Blockchain in Smart Energy Grids: A Market Analysis

Evgenia Kapassa[1](✉), Marinos Themistocleous[1], Jorge Rueda Quintanilla[2], Marios Touloupos[1], and Maria Papadaki[3]

[1] Institute for the Future (IFF), University of Nicosia, Nicosia, Cyprus
{kapassa.e, touloupos.m, themistocleous.m}@unic.ac.cy
[2] Cuerva, Granada, Spain
jruedaq@grupocuerva.com
[3] Faculty of Business and Law, British University of Dubai, Dubai, UAE
maria.papadaki@buid.ac.ae

Abstract. Modern society consumes a huge amount of energy, making the energy industry highly important across the globe. Customers are supplied with the electricity via the energy grid, as part of the utility value chain and pay on per-unit consumed basis. Thus, grid operations and energy prices have little effects on actual energy demand because grid imbalances frequently arise rapidly over very short periods of time, due to imprecise forecasts or unexpected events. Non-predictable renewable energy sources variable generation raises crucial challenges in grid management, making grid defection a rapidly increasing challenge to traditional energy markets. Blockchain technology has been studied to overcome these problems for application in the smart energy grid, and experts agree that it has the potential to change the electricity market. Blockchain and distributed ledger technologies can promote a transparent, secure and decentralized transactions network that will allow new innovative business solutions. Although, the integration of blockchain into the smart energy grid poses some challenges and prohibits the widespread use of blockchain technology in the energy sector. Therefore, in this paper a market analysis was conducted, to investigate the parameters that affect the large-scale adoption of blockchain in smart energy grids. The first part of the paper is setting up the scene, introducing the blockchain and smart grid fundamentals, as well as presenting blockchain's potential impact on different energy use cases. On the second part of the paper the market analysis is presented, providing blockchain technology's market opportunities within the energy grid. The paper ends with a description of threats and market challenges that the technology has to address in order to get through the hype, prove its economic, social and technological potential and eventually be accepted in the mainstream.

Keywords: Blockchain · Distributed ledger technologies · Energy grid · Smart grid · Market analysis

M. Themistocleous et al. (Eds.): EMCIS 2020, LNBIP 402, pp. 113–124, 2020.
https://doi.org/10.1007/978-3-030-63396-7_8

1 Introduction

During the last decade, energy crisis and environmental destruction became two main concerns. Thus, since 2007, the European Union (EU) has committed to reach the 20-20-20 targets. According to the EU [1], greenhouse gas emissions will be decreased by 20% compared to 1990 rates by the end of 2020, 20% of the energy generated will be derived from Renewable Energy Sources (RES), while in total 20% less energy will be used. Additionally, EU expects that greenhouse gas emissions will be reduced by 85–90% by 2050.

As stated in many research studies [2–4], a promising approach for addressing the energy and environmental disruption, is the adoption of smart grid among with the extensive use of RESs. Moving a step forward, over the past few years, blockchain has emerged as a transformative technology in the context of the smart energy grids [5], enabling secure and reliable Peer to Peer (P2P) energy trading between Distributed Energy Resources (DERs) [6–8]. Due to blockchain's nature, a stable, open and decentralized ledger could be established for all data and transactions, related to energy production and consumption. In addition, smart contracts facilitated through blockchain can enable transparent and immutable transactions on the energy grid and promote interconnections between energy producers and energy consumers (i.e. prosumers) in a decentralized and fault-tolerant environment [9, 10]. Thus, a technology such as blockchain, which does not have a centralized trust body, becomes necessary to ensure efficient and reliable energy trading within the smart grid. Nevertheless, the introduction of blockchain into the smart energy grid is also facing some obstacles and prevents the widespread adoption of the technology in the energy sector [11, 12].

Towards this direction, the current work presents a market analysis related to the adoption of blockchain in the area of smart energy grids. Since blockchain in the energy sector is expected to rise in excess of 45% by 2025 [13], the current analysis aims to highlight market opportunities and possible threats that blockchain-enabled energy grids are facing nowadays.

The remaining of the paper is organized as follows. Section 2 presents the blockchain background, while Sect. 3 introduce the incorporation of blockchain in the smart energy grid. In Sect. 4 a market analysis is taking place, considering the opportunities blockchain could provide in the future smart grids, as well as the current threats and challenges the integration of this technology within the grid is facing. Finally, in Sect. 5, we conclude our work.

2 Blockchain Background

Blockchain is one of the most disruptive technology solutions developed in the recent years. In recent years, blockchain has evolved to handle several different types of data. These include information about energy trading, property ownership, national records, outstanding loans, business mergers, shares, stocks and many more [14–17]. Blockchain includes many computers operating together in a decentralized network, leading to a shared infrastructure that consists of distributed computers (i.e. nodes) that are demonstrated in a way that prevents any kind of modification.

Although blockchain performs a wide range of tasks, it is essentially an immutable, decentralized digital ledger. Blockchain holds a permanent record of validated data in a format which is securely encrypted. Each piece of information is encrypted and stored in a data unit called block [18]. Any node with access to this distributed chain of blocks, can "read" it and determine the status of the data that has been shared over the network. For many different blockchain users a node may typically behave as an entry point, but for simplicity purposes we assume that each node represents one user in the network.

The total number of nodes constitutes a P2P network [19]. In order to better understand the P2P transaction process over the blockchain network, it would be helpful to consider as an example the exchange of energy between an energy producer and an energy consumer. The two entities interact via a pair of private-public keys through the blockchain. They use their private keys to approve their energy transactions, and they are recognized via their public key on the network [20]. The transaction is triggered when the producer will request a specific amount of energy to be transacted towards the consumer, identified through its public key. The transaction is then transmitted to all P2P nodes, so that each one can verify it. Once the transaction is verified, a block of data is produced, and attached to previously verified blocks, creating a chain of blocks (i.e. blockchain). Finally, the transaction is completed and confirmed to both the producer and the consumer.

3 Blockchain in the Smart Energy Grid

3.1 Smart Grid

Smart grids are the distribution and transmission systems that use Information Technology (IT), telecommunication and high-level automation resources to significantly increase energy quality and operational efficiency. Due to the high level of aggregate technology, smart grids are able to respond to various demands of modern society, in terms of energy needs and also considering sustainable development [21].

Smart grids represent the revolution in the electric sector and, consequently, the revolution of the world economy. Communication infrastructure eliminates time and reduces distance, connecting people and markets, facilitating new business relationships.

It should be also stated, that the smart grid concept is very so close to the consumers. The innumerable advantages that these intelligent systems can provide for the electrical system, the technological advancement of the equipment and the constant growth of the demand for electric power, drive research on the subject. Smart grid enables real-time metering and bidirectional communication, ensuring the involve of user participation in the power grid. Home appliances (e.g. smart meters, sensors, solar panels, heat pumps etc.) built into smart grids make it possible to determine the power consumption characteristic, allowing the user to control their consumption and reduce their energy tariff costs or adapting their consumptions patterns.

3.2 Blockchain and the Smart Grid

As described in the previous section, smart grids are experiencing a revolutionary shift which is mainly caused by the advent of DERs (e.g. smart meters, sensors etc.). Thus, consideration, discovery and implementation of new paradigms and distributed technologies are becoming necessary. Because of the fundamental design of blockchain, such technology could offer a promising approach for managing decentralized complex energy grids [22–24]. Several technologies and approaches for designing and implementing energy and sustainability platforms have been proposed in the literature, revealing that blockchain technology could act as a game changer in the energy industry [15]. For instance, in study [25], a game-theoretic approach for the demand side management model that incorporates storage components is suggested, and blockchain technology is applied for efficiency and trustworthiness. Additionally, Brooklyn microgrid is one of the first applied systems that facilitate the use of blockchain technology [22]. The whole project is based on P2P energy trading with blockchain, and doesn't need the third party-traditional electricity utility company. Brooklyn microgrid proves blockchain can really be used in practical P2P electricity trading. Moreover, [26] proposed a decentralized on-demand energy supply architecture for miners in the Internet of Things (IoT) network, using microgrids to provide renewable energy for mining in the IoT devices. On the other hand, with the development and popularization of smart city and electric vehicles (EVs), in order to cope with the current situation of the high volume of EV integration, the authors of study [27], with the aim to allow users to actively participate in the energy exchange process, they propose a P2P Electricity Blockchain Trading (P2PEBT) network, based on the existing electric vehicle charging and discharging schemes in the smart grid. An important aspect for both the academia and the industry, is the cyber-physical security of the infrastructure of Battery Energy Storage Systems (BESSs). Towards this direction, the authors in [28], presented a distributed smart-contract based BESS control approach to allow secure operation and stable consensus between the physical and cyber world.

There are several reviews related to blockchain, focusing on various application areas such as finance, IoT, governance, energy and sustainability [29–31]. Along with the previously mentioned applications, the vast growth in energy-related start-ups and research activities (e.g. Flex4Grid, AnyPLACE, BD4OPEM, Energy Shield) indicates that the effect of energy-based blockchain technology can be extended to a number of use cases specific to energy companies' operations and business processes. Some of the main use case implementations and aspects which may be influenced include: a) P2P energy trading [32, 33], Billing services [34], Security and identity management [35, 36], Energy data management [37, 38] and Grid management: [4, 37].

4 Market Analysis

In today's energy ecosystem scientific and technological developments reduce the product and service life-cycles, change business structures and establish new competitors. This growing complexity requires the scope for new business opportunities.

Accordingly, the current section is going to present a market analysis, focusing on market opportunities and current threats and challenges, in order to identify business growth prospects on the market.

4.1 Opportunities

It is obvious by now that blockchain technology has a transformative potential for the energy market. The energy industry take advantage of blockchain in multiple use cases, as it leverages decentralized P2P technology, where both people and energy devices share a common distributed ledger. Thus, blockchain technology is one of the most promising upcoming technological trends in the information technology domain, with a market size valued at USD 1,590.9 million in 2018, and anticipated to grow at a compound annual growth rate (CAGR) of 69.4% from 2019 to 2025, as stated from the relevant report of Grand View Research [22]. Additionally, Gartner stated that by 2025 blockchain technology would generate market value of more than $176 billion, and by 2030 value of $3.1 trillion [23]. Blockchain technology encourages the immutable essence of the operations of the distributed ledger, making energy exchange transactions transparent. Energy-related applications based on blockchain picking up a quick pace, covering many sectors of the industry, and thus creating massive business opportunities. Ms. Litan stated in Gartner that There are many developments in blockchain technology that would change the current paradigm, making Blockchain networks scalable, interoperable and capable of smart contract portability and cross-chain implementations by the end of 2023 [25]. Moreover, very interesting findings were analyzed in a study conducted by Grand View Research, Inc [26]. Below, the most important ones are presented:

- The public segment is forecasted to grow to CAGR of 70% from 2019 to 2025. Such rise can be attributed to the rising willingness of companies or individuals to inculcate open and efficient transactions.
- The Asia Pacific area is expected to witness the fastest growth regional market during the next six years, increasing the adoption of blockchain technology to accelerate global market growth, lower operating costs and optimize business operations.
- Chain Inc., Circle Internet Financial Limited, Digital Asset Holdings, Eric Industries, IBM Corporation, Linux Foundation, Post-Trade Distributed Ledger, R3, Ripple, and Safello are some of the major market players in the blockchain technology.

Many companies (e.g. IBM, Microsoft) have been driving the development of energy-related blockchain applications worldwide over the past few years and it is assumed that others are also working on integrating blockchain solutions, but are still not visible in the energy industry. Moreover, the way blockchain is applied worldwide is influenced by new blockchain projects in various countries and regions. Based on Deloitte's 2019 Global Blockchain Survey, it appears that China, Singapore, Israel and United States are groundbreaking blockchain technology emerging countries, based on their own common objectives and strategies. Figure 1 below, depicts specific blockchain attitudes along many metrics, for the respective countries [27].

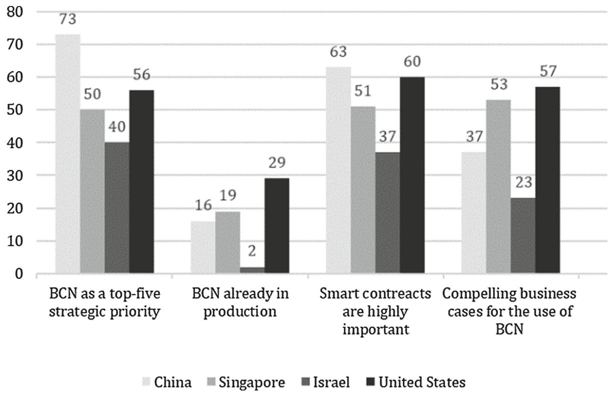

Fig. 1. Blockchain adoption in top emerging countries, Source: [27]

In addition to those major blockchain enablers, Fig. 2 depicts that market participants are migrating towards Blockchain technology. This is justified due to the fact that during 2016 blockchain revenue by area was below $5,000 comparing to $20,000 that it is expected to be until 2025, as described by M. Niranjanamurthy et al. [28].

Fig. 2. Blockchain revenue by region (2016–2025), Source: Tractica

4.2 Threats and Challenges

While companies are investigating opportunities to integrate blockchain into their existing business models, or how to adjust current structures and procedures to cooperate with blockchain technology, emerging disrupters have developed their business around blockchain from the beginning. Theoretically, this makes them more flexible and agile than competitors, and less limited by similar challenges that prevent their more advanced competition from embracing them. As the blockchain environment progresses and various use-cases arise, organizations in the energy sectors should face a dynamic and potentially divisive array of problems, as well as new dependencies. The key blockchain market adoption challenges in this area are described below and depicted in Fig. 3.

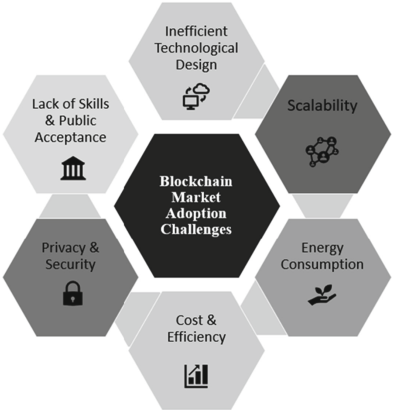

Fig. 3. Blockchain Market Adoption Challenges

- **Inefficient Technological Design:** While the blockchain technology has several business opportunities, it is still lacking in many technological ways. For instance, some dApps tend to be subjected to miscoding and bugs, leading to limitations and hacking issues within the blockchain network. Additionally, as Deloitte refers in a recent report [39], The problem with many current solutions is that they bypass considerable layers of operation and run services and applications on top of those. Therefore, many different chains are being established by many different organizations, with many different characteristics in a single business market.
- **Scalability:** Scalability is a key barrier when applying blockchain to real business environments. The throughput of a blockchain system is related to the amount of transactions in each block and block time period. The conventional blockchain network, is a "broadcast medium", through which each node relays all transactions. This data transfer mode cannot be extended to accommodate a large number of transactions due to the network bandwidth constraint [40]. The nodes require great processing power and time to calculate the validation algorithms in order to add the block to the blockchain network. According to the study in [41], 30 billion kWh of electricity were expended on handling 30 million transactions, representing about 0.13 per cent of global energy usage. In the energy sector, the amount of transactions per second is very high, especially for large-scale activities, due to thousands of prosumers that are concurrently interested in the energy consumption and production. As a promising solution to this issues, a new blockchain platform called EnergyWeb blockchain, targets the energy market with transaction rates as high as a couple of thousands per second [42].
- **Energy Consumption:** Energy use poses another obstacle for blockchain adoption. The mining process require enormous amount of machine power to solve complex equations, taking more and more energy to conquer that. Miners currently use 0.2%

of total electricity, and if it continues to expand, then miners can take on more power than the planet can produce by 2020. Therefore, it is now becoming one of this network's biggest challenges [43].

- **Cost and Efficiency:** The speed and reliability with which blockchain networks can carry out peer-to-peer transactions comes at a high aggregate cost, higher for certain blockchain forms than others [31]. Moreover, integrating blockchain within the smart grid needs high infrastructural costs in order to re-architect the current grid networks, update smart meters to facilitate transfers by smart contracts, implement blockchain-specific ICT systems and other associated Advanced Metering Interfaces (AMI). For instance, the existing smart grid network, currently uses technology such as telemetry that is much more advanced and much less costly compared to blockchain [44].
- **Privacy and Security:** Security problem and blockchain technology has been discussed intensively. Several professionals and academic experts have argued that blockchain technology is inconsistent with privacy laws like the EU General Data Protection Regulation (GDPR) [32]. Although cryptocurrencies such as Bitcoin provide pseudonymity, other future blockchain implementations allow smart transactions and contracts to be unquestionably connected to established identities, posing serious concerns about privacy and data protection stored and available on the public ledger. Participants who transmit personal data to the blockchain are more likely to be called GDPR *controllers* as they specify the processing information, while blockchain nodes who only collect personal data are more likely to be *processors* as they simply promote the function of the blockchain network. This decision, however, is not easy, because not all blockchain networks function in the same way, and there could be various types of members conducting different activities [33–35].
- **Regulation:** Many organizations are transforming blockchain technology into a transactional tool, without following clear guidelines, resulting to technologies like DLT and blockchain to completely by-pass regulation and tackle inefficiencies in traditional intermediated payment networks entirely. A critical issue for regulators about decentralized structures is who will be kept responsible for violations of law and regulation. This is analogous to the problem of assessing network transparency before blockchain emerges [36]. When it comes to the energy market, the regulatory authorities support the active involvement of users and the emergence of processes for green management practices. However, the existing grid regulatory framework does not accept the exchanging of electricity between prosumers when it comes to massive improvements in the main power grid structure, and does not promote the implementation of the distributed ledger in the process [11].
- **Lack of Adequate Skill Sets:** In addition to the requisite tools and equipment, there is a need for properly qualified personnel to handle the blockchain technologies to be implemented on the energy market. Blockchain technology is relatively recent compared to other technologies and is still developing and few individuals actually have the capacity to support this technology [43].
- **Public Acceptance:** Last but not least, the key challenge associated with blockchain is a lack of technology knowledge, especially in non-banking sectors (e.g. the energy and sustainability sector) and a general lack of understanding of how it

functions. The majority of the public is still not aware of the nature of DLTs and its future use. While the technology is making history, attracting more consumers is still not enough.

Distributed ledger technologies and blockchain guarantees trust, immutability/transparency and facilitates disintermediation, as well as providing extra protection for transactions that have been executed. Those are substantial benefits that cannot be overlooked. Although, its cost-of-implementation drawback can be depreciated and minimized in a short period of time, as more expertise is obtained and blockchain becomes a core technology [38].

5 Conclusions

Blockchain technology has attracted significant attention primarily due to the emerging crypto market. Although, the last years researchers are investigating and demonstrating the potential of blockchain in many other sectors, such as finance, IoT, communication technologies and more. Among those, the energy sector is starting a very impressive utilization of blockchain technology, as well. The energy industry, among them, is also making a very remarkable utilization blockchain technology. Blockchain's incorporation into the smart grid requires the society to agree and retain P2P energy transactions within the network. Even if the advantages of blockchain technology within the energy market and specifically the smart energy grids are many, there are still several challenges that need to be passed, in order to fully integrate blockchain technologies within the energy market. Towards this direction, the current paper presents an extensive market analysis, trying to identify possible opportunities and current threats and challenges that need to be addressed. One key point identified through the market analysis is that people are moving towards blockchain technology fast, as in 2016 blockchain revenue by region was below $5,000 and it is predicted to be $20,000 until 2025. On the other hand, though, several challenges were also identified, with the most important ones the regulation and privacy concerns. As clearly identified in the market analysis presented in the current paper, for widespread and large-scale adoption of blockchain in the smart energy grid, industry and the research community will need to work together to tackle the challenges that lie ahead.

Acknowledgements. This work has been partially supported by the PARITY project, funded by the European Commission under Grant Agreement Number 864319 through the Horizon 2020.

References

1. European Commission: 2020 Climate and Energy package (2007) Http://Ec.Europa.Eu/Clima/Policies/Strategies/2020/Index_En.Htm. http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm
2. Aghaei, J., Alizadeh, M.I.: Demand response in smart electricity grids equipped with renewable energy sources: a review. Renew. Sustain. Energy Rev. **18**, 64–72 (2013), Pergamon. https://doi.org/10.1016/j.rser.2012.09.019

3. Poudyal, R., Loskot, P., Nepal, R., Parajuli, R., Khadka, S.K.: Mitigating the current energy crisis in Nepal with renewable energy sources. Renew. Sustain. Energy Rev. **116**, 109388 (2019). https://doi.org/10.1016/j.rser.2019.109388
4. Zhang, M., Eliassen, F., Taherkordi, A., Jacobsen, H.A., Chung, H.M., Zhang, Y.: Energy trading with demand response in a community-based P2P energy market. In: 2019 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids, SmartGridComm 2019 (2019). https://doi.org/10.1109/smartgridcomm.2019.8909798
5. Mollah, M.B., et al.: Blockchain for future smart grid: a comprehensive survey. IEEE Internet Things J. 1–1 (2020). https://doi.org/10.1109/jiot.2020.2993601
6. Fotiou, N., Pittaras, I., Siris, V.A., Voulgaris, S., Polyzos, G.C.: Secure IoT Access at Scale Using Blockchains and Smart Contracts. In: 2019 IEEE 20th International Symposium on "A World of Wireless, Mobile and Multimedia Networks" (WoWMoM), pp. 1–6 (2019). https://doi.org/10.1109/wowmom.2019.8793047
7. Asfia, U., Kamuni, V., Sheikh, A., Wagh, S., Patel, D.: Energy trading of electric vehicles using blockchain and smart contracts. In: 2019 18th European Control Conference, ECC 2019, pp. 3958–396 (2019). https://doi.org/10.23919/ECC.2019.8796284
8. Sengupta, J., Ruj, S., Das Bit, S.: A Comprehensive Survey on Attacks, Security Issues and Blockchain Solutions for IoT and IIoT. J. Netw. Comput. Appl. **14**, 102481 (2020).https://doi.org/10.1016/j.jnca.2019.102481
9. Liu, C., Chai, K.K., Zhang, X., Chen, Y.: Peer-to-peer electricity trading system: smart contracts based proof-of-benefit consensus protocol. Wirel. Netw. 1–12 (2019). https://doi.org/10.1007/s11276-019-01949-0
10. Zhang, P., White, J., Schmidt, D.C., Lenz, G., Rosenbloom, S.T.: FHIRChain: applying blockchain to securely and scalably share clinical data. Comput. Struct. Biotechnol. J. **16**, 267–278 (2018). https://doi.org/10.1016/j.csbj.2018.07.004
11. M. Andoni et al.: Blockchain technology in the energy sector: a systematic review of challenges and opportunities. Renew. Sustain. Energy Rev. **100**, 143–174 (2019), Elsevier Ltd. https://doi.org/10.1016/j.rser.2018.10.014
12. L. Herenčić et al.: Overview of the main challenges and threats for implementation of the advanced concept for decentralized trading in microgrids. In: EUROCON 2019 - 18th International Conference on Smart Technologies (2019). https://doi.org/10.1109/eurocon.2019.8861906
13. Nhede, N.: Blockchain in energy market to reach $3 billion by 2025. Smart Energy International (2019). https://www.smart-energy.com/industry-sectors/energy-grid-management/blockchain-in-energy-market-to-reach-3-billion-by-2025/
14. Themistocleous, M., Rupino, P.: Introduction to blockchain and fintech. In: 51st Hawaii International Conference on System Sciences, vol. 9, p. 9981331 (2018). http://hdl.handle.net/10125/50453
15. Themistocleous, M., Stefanou, K., Iosif, E.: Blockchain in solar energy. Cyprus Rev. **30**(2), 203–212 (2018)
16. da Cunha, P.R., Themistocleous, M., Morabito, V.: Introduction to the Minitrack on The Transformational Impact of Blockchain. In: Proceedings of the 52nd Hawaii International Conference on System Sciences (2019). https://doi.org/10.24251/hicss.2019.819
17. Themistocleous, M.: Blockchain technology and land registry. Cyprus Rev. **30**(2), 195–202 (2018)
18. Garfinkel, H., Drane, J.: What is blockchain? (2016). https://blockchainhub.net/blockchain-intro/

19. He, Y., Li, H., Cheng, X., Liu, Y., Yang, C., Sun, L.: A blockchain based truthful incentive mechanism for distributed P2P applications. IEEE Access **6**, 27324–27335 (2018). https://doi.org/10.1109/ACCESS.2018.2821705
20. Massessi, D.: Blockchain Public/Private Key Cryptography in a Nutshell. Medium (2018). https://medium.com/coinmonks/blockchain-public-private-key-cryptography-in-a-nutshell-b7776e475e7c
21. de Oliveira, G.A., Muthemba, L.J., Unsihuay-Vila, C.: State-of-the-art impacts of Smart Grid in the power systems operation and expansion planning. Brazilian Arch. Biol. Technol. **61** (Special issue), 18000400 (2018). https://doi.org/10.1590/1678-4324-smart-2018000400
22. Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., Weinhardt, C.: Designing microgrid energy markets: a case study: the brooklyn microgrid. Appl. Energy **210**, 870–880 (2018). https://doi.org/10.1016/j.apenergy.2017.06.054
23. Mylrea, M., Gourisetti, S.N.G.: Blockchain for smart grid resilience: exchanging distributed energy at speed, scale and security. In: Proceedings - 2017 Resilience Week, RWS 2017, pp. 18–23 (2017). https://doi.org/10.1109/rweek.2017.8088642
24. van Leeuwen, G., AlSkaif, T., Gibescu, M., van Sark, W.: An integrated blockchain-based energy management platform with bilateral trading for microgrid communities. Appl. Energy **263**, 114613 (2020). https://doi.org/10.1016/j.apenergy.2020.114613
25. Wang, X., Yang, W., Noor, S., Chen, C., Guo, M., van Dam, K.H.: Blockchain-based smart contract for energy demand management. Energy Procedia **158**, 2719–2724 (2019). https://doi.org/10.1016/j.egypro.2019.02.028
26. Miglani, A., Kumar, N., Chamola, V., Zeadally, S.: Blockchain for internet of energy management: review, solutions, and challenges. Comput. Commun. **151**, 395–418 (2020). https://doi.org/10.1016/j.comcom.2020.01.014
27. Liu, C., Chai, K.K., Zhang, X., Chen, Y., Peer-to-peer electricity trading system: smart contracts based proof-of-benefit consensus protocol. Wirel. Netw. (2019). https://doi.org/10.1007/s11276-019-01949-0
28. Mhaisen, N., Fetais, N., Massoud, A.: Secure smart contract-enabled control of battery energy storage systems against cyber-attacks. Alexandria Eng. J. **58**(4), 1291–1300 (2019). https://doi.org/10.1016/j.aej.2019.11.001
29. Minoli, D., Occhiogrosso, B.: Blockchain mechanisms for IoT security. Internet Things **1–2**, 1–13 (2018). https://doi.org/10.1016/j.iot.2018.05.002
30. Deval, V., Norta, A.: Mobile smart-contract lifecycle governance with incentivized proof-of-stake for oligopoly-formation prevention. In: Proceedings - 19th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing, CCGrid 2019, pp. 165–168 (2019). https://doi.org/10.1109/ccgrid.2019.00029
31. Li, Y., Yang, W., He, P., Chen, C., Wang, X.: Design and management of a distributed hybrid energy system through smart contract and blockchain. Appl. Energy **248**, 390–405 (2019). https://doi.org/10.1016/j.apenergy.2019.04.132
32. Alam, M.R., St-Hilaire, M., Kunz, T.: Peer-to-peer energy trading among smart homes. Appl. Energy **238**, 1434–1443 (2019). https://doi.org/10.1016/j.apenergy.2019.01.091
33. Long, C., Wu, J., Zhang, C., Thomas, L., Cheng, M., Jenkins, N.: Peer-to-peer energy trading in a community microgrid. In: IEEE Power and Energy Society General Meeting, vol. 2018, pp. 1–5 (2018). https://doi.org/10.1109/pesgm.2017.8274546
34. Alam, M.T., Li, H., Patidar, A.: Bitcoin for smart trading in smart grid. In: IEEE Workshop on Local and Metropolitan Area Networks, vol. 2015 (2015). https://doi.org/10.1109/lanman.2015.7114742
35. Aitzhan, N.Z., Svetinovic, D.: Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams. IEEE Trans. Dependable Secur. Comput. **15**(5), 840–852 (2018). https://doi.org/10.1109/TDSC.2016.2616861

36. Zyskind, G., Nathan, O., Pentland, A.S.: Decentralizing privacy: using blockchain to protect personal data. In: Proceedings - 2015 IEEE Security and Privacy Workshops, SPW 2015, pp. 180–184 (2015). https://doi.org/10.1109/spw.2015.27
37. Mengelkamp, E., Notheisen, B., Beer, C., Dauer, D., Weinhardt, C.: A blockchain-based smart grid: towards sustainable local energy markets. Comput. Sci. Res. Dev. **33**(1–2), 207–214 (2018). https://doi.org/10.1007/s00450-017-0360-9
38. Omar, A.S., Basir, O.: Identity management in IoT networks using blockchain and smart contracts. In: 2018 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), pp. 994–1000 (2018). https://doi.org/10.1109/cybermatics_2018.2018.00187
39. Diloitte: Blockchain Trends for 2020 (2020). https://www2.deloitte.com/content/dam/Deloitte/ie/Documents/Consulting/Blockchain-Trends-2020-report.pdf
40. Xie, J., Yu, F.R., Huang, T., Xie, R., Liu, J., Liu, Y.: A survey on the scalability of blockchain systems. IEEE Netw. **33**(5), 166–173 (2019). https://doi.org/10.1109/MNET.001.1800290
41. Digiconomis: Bitcoin Energy Consumption Index. https://digiconomist.net/bitcoin-energy-consumption
42. EnergyWeb: The Energy Web Chain (2019). https://www.energyweb.org/wp-content/uploads/2019/05/EWF-Paper-TheEnergyWebChain-v2-201907-FINAL.pdf
43. Frizzo-Barker, J., Chow-White, P.A., Adams, P.R., Mentanko, J., Ha, D., Green, S.: Blockchain as a disruptive technology for business: a systematic review. Int. J. Inf. Manage. **51**, 102029 (2020). https://doi.org/10.1016/j.ijinfomgt.2019.10.014
44. Alladi, T., Chamola, V., Rodrigues, J.J.P.C., Kozlov, S.A.: Blockchain in smart grids: a review on different use cases. Sensors **19**(22), 4862 (2019). https://doi.org/10.3390/s19224862