2017 IEEE Conference on, IEEE, 2017, November, pp. 1–5.
[30] N. Zhang, Y. Wang, C. Kang, Blockchain technique in the energy internet: preliminary research framework and typical applications, Proc CSEE 36 (15) (2016) 4011–4022.
[31] X. Tai, H. Sun, Q. Guo, Electricity transactions and congestion management based on blockchain in energy Internet, Power Syst. Technol. 40 (2016) 3630–3638.
[32] L. Wu, K. Meng, S. Xu, S. Li, M. Ding, Y. Suo, Democratic centralism: a hybrid blockchain architecture and its applications in energy internet, Energy Internet (ICEI), IEEE International Conference on, IEEE, 2017, April, pp. 176–181.
[33] J. Cai, S. Li, B. Fan, L. Tang, Blockchain based energy trading in energy internet, Dianli Jianshe/Electric Power Construction 38 (9) (2017) 24–31 1 September 2017.
[34] M. Zeng, J. Cheng, Y. Wang, Y. Li, Y. Yang, J. Dou, Primarily research for multi module cooperative autonomous mode of energy internet under blockchain framework, Proc. CSEE 37 (13) (2017) 3672–3681.
[35] B. Li, H. Xiao, Y. Wen, et al., Cloud service mode analysis of smart electricity based on block Chain, Dianli Jianshe/Elect. Power Construct. 38 (9) (2017) 8–14.
[36] W. She, Y. Hu, X. Yang, S. Gao, W. Liu, Virtual power plant operation and scheduling model based on energy blockchain network, Zhongguo Dianji Gongcheng Xuebao/Proc. Chin. Soc. Elect. Eng. 37 (13) (2017) 3729–3736.
[37] L. Thomas, C. Long, P. Burnap, J. Wu, N. Jenkins, Automation of the Supplier Role in the GB Power System Using Blockchain Based Smart Contracts, (2017).
[38] J. Horta, D. Kofman, D. Menga, Novel Paradigms for Advanced Distribution Grid Energy Management, (2017) arXiv preprint arXiv:1712.05841.
[39] J. Horta, D. Kofman, D. Menga, A. Silva, Novel Market Approach for Locally Balancing Renewable Energy Production and Flexible Demand, (2017) arXiv preprint arXiv:1711.09565.
[40] X. Ouyang, X. Zhu, L. Ye, J. Yao, Preliminary applications of blockchain technique in large consumers direct power trading, Zhongguo Dianji Gongcheng Xuebao/Proc. Chin. Soc. Elect. Eng. 37 (13) (2017) 3737–3745.
[41] T. Thurner, L. Proskuryakova, Sectoral entry-barriers for entrepreneurial activities–a Russian start-up between challenging global markets and local conservative path dependencies, Foresight 18 (6) (2016) 649–659.
[42] T. Thurner, L.N. Proskuryakova, Out of the cold–the rising importance of environmental management in the corporate governance of Russian oil and gas producers, Bus. Strat. Environ. 23 (5) (2014) 318–332.
[43] R.P. Stastny, Thinking like a Start-up: Oil and Gas Innovation Needs to Go beyond Just Cool New Gadgets, JWN Trusted Energy Intelligence, 2017 [Online] Accessed on 01.05.2018. Available at: http://www.jwnenergy.com/article/2018/5/canadian-oil-and-gas-employment-continues-rise-q1/.
[44] Impact Amplifier, Energy Provision at the Base of the Pyramid, (2017) http://www.impactamplifier.co.za/our-insights/reports/.
[45] B. Msimanga, A.B. Sebitosi, South Africa's non-policy driven options for renewable energy development, Renew. Energy 69 (2014) 420–427.
[46] Government Technical Advisory Centre, ERLN Learning Event Report: Local and Subnational Renewable Energy and Energy Efficiency; Challenges and Opportunities for Economic Development, (2015).
[47] S. Albrecht, S. Reichert, J. Schmid, J. Strüker, D. Neumann, G. Fridgen, Dynamics of blockchain implementation-A case study from the energy sector, Proceedings of the 51st Hawaii International Conference on System Sciences, 2018.
[48] Grigorev, et al., Sanctions in the global energy policy, Energy Bull. 64 (2018) September 2018.
[49] Minenergo, V Minenergo Rossii Sostoyalos' Pervoye Zasedaniye Rabochey Gruppy Po Tsifrovoy Transformatsii Tek, (2018) [Online] Accessed on 01.05.2018. Available at: https://minenergo.gov.ru/node/11009.
[50] A. Khokhlov, J. Melnikov, F. Veselov, D. Kholkin, A. Datsko, Raspredelennaya Energetica V Rossii: Potential Razvitija, Moscow School of Management SKOLKOVO, 2018.
[51] L. Coleman, Russian Crypto Firm Qiwi Is Working on a Blockchain Energy Project in Crimea. CCN, (2016) Available at: https://www.ccn.com/qiwi-blockchain-crimea-energy-project/ , Accessed date: 1 May 2018.
[52] Gazprom Neft, V «Gazprom Nefti» Ispytali Blokcheyn I Internet Veshchey V Logistike, (2018) [Online] Accessed on 01.05.2018. Available at: http://www.gazprom-neft.ru/press-center/news/1388456/.