**International Conference on Applied Energy 2019**
**Aug 12-15, 2019, Västerås, Sweden**
**Paper ID: 95**

# PRACTICAL CHALLENGES AND OPPORTUNITIES OF BLOCKCHAIN IN THE ENERGY SECTOR: EXPERT PERSPECTIVES IN GERMANY

Amanda Ahl[1], Mika Goto[1], Masaru Yarime[2,3,4], Kenji Tanaka[5], Daishi Sagawa[5]

1 Department of Innovation Science, Tokyo Institute of Technology

2 Division of Public Policy, The Hong Kong University of Science and Technology

3 Department of Science, Technology, Engineering and Public Policy, University College London

4 Graduate School of Public Policy, The University of Tokyo

5 Graduate School of Engineering, The University of Tokyo

## ABSTRACT

The energy sector is undergoing decarbonization, decentralization, and digitalization. This paper explores the application of blockchain in this transition. Based on structured interviews with 15 experts of energy and blockchain in Germany, practical challenges and opportunities are explored from multiple perspectives: technological, economic, social, environmental, and institutional dimensions. A critical identified issue is the matching of regulatory change with technological advancements, potentially facilitated through multi-stakeholder engagement and regulatory sandboxes. At large, this paper aims to contribute with holistic insights and outlooks for blockchain in the energy sector.

**Keywords:** Blockchain, Digitalization, Distributed Energy, Renewable Energy, Germany, Interviews

## NONMENCLATURE

| | |
|---|---|
| AI | Artificial Intelligence |
| BaaS | Blockchain-as-a-Service |
| EaaS | Energy-as-a-Service |
| GDPR | General Data Protection Regulation |
| GoO | Guarantee-of-Origin |
| IoT | Internet of Things |
| M2M | Machine-to-machine |
| ML | Machine Learning |
| P2P | Peer-to-Peer |
| PoA | Proof of Authority |
| PoS | Proof of Stake |
| PoW | Proof of Work |
| REC | Renewable energy certificate |
| spt | Seconds per transaction |
| tps | Transactions per second |
| V2G | Vehicle-to-Grid |
| VPP | Virtual Power Plant |

## 1. INTRODUCTION

Energy systems worldwide are undergoing decentralization, digitalization, and decarbonization [1, 2]. The expansion of distributed energy alongside the electrification of transportation is likely to increase stress on the power grid, calling for increased grid intelligence and coordination [3]. Local energy production [4] and the diversity of producers, including prosumers, is rising [5].

Management of a large number of data streams and incorporation of information is likely to become increasingly difficult as energy decentralization and complexity surges [3]. Digitalization in the energy sector can contribute to managing complexity and facilitating renewable energy. Smart energy systems require various technologies, such as ML, AI, and blockchain, to support real-time learning, decision-making, and automation [3].

With digitalization in the energy sector alongside a rise in distributed energy technologies, centralized digital systems are both a bottleneck in managing an increasing amount of data and raise security issues due to a single point of failure [6]. Distributed computing is needed to support the management of increasingly numerous and distributed sources, and blockchain can offer key advantages in this context [6, 7].

Blockchain is a distributed ledger technology which can facilitate transactions without a globally trusted intermediary, based instead on encryption and consensus mechanisms [6]. Consensus mechanisms are processes used to reach agreement on a value or state in a multi-agent blockchain network. In addition, smart contracts can be added to blockchain platforms for autonomous and disintermediated P2P transactions based on pre-determined conditions [7]. With such mechanisms, blockchain has potential to contribute to energy decentralization, autonomy, and intelligence [4, 8, 9].

There are several opportunities to leverage blockchain in energy value chain innovation, such as for P2P-trading, V2G coordination, ancillary services, and RECs [2, 9]. However, blockchain energy applications are mainly in the form of pilot projects [4], with numerous challenges yet to be overcome. There is a need of research and discussion on challenges exposed in practice [9]. The current study aims to explore the practical challenges and opportunities of blockchain in the energy sector, and suggest holistic insights.

## 2. METHODOLOGY

Blockchain in the energy sector can be investigated from technological, economic, social, environmental and institutional dimensions [10]. Challenges in each dimension and opportunities to overcome them were explored based on structured interviews with 15 blockchain players connected to the German energy sector. Germany was selected as it is one of the forerunners in blockchain, including for energy. This can be seen both in the private and public sector [11]. By examining the current situation in Germany, which is among the leading countries in the field of blockchain energy applications, it is suggested that key opportunities and challenges in this field which would be relevant across the globe can be identified. Applying open-coding in a grounded theory method to interview transcripts, challenges and opportunities to overcome them were discussed. Based on the results and discussions, this study was concluded with key insights and outlooks for blockchain applications in the energy sector.

Fourteen of the interviewed experts are based in Germany and one in the United States, which indicates a likelihood of bias. However, the experts are all globally active in the blockchain and energy space. Therefore, it can be suggested that the practical insights provided are valuable indicators of key factors for further progress of blockchain energy applications, both in Germany and worldwide. While these insights can provide initial directions for future research and development, there would also be a need for further studies on specific contexts, such as for local blockchain pilot projects.

## 3. RESULTS AND DISCUSSION

### *3.1 Technological dimension*

Experts noted that blockchains and smart contracts are likely to be important in the energy sector, but to change significantly over time. Blockchain is not a panacea developing in isolation, but likely part of a "toolbox" with other technologies, such as AI, ML, and IoT. The following technological challenges were derived:

A) **Smart meters:** lack of rollout in Germany
B) **Interoperability:** cross-chain and blockchain-hardware integration
C) **Scalability:** throughput (tps), latency (spt), block size limits, large-scale data storage
D) **Privacy and security** of data

Andoni et al. [2] and dena [11] similarly emphasized smart meter infrastructure and integration for blockchain applications. Experts noted, however, that smart meter expansion coupled with smart meter gateways and digital twins can improve meter infrastructure and technical integration.

The ongoing advancement of multi-chain blockchains and blockchain bridges was given by several experts as a pathway to support interoperability and scalability. For example, a relay channel network such as "Polkadot" can be used to parallelize blockchains, support cross-chain communication [4], increase throughput, and support scalability. A potential use case is a parallel chain representing one microgrid, with multiple microgrids connected to the main relay chain. Scalability is being improved with sharding (database partitioning), multi-chain structures, off-chain storage, and new consensus mechanisms, e.g. PoA and PoS [12].

Experts discussed pseudonymity for privacy and security. However, identities can be deciphered behind pseudonymous addresses by analyzing data patterns [4]. Enhanced scalability while maintaining privacy and cybersecurity is a key objective moving forward.

### *3.2 Economic dimension*

Experts discussed several economic challenges:

A) **Power grid:** capital-intensive development
B) **Power market:** inflexibility, non-dynamic mechanisms, high transaction costs
C) **Risk:** uncertain use cases, business models, and financial returns on digital solutions
D) **User base:** uncertain user base, and need of network effects

Experts noted the importance of smart solutions for power grid coordination and avoiding grid expansion expenses. One expert noted that the integration of digital solutions in grid fees may also reduce investment risk. In terms of power markets, transaction costs such as brokerage fees were described as prohibitive of small-scale distributed energy. Blockchain and smart contracts may be useful for wholesale-trading based on quantity, prices, zones, time, and so on. This may contribute to disintermediation, granularity, reduced transaction costs, and incorporation of diverse market players.

If participants benefit from decentralization and disintermediation, blockchain makes economic sense. There are several potential use cases discussed by experts, including EaaS platforms, VPPs, IoT and M2M platforms, wholesale aggregators for distributed energy, ancillary service coordination, peak-shaving, P2P-trading, EV charging/discharging/payments, RECs, electricity billing, and community ownership models.

EaaS platforms were given as an important opportunity to explore new business models. Numerous authors have also discussed an energy platform economy [2, 8, 9]. Furthermore, experts discussed user base uncertainties, and the need of network effects for an effectual platform economy. A critical user mass would be needed for blockchain-based wholesale markets [4].

### *3.3 Social dimension*

On the one hand, experts emphasized user-centricity and network effects. "There will be no personal user gains (of platforms) without mass-scale adoption." On the other hand, conservatism among traditional actors in the energy sector was discussed as an inhibitor of innovation. Key discussed challenges included:

A) **Conservatism:** among incumbent utilities
B) **Role disruption:** effects on roles and jobs
C) **Skills:** lack of digital skills, including blockchain
D) **User-friendliness:** development needed
E) **Digital engagement:** development needed
F) **Security and privacy**: concerns and acceptance
G) **Network effects:** mass-scale adoption

There is a strong social shift towards a digital economy leveraging new technologies [13]. Experts noted that some utilities are reacting by hiring IT experts and creating innovation departments. Skill development on multiple levels is needed, from professionals to communities. Further integration of digital skills in human resource management was also suggested.

On the user side, experts noted that blockchain interfaces are not sufficiently user-friendly. Interactive dashboards and user-friendliness may indeed encourage participation [3]. Mobile and digital payments are becoming more commonplace. Purchase and sales of energy as well as investments may change with the expansion of blockchain platforms [2]. Experts also highlighted new investment prospects, such as co-funding and value-splitting of renewable energy. Other digital technologies such as AI can also be integrated for new services, such as customized insights and bill forecasts, if users are willing to share data.

Experts discussed the need to clarify user value in digital energy platforms. User-centric design and testing can aid in identifying this value and managing any concerns. The purpose(s) of data collection would be imperative to communicate clearly, as a perception of service provision as opposed to surveillance may be more accepted [3]. Engagement and the gathering of user feedback would be important for smart energy system development [3]. Considering the importance of behavioral change and network effects, social science, psychology, and marketing were given by an expert as perspectives to be further integrated in pilot projects.

### *3.4 Environmental dimension*

Key discussed challenges of environmental sustainability included:

A) **Costs:** of renewable energy technology
B) **Intermittency:** curtailment of renewables
C) **Fraud:** in carbon certificates and RECs
D) **Resource-intensity:** of crypto mining

One expert discussed modular systems for reduced renewable energy costs. Reducing costs can drive installation, and blockchain is a potential tool for power coordination. Blockchain may, for example, contribute to tracking and tracing of resources. With an increasing number of e-mobility systems [3, 9], for example, blockchain can contribute to coordination of micro-transactions in charging and discharging these systems.

Blockchain was also discussed in academia [2, 9] and by experts for fraud prevention, such as for RECs. Via encryption and its immutability [2], blockchain can support "…data for electricity, gas, water… via GoOs."

The energy intensity of crypto-currency mining based on PoW consensus mechanisms is a common critique of blockchain sustainability. However, new consensus mechanisms, such as PoS and PoA, avoid mining and have lower energy consumption [14].

### *3.5 Institutional dimension*

Experts noted several institutional challenges:

**A) Regulatory complexity**
**B) Smart meters:** stalled rollout

C) **Electricity billing:** inefficiency, inflexibility
D) **Double surcharges:** network fee and taxation for storage charging/discharging
E) **GDPR:** data ownership, privacy and sovereignty
F) **Legal uncertainty:** lack of standardization (e.g. dispute management), transaction reversals, cryptocurrency taxation.
G) **Role uncertainty:** changing and unclear roles
H) **Use case uncertainty:** lack of clear use cases
I) **Incumbent interests:** in energy sector
J) **Political risk aversion:** critical infrastructure

Regulatory complexity and uncertainty of blockchain applications encompass key issues. Several institutions affect blockchain use cases, from data security to energy laws [11]. Blockchain integration and digital gateways in smart meter rollouts may be of interest. The German Energy Agency noted electricity billing and network charges as bottlenecks in energy sector development [11]. Enhanced tariff flexibility is needed for local energy-trading [2]. Experts discussed double surcharge of tax and network fees for battery charging/discharging as a grid flexibility challenge. This was also noted by Kreeft [15]. Blockchain tracking and tokenization may improve pricing and network fees [11].

Regulations would require adjustment for P2P-trading. This may include smart meter rollouts, prosumer licenses with rights to trade on wholesale markets, adjustments in network fees, and so on. Experts noted that P2P-trading would involve among the highest degrees of regulatory change. Therefore, it would likely be more feasible in the long-term, with other blockchain applications initially implemented more viably under current regulatory frameworks. As put by one expert, "a lot of focus has been on P2P-trading but right now the most viable are grid management and system operation. P2P can come in the future." Another expert commented further on how regulations may be developed: "for P2P we need to change energy laws… Regulations need to be developed with regulatory sandboxes and empirical evidence."

The GDPR was given as one of the largest regulatory hurdles. Based on the GDPR, a European citizen has the right to delete their data and to hold data sovereignty. However, this is counter to the immutability and cross-border nature of blockchain. Experts discussed solutions such as off-chain or cloud storage, as well as multi-chain infrastructures to manage cross-border limitations. Experts also emphasized opt-in and opt-out laws. Both with regard to blockchain and other forms of digital innovation in the energy sector, the experts discussed data privacy issues. As put by one expert, "generally, there is of course a long discussion on data handling and data privacy. What data is appropriate to handle and not appropriate to handle?"

Experts also noted a lack of standards for blockchain. Among industrial and fintech players, interoperability and standardization tendencies can albeit be seen. For example, BaaS by companies such as Amazon, IBM and SAP indicates such tendencies [11]. An expert highlighted that energy regulation would need to be developed in parallel with fintech and industry. However, high risk aversion among actors in the public sector in decisions pertaining to energy was noted. Few actors are granted control and insight in regulatory environments for power grids [4]. However, "political systems are risking to lose governance if they do not also change with technology."

Experts discussed open source models to reach out to a broader developer community and B2B platforms for service procurement. Multi-stakeholder setups were clearly emphasized. "We can show credibility by partnering with multiple stakeholders and showing clear use cases." Experts noted that regulatory change itself would require transparency and multi-stakeholder innovation ecosystems. O'Dwyer et al. [3] also emphasized multi-stakeholder test-beds for understanding solutions prior to full-scale operation. Experts noted the importance of regulatory experimentation in parallel with technological change, especially via regulatory sandboxes.

## 4. CONCLUSIONS

Energy is undergoing a transition towards decarbonization, decentralization, and digitalization. The purpose of this paper was to explore blockchain in this transition, its practical challenges and opportunities. This was done based on interviews with 15 players at the junction of energy and blockchain in Germany. Insights on multiple dimensions were discussed. At large, this paper offers insights in each dimension, as well as emphasizes the multi-faceted nature of the energy transition. These insights may be built upon for holistic approaches in both academia and among practitioners for blockchain-based innovation in the energy sector.

## REFERENCES

[1] Di Silvestre ML, Favuzza S, Riva Sanseverino E, Zizzo G. How Decarbonization, Digitalization and Decentralization are changing key power infrastructures. Renewable and Sustainable Energy Reviews 2018;93:483–498.

 

[2] Andoni M, Robu V, Flynn D, Abram S, Geach D, Jenkins D, McCallum P, Peacock A. Blockchain technology in the energy sector: A systematic review of challenges and opportunities. Renewable and Sustainable Energy Reviews 2019;100:143–174.
[3] O'Dwyer E, Indranil P, Salvador A, Nilay S. Smart energy systems for sustainable smart cities: Current developments, trends and future directions. Applied Energy 2019;237;581-597.
[4] Albrecht S, Reichert S, Schmid J, Struker J, Neumann D, Fridgen G. Dynamics of Blockchain Implementation - A Case Study from the Energy Sector. Proceedings of the 51st Hawaii International Conference on System Sciences 2018;3527-3536.
[5] Luth A, Zepter JM, Crespo del Granado P, Egging R. Local electricity market designs for peer-to-peer trading: The role of battery flexibility. Applied Energy 2018;229;1233-1243.
[6] Pieroni A, Scarpato N, Di Nunzio L, Fallucchi F, Raso M. (2018). Smarter City: Smart Energy Grid based on Blockchain Technology. International Journal on Advanced Science Engineering Information Technology, 8:1.
[7] Sun J, Yan J, Zhang KZK. (2016). Blockchain-based sharing services: What blockchain technology can contribute to smart cities. Financial Innovation, 2:26.
[8] Li Z, Kang J, Yu R, Ye D, Den Q, Zhang Y. Consortium Blockchain for Secure Energy Trading
in Industrial Internet of Things. IEEE Transactions on Industrial Informatics 2017;14;3690-3700.
[9] Wu J, Tran NK. Application of Blockchain Technology in Sustainable Energy Systems: An Overview. Sustainability 2018;10;1-22.
[10] Ahl A, Yarime M, Tanaka K, Sagawa D. Review of blockchain-based distributed energy: Implications for institutional development. Renewable and Sustainable Energy Reviews 2019;107;200-211.
[11] dena. Blockchain in the integrated energy transition: Study findings. dena (German Energy Agency) 2019.
[12] Bocek T, Stiller B. Smart Contracts – Blockchains in the Wings. In: Linnhoff-Popien C, Schneider R, Zaddach M (eds) Digital Marketplaces Unleashed, Springer, Berlin, Heidelberg, 2018;169-184.
[13] Bheemiah K. The Blockchain Alternative: Rethinking Macroeconomic Policy and Economic Theory, Springer Science+Business Media, New York USA, 2017.
[14] Energy Web Foundation. 2018. https://www.energy.senate.gov/public/index.cfm/files/serve?File_id=65FFD01C-4437-457A-AD60-736F58DCC43E
[15] Kreeft G. Legislative and Regulatory Framework for Power-to-Gas in Germany, Italy and Switzerland. STORE&GO Project, Deliverable 7.3.