Blockchain Technology in the Future Smart Grids: A Comprehensive Review and Frameworks

Arezoo Hasankhani[1], Seyed Mehdi Hakimi[2,3]*, Mojtaba Bisheh Niasar[1], Miadreza Shafie-khah[4], Hasan Asadolahi[2,3]

1. Department of Computer and Electrical Engineering and Computer Science, Florida Atlantic University, Florida, U.S.

2. Department of Electrical Engineering, Damavand Branch, Islamic Azad University, Tehran, Iran.

3. Renewable Energy Research Centre, Damavand Branch, Islamic Azad University, Tehran, Iran.

4. School of Technology and Innovations, University of Vaasa, Vaasa, Finland

* Corresponding author: sm_hakimi@damavandiau.ac.ir

Abstract: Development of the smart grids (SGs) has led to many changes in the current power grid structure. Application of new devices, technologies, renewable energy resources, and electric vehicles (EVs) increases the need for decentralized energy management and the data transactions, i.e., the secure and economic transactions are realized through the decentralized networks. The blockchain technology can be used as a solution for these modifications, so a comparative literature review is presented to identify all possible applications of blockchain in SG. The renewable energy development and its interaction with the blockchain technology are investigated, so the blockchain technology is verified as a promising option to increase the renewable energy share. Then, the applications of blockchain technology in SG are categorized in different areas, including the smart contracts and demand response (DR), EVs, the Internet of Things (IoT), the decentralized energy management, the energy trading, the financial transactions, the cybersecurity, the testbeds, and the environmental issues. Therefore, all possible opportunities and challenges of blockchain's applications in SG are identified. A comprehensive literature review is done to introduce the current improvements related to the blockchain technology's applications in SG, while the future opportunities and current challenges of blockchain are discussed. This paper aims to present a structure of SG according to the blockchain application and discuss all benefits and drawbacks caused by blockchain in different areas of SG.

Keywords: Blockchain, Decentralized energy management, Electric Vehicle (EV), Internet of Things (IoT), Peer-to-Peer (P2P), Renewable energy, Security, Smart contract, Smart grid.

1. Introduction

The future of the smart grid (SG) considering the energy industry is very complicated, and the development of uncertain renewable resources, in addition to the rising cost of SG systems, has led to changes in the present networks. Therefore, blockchain technology can be considered as an appropriate option due to these modifications. A Peer-to-peer (P2P) approach for SGs can support the renewable energies and provide economic benefits for both the consumers and the prosumers. However, the rapid development of blockchain and the promising perspective of P2P-based SGs requires a careful study and a proper structure design.

In [1], the opportunities of blockchain technology in the power grids are introduced, while its drawbacks and benefits are recognized. Further, a specific type of blockchain considering its application in the power systems is introduced. In another study [2], the current difficulties and the future opportunities for the blockchain technology development in the energy transaction field are reviewed. In this study, different models and consensus methods are studied, while the ongoing start-ups and the projects are introduced. In addition, the future trend of blockchain in the energy sectors is investigated [3], and the importance of distributed energy transaction is highlighted. Moreover, the long-term effects of deploying the blockchain technology are studied according to electric vehicles (EVs) and renewable energy development. Also, the proposed structure for the blockchain technology addresses the drawbacks of regular structures, while some changes in energy sectors should be considered to realize the efficient energy trading by the blockchain.

The development of solar energy resources in the smart homes equipped with EVs are tackled by the distributed energy transaction, while the blockchain technology is proposed in order to address these changes [4]. Further, residential consumers can participate in distributed energy transactions using the proposed blockchain structure. In another study [5], the need for a variety of changes in the present network due to an increase in the decentralized resources is highlighted, and the blockchain technology is presented as a solution to this problem. Furthermore, the modifications in the end-user roles and the energy sectors are explained, and the current challenges in Europe for the blockchain technology are discussed. The requirements of SG for the distributed transaction are addressed with the blockchain technology, which empowers SG with P2P and the secure transactions [6]. In addition, the benefits and the drawbacks of applying the blockchain technology in the smart communities, such as SG, are comprehensively reviewed [7].

The current state, the future trend, and the difficulties of blockchain development in different aspects, including data transactions, energy trading, security, and the Internet of Things (IoT) are reviewed [8]. In another study [9], smart meter's applications in the data flow between the prosumers and the users are addressed with the blockchain technology. Furthermore, since there is a high dependence on the data from smart meters, they should be checked, especially in terms of security. The growth of blockchain technology's application in the energy storage system in SGs is investigated [10], and its positive effects are proven. In addition, the energy storage systems are applied in an auction market, while the smart contracts are responsible for their secure and economic transactions with the network. Further, a literature review is done on sidechain technologies as a blockchain connected to the main blockchain [11]. The blockchain patent documents are analyzed in [12], while their classification and materials are considered.

A comparative literature review on the blockchain's application, according to the web of science, is done over the period between 2013 to 2019 [13]. Security issues as one of the most important concerns of the blockchain technology are addressed in [14], while its application in cryptocurrency network is also assessed. Further, the public key and the key management architecture for the financial transactions are reviewed in [15], and a trustable way of communication is proposed. In another study [16], the power consumption of blockchain technology is investigated according to its application in the energy industry. Further, the amount of energy consumption growth in the specific case study, and the following increase in the carbon emission is analyzed. A decentralized review system is proposed in [17] to ensure secure transactions and to avoid cyber-attacks. In addition, the proposed system is based on the Ethereum blockchain, and its rules are defined using smart contracts. The smart contracts are developed according to the blockchain technology for supplying the energy demand [18]. The blockchain technology's applications in SG are summarized in Table 1 [19].

Table 1. Blockchain technology applications in the smart grid proposed by [19]

Application	Type	Capabilities	Technologies
P2P energy trading	Consortium	Energy trading between prosumers and consumers, development of renewable energy resources	Smart contracts, virtual currency, credit-based wallet
Energy trading between EVs	Consortium	Energy trading between EVs, the security of EVs	Smart contracts, energy coins
Security	Private	Protecting the blockchain vs. cyber-attacks	Smart contracts, dApps, IoT devices
Secure equipment maintenance	Consortium	Privacy protection	Smart contracts, smartphones

In our study, a comprehensive literature review of blockchain technology according to its application in SG is provided, while the opportunities of blockchain technology's application in the smart grid are analyzed. In addition, the blockchain's application in SG and its relation to renewable energy development are fully discussed. Since a variety of areas in SG are affected by the blockchain technology development, the application of blockchain technology in SG is categorized in different sectors as follows:

- Smart contracts and demand response (DR) in SG
- Blockchain and EVs
- Blockchain and IoT technology
- Blockchain and decentralized energy management
- Blockchain applications in energy trading
- Blockchain applications in financial transactions
- Blockchain applications in cybersecurity
- Blockchain testbed
- Blockchain for environmentalism

All in all, it is critical to precisely identify the state of the art of applying blockchain technology in the SGs and investigate the main opportunities, the challenges, as well as the feasible solutions to facilitate the integration of the blockchain technology in the SGs. Hence, our paper aims to draw a realistic perspective of the main opportunities and drawbacks of applying blockchain technology in the SGs. The knowledge gaps in the literature are carefully recognized. This paper's main contribution is to identify and categorize blockchain technology applications in the SGs in nine major areas. In addition, the main opportunities, challenges, and solutions of the blockchain technology application in the SGs are investigated. The main contributions of our article are:

- We first provide a detailed overview of blockchain technology and its concepts and discuss its opportunities to facilitate renewable energy resources integration into the SGs.
- Then, we identify the main areas for blockchain technology applications in the SGs, including smart contract and DR, EVs, IoT technology, decentralized energy management, energy trading, financial transactions, cybersecurity, and environmentalism. Also, we identify the main opportunities, challenges, and solutions of the blockchain technology application in the SGs.

- Third, we present an in-depth and comprehensive review of the blockchain's applications in the SGs in each area.
- Finally, we present some recent testbeds and industrial applications of blockchain technology in the SGs.

The rest of this paper is organized as follows. Section 2 provides the blockchain basics. Section 3 addresses the relationship between the blockchain technology and renewable energy in SG. Section 4 is devoted to the impacts of blockchain's applications in SG, including the smart contracts, EVs, IoT technology, decentralized energy management, the changes in energy trading, the improvement and the difficulties for cybersecurity, the testbeds, and the environmental concerns. Finally, section 4 provides some relevant conclusions.

2. Blockchain basics

The blockchain technology is a set of blocks containing data, which is suitable for different applications. In our study, we focus on its application in SG, so only some fundamental explanations of the blockchain are reviewed in this section. Different nodes can transfer data and digital coin with each other, which is the main difference between the blockchain technology and centralized networks. The main differences between the centralized networks and the blockchain structures are shown in Fig.1.

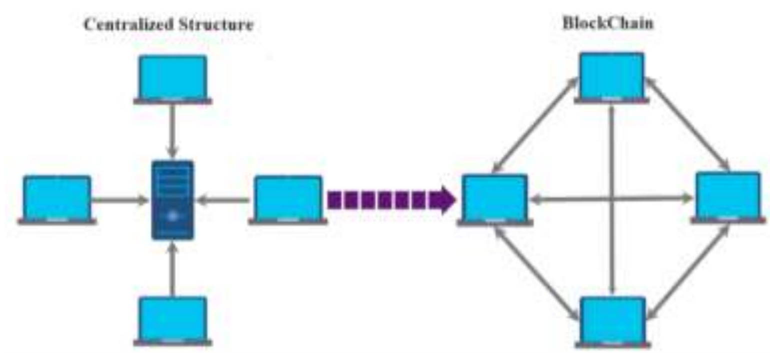

Fig. 1. Difference between centralized networks and blockchain structures proposed by [2].

2.1. Concepts

In the set of blocks, the first block is called the Genesis block, while each block is connected to the Genesis block, either directly or by some interfaces. Furthermore, each block is distinguished from others with the special hash. Hence, each hash determines a specific block and its information. In addition, a new hash is defined for each block if its information is changed, so its modifications can play an important role in security issues [20]. Therefore, blockchain technology can improve security concerns according to its features. Although the specific hash can improve the security of blockchain, there are some possible cyber-attacks to the blockchain. As a result, the consensus algorithms are developed to decrease the cyber-attacks. The consensus algorithms assess transactions before they are added to a chain. A process of transaction in the blockchain is done as follows [21]:

- Sending a transaction request by one of the users.
- Sharing this request between all nodes in the blockchain.
- The user and his requested transaction are assessed by other nodes.
- If the user and his requested transaction are verified, the new block is added to the chain.
- The transaction procedure is completed.

The blockchain and digital currency were initialized in 2008 [22], so this novel concept was introduced to different areas, including SGs, due to its capability in secure and clear data transactions, energy trading, and the decentralized energy management [23]. In addition, the mathematical equations of blockchain are formulated, and its interoperability is verified [24]. Furthermore, both the private blockchain and the public blockchain are applied in the construction industry, which is verified by proposing the blockchain structure for two different industries [25]. Moreover, the feasibility of blockchain in the construction industry is assessed in [26].

2.2. Types

In this section, different types of the consensus algorithm and the blockchain technology are introduced. As it is explained in the previous section, the consensus algorithm can be applied to the transaction at any time before adding to the chain. The duration of consensus depends on its algorithm type and transaction features. There are four different consensus algorithms [27]:

- Proof of Work (PoW): in this type of consensus algorithm, the miners are responsible for verifying the new transactions in addition to connecting the new blocks, which is mostly used in industries.
- Proof of Stake (PoS): all users can assess the reliability of transactions, so PoS are time efficient and energy-efficient compared to the PoW algorithms.
- Proof of Authority (PoA): this algorithm allows the trustable users to offer new transactions, which makes the verifying process faster.
- Practical Byzantine Fault Tolerance (PBFT): this algorithm asses the blockchain ability against the Byzantine faults.

The blockchain technologies can be categorized in other aspects, i.e., categorizing based on the users who access to the blockchain technology. In the public type, all users have access to the blockchain, so they can add new blocks to the chain. In the private type, there are a few users who are allowed to add new blocks to the blockchain. In the consortium type, the blockchain is managed and assessed with some authorized users. Furthermore, the blockchain can be grouped into the regional blockchain and the wide-area blockchain (Fig. 2). As it is shown in this figure, the smart meters data received from different networks are recorded in the regional blockchain, while a variety of networks are located in different places. In addition, the wide-area blockchain includes substation and cluster gate, which are responsible for both the security and process of data collected from the regional blockchains [28].

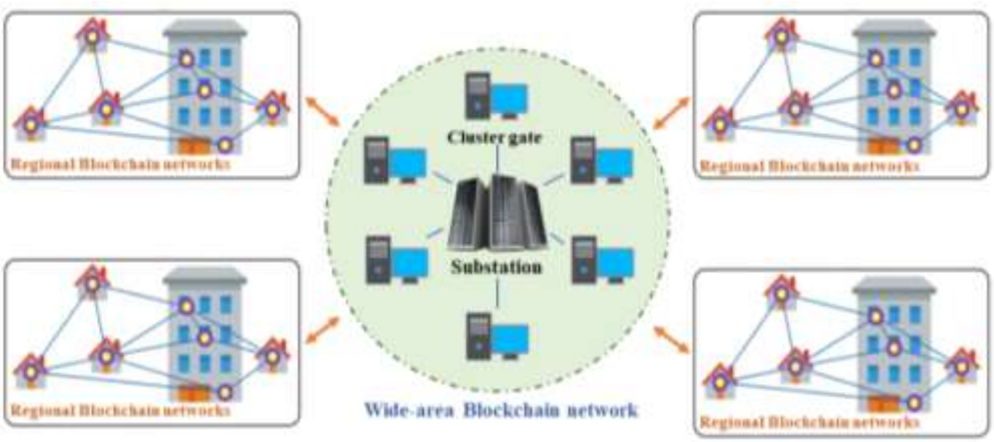

Fig. 2. Diagram of data transactions between the regional blockchain and the wide-area blockchain [28].

3. Blockchain and renewable energies

The high penetration of renewable energies can be realized in the condition that a transparent environment is provided for the energy transaction from the prosumers to the consumers. Blockchain technology can be applied in different aspects in order to improve the adoption of renewable energy. Hence, renewable energy systems can transfer energy directly with the smart homes and the loads in SGs based on blockchain technology. Furthermore, renewable energy systems are used as prosumers, and smart homes play the role of consumers. The relations between renewable energy systems and smart homes as the main loads in SGs are shown in Fig.3. The prosumers and the consumer can transfer energy, data, and digital coin together.

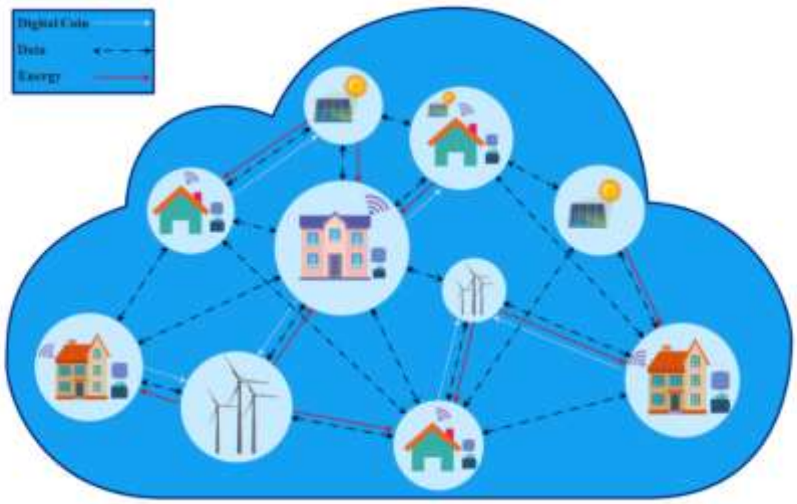

Fig. 3. Transactions between prosumers and consumers through the blockchain in the presence of wind turbines and PV units.

In [29], blockchain technology is proposed as a solution for the widespread development of renewable energy, which simplifies a clean energy transaction by the smart contracts. Moreover, the clean energy blockchain network is introduced to reduce time and cost in order to reach practical economic transactions. On the other hand, the high penetration of renewable energy systems into SG is addressed with the blockchain technology in order to increase their financial benefits [30]. Further, the socioeconomic advantages are also considered to encourage the development of renewable energy plants.

The complex energy trading and difficult tracking procedure are introduced as the barriers to renewable energy development, which can be solved by the blockchain-based network. As a result, the developments of renewable energies, including wind and solar energy in smart homes, are investigated, and the blockchain concepts are proposed in order to transfer energy between smart homes [31]. Furthermore, the blockchain is considered in relation to the power grid, and the users are divided into two different groups. In the first group of users, the renewable energy generation is more than consumption, while the second group generates less power than their consumption. In addition, the proposed blockchain structure contains six different phases, including user registration, transaction information declaration, leader node generation, market transaction matching, writing transaction information to the blockchain, transaction settlement.

The blockchain-based technology is applied in order to integrate the higher renewable energies into SG and develop a carbon price scheme [32]. In other words, the prosumers should take responsibility for the carbon emission, so the blockchain-based P2P scheme is developed in this paper, which combines the energy and carbon market together. Furthermore, the development of solar energies is investigated by the blockchain-based technologies [33], while the proposed blockchain-based technology is set to use the current smart meters installed in SG. In addition, it is noted that a self-consumption structure causes some implications, including the technical issues and the variable consumption, especially during holidays.

The feasibility of applying blockchain technology in the energy sectors is analyzed in [34], while renewable energy systems are considered. Furthermore, the development of renewable energy systems in SGs highlights the requirements for the distributed energy management system and the fundamental changes in energy trading, which is investigated in China [35]. In addition, the relation between the blockchain structure and the smart contracts, in addition to the possible benefits of the blockchain technology on the environmental issues, are addressed in [36], while the renewable energy systems are integrated into SG. Further, the high integration of renewable energy systems in low-voltage networks is analyzed using a concept named NRGcoin [37]. The effects of applying the blockchain structure on renewable energy sectors are shown using a real case study, including 37 residential sectors equipped with 75 smart meters in Walenstadt [38].

The role of renewable energy resources as prosumers and their effects on data sharing considering distributed energy transactions are investigated in [39], while the proposed model of this paper considers the blockchain technology, IoT, and big data. In [40], the renewable energy transaction structure has been proposed using the Ethereum smart contracts between the blockchain-based smart homes. Hence, in smart homes, IoT and blockchain technologies provide the data flow, which facilitates energy transactions between smart homes. Furthermore, a secure renewable energy trading scheme is proposed based on smart contracts. Moreover, there are two different nodes in this network, including consumers (only consuming energy at home) and prosumers (capable of producing power from PV units). IoT devices and storage are also connected to the internet, and all information on energy use has been monitored.

In [41], renewable energy transactions are studied in the Ethereum blockchain-based platform, while the proposed structure is tested in a real testbed. The uncertainties caused by high penetration of renewable energies are addressed with the blockchain-based network between prosumers and users [42]. Meanwhile, it is assumed in this study that both sides can participate in energy transactions according to the P2P structure. Moreover, there is also a need for developing the local energy market due to the development of renewable energy systems, which can facilitate energy trading between prosumers and consumers [43]. In [44], fog computing is applied for renewable energy systems, while the blockchain technology is used in order to consider security issues in data transaction. Furthermore, the efficiency and lower energy consumption of the proposed method is verified through simulation under different operation modes.

The advantages and disadvantages of blockchain's application for facilitating renewable energy development are reviewed [45]. Hence, the industrial and academic challenges of blockchain development are discussed in different technical, financial, social, environmental, and institutional aspects. On the other hand, the importance of developing a new structure for energy trading between smart homes equipped with renewable energies is discussed, while a distributed network is considered as the best solution for this energy transaction [46]. Moreover, the consortium blockchain-based network is used for energy transactions in this study. The high penetration of solar energy in smart homes and the need for defining new structures for energy transactions between smart homes are discussed in [47]. Furthermore, smart homes as prosumers can share their energy in the blockchain-based network, and the stochastic study is done in order to consider the uncertainties in both loads and solar energy.

Application of the blockchain technology in improving energy transactions and protection of the network from cyber-attacks in SG are addressed [48], while EVs are considered as both energy storage and load in SG, so EVs meet the difference between supply and demand. On the other hand, the blockchain technology development to address the distributed renewable energy is analyzed in different technical, financial, social, environmental, and institutional aspects [49]. Therefore, it is anticipated that the multi-stakeholder ecosystems and some changes in the management sector should be considered toward 2050. In [50], a real-time model is proposed to address the stochastic behavior of renewable energy resources according to the blockchain technology. Also, the proposed method prioritizes the energy production of renewable energy resources and EVs in order to meet the high uncertainties of these resources.

A novel structure should be proposed in order to introduce the blockchain technology into the distribution network in the presence of renewable energy systems. Firstly, the network operator should control and plan the blockchain structure. Then, the transactions between prosumers and consumers with the blockchain are organized through smart contracts. Finally, the blockchain technology provides a suitable infrastructure for the data transaction, while the operators and the prosumers are considered as the miners. The proposed structure for using the blockchain technology in the distribution network is shown in Fig.4, while the renewable energy systems are integrated into the distribution network.

Fig. 4. A proposed structure for using blockchain technology in the distribution network in the presence of renewable energy systems.

4. Blockchain applications in smart grid

The specific features of SG and the integration of renewable energy systems, IoT devices, EVs, and smart meters highlight the needs for a novel structure. Therefore, blockchain technology is introduced as a feasible solution to satisfy a lot of SG requirements, considering the decentralized energy resources and data transactions. Meanwhile, different issues should be considered according to the blockchain technology development in SG. Hence, the current technologies in SGs, i.e., IoT and the smart meters, should be utilized to simplify the blockchain integration into SGs. On the other hand, the blockchain pros and cons in each area of SGs should be carefully studied to ensure that this technology improves SG performance. The blockchain technology's applications in SGs are categorized into nine different areas, i.e., security, energy trading, decentralized energy management, blockchain testbed, EV, IoT, smart contract, and environmentalism, shown in Fig.5. The current studies done in a variety of areas of the blockchain technology's applications in SGs are reviewed in the following sections.

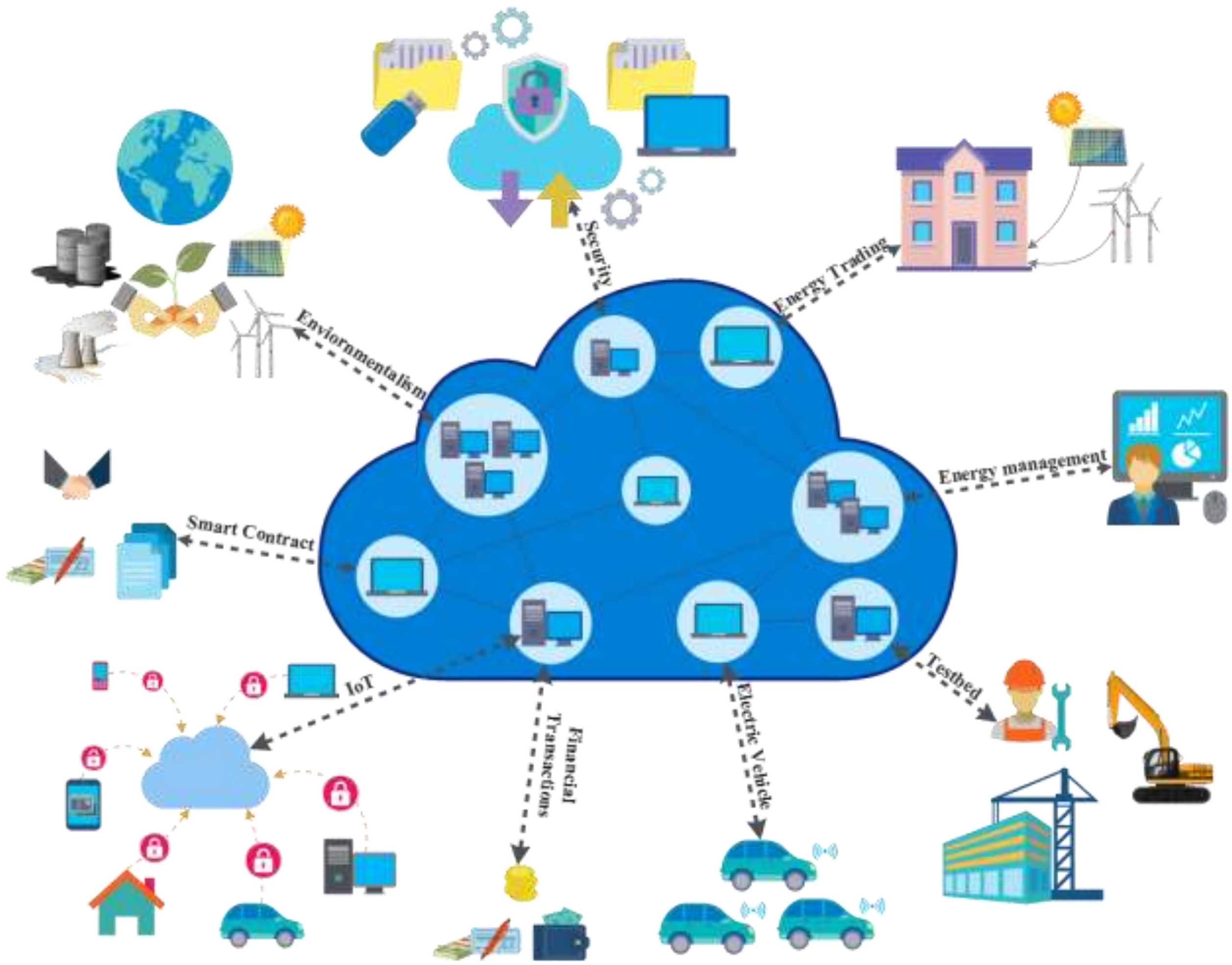

Fig. 5. Different areas affected by the blockchain's applications in the smart grid, including security, energy trading, energy management, blockchain testbed, electric vehicle, financial transactions, IoT, smart contract, and environmentalism.

In our study, the main sectors affected by the blockchain in SGs are identified, while the major studies related to each sector are reviewed. The main opportunities, challenges, and solutions for applying blockchain technology in each sector are presented in Table 2. In addition, a comparative summary of reviewed studies on the blockchain technology's application in SG is presented in Appendix 1, which identifies the main focus of each reference according to our defined sectors.

Table 2. Identifying opportunities, challenges, and solutions for blockchain technology's application in the smart grid analyzed in eight different sectors.

Sectors	Opportunities	Challenges	Solutions
Smart contracts for demand response (DR)	• Facilitating financial transactions between the decentralized nodes. • Increasing security in financial transactions.	• Lacking standardized contracts, protocols, and interfaces between parties. • Increasing the probability of manipulating data and contracts.	• Providing and employing a standardized contract draft. • Embedding security features in smart contracts based on the contract value.

	• Utilizing a trustable way to pay digital incentives to consumers. • Encouraging consumers to participate in the DR program. • Defining all conditions of participation in the DR program between prosumers and consumers.	• Need for high allocated resources to monitor contracts. • Resistance to change and use new technology to participate in the DR program. • Increasing security and privacy concerns.	• Reducing the dispute risk by providing a contract management plan based on the standardized agreements. • Increasing social knowledge and introducing trusted markets. • Providing general data protection regulation.
Electric vehicles	• Utilizing the safe charging model for EVs. • Improving security issues in the energy trading between EVs and charging stations. • Increasing security in data transactions between EVs. • Encouraging EVs to participate in the DR program. • Defining a digital wallet for each EVs and storing its digital coins in order to ease financial transactions. • Developing an online monitoring of EVs. • Developing the concept of vehicular network and internet of EVs.	• Poor Internet connectivity and mobile penetration area. • Increasing the size of data due to the multiple collections of EV's data according to its mobility. • Facing different interfaces and protocols. • Increasing the average transaction size per block. • Increasing the privacy concerns of parties and security concerns of transactions.	• Developing infrastructures and employing mobile utilities. • Avoiding double-spending and managing overlapping chains. • Providing a standardized protocol with performance evaluation. • Designing dynamic hierarchical process architecture. • Employing the standardized security tools and authorization methods.
IoT	• Increasing IoT devices in the network. • Managing connection between IoT devices. • Developing the decentralized control of IoT devices. • Authentication and secure data transactions between IoT devices. • Developing an IoT-based healthcare structure. • Facilitating data collection from smart home devices.	• Increasing the processing capacity, especially in the edges with limited capacity. • Need for high power consumption in IoT devices. • Increasing the bottleneck issues such as data storage and data analysis. • Increasing copyright issues in terms of data ownership. • Highlighting security and privacy concerns. • Facing a variety of data types and heterogeneous data issues.	• Developing cloud computing considering linkability and using the interoperability of related data. • Proposing the appropriate hierarchical processing architecture to manage pervasive social networks with low power devices. • Developing efficient data compression and analysis model. • Providing a management plan to identify ownership. • Employing the standardized and secure protocols, as well as developing verification and validation criteria. • Managing the heterogeneous data.

Decentralized energy management	• Developing the decentralized energy management through distributed ledger technology. • Facilitating energy management of distributed renewable energy resources and compensating their intermittencies. • Developing the day-ahead scheduling and real-time management. • Addressing the operational challenges due to renewable energy development. • Managing all financial transactions between prosumers and consumers. • Improving security issues in energy management.	• Increasing the complexity of energy management and the probability of unpredicted issues due to the immaturity of the technology. • Accompanying difficulties in scalability. • Need for greater processing units in edges and higher energy consumption. • Facing problem in encouraging consumers and prosumers to participate in decentralized energy management due to social apprehension for using new technology. • Increasing privacy concerns.	• Accelerating technology development by increasing financial investments and collaboration of academic institutions. • Building a scalable blockchain database and removing limitations. • Designing the appropriate hierarchical processing architecture regarding the problem to reduce the processing units. • Increasing social knowledge and developing trusted markets. • Maintaining the privacy and security of existing records and data.
Energy trading	• Developing the new structure for energy trading according to Ethereum contracts. • Realizing a new concept of P2P energy trading. • Facilitating the energy trading between all nodes in SG. • Improving trustworthiness in energy trading. • Improving transparency in energy trading and the ability to track all transactions. • Clarifying all financial transactions related to each energy trading. • Facilitating the financial transactions by utilizing a token-based structure.	• Increasing size of the average transaction per block • Deficiencies in technical bottlenecks such as data storage, security, and skill shortages. • Need for (near-) real-time analysis and increasing the required processing capacity. • Increasing complexity due to the need for energy trading with a huge variety of power quality and multimodal requirements. • Inhibiting local energy markets in some countries. • Increasing security concerns to carry out large-scale decentralized energy trading. • Facing an intermediary to audit and verify the transaction record. • Mismatching between the supply and demand.	• Developing the required infrastructure and designing dynamic hierarchical process architecture. • Increasing financial investments and collaboration of academic institutions. • Improving and sharing the processing units to avoid wastage of computing resources. • Managing heterogeneous data/requirements for diverse use cases with physical utility infrastructure. • Modifying the current policy and providing a suitable consensus protocol with performance evaluation. • Designing a unified and trusted energy trading/verification platform. • Providing a trusted platform for all nodes.

Financial transactions	• Facilitating the financial transactions between different nodes in SG using the digital currency. • Speeding up the financial transaction by appropriate cryptocurrencies. • Improving the security of financial transactions and tracing all payments and transactions. • Addressing the intermittencies in energy trading with renewable resources through smart contracts and guaranteed financial transactions in the blockchain. • Decreasing the electricity cost compared to the real-time electricity market.	• Need for defining an appropriate cryptocurrency to address the uncertainties in renewable energy resources and market price. • Increasing the security issues in cryptocurrency transactions and the possibility of being attacked by hackers. • Need for addressing the flexibility of the SGs and price fluctuations in the electricity market. • Increasing electricity consumption due to cryptocurrencies mining.	• Applying the cryptocurrencies as incentives to encourage consumers to manage their consumption and increase the energy arbitrage of the SGs. • Managing the time of cryptocurrency mining to avoid a huge increase during on-peak hours.
Cyber-physical security	• Avoiding cyber-attacks to SG. • Solving false data injection problem. • Decreasing the possibility of forgery according to the decentralized structure of the blockchain. • Checking all financial transactions and utilizing a secure wallet. • Increasing security in energy trading due to avoiding any data manipulation. • Increasing the security of EVs against the forged data and cyber-attacks. • Maintaining the privacy of networks. • Limiting the accessibility of different persons to data. • Satisfying true transmission of data. • Proposing a novel method to detect attacks to SG. • Addressing the self-healing of SG after attacks. • Validating all stored data in the cloud.	• Increasing the privacy concerns of parties and security concerns of transactions. • Increasing the probability of manipulating data. • Facing big data issues such as gaining, storing, and analyzing data without disturbing the privacy feature. • Lagging of policy compared to technology development. • Increasing complexity due to mobility, overlapping chains, and a variety of access controls.	• Employing the latest standardized security tools and authorization methods to prevent leakage of information. • Using a digital signature to verify the confidentiality and integrity of data. • Developing and utilizing a secure processing method, such as fully homomorphic encryption. • Accelerating the standardization process and the required regulations, and embedding additional security countermeasures to decrease security broken risk. • Providing an appropriate consensus protocol to manage access control and authorization.

Environmentalism	• Utilizing a new concept of carbon trading, • Decreasing the carbon emission. • Encouraging persons to recycle by defining token-based incentives. • Developing renewable energy resources resulting in decreasing fossil fuel-based powerplants. • Tracking all financial aids to environmental entities and their activities. • Defining a novel concept of carbon tax according to digital currency. • Tracking pollution caused by all units in SG in addition to identifying polluting units.	• Increasing pollution due to an increase in energy consumption and the number of processing units. • Growing the computational cost in case of using clean energy.	• Encouraging consumers to move towards renewable energy by defining the incentive regulations. • Increasing the processing unit efficiency and developing a pricing management solution.

As blockchain technology has been developed in the SG, it is noteworthy to identify a trend of technology development and a variety of researches throughout recent years. Therefore, the number of published researches in each sector is shown in Fig. 6.

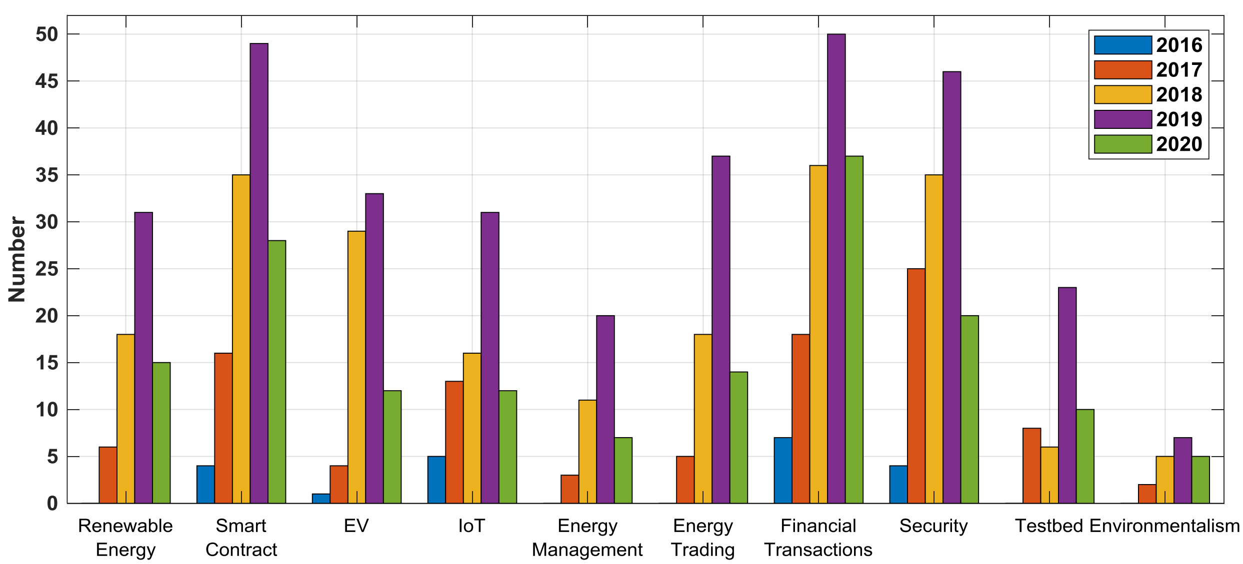

Fig. 6. Comparing trend of published resources in each sector of applications of blockchain technology in the smart grid between 2016 and 2020: (1) renewable energy, (2) smart contract for demand response, (3) electric vehicle, (4) IoT, (5) energy management, (6) energy trading, (7) financial transactions, (8) security, (9) testbed, and (10) environmentalism.

5. Blockchain applications for demand response, energy management, financial transactions, and energy trading

5.1. Smart Contracts for Demand Response (DR) in smart grid

DR concept has been developed according to SG capabilities, which can be used in order to improve SG economics and load profile. An efficient DR program should satisfy consumers with different factors, such as financial incentives, security in energy trading, security in data transaction, and reliability in meeting all demand. Hence, some fundamental modifications should be made in SG to address the abovementioned factors caused by using DR programs. The blockchain technology can offer smart contracts to determine the transparent involvement of consumers, while their role and incentives are specified. In addition, blockchain technology can provide digital transactions, which accelerates all financial trading and provides a more reliable method to pay incentives.

EVs are used as the main component in the DR algorithm, while charging/discharging is managed in order to maximize consumer satisfaction [51]. Moreover, the main objective of this study is maximizing total profit considering the operational constraints and supplying all needed energy of SG. On the other hand, the importance of smart contracts in the blockchain is studied [52], while these smart contracts are stored in the blockchain. Furthermore, the smart contract features include the specific state for each contract, the capability of defining business logic, considering all possible outcomes in the smart contracts, triggering at its address, and tracing all operations done by each contract. The concept of DR is investigated in [53], while the blockchain technology is used in order to manage the financial and data transactions. In addition, smart contracts are developed based on the power flow and the financial states of the network. In [54], the relation between the energy market and the blockchain technology in the decentralized SG is investigated in the condition that the smart contracts determine the transactions and the financial benefits for all participants. Meanwhile, simulation results verify the efficiency of the proposed method to supply all demand using distributed sources.

In [47], two different approaches, including real-time pricing and the day-ahead pricing, are considered for the solar energy-based SG, while the main objective of energy management is to minimize total cost. In addition, each smart home is planned to manage the solar energy resources and the loads to realize the minimum cost. DR method is proposed to encourage EVs in order to improve their participation in the energy trading procedure [55]. Further, the proposed method is working according to the consortium blockchain, which aims to minimize total cost considering the smart contract optimization. In this study, different contracts are considered based on EV type, while the state of charge of EVs is estimated using the gaussian process regression. Moreover, the DR method is designed for the internet of EVs using the consortium blockchain technology, while the stochastic behaviors of EVs are modeled and determined by the specific smart contract.

DR program is considered for different types of loads in order to manage the secure energy transaction [56], while the miner nodes are used to authenticate the energy trading through the blockchain. In another study [57], DR of different loads, i.e., the residential load, the commercial load, and the industrial load in relation to the blockchain technology, are studied in the real-time market. Further, a non-cooperative game, in addition to the uncertainties in different loads and renewable energies, are investigated in this study, while the smart contracts are applied to provide secure and reliable energy trading and data flow. The energy transactions between storages are managed through an automated DR algorithm in the decentralized blockchain network [58]. In addition, the proposed DR method is tested in the blockchain-based network, and its efficiency in improving security in energy trading is verified. On the other hand, the decentralized energy management system without the need for another supervision is developed to facilitate energy trading between energy storage systems.

The blockchain technology is considered for the optimal industrial load management, while the blockchain is tested in different types of electricity markets [59]. In addition, the DR program considers the direct control of industrial users, so the results prove the decrease in total cost. The smart contracts are applied to determine the cost and the duration of using a variety of devices from each entity, such as the decentralized storage applied for the data transaction during the decentralized energy management in SGs [60]. Further, the smart contracts are applied for the prosumers in order to announce their price and offers with the trustable structure, while security issues are also met [61]. Different interactions between blockchain technology and decentralized energy management, considering its impact on solving environmental issues, are investigated in [62]. Further, a two-way connection and energy trading between SG components are studied in order to find the appropriate energy management and DR structure [63]. Moreover, encouraging consumers to participate in the DR program is addressed through the blockchain structure, which facilitates the secure and trustable financial transaction [64]. Also, the DR program acceptability between consumers is improved, while the consumers are assured of the reliable energy trading and the financial transactions provided by the flexible electricity market [65]. On the other hand, managing consumption for both prosumers and consumers is important, which is satisfied using the blockchain-based DR programs [66].

5.2. Blockchain and decentralized energy management

The blockchain technology can be applied to ease the decentralized energy management, which is developed according to the P2P concept provided by the blockchain. In the centralized energy management, all data about the energy transfer, the consumption, and the generation should be centrally managed, while the information flow and the energy management are done through the decentralized networks in the decentralized energy management [67]. The distributed energy exchange structure is proposed according to the blockchain and software, which is used for networking, while the proposed structure also considers security issues, and its efficiency is shown [68]. In [69], a real-time and decentralized energy market is investigated using smart contracts. Furthermore, all players in this market send their requests, while the market is operating according to the smart contracts and the Ethereum blockchain.

It is claimed in [43] that the energy transaction between different peers is done through the distributed energy management, which is solved using the distributed ledger technology. Moreover, the energy trading between the prosumers and the consumer is done only through the local energy market, and there is no need for a central intermediary. Therefore, the economic issues and the technical aspects of local energy management are investigated in this study, and it is shown that the blockchain technology is a suitable option in both aspects. The distributed energy management of SG is done by the blockchain, and the economic and operational issues are investigated [70]. Hence, the superiority of blockchain technology in both energy trading and the data transaction is used to meet the social and financial criteria. In addition, smart contracts are utilized to ensure a secure data flow between different sectors for distributed energy management.

The blockchain technology is applied in order to utilize the stochastic energy management for SG [71], so the proposed method aims to minimize the cost and improve security by a directed acyclic graph considering the stochastic behavior of load and renewable resources. In [72], the blockchain-based network is proposed in order to increase the security of data transaction, while the data are stored in the blocks by a Byzantine method. The distributed energy management for the decentralized renewable energy resources and the energy storage systems is addressed through the blockchain technology [73]. Hence, a game-theoretic model is assumed to flatten the load curve and decrease the peak to average ratio, while the final goal is maximizing the total profit of consumers.

The energy trading is managed in the blockchain-based smart homes equipped with the energy storage systems, IoT, the smart meter, and the home miner, while the consumer nodes can sell their required energy from the prosumers [40]. Furthermore, the prosumers produce energy by their PV units and store their produced energy in the storages, which can also be sold to the consumers. Moreover, the home miner monitors all data sharing and energy flow between different devices, renewable energy systems, and energy storage, so the home miner contains all information about the energy consumption, energy production, and the stored energy.

The distributed energy system based on the blockchain is proposed in order to supply the demand for IoT devices [74], while the proposed blockchain-based technology operates according to the consensus protocols. Therefore, the main goal is to maximize the benefits for both SGs and IoT devices. In addition, the proposed system is provided in three different layers, including the chain service, the energy consumer, and the energy supply. On the other hand, the proposed model includes different supplies and storages, consensus protocols, and different modes of processing. In [75], distributed energy management is done in order to minimize the power losses caused by energy transactions. Moreover, the energy management of smart buildings in the presence of electrical and thermal loads, energy storage systems, and renewable energy resources is investigated [76], while blockchain technology is proposed as a secure and reliable method for the energy transaction.

The distributed renewable energy sources are managed using a crowdsources energy system and P2P trading [77], while two different approaches are proposed to address the distributed energy management, i.e., the day-ahead scheduling for the resources and the real-time scheduling. The energy management is investigated to address both the financial and the operational aspects, considering the ancillary service of blockchain technology [78]. Hence, reactive power flow is solved under the high penetration of PV units. The potential applications of blockchain technology in the IoT area are predicted, and future difficulties, needs, and gaps are highlighted [79]. Furthermore, the future developments of the blockchain in different use cases, i.e., SG, supply chain, and healthcare, are investigated, and its security challenges are discussed. On the other hand, one of the challenges in decentralized energy management is the data sharing between entities, which can be addressed through decentralized storage. Moreover, the decentralized storages are defined as the units which rent their hardware storage space, so all possible challenges and opportunities of using these decentralized storages are reviewed in [60].

The application of blockchain structure for the decentralized management of an industrial system named Predix is investigated [80], which includes energy storage and renewable energy. Furthermore, security issues in the management of data and the energy trading addressed through the blockchain-based SG are analyzed [81]. Also, the proof of concept is met using security in energy trading, secure data transactions, and reliable financial issues. The development of IoT devices in SG and security issues for the data trading are changed the centralized energy management of conventional electricity network to the decentralized one, which guarantees the secure communication between all SGs [82]. The blockchain technology is applied to collect data from IoT devices in SGs in order to manage the energy transactions between the prosumers and the consumers [83].

In addition, the smart contracts assure meeting all demand, while the residential consumers are participating in DR programs. Integration high share of renewable energy systems into the distribution network needs the fundamental changes in these networks to manage the energy transactions between the prosumers and the consumers. Hence, the blockchain-based market is proposed to meet all demand considering the decentralized structure of SGs [84]. The blockchain technology is presented as a solution for the decentralized energy transactions between PV units, the wind turbine, the energy storage, and EVs as the prosumers with the smart homes as the consumers [85]. A fully decentralized electricity market is satisfied using blockchain-based energy management, which also satisfies the collective self-consumption [86]. Furthermore, the features of blockchain technology as an option to improve energy management in the decentralized energy sectors are assessed in [87]. In addition, P2P energy trading between the renewable energy-based prosumers and consumers is met through the blockchain-based energy management software [88].

5.3. Blockchain application in energy trading

Blockchain technology can reduce time, the cost, and the complexity of energy trading. A novel structure of SG leads to some fundamental modifications in conventional energy trading. In the conventional electricity network, energy trading is done only through the main network, so all electricity costs should be paid to the system operator. However, energy can be traded between the prosumers and the consumers, so the financial transactions are more complicated. Furthermore, time is considered as an important factor in both energy trading and financial transactions, i.e., every transaction should be done online. Hence, blockchain technology is proposed as a suitable option to address all the mentioned challenges. The energy trading process has been developed between the blockchain-based smart homes [40], while energy is stored in the energy storage, and the consumption is monitored by the consumer nodes equipped with the miners. Hence, if the stored energy is not enough to supply the loads, the extra energy is bought from the prosumer nodes, which should be managed through the smart contracts. Furthermore, the energy trading procedure is done in 4 different phases based on the Ethereum smart contract:

- All conditions of energy trading should be specified to exchange energy with the prosumers.
- Price and exchange procedures should be determined by both prosumers and consumers, and the proof-of-work should be completed.
- If the stored energy is below a certain limit in the consumer nodes, their home miners should send their request to the prosumers.
- Energy trading is done in the condition that prosumer conditions and consumer requirements match, so the prosumer sells its energy to consumers.

Energy transaction between different nodes is tremendously affected using the blockchain technology in SGs. Therefore, the anticipated modifications in energy trading, if the blockchain structure is applied in SGs, is shown in Fig.7. As it is shown in this figure, a variety of units, including the wind turbine and PV units, are exchanging energy through the electricity network in the conventional structure. In other words, the network operator should be informed about any energy transaction, while the operational constraints should be met. However, different components can exchange energy together using the blockchain-based network without any need for the electricity network. Hence, only the initial agreement should be utilized between both sides of energy trading, which is addressed through smart contracts.

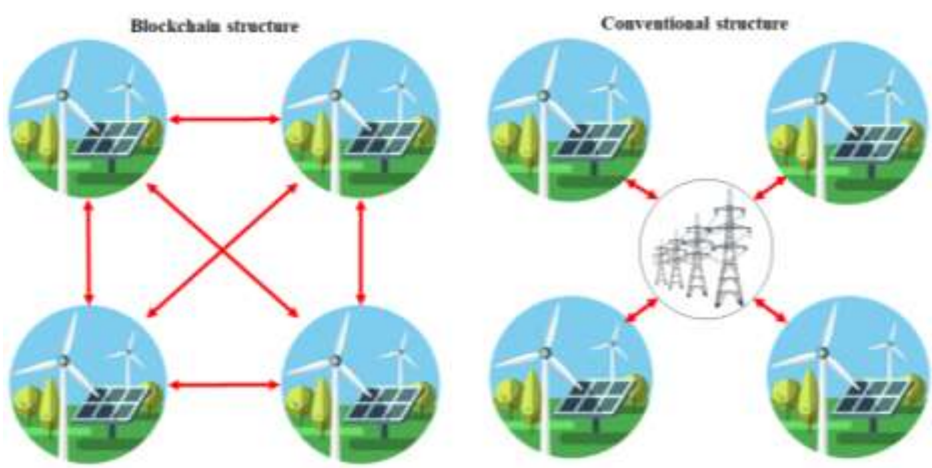

Fig. 7. Comparison between energy trading in the conventional structure vs. blockchain structure [70].

A system model is presented based on the blockchain technology in order to facilitate the energy transactions [89], while an emission trading scheme is applied in this paper to avoid the fraud and guarantee a secure data sharing. In another study [30], the energy trading between the prosumers and the consumers are analyzed in the decentralized network using P2P technology. Furthermore, the challenges caused by the penetration of distributed resources in energy trading are considered, which are minimized using the blockchain-based structure. The application of blockchain technology and P2P energy trading in the development of PV units are studied in [90], while a model for P2P energy trading is proposed considering the k-double auction, and the financial benefits are verified through the simulation.

In addition, blockchain technology can be applied to manage energy trading between different prosumers and consumers on the consumer side. Hence, a variety of components, including residential consumers, renewable energy resources, energy storage, EVs, and so on, can participate in the blockchain-based market. Further, each component can propose the energy cost due to its capability and the energy production cost, which leads to a competitive energy market. Therefore, the blockchain structure can guarantee transaction security, while it also facilitates energy trading and data transactions. A diagram of energy transactions between a variety of prosumers and consumers through the blockchain-based network is shown in Fig. 8.

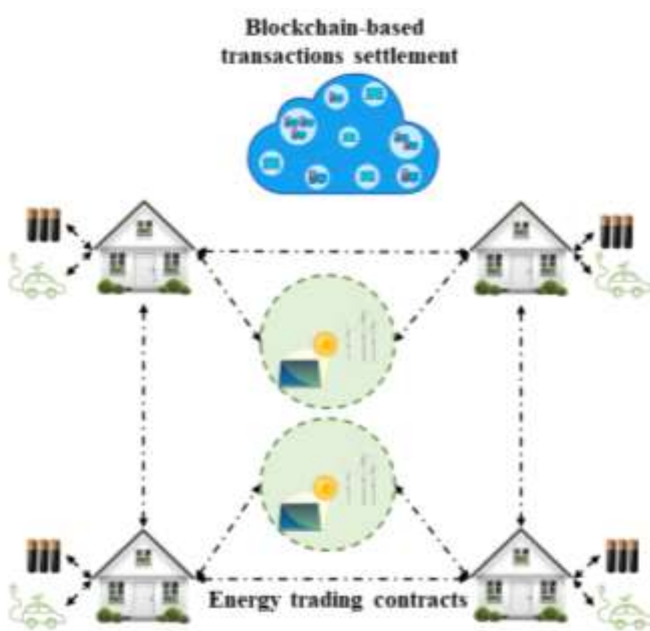

Fig. 8. Blockchain's application in order to facilitate energy transactions between prosumers and consumers.

In addition, the energy trading between the renewable energy-based prosumers and the consumers must be satisfied through a costly and reliable structure, which is realized by the blockchain technology [91]. P2P energy trading considering double auction is proposed in order to address the energy trading between the decentralized SGs. Further, the trustworthiness of the proposed structure is assured by the smart contracts, while the thermal consumption and the running time are also considered [92]. In addition, the energy trading between different participants in SGs faces with a lot of challenges, including the fraud, the false data injection, the high price, and the unreliable transactions. Hence, the blockchain technology can help to improve transparency and ease the financial transactions and the data flow between the prosumers and the consumer without human involvement [93]. Furthermore, the blockchain technology features for P2P energy trading are assessed in [94], while its security concerns and its acceptability between all participants in the electricity market are investigated.

The consortium blockchain is applied to address security and privacy issues in energy trading through SGs in order to avoid any manipulation and attack [95]. On the other hand, the energy trading between the smart buildings equipped with PV units causes some challenges, such as vague pricing and the possibility of sending or receiving false data, which can be solved through the blockchain and the digital financial transactions [96]. In addition, reducing the possibility of data manipulation and financial fraud during decentralized energy trading are investigated through the blockchain technology [97]. The Ethereum blockchain is presented in order to meet P2P energy trading between the prosumers and the consumers in SGs [98]. The decentralized energy trading can cause some issues, such as security issues, the difficulties in financial transactions, and reducing efficiency through the current network, but these challenges can be solved using the blockchain technology [99]. However, some difficulties, including the environmental issues and the comprehensive control system, should be addressed.

The feasibility of using the blockchain technology for energy trading is assessed through a project named Crypto-trading, which uses smart contracts to improve energy management in a specific area [100]. In addition, the obtained results verify the blockchain technology capability to manage energy trading. On the other hand, the smart contracts and the blockchain structure are used to address the high development of renewable energy resources in SGs, while the token-based system is proposed for the financial transactions [101]. The blockchain structure is considered as a promising technology to manage the energy trading between the network and EVs, while it empowers the vehicle to grid networks, which is operating according to a protocol named directed acyclic graph-based V2G [102]. Different projects for P2P energy trading according to the blockchain technology are reviewed in [103], while their strengths and drawbacks are identified. Moreover, the advantages and the disadvantages of a crowdsourced energy system operating based on the blockchain technology are discussed in [104], while the renewable energy systems, EVs, and the programmable loads are considered.

The blockchain technology can be applied to facilitate data transmission in energy trading between different participants in the smart grid. A distribution ledger is proposed as an option to realize a trustful trading environment, but the privacy concerns in terms of attacks (i.e., linking attacks) should be considered. The linking attacks are highly probable for the open information stored in the blocks. In the energy trading process, the blocks are used to store all information related to transactions where all participants in the energy trading can trace their trading.

A privacy-preserving method is proposed to address the data transmission and privacy in energy trading, which applies an account mapping algorithm and also creates some noises on data to ensure privacy [105]. The privacy in data transmission is also ensured using the cryptocurrency and cryptography systems to verify the data transmission between different users [106]. It should be noted that a blockchain can interpret as a chain of digital signatures and nodes in a mesh topology, while each node has a ledger to store its transactions. A secure and trustworthy blockchain-based structure is proposed to address the data transmission between different users, where some entities are chosen as miner nodes to compute proof of work and hash functions. In addition, a software defined networking (SDN) structure is proposed to ensure the privacy in data transmission between different nodes [107].

Data transmission through the wireless network is reviewed in [108] considering four participants, i.e., consumer, local producer, renewable energy producer, and grid. This transmission includes uploading information to the blockchain, uploading power demand, trading renewable energy, distributing power, returning trading feedback. According to the user requirement and maximize the benefits of both parties, the trading matching scheme is introduced in [109]. The flow of P2P electricity trading employing Ethereum blockchain is simulated in [110], while the data transmission between prosumers and consumers through the blockchain is discussed. The storage data unit on the blockchain is called blocks. A block includes two main parts: (i) the block body to store the primary data, and (ii) the block header to save the hash of the primary data and its timestamp [108]. Hashing causes data dependency between all blocks in the network. Hence, an attacker should modify all dependent blocks in a chain for modifying a block, which is difficult to achieve.

Several cryptography modules are employed to achieve an enhanced platform for data transmission. In [111], different architecture for key-exchange is introduced based on time-constraints and resource-constraint devices. Moreover, in [112], an anonymous signature-based authenticated key exchange targeting IoT-enabled smart grid environment is proposed. Furthermore, [113] proposed a blockchain-based distributed network scheme in the SG protection relays to decrease latency. Additionally, a high-performance hash function is proposed in [114].

5.4. Blockchain application in financial transactions and electricity market

The blockchain technology can be applied to facilitate the financial transactions in the electricity market while the security of transactions is guaranteed by using the digital currencies and smart contracts. It should be noted that each block in the blockchain structure can record multiples of financial transactions, which is identified by a specific hash. Therefore, all financial transactions can be traced by both prosumers and consumers, and the transparency of financial transactions increases. Since many financial transactions are going to be done in the blockchain structure, fundamental modifications should be done to manage a large number of financial transactions and data transmission, which is going to be addressed through digital currencies.

The concept of digital currencies is defined to ease financial transactions in the electricity market. The structure of blockchain technology should be modified to be compatible with the electricity market, where the prosumers and consumers should access the specific data to ensure security issues. Among different digital currencies, the IOTA and Ether are proposed as suitable options to address the high speed of the financial transactions in the electricity market in SGs [115]. A conceptual framework and the structure of smart contracts in a blockchain-based electricity market is investigated in [70] to address the financial transactions and energy trading between different nodes. Furthermore, a framework of the blockchain-based electricity market is suggested in [116], which investigates all modifications from a centralized framework to a decentralized structure by blockchain technology. The decentralized structure of the blockchain-based SGs is designed according to the NIST standard conceptual model, which is provided by cryptocurrencies and P2P transactions [117].

The concepts of digital currencies and the structure of the blockchain technology and smart contracts can be applied instead of the real-time electricity market, which benefits both lower price transactions and lower intermittencies in the electricity cost of renewable resources. However, addressing the uncertainties in market price results in some challenges for defining a suitable cryptocurrency and financial transactions, which is addressed through specific monetary tokens bonded with a fixed ratio to the Euro in [118]. A comprehensive framework is proposed in [119] to address the energy trading and financial transactions between different nodes through the electricity market in the SGs. In a specific case study, the features of developing a blockchain-based SG is investigated in Kazakhstan, where the procedure of energy trading, financial transactions, and smart contracts are defined [120]. The main challenges of blockchain and specifically digital cryptocurrency applications in the SGs are discussed in [121], and the main solutions to address the current challenges and future trends are identified.

The safe financial transactions can be addressed through different methods by applying the blockchain technology in the smart grids. A safe transaction can be realized through the blockchain technology application and cryptocurrencies, where the blockchain can handle and trace all transactions. The smart contracts, distributed ledger technology, scalability, and resilience of the blockchain technology are considered to address the trustworthy of the blockchain-based transactions [117]. The security considerations of application of the blockchain technology in the SGs are investigated in [6], where the framework of the financial transaction, its verification, and smart contracts are designed. In a specific application of the blockchain technology in the SGs, the healthcare area, and using bitcoins to facilitate the financial transactions are addressed to ensure the security and authentication [122].

One of the most important issues in the financial transactions in the electricity market is security, which can be addressed by blockchain technology. The longer blockchain time can impact the security of financial transactions, where the P2P structure of blockchain can improve the security of financial transactions compared to the centralized transactions. The blockchain technology is applied to boost the privacy, anonymity, and confidentiality in the SGs, where dynamic pricing is addressed through financial bidding by blockchain structure, and smart contracts are defined to automate the bidding process [123]. The blockchain opportunities for a variety of areas, including healthcare, transportation, SGs, and financial systems, are reviewed in [124], and the main features of the blockchain technology to improve the privacy in different applications are highlighted. The decentralized structure of blockchain-based SG is proposed to meet financial transactions, trustworthiness, transparency, and resiliency [125].

6. Blockchain and electric vehicles in the smart grid

EVs have a great potential to be entered into the blockchain-based networks, while they can be utilized either as the energy storage system or as the load. EVs are considered as the controllable loads which can be shifted to different hours in order to manage a demand curve. Furthermore, they are also capable of selling their energy to other EVs or loads if there is enough incentive for them. Having said that, the most important issues for EV interaction with the blockchain technology includes secure financial transactions and data transactions shown in Fig. 9. As it is shown in this figure, EVs are operating in the internet-based network, so they can send their information to other EVs in order to transfer the energy and the data. Furthermore, the data should be transferred in a trustable way, which includes all information about EV state of charge. On the other hand, EVs are either paid for their energy transaction to other EVs or transfer money to a charging station in order to be charged, which are facilitated through the digital currency.

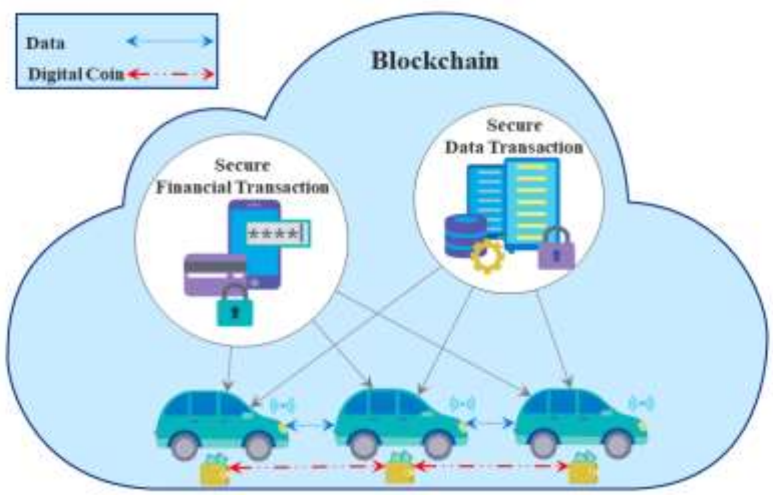

Fig. 9. Interactions between blockchain and EVs in the smart grid, including secure financial transactions and secure data transactions.

The high penetration of EVs in the energy market is investigated through the blockchain-based structure, while this structure is proposed in order to optimally charge EVs [126]. Furthermore, the authors apply a delegated Byzantine fault tolerance consensus method in the blockchain-based network, and a contract game is used to model different EV types in addition to their selected energy type, i.e., renewable energy and fossil fuel energy. Also, the optimal dynamic contract is proposed to address the stochastic behavior of renewable energies and EVs. In [127], the control problem for charging EVs from stations and secure energy transaction are discussed, and the blockchain structure is presented to address these challenges. Furthermore, distributed data management, in addition to the decentralized energy management near EV nodes, are proposed, which are helpful in improving secure way on the consensus blockchain.

A vehicular energy network is assessed, and the application of blockchain technology in safe charging of EVs is investigated [128], while the distributed ledgers are used in order to safely charge EVs at each node. Furthermore, EV utilities are optimized in this paper by proposing an incentive-based method for EV charging management. In [48], EVs are managed in order to improve the energy transaction and security in the consensus blockchain-based network. EV discharging is addressed by proposing the DR algorithm in order to encourage EVs to participate as the controllable loads [55]. Furthermore, EVs are categorized into different groups in order to specify their priority to participate in DR, and the special smart contract is considered for each EV type. In addition, security issues caused by the integration of EVs into the blockchain structure are described in [129], which also considers the data transactions and the financial issues to realize the proof of work.

The blockchain technology is used in order to integrate EVs into SG, and an energy exchange method is investigated based on the consortium [130]. Meanwhile, the proposed consortium consists of three parts, i.e., the edge computing service provider, the local energy aggregator, and EVs. Furthermore, the mechanism for EV charging and discharging is designed in a way that encourages EV owners to charge their cars during the off-peak period. In other words, EVs have a bidirectional relationship with the network, so they can be used as both the energy supply to inject power to the electricity network and the energy storage system. In addition, the main objective in designing the incentive-based method is to encourage EVs to change their charging/discharging time in order to improve the load profile. On the other hand, the local energy aggregator monitors all energy transactions and determines the number of coins to be paid to each side, while it consists of three different servers, including the memory, the account, and the transaction servers. Moreover, the memory server is responsible for saving all transactions, and coins are placed in a digital wallet according to each financial transaction, while the transactions related to any EV and charging/discharging are recorded in its transaction account. Therefore, the account server is applied to specify the relationship between the digital wallet and the account server.

The decentralized charging of EVs is investigated [51], while the blockchain technology is proposed to meet the requirements of distributed charging. Furthermore, the consortium blockchain is applied in this paper, and security concerns in addition to the consumer welfare are considered. On the other hand, in the proposed blockchain, the data on EV charging/discharging states are transmitted between local aggregators. Therefore, the main components of this proposed system are EVs, the smart meters, and the local aggregators, while the local aggregators include the transaction server, the account, and the memory. In [131], EV development in SG is managed through the blockchain structure in order to improve the financial and operational issues. Moreover, the charging/discharging of EVs is controlled through the blockchain-based structure, which considers the model of EVs and their owner's behavior. Hence, the main goal of this study is to minimize total cost and improve power characteristics.

EVs participate in P2P energy trading in the blockchain-based network, which uses the smart contract at the same time [132]. Furthermore, dynamic pricing is considered for energy transactions to minimize total cost. In [133], the optimal charging of electric taxis is considered, which is solved by the consortium blockchain, while the objective function aims to minimize the charging cost, maximize the passenger relief, and considers the operational constraints. Therefore, the simulation results of this study verify the effectiveness of the proposed method to reach the expected goals. The charging management of EVs is done through the blockchain technology in order to maximize the consumer welfare and minimize total cost [134], while other constraints, such as charging station location and the stochastic behavior of EVs in terms of the traveling time and the distance are considered. In addition, the consortium blockchain is applied to satisfy secure and reliable energy trading.

In another study [135], the battery-swap problem for EVs is studied, while the consensus blockchain is applied in order to realize the distributed energy management. Furthermore, the main goals of the proposed objective function are minimizing total cost and load shaving. On the other hand, the current drawbacks in EV development are reviewed [136], and the consortium blockchain is proposed as the solution to improve charging and payment issues. The relation between the internet of energy and improving the charging pile of EVs are discussed, while the blockchain-based network is proposed for managing EV charging [137]. Moreover, the proposed method is operating according to the smart contract named the lightning network and the smart contract, while it considers all phases from EV participation in the blockchain-based network to charging. EVs are robustly monitored by proposing the edge computing blockchain-based authentication method [138]. Meanwhile, the main advantage of the proposed method is fast access to storage and resources for all EVs, which contains three layers, including the vehicular network, the blockchain edge, and the blockchain network.

In [139], the IoT problem is discussed for EVs, and its consequences in the data sharing and the energy exchange are explained. Therefore, the blockchain structure is proposed in order to reach the secure and real-time management considering the big data problem. Further, different types of nodes are defined, while the blockchain is divided into some smaller blockchain. The internet of vehicles is also studied in [140], while the Byzantine consensus method is presented according to the blockchain technology in order to satisfy all requirements to reach a comprehensive structure of the internet of vehicles. On the other hand, the efficiency of the proposed method is verified for a secure data transaction, the consensus authentication, and the fault tolerance. The social IoT is discussed for EVs, while the social internet of vehicles is introduced to satisfy the social acceptance of EVs among the drivers and the passengers [141]. At the same time, this study considers a large amount of data and their privacy.

In [142], the vehicle to grid energy transaction is considered, while the transferred energy can be sold to other EVs and network. However, increasing the amount of data, energy, and financial transactions need a private and secure process. Hence, an efficient structure is proposed for secure financial transactions, while it is operating based on the blockchain technology and Hyperledger. The problem of true data transactions in the EV network is studied, while the blockchain-based structure is proposed in order to address this issue [143]. Furthermore, in the proposed method, EVs can assess the received data using a Bayesian algorithm. Therefore, the assessed data and their calculated score are saved in the block. In another study [144], the secure data sharing structure between EVs is designed using the blockchain technology in order to prevent 51% of cyber-attacks in a specific area. The advantages of the blockchain's application in the vehicle industry are reviewed in [145], while the main focus of this study is on the security issue of blockchain technology. Then, this article discusses the current difficulties in the blockchain development.

In [146], EVs are considered as the promising technology for solving the operational and environmental issues in the condition that a secure method for data transaction is defined. Moreover, the privacy in energy transactions is maintained through developing the contract-based method, which eases the distributed data exchange. Security for vehicular networks is addressed in [147], while the anonymous reputation method using blockchain technology is proposed in order to solve this problem. On the other hand, the effect of mobility on the blockchain-based vehicular and the hoc network is studied [148]. Moreover, it is claimed that mobility intensifies the proof-of-work, so a precise model is needed. In addition, this paper studies the process of block addition to the blockchain through an assessment of success in the block addition and rendezvous. In [50], the incentives are defined for consumers to be encouraged to increase EVs and the renewable energy resources according to the blockchain technology. In addition, it is claimed that using the blockchain technology increases the economic benefits of both consumers and aggregators.

The challenges of an announcement network for EVs are divided into reliability without recognizing drivers and the reluctance in forwarding announcements [149]. Hence, these challenges are solved by introducing a Creditcoin network, which lets the unknown users to send their announcements and encourages the users to forward these messages. In [150], a platoon structure is proposed for EVs in order to address the pollution and traffic problems. Moreover, the path trajectory of EVs is defined by a platoon head, while the incentives are determined for EVs to follow this path. In addition, a true financial transaction is guaranteed through the smart contract. The dynamic nature of electricity cost to charge EVs is addressed through the blockchain structure, which facilitates the financial transactions using the digital coins [151]. Further, the security of charging and data transactions between EVs and networks are considered in this study. Another problem for EVs is the battery refueling, which is addressed using the battery swapping [152], while the blockchain structure is applied to provide a trustable and transparent environment for these trading.

On the other hand, the blockchain is applied to make a billing system in order to clarify information about the amount of charging and electricity cost due to the high development of EVs and the lack of a trustable system to avoid any fraud [153]. In addition, the charging issue of decentralized EVs can be met through the blockchain technology, while a secure energy transaction is also considered according to a real-time electricity market [154]. The optimal charging station is selected according to the vehicle trajectory, the traffic, the battery charge, and EV owner satisfaction, which is chosen using the blockchain structure and considers the Ethereum in addition to the smart contracts [155]. In addition, applying the Ethereum for EV transactions is addressed in [156], which investigates these technology features to meet the high development of EVs. On the other hand, security problems, including identifying EV place and the hijacking of EVs, are solved using the cryptocurrencies and the smart contracts in the blockchain [157]. A charging structure of EVs using the smart contract and the lightning system to avoid any attack on the charging network is proposed in [158], while the constant and reliable pricing of electricity to charge EVs is addressed in [159].

7. Blockchain applications for IoT and security

7.1. Blockchain application in the Internet of Things (IoT)

One of the most important applications of blockchain technology is associated with IoT technology, which is tremendously used in SGs. Furthermore, IoT-based blockchain infrastructure requires a lot of devices, storage, servers, and local bridges to integrate all IoT components into SGs [160]. The sample infrastructure of using IoT devices according to the blockchain technology is shown in Fig. 10. Meanwhile, a server is applied to receive data from different sensors, manage the operation of IoT devices, and control different components in the blockchain. In addition, it should be notified that a large amount of data can be stored in the hardware storage or software storage. On the other hand, the consumers can interact with the blockchain through their computers in order to be informed about any changes in the data transactions. Moreover, the local bridges are applied to facilitate the connection between IoT devices and servers using the communication protocols.

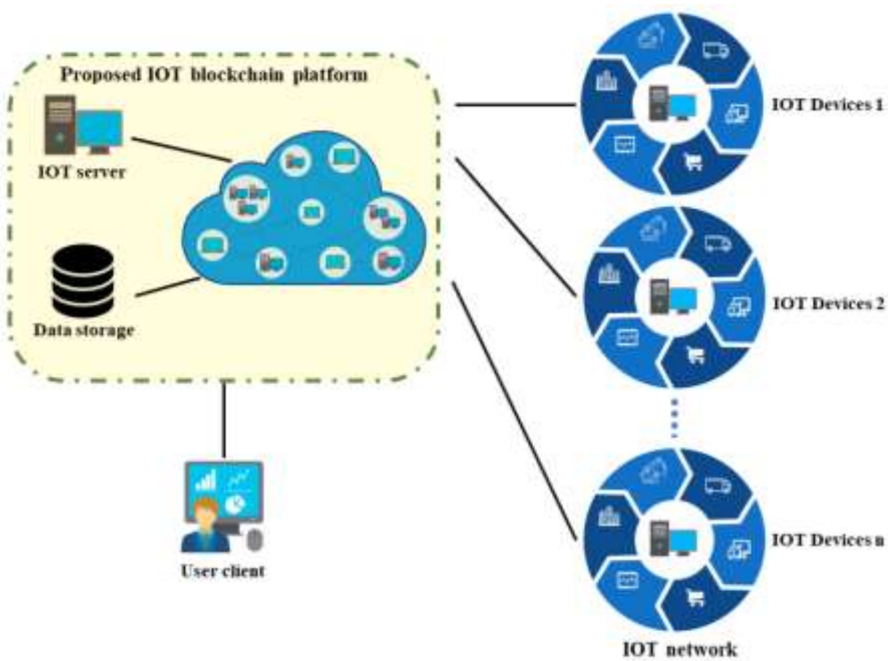

Fig. 10. Diagram of the proposed infrastructure of using IoT devices according to the blockchain technology in smart grids [160].

Blockchain technology is increasingly applied in IoT sectors and devices, so the application of blockchain technology in the IoT field is investigated [52]. In another study [161], the problems of security and privacy due to IoT are studied in the blockchain networks. Furthermore, the blockchain technology challenges, such as high energy consumption, time-consuming, and its complexity is addressed, while the blockchain is applied in smart homes. On the other hand, different devices are communicating through the miners, so these miners are responsible for privacy and security. In addition, the proposed structure includes the home appliances equipped with IoT, the local storage, the miner, and the local blockchain. An industrial IoT is investigated in relation to the decentralized energy trading and the blockchain technology [162], while IoT application enables the data flow between the distributed energy resources and the users. However, the proposed structure deteriorates the security and privacy of data flow. Hence, a new structure for the blockchain is proposed to meet both security and supplying all loads.

The blockchain-based structure for energy trading between IoT devices is proposed to address security issues and privacy [163]. The energy can be exchanged through the blockchain-based structure in SG, which assures a secure data transfer between IoT devices. Furthermore, a novel concept of digital loan is defined in order to facilitate the financial transactions, while the main goal of this credit-based financial transaction is to maximize profits for a digital bank. The limitations on the control of IoT devices are investigated [164], which is mainly caused by the lack of central supervision. However, the control issues can be solved through the blockchain-based structure to manage the connections between IoT devices. In [165], the internet of energy application in the energy sectors is investigated, and its collaborations with the distributed renewable resources and EVs are reviewed. Furthermore, the current application of blockchain technology in terms of the internet of energy is studied, and the future challenges for consumers are introduced. The applications of IoT and communication networks in the SGs and its importance to realize the blockchain technology application in the SGs are investigated in [166].

The operation of SG considering IoT devices and renewable energy penetration is reviewed, while the blockchain technology is presented for improving its operation [21]. Further, this study highlights the advantages and the disadvantages of blockchain's application in SG and proposes a novel structure for the blockchain-based SG. In another study [167], the blockchain efficiency is studied in two different IoT-based case studies, including 5G network and SG, while its suitability is verified under different cases. In [168], the industrial IoT drawbacks due to using the blockchain are explained, while the Fabric blockchain method is proposed according to the dynamic model. Moreover, the proposed method is tested on a sample case study, so the results show an increase in both the trading rate and the receiving rate. A new framework based on both the blockchain and the deep learning is proposed named Deepcoin, which operates in five different phases using a Byzantine method, and it is tested on an IoT-based network [169].

The advantages of blockchain structure for IoT is discussed in different aspects, including the authentication and secure data transaction, while some practical difficulties should be addressed in order to adapt the blockchain technology to IoT technology [170]. Hence, this study determines all requirements of IoT associated with blockchain technology. In another study [171], the current blockchain technology is reviewed, and its use case in the IoT area is investigated. Moreover, it is claimed that the blockchain technology fits IoT requirements, although some technical challenges should be solved. Further, the relation between the blockchain technology and IoT concept is comprehensively reviewed in [170], while security issues and attacks on IoT, especially the industrial IoT, are investigated in [172]. Application of the IoT in the blockchain technology application in the SGs can result in different challenges for security and data privacy, where its opportunities, including fastening the transactions and its intelligence, surpass its challenges [173].

The development of IoT devices requires both the communication infrastructure and the management of different IoT devices, which can be addressed through the blockchain structure [174]. Hence, the Ethereum is used as a platform verified by the system, which includes a lot of IoT devices. All issues related to IoT security and its difficulties are reviewed [175], while all possible methods to address these drawbacks are thoroughly discussed. In addition, the advantages and the disadvantages of applying the blockchain with IoT technology are identified [176]. Further, an efficient structure of blockchain is proposed in [177] to address the security of IoT devices integration into SGs, which is tested in the smart home. On the other hand, the feature of the distributed structure of blockchain can be applied to meet the challenges, such as the big data from IoT devices, the control of IoT devices, and the financial transactions [178]. An IoT-based E-business model is presented, which is operating according to the blockchain technology and applies the smart contracts to set all transactions in the presented model [179]. Further, the data transactions between IoT devices and storing this huge volume of data in the decentralized structure are realized through the auditable storages using the blockchain structure [180].

The development of IoT devices associated with the blockchain technology is reviewed in terms of categorizing its application, the management of IoT devices, and the data transactions in addition to analyzing the available methods [181]. The data transactions between IoT devices in the blockchain structure are also investigated in [182] according to the integrity service. Furthermore, the secure blockchain structure for managing IoT devices is proposed to satisfy the privacy of data and financial transactions [183]. Since IoT technology connects a lot of devices through the internet, a high possibility exists for the attacks and the frauds.

Hence, the blockchain-based structure is proposed to avoid these security issues [184] and [185]. On the other hand, a specific application of applying the blockchain technology in IoT-based healthcare is investigated in order to control a large amount of data collected from the patients and doctors [186]. Moreover, the lightweight, scalable blockchain is presented to satisfy IoT necessities, which is tested in the smart home in the presence of IoT-based appliances [187]. In addition, the blockchain structure is applied to solve all problems due to IoT integration into smart homes, including the data collection problems, the communication between IoT devices and network, the big data issues, and the false data injection [188]. One of the main challenges in IoT application in the blockchain is big data and large size of information, which should be transmitted between different nodes [189].

7.2. Blockchain application in cyber-physical security

Security in the networks has been recently considered as an important issue due to an increase in the cyber-attacks, which can affect the networks in different aspects, i.e., the financial fraud, the false data injection, the data manipulation, and so on. On the other hand, a large amount of data is transmitted through SG between the prosumers and the consumers, including the energy request sent from the consumers, the cost data proposed by the prosumers, and the amount of energy provided by each prosumer. Hence, security issues should be strictly addressed in SG equipped with a variety of sensors, miners, renewable energy systems, and smart devices, which are considered as the vulnerable nodes in the network. Therefore, one of the efficient solutions to increase the security of SG is applying the blockchain technology, which can be utilized in order to prevent fraud and provide reliable transactions.

The cyber-attacks and the false data injection problems are solved by the blockchain-based network [72], while the proposed framework is added to the present network, so the modifications in the current infrastructure are minimized. Furthermore, the presented SCADA system includes the network components, such as the sensors, the controllers, and the actuators, which are connected through the communication system and are controlled by the central control. On the other hand, the considered protocols for the data transmission between different components are Modbus/TCP, Ethernet/IP, and DNP3, which are vulnerable, especially in the cyber-attacks. Moreover, the proposed blockchain-based technology keeps the data collected from all sensors in the base distributed stations. Then, the base stations share the data together in each blockchain autonomy system.

Finally, the data is collected in one block and is stored in the ledgers. As a result, the efficiency of the proposed method of increasing SG security and its potential advantages and disadvantages are analyzed.

In [190], the blockchain is introduced as a technology to address the security issue of the network, while the superiority of the blockchain technology's application in the IoT area is verified due to its decentralized structure, which decreases the possibility of forgery. In addition, the blockchain-based structure for energy trading between IoT devices is investigated for security issues, and different criteria are considered in security analysis, including the intermediary, the wallet security, checking the correct data transaction, the unforgeability, and checking all financial transactions [163]. In another study [146], the Byzantine method is used in order to increase the security of energy and the data sharing in vehicular networks, which is proven through the simulation results. Furthermore, the data sharing security between the smart meters is addressed by proposing the signature scheme method [191], while the presented method applies the consortium blockchain, and there is no need for the third party. In addition, a secure connection between different entities in the blockchain structure is studied [7].

The blockchain-based network is proposed in [51], which is successfully tested for the normal security attacks. Furthermore, it is also shown that the proposed system can operate robustly without any need for external supervision. In addition, the data is totally private, while the proposed network considers both a secure wallet and the energy transaction. Hence, the proposed system and its decentralized structure, according to blockchain technology, prevent the data forgery, while security is also improved. It is also investigated that the blockchain is useful to maintain security issues in different applications, such as SGs, which is verified through testing on the simple blockchain network [192]. In [147], security concerns of EVs against the cyber-attacks and the forged data is assured using the blockchain technology, which applies a reputation method. Different protocols can be used for the communication and the data transaction in the blockchain structure, and all these protocols should consider the security of data transactions. Hence, a 5G network is proposed for communication between different entities through the blockchain, which also maintains security issues and network privacy [193].

The decentralized storages are used to improve the security of data transactions between different entities through the blockchain, which compensates for the failures of centralized structure [60]. Furthermore, security and privacy issues of blockchain technology are addressed in [194], while the cryptography algorithms are investigated to address the privacy issues, and the future trends in maintaining privacy are analyzed. The security of the smart home is investigated in three different aspects [161], which are shortly introduced here. The first aspect, named confidentiality, assures that only the specific persons have access to the data. Furthermore, the second aspect is called integrity, which satisfies that data are transmitted truly, and the last aspect is related to the accessibility of all persons to the data over their requested period. Then, the efficiency of the proposed method is analyzed by testing it against the distributed denial of service and the linking attacks. In [195], the security problem in the multi SGs is analyzed, while the distributed structure of multi SG is also considered. Since these multi SGs are highly possible to be attacked, they should be tested against different attacks. Hence, the intrusion detection system is proposed in this study, which operates according to the consensus-based blockchain. In addition, the proposed method can operate in a distributed structure without any need for central supervision.

The cyber-attacks to SG are analyzed, while the detection methods and the protection solutions are studied [196]. Furthermore, a novel method is proposed to address the self-healing procedure after the cyber-attacks to SG, which operates based on the blockchain technology. In addition, the authors thoroughly discuss the effectiveness of the blockchain network to improve the protection ability of SG against cyber-attacks. In [145], the security benefits of blockchain technology for the vehicular network is reviewed, while the efficiency of this technology in secure data sharing is verified. In addition, blockchain technology is used to verify the identity of people in order to increase the security of the system, while the procedure of identity approval is comprehensively reviewed considering all related researches and patents [197].

The role of blockchain technology in solving different challenges, i.e., the security issues, the financial transactions in the decentralized structure using bitcoin, and the integration of IoT devices into SG are fully investigated [198]. A comprehensive literature review on the cybersecurity concept in the blockchain is done, which covers all subjects of cryptography, the security of IoT technology, and security in storing data, while all challenges and the future opportunities are recognized [199]. In addition, the application of blockchain in the specific industry, i.e., healthcare, is investigated in terms of cybersecurity concerns [200]. Further, its application in other areas like the financial, the governmental, and all security-based areas are verified. Also, the application of blockchain technology in the healthcare area is assessed in terms of financial concerns and the fast access to the patient's data [201] and its availability in the cloud [202]. On the other hand, the feasibility and the capabilities of different consensus protocols to meet security in the blockchain are analyzed [203].

In addition, a comparative study on the assessment of the suitability of the blockchain technology and its cost to satisfy security in different industries is done [204], which also highlights the ongoing trend of this technology. Security issues of blockchain technology are reviewed in order to find all its difficulties and benefits [205]. Furthermore, the features of Hyperledger fabric and the Ethereum to solve security issues, especially the Byzantine fault tolerance, are addressed [206]. The development of IoT technology in a variety of areas in SG, such as IoT in EVs, IoT in healthcare, and IoT in security-based applications are analyzed [207], while a novel structure is proposed to address data transmission. Another study presents a model of blockchain cloud and its challenges in terms of being attacked, which specifically studies the block withholding attack and its identification methods [208].

The blockchain technology is applied to address security in the transportation application and the vehicular networks [209]. Furthermore, this study considers security in both data transactions and energy trading. The conventional cloud structure is combined with the blockchain-based network in order to assure security in the data transactions and the data collection from IoT devices [210]. In addition, a novel structure for the management of drone data in the cloud is presented. Also, the capabilities of blockchain technology to address security concepts in a variety of consensus models are reviewed, while its drawbacks and the future scopes are identified. A novel structure named Provchain is proposed to address security in collecting data, storing data in the cloud, and finally validating the collected data, while the proposed method meets the temper-proof and security concerns [211]. The specific application of blockchain technology on the digital identity in SG is assessed in [212], while all its benefits and drawbacks are highlighted.

8. Blockchain testbed implementations

The blockchain structure has been implemented in some testbeds, while the obtained results have proven its efficiency. In [33], the blockchain is used in order to develop PV self-consumption structure, which includes two producers and three consumers located in France. Therefore, the produced power is divided between 3 consumers through the public network. Furthermore, the smart meter connection to IoT devices and its frequency in sending the energy data to the blockchain network is tested in this prototype. In addition, the system operator and the blockchain networks calculate the demand curve and the supply curve using the data gathered from the smart meters, while the self-consumed energy is determined. The applications of blockchain technology in different sectors of the energy industry are reviewed, and the active companies in this area are introduced [213].

Moreover, the challenges of blockchain development in developing countries, in addition to the existing barriers, are investigated. A real-time market in relation to the blockchain technology is tested in a prototype located in Seattle, US, and its practical results are shown [69].

The Ethereum-based smart contract is implemented in the blockchain-based smart homes, while two different consumer and prosumer nodes are exchanging energy together [40]. Moreover, it is shown that the energy transaction is completely done using the blockchain technology, and it is not possible to forge the transaction. The renewable energy transactions are tested in the Ethereum blockchain network, while the tested platform includes the marketplace web application, three Ethereum nodes, three Ethereum contracts [41]. Furthermore, the energy transaction and the counter values are specified as the tokens. In [214], some projects based on blockchain technology are reviewed in the energy sector in the US, while their pros and cons are identified. In addition, the future trends for improving the blockchain technology in the energy industry are recognized. Further, applying the blockchain technology in the healthcare sector is studied in [215], which investigates security and smart contracts according to this application. The current states of renewable energies and the blockchain are studied in China, while a Michael Porter model is investigated [216]. Further, the potential strength of blockchain technology to improve the renewable energy sectors in China is analyzed, while some policies are recommended to address this issue.

The blockchain technology is used in the local energy management, which is tested on 100 residential houses equipped with PV units [43]. Furthermore, this case study is tested over a one-year period, while energy is traded every 15 minutes. In addition, each smart home is considered as the prosumer which can sell or buy energy according to its generation and consumption. Hence, the main objective of this study is minimizing the local energy management cost, which is successfully realized. However, the suitability of blockchain technology for the local energy management is limited due to its disadvantages, including the complexity, the scalability, consuming high energy, immaturity, and the uncertainties about the success of blockchain technology. The current problems and the future challenges of blockchain's application in the energy sector in Japan are studied [49]. The energy trading through the blockchain-based network is tested in a prototype, i.e., IBM Hyperledger Fabric, to meet the distributed resources, while the results show the efficiency of the proposed method in both the day-ahead planning and the real-time scheduling.

In [57], the energy management of different residential sectors and industrial sectors through the blockchain technology is tested in Singapore, while a flat demand curve is obtained. The impact of blockchain technology on renewable energy development in a sample Brooklyn microgrid is studied [30], while the decentralized energy market is applied in this case study. Hence, the results verify the superiority of P2P energy transactions to create an efficient energy transaction. On the other hand, all projects related to the blockchain technology and SGs are listed in [2]. The Blockzoom testbed is operating based on the blockchain structure, which includes the decentralized ledgers and the smart contracts [217]. Further, a novel testbed for developing IoT technology is proposed in [218], which is operating according to the Ethereum. Therefore, the efficiency of the proposed testbed is assessed by a Markov chain algorithm. The blockchain-based structure is presented to address P2P interactions and the communication between the virtual power plants in SG, considering security issues [219].

Some of the blockchain-based projects to facilitate the decentralized energy transactions are listed in [1], which are briefly introduced here. The Enerchain project is developed to transfer energy in the P2P structure between European countries, which applies Tendermint/Proprietary smart contracts. Further, the Viertel district project aims to improve the vehicle to grid application and the decentralized energy trading through Interbit BTL. In addition, the Tennet-Vanderbron-Sonnen project is developed for the vehicle to grid application and the improvement of residential storage using Hyperledger. Another project named Electron aims to satisfy DR and P2P in the decentralized structure using Ethereum. Further, the Energy web foundation is also utilized according to the Ethereum in order to meet the decentralized energy trading requirements. Four different projects, including Conjooule, Grid+, Green Powerexchange, and Brooklyn microgrid, are developed to respond to P2P needs to be constructed based on the Ethereum and Tendermint/Proprietary smart contract. On the other hand, Alastria and Solara projects are operating based on Hyperledger and the energy web foundation technology.

The opportunities and challenges of the blockchain development in the Netherland and the proposed modifications to match the blockchain technology are introduced [220]. In another study [221], the energy supply shortages in the rural areas are considered, which are addressed using the blockchain technology. Furthermore, the agricultural wastes are considered as the important sources of energy, and the digital coin is applied to set the economic transactions in Changzhi city, China. Hence, the main aim of this study is to encourage the farmers to participate in the energy transactions by their agricultural wastes and connect to the enterprises. The digital coin and the blockchain technology are applied in order to simplify the renewable energy integration in a sample network in China [16]. Moreover, the amount of energy consumption for Monero mining in China is calculated over a 9-month period, which is equal to 30.34 GWh. Different verifying methods of testbeds for the blockchain technology are reviewed in Table 3 [21]:

Table 3. Different verifying methods of testbeds for blockchain technology presented in [21]

No.	Verifying methods
1	Multichain is used for verifying the transactions.
2	The energy market is developed based on Corda and the Predix platform.
3	Smart contracts are developed with the Solidity platform.
4	Blockchain is developed with the Volttron platform at Washington state university
5	Blockchain is built with Ethereum homestead.
6	Blockchain is simulated with a Java agent development environment JADE software.
7	Blockchain is verified via EthereumJS testrpc.
8	Blockchain is built with Zig-Ledger.
9	Blockchain is implemented on TestRPC-Ethereum.
10	Blockchain is tested by Hyperledger.

9. Blockchain for environmentalism

The blockchain technology development in SGs affects the environmental issues in two different aspects. Firstly, blockchain technology development increases renewable energy resources, which can decrease the amount of pollution caused by fossil fuel powerplants. Secondly, the mining procedure of blockchain increases energy consumption, so if the fossil fuel-based power is applied to supply this electrical demand, the amount of carbon emission increases. Therefore, it is important to consider both the advantages and the disadvantages of using the blockchain technology on the environment.

The carbon trading is combined with the blockchain technology, while the suitability of using the blockchain technology and its difficulties in this area are highlighted [222]. Moreover, blockchain technology is applied for both fast and safe energy trading and data transactions, while it is also useful in decreasing the carbon emission. Hence, the authors claim that a combination of blockchain and carbon trading can be helpful in addressing environmental issues. In [223], the roles of blockchain technology in increasing climate changes and energy consumption are discussed, while it is explained how the current blockchain technology can affect energy consumption and leads to environmental pollution. Moreover, the main actions and policies, especially considering the digital coins and using renewable energy systems as the supplies, are investigated in this paper.

The destructive effects of blockchain technology and the digital coins on increasing the carbon emission are studied in [224], while a method is proposed to estimate the power consumption of blockchain technology.

Moreover, it is anticipated that 22 million tons of carbon will be emitted in Jordan and Sri Lanka nations due to the mining and the bitcoin technologies. In addition, the effects of blockchain technology in the energy industry are studied in two different aspects of carbon emission and energy consumption [16]. Hence, analyzing the obtained results of blockchain technology development in a specific case study in China shows about 19 thousand tons of carbon emission over nine months. The efficiency of blockchain technology's application in improving the environmental issues is verified through its application for IBM water management [225].

The blockchain technology can affect the environmental issues from different perspectives, such as the carbon tax, recycling, the supply chain, the energy, the incentive, the non-profits, and the environmental treaties shown in Fig. 11. The interactions between the blockchain technology and the abovementioned factors are discussed as follows [226]:

- Recycling: nowadays, a large number of people have not been encouraged to participate in recycling programs due to the lack of appropriate incentives. However, the current structure can be modified through the token-based incentives, so all consumers immediately receive their incentives using the digital coins.
- Supply chain: the blockchain can be applied in order to clarify the process of manufacturing products, its shipment, and finally its delivery to consumers. In other words, the consumers prefer to purchase their products from actual manufactures in order to decrease the environmental pollutions, which can be realized through blockchain technology. Hence, the consumers can track any information related to their products through the blockchain and buy directly from the manufactures.
- Energy: trading energy is facilitated through the blockchain structure, while renewable energy resources are also applied. Hence, developing renewable energy resources can solve the environmental pollutions caused by fossil fuel-based power plants. In addition, natural disasters, such as hurricanes, floods, and so on, can cause power loss, which is compensated through the distributed energy supplies.
- Incentives: although the greenhouse gas emission is among the important concerns, a large number of factories and persons do not intend to decrease or even control their air pollution due to financial reasons. The blockchain technology can provide the new digital incentives according to the environmental pollutions and encourage all entities to reduce their Co_2 emission.

- Non-profits: any financial aid can be directly devoted to the environmental issues using the blockchain structure and the digital coins. Hence, all people can track their financial aids to specific environmental entities and track their activities. In other words, the blockchain increases transparency in financial transactions.
- Environmental treaties: secure data sharing in the blockchain can help to clarify any activities related to environmental treaties. Therefore, the possibility of manipulating data is decreasing, while the government and all entities should keep their commitments to these treaties.
- Carbon tax: secure data flow and digital financial transactions through the blockchain can help to determine the carbon tax for each company or product. In fact, the amount of emitted carbon can be determined through the collected data for each product, and the carbon tax is determined according to Co_2 emission. On the other hand, the carbon tax can be easily charged through digital transactions, which avoid any possible fraud in paying the carbon tax.

Fig.11. Potential impacts of applying blockchain technology on environmental issues, including the carbon tax, recycling, supply chain, energy, incentive, non-profits, and environmental treaties.

10. Conclusion

In this paper, the current studies on the blockchain technology's application in SGs are reviewed, so it is verified that the blockchain technology can be considered as the promising option for the current SG according to its specifications and requirements despite the current challenges. The opportunities and main challenges of applying blockchain technology in the SGs are identified, and some ideas and solutions are proposed to address the challenges. Although the blockchain technology can be applied as a useful option for the SGs, the security issues should be carefully investigated to reduce the probability of fraud and manipulation and improve the reliability and trustworthiness of the smart grids. The renewable energy development and needs for the distributed energy and the data transactions between the prosumers and the consumers are investigated in a lot of studies, which can be met by the blockchain. Therefore, application of the blockchain technology due to the renewable energy development is tested in the real prototypes, and its pros surpass the cons. In addition, the application of the blockchain technology in SGs is reviewed in different categories, i.e., security, energy trading, energy management, blockchain testbed, EVs, IoT, smart contract, financial transactions, and environmentalism. The smart contracts are determined in order to incentivize the consumers to participate in the DR program. Furthermore, the impacts of the blockchain technology in the integration of EVs in SGs are discussed, while the blockchain-based vehicular network is considered in order to share energy and data between EVs and to facilitate the digital financial transaction. On the other hand, blockchain technology can be efficiently developed due to the presence of IoT technology in SGs, but the security issues caused by high-volume data transactions should be addressed. In addition, applications of the blockchain technology are thoroughly discussed in terms of the decentralized energy management and the energy trading between the distributed prosumers and the consumers. The real testbeds and some projects related to the blockchain technology applications in SGs are introduced. Finally, the opportunities and the challenges of blockchain technology on the environment are discussed. As a result, blockchain technology is identified as the promising option to satisfy a variety of issues related to the novel structure of SGs, although the possible challenges should be comprehensively analyzed and addressed by applicable solutions.

Appendix 1

Table 4. Comparative study on the reviewed references on blockchain technology applications in the smart grid in a variety of areas: 1: Renewable energy, 2: Smart contracts for demand response, 3: Electric vehicles, 4: IoT, 5: Decentralized energy management, 6: Energy trading, 7: Financial transaction 8: Cyber-physical security, 9: Testbed implementation, 10: Environmentalism.

Ref.	Description	Area									
		1	2	3	4	5	6	7	8	9	10
[1]	Reviewing opportunities and drawbacks of the blockchain technology in the power grids and introducing some blockchain-based testbeds.	■	■				■	■	■	■	
[2]	Reviewing the current difficulties and future opportunities for the blockchain technology development in the energy area and introducing some blockchain-based projects.	■	■	■	■		■	■	■	■	
[3]	Investigating the future trend of the blockchain in the energy sectors and highlighting the importance of the distributed energy transactions.	■	■	■			■	■			
[4]	Developing solar energy resources in the smart homes and EVs using the distributed energy transaction and the blockchain technology	■	■	■	■	■	■	■			
[5]	Proposing blockchain technology as the solution for the decentralized resources, investigating modifications in the end-user, and the energy sectors in addition to discussing the current challenges in Europe due to the development of the blockchain.	■					■			■	
[6]	Addressing the requirements of SG for the distributed transaction with the blockchain technology considering both P2P and the secure transactions.	■	■				■	■	■		
[7]	Reviewing the benefits and drawbacks of applying blockchain technology in smart communities.		■	■	■		■	■	■		
[8]	Reviewing the current state, the future trend, and difficulties of the blockchain development in different aspects, including data transaction, energy trading, security, and IoT.		■		■		■	■	■		
[9]	Addressing smart meter's application in the data flow between the prosumers and the users with the blockchain technology and checking the security issues.								■	■	
[10]	Using the blockchain technology for the energy storage system in SGs and verifying its positive effects, applying the energy storage systems in an auction market, and using the smart contracts for the secure and economic transaction.		■		■		■	■			
[11]	Reviewing the sidechain technologies like the blockchain connected to the main blockchain.		■					■	■	■	
[12]	Analyzing the blockchain patent documents considering their classification and materials.		■					■		■	
[13]	Reviewing the blockchain's application in China over the period between 2013 to 2019.		■		■			■	■	■	
[14]	Addressing the security issues of SG using the blockchain technology and assessing its application in the cryptocurrency network.		■		■			■	■		
[15]	Reviewing the public key and the key management architecture for the financial transactions and proposing a trustable way of communication.				■				■		
[16]	Investigating power consumption of the blockchain technology according to its application in the energy industry, analyzing the amount of energy consumption growth in the specific case study in addition to an estimated increase in the carbon emission due to the digital coin and the blockchain technology in China.	■									■
[17]	Proposing a decentralized review system to guarantee secure transactions and avoid the cyber-attacks based on the Ethereum blockchain and the smart contracts.		■					■	■		
[18]	Developing smart contracts according to the blockchain technology for supplying the energy demand.	■	■			■		■			
[19]	Summarizing the blockchain technology's applications in SG, i.e., P2P energy trading, the energy trading between EVs, the security, and secure equipment maintenance.				■		■		■		
[20]	Determining the structure of the blockchain and its concept, defining a new hash for each block to assure the security in								■		

	addition to decreasing the cyber-attacks through the consensus algorithm.										
[21]	Investigating a process of the transaction in the blockchain using the consensus algorithm, reviewing the operation of SG considering IoT devices and the renewable energy, highlighting the advantages and the disadvantages of the blockchain's application in SG in addition to reviewing different verifying methods of the testbeds for the blockchain technology.	■	■	■	■		■	■	■	■	
[23]	Reviewing the application of the blockchain technology in SG due to its capability in the secure and clear data transactions, the energy trading in addition to the decentralized energy management.		■		■			■	■	■	
[25]	Applying both the private blockchain and the public blockchain in the construction industry in addition to proposing the blockchain structure for two different industries.		■		■			■	■	■	
[26]	Assessing the feasibility of the blockchain in the construction industry.		■			■		■	■		
[28]	Proposing the wide-area blockchain, including the substation and the cluster gate for both security and process of data collected from the regional blockchains.	■	■		■		■	■	■		
[29]	Proposing the blockchain technology as the solution for renewable energy development, simplifying the clean energy transaction using the smart contracts in addition to introducing the clean energy blockchain to reach the practical economic and time-efficient transactions.	■	■					■	■		■
[30]	Addressing high penetration of the renewable energy systems into SG with the blockchain technology to increase their financial benefits, analyzing the socio-economic advantages to encourage the development of renewable energy plants, analyzing the energy trading between the prosumers and the consumers using P2P technology considering challenges of the distributed resources in addition to assessing the blockchain technology in the Brooklyn microgrid.	■				■	■		■	■	
[31]	Proposing the blockchain technology to transfer energy between the smart homes equipped with PV and wind turbines, including differing steps, i.e., user registration, transaction information declaration, leader node generation, market transaction matching, writing transaction information to the blockchain, transaction settlement.	■	■				■	■			
[32]	Applying the blockchain-based technology to integrate higher renewable energies into SG and developing a carbon price scheme.	■					■				■
[33]	Developing the solar energies by the blockchain-based technologies considering the current smart meters installed in SG, assessing a testbed located in France, analyzing frequency in sending the energy data to the blockchain network, reviewing applications of the blockchain technology in different sectors of the energy industry, introducing active companies in the blockchain area in addition to investigating challenges of the blockchain's development in developing countries.	■	■		■		■	■		■	
[34]	Analyzing the feasibility of applying the blockchain technology in the energy sectors considering the renewable energy systems.	■	■			■		■	■	■	
[35]	Investigating the importance of distributed energy management in the development of renewable energy systems in SGs in addition to the fundamental changes in energy trading in China.	■	■				■	■	■	■	■
[36]	Studying the relationship between the blockchain structure and the smart contracts in the high presence of renewable energy systems in addition to investigating its possible benefits on the environmental issues.	■	■				■	■			■
[37]	Analyzing the high integration of renewable energy systems in the low-voltage networks using a concept named NRGcoin.	■	■					■			

[38]	Showing the effects of applying the blockchain structure on the renewable energy sectors using a real case study, including 37 residential sectors equipped with 75 smart meters in Walenstadt.	■			■				■	■	
[39]	Investigating the role of renewable energy resources as the prosumers and their effects on data sharing, considering the blockchain technology, IoT, and big data.	■			■						
[40]	Proposing a renewable energy transaction structure using the Ethereum smart contracts between the blockchain-based smart homes, managing the energy trading using the blockchain-based smart homes equipped with the energy storage systems, IoT, smart meter, and home miner, developing the energy trading procedure in 4 different phases based on the Ethereum smart contract in addition to verifying the security of energy transaction.	■	■		■	■	■	■	■	■	
[41]	Analyzing renewable energy transactions using the Ethereum blockchain verified in a real testbed, including marketplace web application, three Ethereum nodes, and three Ethereum contracts.	■	■				■	■	■	■	
[42]	Addressing the uncertainties caused by the high penetration of renewable energies with the blockchain-based network and P2P trading between the prosumers and the users.	■	■	■	■	■	■	■	■		
[43]	Developing a local energy market due to the development of renewable energy systems to facilitate the energy trading between the prosumers and the consumers, investigating a novel distributed energy management solved using the distributed ledger technology to minimize total cost in addition to testing the proposed method on 100 residential houses equipped with PV units.	■	■			■		■		■	
[44]	Applying the fog computing for the renewable energy systems in addition to the blockchain technology to address security issues in the data transaction, verifying efficiency and lower energy consumption of the proposed method through simulation under different operation modes.	■			■	■					
[45]	Reviewing the advantages and the disadvantages of the blockchain's application for facilitating renewable energy development in addition to discussing the industrial drawbacks and the academic challenges of the blockchain development in different technical, financial, social, environmental, and institutional aspects.	■	■			■		■	■		■
[46]	Discussing the importance of developing a new structure for energy trading between the smart homes equipped with renewable energies using the consortium blockchain network.	■					■		■		
[47]	Proposing the blockchain structure to address the high penetration of solar energy in the smart homes and the energy transaction issue in addition to realize the minimum cost.	■	■	■		■		■			
[48]	Applying the blockchain technology in improving the energy transaction and protection of the network from the cyber-attacks in SG.	■	■	■			■	■	■		
[49]	Analyzing the blockchain technology development to address the distributed renewable energy in different technical, financial, social, environmental, and institutional aspects, anticipating the structure of the multi-stakeholder ecosystems and some changes in the management sector toward 2050 in addition to studying the current problems and the future challenges of the blockchain's application in a prototype, i.e., IBM Hyperledger Fabric.	■	■	■	■			■	■	■	■
[50]	Proposing a real-time model to address the stochastic behavior of renewable energy resources according to the blockchain technology and defining the incentives for the consumers to increase EVs.	■		■							

[51]	Investigating the decentralized charging of EVs in SG using the consortium blockchain to maximize total profit considering security issues in addition to consumer welfare in addition to applying both the secure wallet and the energy transaction in the proposed structure to prevent the data forgery.		■	■			■	■	■		
[52]	Studying the importance of smart contracts in the blockchain, identifying the smart contract features, i.e., specific state for each contract, capability of defining business logic, considering all possible outcomes in the smart contracts, triggering at its address, and tracing all operations done by each contract in addition to investigating the blockchain technology in IoT area.		■		■			■	■		
[53]	Investigating DR and the blockchain technology to manage the financial trading and data transactions in addition to developing smart contracts based on the power flow and the financial states of the network.		■					■			
[54]	Analyzing the relation between the energy market, the smart contracts, and the blockchain technology in the decentralized SG.		■					■			
[55]	Proposing the DR method according to the consortium blockchain to encourage EVs in order to improve their participation in the energy trading procedure, defining different contracts based on EV type, and considering the internet of EVs.		■	■			■	■	■		
[56]	Considering the DR program for different types of loads in order to manage the secure energy transaction in addition to using miner nodes to authenticate the energy trading through the blockchain.		■	■			■	■	■		
[57]	Studying DR of different loads, i.e., residential load, commercial load, and industrial load in relation to the blockchain technology in a real-time market, applying the smart contracts to provide the secure and reliable energy trading and data flow in addition to testing the energy management of different residential sectors and industrial sectors through the blockchain technology in Singapore.	■	■			■		■	■	■	
[58]	Managing the energy transactions between storages through an automated DR algorithm in the decentralized blockchain network, testing the proposed DR method in the blockchain-based network, improving security in the energy trading.	■	■	■			■	■	■		
[59]	Proposing the blockchain technology for optimal industrial load management in different types of electricity markets.	■	■				■	■	■		
[60]	Applying the smart contracts to estimate the cost and the duration of using a variety of devices, defining the decentralized storages as the units which rent their hardware storage space, reviewing all possible challenges and opportunities of using the decentralized storages, analyzing the decentralized storages to improve the security of data transaction between different entities.		■		■	■		■	■		
[61]	Applying the smart contracts for the prosumers to announce their price and offers according to the trustable and secure structure.		■					■	■		
[62]	Investigating different interactions between blockchain technology and decentralized energy management considering its role in solving environmental issues.	■	■		■	■	■	■	■		■
[63]	Studying a two-way connection and the energy trading between SG components in order to find the appropriate energy management and DR structure.		■	■		■	■	■	■		
[64]	Encouraging the consumers to participate in the DR program through the blockchain structure, which facilitates the secure and trustable financial transaction.		■				■	■	■		
[65]	Improving DR program acceptability between the consumers and assuring the consumers of reliable energy trading according	■	■					■			

	to the financial transactions provided by a flexible electricity market.										
[66]	Managing consumption for both the prosumers and the consumers using the blockchain-based DR programs.	■	■				■	■			
[67]	Investigating the information flow and energy trading in the decentralized networks through the blockchain-based decentralized energy management.					■	■				
[68]	Proposing the distributed energy exchange structure according to the blockchain and software used for networking in addition to considering the security issues.	■	■			■	■	■	■		
[69]	Investigating the smart contract in the real-time and decentralized energy market according to the Ethereum blockchain.		■			■		■	■		
[70]	Managing the energy flow in SG according to economic, social, and operational issues in addition to using the smart contracts to ensure the secure data flow between different sectors.	■	■			■	■	■	■	■	
[71]	Applying the blockchain technology in order to utilize the stochastic energy management for SG to minimize cost and improve the security by a directed acyclic graph.	■				■	■		■		
[72]	Proposing the blockchain-based network in order to increase the security of data transaction, storing data in the blocks by a Byzantine method, solving cyber-attacks and false data injection problems, considering protocols for the data transmission between different components, including Modbus/TCP, Ethernet/IP, and DNP3 in addition to analyzing the efficiency of the proposed method on increasing SG security and its potential advantages and disadvantages.					■			■		
[73]	Proposing the blockchain structure to address the distributed energy management for the decentralized renewable energy resources and the energy storage systems.	■	■			■	■	■			
[74]	Proposing the distributed energy system based on the blockchain to supply the demand of IoT devices according to the consensus protocols, meeting the main goal to maximize benefits for both SGs and IoT devices, investigating the proposed system in three different layers, including chain service, energy consumer, and energy supply.	■	■		■	■		■	■		
[75]	Proposing the blockchain technology for the distributed energy management in order to minimize the power losses caused by energy transactions.		■			■		■			
[76]	Investigating the energy management of the smart buildings in the presence of electrical and thermal loads, energy storage systems, and renewable energy resource using the blockchain technology.	■	■			■	■	■			
[77]	Investigating the crowdsources energy system and P2P trading considering both the day-ahead scheduling and the real-time scheduling.	■	■			■	■	■		■	
[78]	Investigating the energy management to address both the financial and the operational aspects considering the ancillary service of the blockchain technology.		■			■		■	■		
[79]	Predicting the potential applications of the blockchain technology in the IoT area and the future difficulties, the needs, and the gaps in addition to investigating the future developments of the blockchain in different use cases, i.e., SG, supply chain, and healthcare.		■		■	■		■	■		
[80]	Investigating the application of the blockchain structure for the decentralized management of the industrial system named Predix considering the energy storage and renewable energy.	■	■			■		■	■		■
[81]	Analyzing security issues in the management of data and the energy trading addressed through the blockchain-based SG in addition to meeting the proof of concept using secure energy trading and secure data transactions.		■			■	■	■	■		

[82]	Developing IoT devices in SG and security issues for the data trading and considering the decentralized energy management for secure communication between all SGs.	■	■		■	■	■	■	■		
[83]	Applying the blockchain technology to collect data from IoT devices in SGs in order to manage the energy transactions between the prosumers and the consumers in addition to using the smart contracts to meet all demand.		■		■	■		■	■		
[84]	Proposing the blockchain-based structure to meet all demand, considering the decentralized structure of SGs under the high share of renewable energy resources.	■	■			■	■	■	■		
[85]	Presenting blockchain technology as the solution for the decentralized energy transactions between PV units, wind turbines, energy storage, and EVs as the prosumers with the smart homes as the consumers.	■	■			■		■			
[86]	Investigating the fully decentralized electricity market using blockchain-based energy management in addition to satisfying the collective self-consumption.	■	■	■		■		■	■		
[87]	Assessing the features of blockchain technology as an option to improve energy management in the decentralized energy sectors.					■					
[88]	Investigating P2P energy trading between the renewable energy-based prosumers and the consumers through the blockchain-based energy management software.	■	■			■	■	■			
[89]	Presenting a system model based on the blockchain technology in order to facilitate the energy transactions, avoid the fraud, and guarantee secure data sharing.						■		■		
[90]	Applying the blockchain technology and P2P energy trading in the development of PV units according to a k-double auction.		■				■	■		■	
[91]	Investigating the energy trading between the renewable energy-based prosumers and the consumers through the costly and reliable structure realized by the blockchain technology.	■					■		■		
[92]	Proposing P2P energy trading considering double auction in order to address the energy trading between the decentralized SGs in addition to assuring the trustworthiness of the proposed structure by the smart contracts.	■	■				■	■	■		
[93]	Analyzing the challenges of energy trading between different participants in SGs, including fraud, false data injection, high price, and unreliable transactions, in addition to investigating the blockchain technology to address these issues.		■		■	■	■	■	■	■	
[94]	Assessing the blockchain technology features for P2P energy trading and investigating its security concerns in addition to its acceptability between all participants in the electricity market.		■				■	■	■		
[95]	Applying the consortium blockchain to address security and privacy issues in energy trading through SGs in order to avoid any manipulation and attack.		■	■			■	■	■		
[96]	Assessing the challenges of energy trading between the smart buildings equipped with PV units, such as the vague pricing and the possibility of sending or receiving false data.	■					■		■		
[97]	Investigating the reduction in the possibility of data manipulation and financial fraud during the decentralized energy trading through the blockchain technology.		■				■	■	■		
[98]	Presenting the Ethereum blockchain in order to meet P2P energy trading between the prosumers and the consumers in SGs.		■				■	■			
[99]	Analyzing the challenges of decentralized energy trading, such as security issues, difficulties in financial transactions, and reducing efficiency through the current network, proposing the blockchain technology to address these issues in addition to investigating the potential difficulties caused by the blockchain, including the environmental issues.	■					■		■		■

[100]	Assessing the feasibility of using the blockchain technology for energy trading through a project named Crypto-trading and using smart contracts to improve energy management in the specific area.	■	■				■	■	■	■	
[101]	Proposing smart contracts and the blockchain structure to address the high development of renewable energy resources in SGs and using the token-based system for financial transactions.	■	■				■	■	■		
[102]	Managing the energy trading between network and EVs using the blockchain structure and empowering the vehicle to grid networks through a protocol named directed acyclic graph-based V2G.	■	■	■	■		■	■	■		
[103]	Reviewing different projects for P2P energy trading according to the blockchain technology in addition to identifying their strengths and drawbacks.	■	■				■	■		■	
[104]	Discussing the advantages and the disadvantages of a crowdsourced energy system operating based on the blockchain technology considering the renewable energy systems, EVs, and programmable loads.	■	■	■			■	■			
[105]	Proposing a privacy-preserving method to address the data transmission and privacy in energy trading, which applies an account mapping algorithm and creates some noises on data.						■		■		
[106]	Ensuring privacy in data transmission using the cryptocurrency and cryptography systems to verify the data transmission between different users.						■		■		
[107]	Proposing a software defined networking (SDN) structure to ensure the privacy in data transmission between different nodes.						■		■		
[108]	Reviewing data transmission through the wireless network considering four participants, i.e., consumer, local producer, renewable energy producer, and grid.	■				■	■				
[110]	Investigating the flow of P2P electricity trading employing Ethereum blockchain, while the data transmission between prosumers and consumers through the blockchain is discussed.					■	■				
[111]	Employing cryptography modules to achieve an enhanced platform for data transmission and introducing different architecture for key-exchange based on time-constraints and resource-constraint devices.						■		■		
[112]	Proposing an anonymous signature-based authenticated key exchange targeting IoT-enabled smart grid environment.				■			■	■		
[113]	Proposing a blockchain-based distributed network scheme in the SG protection relays to decrease latency.						■	■	■		
[114]	Proposing a high-performance hash function.						■				
[115]	Proposing the IOTA and Ether as suitable options to address the high speed of the financial transactions in the electricity market in SGs.						■	■			
[116]	Suggesting a framework of the blockchain-based electricity market, which investigates all modifications from a centralized framework to a decentralized structure by blockchain technology.					■	■	■			
[117]	Designing the decentralized structure of the blockchain-based SGs according to the NIST standard conceptual model, which is provided by cryptocurrencies and P2P transactions.		■				■	■			
[118]	Defining specific monetary tokens bonded with a fixed ratio to the Euro to address the uncertainties in market price.		■				■	■			
[119]	Proposing a comprehensive framework to address the energy trading and financial transactions between different nodes through the electricity market in the SGs.						■	■			
[120]	Identifying the features of developing a blockchain-based SG is investigated in Kazakhstan, where the procedure of energy trading, financial transactions, and smart contracts are defined.		■				■	■			
[121]	Reviewing the main challenges and solutions of blockchain and specifically digital cryptocurrency applications in the SGs.		■			■	■	■			

[122]	Using bitcoins to facilitate financial transactions in healthcare to ensure security and authentication.							■	■		
[123]	Applying blockchain technology to boost the privacy, anonymity, and confidentiality in the SGs, where dynamic pricing is addressed through financial bidding by blockchain structure, and smart contracts are defined to automate the bidding process.		■					■	■		
[124]	Reviewing the blockchain opportunities for a variety of areas, including healthcare, transportation, SGs, and financial systems, and highlighting the main features of the blockchain technology to improve privacy.							■	■		
[125]	Proposing the decentralized structure of blockchain-based SG to meet financial transactions, trustworthiness, transparency, and resiliency.					■	■	■	■		
[126]	Managing the high penetration of EVs in the energy market through the blockchain-based structure, applying a delegated Byzantine fault tolerance consensus method in the blockchain-based network, using a contract game to model different EV types, proposing an optimal dynamic contract to address the stochastic behavior of renewable energies and EVs.	■	■	■	■		■	■	■		
[127]	Discussing a control problem for charging EVs from stations and the secure energy transaction, proposing the consensus blockchain structure to address these challenges.			■			■		■		
[128]	Assessing a vehicular energy network and application of the blockchain technology in safe charging of EVs, using the distributed ledgers to charge EVs safely at each node.	■		■	■		■		■		
[129]	Describing security issues caused by the integration of EVs into the blockchain structure according to the data transactions and the financial issues to realize proof of work.			■					■		
[130]	Using the blockchain technology to integrate EVs into SG, investigating the energy exchange method based on the consortium consisting of three parts, i.e., the edge computing service provider, the local energy aggregator, and EVs in addition to applying the account server to specify the relationship between the digital wallet and the account server.		■	■			■	■	■		
[131]	Managing EV development in SG through the blockchain structure to improve the financial and operational issues.		■	■				■			
[132]	Investigating EV participation in P2P energy trading in the blockchain-based network in addition to considering the smart contracts and dynamic pricing for the energy transactions to minimize total cost.		■	■			■	■	■		
[133]	Analyzing the optimal charging of electric taxis using the consortium blockchain.		■	■				■			
[134]	Managing charging of EVs through the consortium blockchain technology in order to maximize consumer welfare and minimize total cost.			■	■			■	■		
[135]	Studying the battery-swap problem for EVs, applying the consensus blockchain in order to realize the distributed energy management.			■					■		
[136]	Reviewing the current drawbacks in EV development and proposing the consortium blockchain as the solution to improve the charging and the payment issues.		■	■	■			■	■		
[137]	Analyzing the relationship between the internet of energy and improving the charging pile of EVs considering the blockchain-based network.		■	■	■			■	■		
[138]	Monitoring EVs through the edge computing blockchain-based authentication method with fast access to the storage and the resources for all EVs containing three layers, including the vehicular network, the blockchain edge, and the blockchain network.		■	■	■			■	■		

[139]	Investigating the IoT problem for EVs and its consequences in the data and energy exchange, proposing the blockchain structure to reach secure and real-time management considering the big data problem.		■	■	■			■	■		
[140]	Defining different types of nodes, dividing the Byzantine consensus blockchain into some smaller blockchain in addition to verifying the efficiency of the proposed method for the secure data transaction, the consensus authentication, and the fault tolerance.		■	■	■			■	■		
[141]	Discussing the social IoT for EVs and introducing the social internet of vehicles to satisfy the social acceptance of EVs among the drivers and the passengers.		■	■	■			■	■		
[142]	Considering the vehicle to grid energy transaction to sell the energy to other EVs and the network, proposing an efficient structure for the secure financial transactions based on the blockchain technology and the Hyperledger.			■					■		
[143]	Proposing the blockchain-based structure to address the true data transaction in the EV network.			■					■		
[144]	Designing the secure data sharing structure between EVs using the blockchain technology in order to prevent 51% of cyber-attacks.			■					■		
[145]	Reviewing the advantages of the blockchain's application in the vehicle industry considering security issue of the blockchain technology, discussing the current difficulties in the blockchain development in addition to reviewing security benefits of the blockchain technology for the vehicular network.		■	■	■			■	■		
[146]	Developing the contract-based method to ease the secure distributed data exchange in addition to using the Byzantine method to increase the security of the energy and data sharing in the vehicular networks.		■	■			■	■	■		
[147]	Addressing security, i.e., the cyber-attacks and the forged data, for the vehicular networks using the anonymous reputation method according to the blockchain technology.			■					■		
[148]	Studying effects of mobility on the blockchain-based vehicular and the hoc network in addition to investigating the process of block addition to the blockchain through the assessment of success in block addition and rendezvous.			■							
[149]	Meeting the challenges of announcement network for EVs, i.e., reliability without recognizing drivers and reluctance in forwarding announcement by introducing a Creditcoin network.			■				■	■		
[150]	Proposing a platoon structure for EVs in order to address the pollution and the traffic problems, defining the path trajectory of EVs by a platoon head in addition to assuring the true financial transaction through the smart contract.		■	■				■			
[151]	Addressing the dynamic nature of electricity cost to charge EVs through the blockchain structure considering the security of charging and the data transactions between EVs and the network.		■	■				■	■		
[152]	Proposing the battery swapping for EVs to address the battery refueling according to the blockchain structure to provide a trustable and transparent environment for these trading.		■	■				■			
[153]	Applying the blockchain to make a billing system in order to clarify information about the amount of charging and the electricity cost.			■							
[154]	Addressing the charging issue of decentralized EVs using the blockchain technology considering the secure energy transaction through the real-time electricity market.			■			■	■			
[155]	Selecting the optimal charging station according to vehicle trajectory, traffic, battery charge, and EV owner satisfaction using the blockchain structure considering the Ethereum-based smart contracts.		■	■	■			■			

[156]	Applying the Ethereum for EV transactions in addition to defining the smart contracts for a variety of transactions.		■	■				■			
[157]	Solving security problems, including identifying EV place and the hijacking of EVs using cryptocurrencies and the smart contracts in the blockchain.		■	■	■			■	■		
[158]	Proposing the charging structure of EVs using the smart contract and the lightning system to avoid any attack on the charging network.		■	■	■			■	■		
[159]	Addressing the constant and reliable pricing of electricity to charge EVs using the smart contract.		■	■				■			
[160]	Proposing an infrastructure named Hyperledger fabric for using IoT devices according to the blockchain technology in SG to address security in addition to using the smart contract to determine all transactions.		■		■			■	■		
[161]	Studying the problems of security and privacy due to smart homes equipped with IoT, local storage, miner, and the local blockchain, addressing the blockchain technology challenges, such as high energy consumption, time-consuming, and its complexity, in addition to investigating the security of smart home in three different aspects, i.e., confidentiality, integrity, and accessibility of all persons to data.				■				■		
[162]	Investigating the industrial IoT in relation to the decentralized energy trading and the blockchain technology in addition to proposing a novel structure to meet the security.				■		■		■		
[163]	Investigating the blockchain-based structure for the energy trading between IoT devices for security issues, including intermediary, wallet security, in addition to checking the correct data transaction, unforgeability, and checking all financial transactions.			■	■		■		■		
[164]	Proposing the blockchain-based structure to manage the connections between IoT devices to address limitations on control of IoT devices.		■		■			■	■		
[165]	Investigating the internet of energy application in the energy sectors, reviewing its collaborations with the distributed renewable resources and EVs, studying the current application of the blockchain technology in terms of the internet, as well as the future challenges for consumers.	■	■	■	■	■	■	■	■		
[167]	Studying the blockchain efficiency in two different IoT-based case studies, including 5G network and SG.	■	■		■		■	■	■		
[168]	Discussing the industrial IoT drawbacks due to using the blockchain, proposing the Fabric blockchain method in addition to testing the proposed method on the sample case study.		■		■			■	■		
[169]	Proposing a new framework based on both the blockchain and the deep learning named Deepcoin operating in five different phases using a Byzantine method.				■	■	■		■		
[170]	Discussing the advantages of the blockchain structure for IoT in different aspects, including the authentication and the secure data transaction.		■	■	■			■	■		
[171]	Reviewing the current blockchain technology and its use case in the IoT area in addition to identifying both the challenges and the benefits of using the blockchain technology in the IoT area.		■	■	■			■	■	■	
[172]	Investigating security issues and the attacks on IoT, especially the industrial IoT, in relation to the blockchain technology.		■	■	■			■	■		
[174]	Developing both the communication infrastructure and the management of different IoT devices through the Ethereum platform structure.		■		■			■	■		
[175]	Reviewing all issues related to IoT security and its difficulties in addition to discussing all possible solutions based on the blockchain technology.		■		■			■	■		
[176]	Identifying the advantages and the disadvantages of applying the blockchain with IoT technology.		■		■			■	■		

[177]	Proposing an efficient structure of the blockchain to address the security of IoT devices in SGs.				■				■		
[178]	Meeting IoT challenges, such as the big data from IoT devices, the control of IoT devices, and the financial transactions using the distributed blockchain.		■		■			■			
[179]	Presenting an IoT-based E-business model operating according to the blockchain technology and the smart contracts.				■						
[180]	Investigating the data transactions between IoT devices and storing this huge volume of data in the decentralized structure through the auditable storage using the blockchain structure.				■				■		
[181]	Reviewing the development of IoT devices associated with the blockchain technology in terms of categorizing its application, management of IoT devices, and data transactions in addition to analyzing available methods.				■				■		
[182]	Investigating the data transactions between IoT devices in the blockchain structure according to the integrity service.		■		■				■		
[183]	Proposing a secure blockchain structure for managing IoT devices to satisfy the privacy of data and financial transactions.				■			■	■		
[184]	Proposing the blockchain-based structure to avoid security issues, i.e., attacks and frauds.		■	■	■			■	■		
[185]	Assessing security problems caused by IoT devices connected through the internet and presenting the blockchain to avoid these security issues.		■	■	■			■	■		■
[186]	Applying the blockchain technology in IoT-based healthcare in order to control the large amount of data collected from the sick persons and the doctors.		■	■	■			■	■		
[187]	Presenting the lightweight, scalable blockchain to satisfy IoT necessities and testing the proposed method in the smart home in the presence of IoT-based appliances.				■				■		
[188]	Applying the blockchain structure to solve all problems due to IoT integration into smart homes, including data collection problems, communication between IoT devices and network, big data issues, and false data injection.				■				■		
[190]	Proposing the blockchain as the technology to address the security issue of network and assessing the superiority of blockchain technology's application in the IoT area due to its decentralized structure.		■		■			■	■		
[191]	Addressing the data sharing security between the smart meters by proposing the signature scheme method according to the consortium blockchain.								■		
[192]	Investigating the blockchain to maintain security issues in different applications, i.e., SGs and its verification through testing on the sample blockchain.		■					■	■		
[193]	Proposing a 5G network for the communication between different entities through the blockchain in addition to maintaining security issues and network privacy.		■	■	■		■	■	■		
[194]	Addressing security and privacy issues of the blockchain technology, investigating the cryptography algorithms to address privacy issues, and analyzing the future trends in maintaining privacy.		■					■	■		
[195]	Analyzing security problems in the multi SGs considering its distributed structure and proposing the intrusion detection system according to the consensus-based blockchain in order to avoid attacks.						■		■		
[196]	Analyzing cyber-attacks to SG and potential detection methods and protection solutions, proposing a novel method to address the self-healing procedure after the cyber-attacks to SG.					■			■		
[197]	Using blockchain technology to verify the identity of people in order to increase the security of the system and reviewing the procedure of identity approval considering all related researches and patents.		■					■	■		

[198]	Investigating the role of blockchain technology in solving different challenges, i.e., security issues, financial transactions in the decentralized structure using bitcoin, and integration of IoT devices into SG.				■				■		
[199]	Reviewing on the cybersecurity concept in the blockchain, including all subjects of cryptography, the security of IoT technology, and security in storing data in addition to recognizing all challenges and the future opportunities.		■		■			■	■		
[200]	Applying the blockchain in healthcare, investigating its cybersecurity concerns, and analyzing the blockchain application in other areas like the financial and the governmental sectors.		■		■			■	■		
[201]	Assessing the financial concerns and fast access to the patient's data using the blockchain technology in the healthcare area.								■		
[202]	Analyzing the application of blockchain technology in the healthcare area and data availability in the cloud.								■		
[203]	Analyzing the feasibility and capabilities of different consensus protocols to meet security in the blockchain.		■					■	■		
[204]	Assessing the suitability of blockchain technology and its cost to satisfy security in different industries and highlighting the ongoing trend of this technology.				■				■		
[205]	Reviewing security issues of the blockchain technology in order to find all its difficulties and benefits.								■		
[206]	Investigating the features of Hyperledger fabric and the Ethereum to solve security issues, especially the Byzantine fault tolerance.		■					■	■		
[207]	Analyzing the development of IoT technology in a variety of areas in SG, such as IoT in EVs, IoT in healthcare, and IoT in security-based applications.			■	■				■		
[208]	Presenting a model of the blockchain cloud and its challenges in terms of being attacked in addition to investigating the block withholding attack and its identification methods.								■	■	
[209]	Applying the blockchain technology to address security in the transportation application and the vehicular networks considering security in both the data transactions and energy trading.			■					■		
[210]	Combining the conventional cloud structure with the blockchain-based network in order to assure security in data transactions and data collection from IoT devices, proposing a novel structure for management of drone data in the cloud, and reviewing capabilities of the blockchain technology to address security concepts in a variety of consensus models.				■				■	■	
[211]	Proposing a novel structure named Provchain to address security in collecting data, storing data in the cloud, and finally validating collected data.								■	■	
[212]	Assessing a specific application of blockchain technology on the digital identity in SG and analyzing its benefits and drawbacks.								■		
[213]	Reviewing applications of the blockchain technology in different sectors of the energy industry and introducing the active companies in this area in addition to investigating the challenges of blockchain development in developing countries.	■	■	■			■	■	■	■	
[214]	Reviewing some projects based on the blockchain technology in the energy sector in the US and identifying their pros and cons in addition to recognizing the future trends for improving the blockchain technology in the energy industry.				■		■			■	
[215]	Studying the blockchain technology in the healthcare sector considering security issues and smart contracts.		■		■			■	■	■	
[216]	Investigating the current states of renewable energies and the blockchain in China using a Michael Porter model and	■	■				■	■	■	■	

	analyzing the potential strengths of the blockchain technology to improve the renewable energy sectors.										
[217]	Analyzing a Blockzoom testbed operating based on the blockchain structure, including the decentralized ledgers and the smart contracts.		■					■		■	
[218]	Proposing a novel testbed for developing IoT technology operating according to the Ethereum and its assessment by a Markov chain algorithm.				■				■	■	
[219]	Presenting the blockchain-based structure to address P2P interactions and communication between the virtual power plants in SG considering security issues.		■			■		■		■	
[220]	Investigating the opportunities and the challenges of the blockchain development in the Netherland and the proposed modifications to match the blockchain technology.					■	■			■	
[221]	Analyzing the energy supply shortages in the rural areas using the blockchain technology, using the agricultural wastes as the important sources of energy in addition to applying the digital coin to set the economic transactions in Changzhi city.	■					■			■	
[222]	Investigating the carbon trading and the blockchain technology, applying the blockchain for both the fast and safe energy and the data transactions in addition to analyzing its effects on decreasing the carbon emission.										■
[223]	Investigating the roles of blockchain technology in increasing climate changes and energy consumption and discussing its effects on the increase in energy consumption and environmental pollution.		■	■				■			■
[224]	Studying the destructive effect of blockchain technology and the digital coins on increasing the carbon emission and proposing a method to estimate the power consumption of blockchain technology in addition to anticipating the amount of carbon emission in Jordan and Sri Lanka nations due to mining and the bitcoin technologies.										■
[225]	Analyzing the obtained results of blockchain technology development in a specific case study in China and its carbon emission in addition to verifying the efficiency of the blockchain application for IBM water management.									■	■

References

[1] M. L. D. Silvestre, P. Gallo, J. M. Guerrero, R. Musca, E. R. Sanseverino, G. Sciume, J. C. Vasquez and G. Zizzo, "Blockchain for power systems: Current trends and future applications," *Renewable and sustainable energy reviews,* p. To be published, 2019.

[2] M. Andoni, V. Robu, D. Flynn, S. Abram, D. Geach, D. Jenkins, P. McCallum and A. Peacock, "Blockchain technology in the energy sector: A systematic review of challenges and opportunities," *Renewable and Sustainable Energy Reviews,* vol. 100, pp. 143-174, 2019.

[3] V. Brilliantova and T. W. Thrner, "Blockchain and the future of energy," *Technology in Society,* vol. 57, pp. 38-45, 2019.

[4] Y. Li, R. Rahmani, N. Fouassier, P. Stenlund and K. Ouyang, "A Blockchain-based Architecture for Stable and Trustworthy Smart Grid," *Procedia Computer Science,* vol. 155, pp. 410-416, 2019.

[5] L. Diestelmeier, "Changing power: Shifting the role of electricity consumers with blockchain technology – Policy implications for EU electricity law," *Energy Policy,* vol. 128, pp. 189-196, 2019.

[6] A. A. G. Agung and R. Handayani, "Blockchain for Smart Grid," *Journal of King Saud University - Computer and Information Sciences,* p. To be published, 2020.

[7] S. Aggarwal, R. Chaudhary, G. S. Aujal, N. Kumar, K.-K. Raymond Choo and A. Zomaya, "Blockchain for smart communities: Applications, challenges and opportunitie," *Journal of Network and Computer Applications,* vol. 144, pp. 13-48, 2019.

[8] L. Yang, "The blockchain: State-of-the-art and research challenges," *Journal of Industrial Information Integration,* vol. 15, pp. 80-90, 2019.

[9] A. Meeuw, S. Schopfer and F. Wortmann, "Experimental bandwidth benchmarking for P2P markets in blockchain managed microgrids," *Energy Procedia,* vol. 159, pp. 370-375, 2019.

[10] C. N. Truong, M. Schimpe, U. Burger, H. C. Hesse and A. Jossen, "Multi-Use of Stationary Battery Storage Systems with Blockchain Based Markets," *Energy Procedia,* vol. 155, pp. 3-16, 2018.

[11] A. Singh, K. Click, R. Parizi, Q. Zhang, A. Dehghantanha and K.-K. Raymond Choo, "Sidechain technologies in blockchain networks: An examination and state-of-the-art review," *Journal of Network and Computer Applications,* vol. 149, p. 102471, 2020.

[12] N. Clarke, B. Jürgens and V. Herrero-Solana, "Blockchain patent landscaping: An expert based methodology and search query," *World Patent Information* , vol. 61, p. 101964, 2020.

[13] Q. Wang, M. Su and R. Li, "Is China the world's blockchain leader? Evidence, evolution and outlook of China's blockchain research," *Journal of Cleaner Production,* vol. 264, p. 121742, 2020.

[14] A. Ghosh, S. Gupta, A. Dua and N. Kumar, "Security of Cryptocurrencies in blockchain technology: State-of-art, challenges and future prospects," *Journal of Network and Computer Applications,* vol. 163, p. 102635, 2020.

[15] O. Pal, B. Alam, V. Thakur and S. Singh, "Key management for blockchain technology," *ICT Express,* p. Article in press, 2019.

[16] J. Li, N. Li, J. Peng, H. Cui and Z. Wu, "Energy consumption of cryptocurrency mining: A study of electricity consumption in mining cryptocurrencies," *Enegry,* vol. 168, pp. 160-168, 2019.

[17] K. Wang, Z. Zhang and H. S. Kim, "ReviewChain: Smart Contract Based Review System with Multi-Blockchain Gateway," *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),* 2018.

[18] X. Wang, W. Yang, S. Noor, C. Chen, M. Guo and K. H. v. Dam, "Blockchain-based smart contract for energy demand management," *Energy Procedia,* vol. 158, pp. 2719-2724, 2019.

[19] T. Alladi, V. Chamola, J. Rodrigues and S. A. Kozlov, "Blockchain in smart grids: a review on different use cases," *Sensors,* vol. 19, no. 22, 2019.

[20] G. Karame and S. Capkun, ""Blockchain security and privacy"," *IEEE security & privacy,* vol. 16, no. 4, pp. 11-12, 2018.

[21] A. S. Musleh, G. Yao and S. M. Muyeen, "Blockchain Applications in Smart Grid–Review and Frameworks," *IEEE Access,* vol. 7, pp. 86746-86757, 2019.

[22] S. Nakamoto, Bitcoin: a peer-to-peer electronic cash system, 2008.

[23] F. Casino, T. K. Dasaklis and C. Patsakis, "A systematic literature review of blockchain-based applications: current status, classification and open issues," *Telematics Informat,* vol. 36, pp. 55-81, 2018.

[24] P. Lafourcade and M. Lombard-Platet, "About blockchain interoperability," *Information Processing Letters,* p. Article in Press, 2020.

[25] R. Yang, R. Wakefield, S. Lyu, S. Jayasuriya, F. Han, X. Yi, X. Yang, G. Amarasinghe and S. Chen, "Public and private blockchain in construction business process and information integration," *Automation in Construction,* vol. 118, p. 103276, 2020.

[26] S. Perera, S. Nanayakkara, M. Rodrigo, S. Senaratne and R. Weinand, "Blockchain technology: Is it hype or real in the construction industry?," *Journal of Industrial Information Integration,* vol. 17, p. 100125, 2020.

[27] D. Mingxiao, M. Xiaofeng, Z. Zhe, W. Xiangwei and C. Oijun, "A review on consensus algorithm of blockchain," *2017 IEEE international conference on systems, man, and cybernetics (SMC)*, 2017.

[28] Z. Dong, F. Luo and G. Liang, "Blockchain: a secure, decentralized, trusted cyber infrastructure solution for future energy systems," *Journal of Modern Power Systems and Clean Energy,* vol. 6, pp. 958-967, 2018.

[29] M. J. Ashley and M. S. Jhonson, "Establishing a Secure, Transparent, and Autonomous Blockchain of Custody for Renewable Energy Credits and Carbon Credits," *IEEE Engineering Management Review,* vol. 46, no. 4, pp. 100-102, 2018.

[30] E. Mengelkamp, J. Garttner, K. Rock, S. Kessler, L. Orsini and C. Weinhardt, "Designing microgrid energy markets: A case study: The Brooklyn Microgrid," *Applied Energy,* vol. 210, pp. 870-880, 2018.

[31] P. Xie, W. Yan, P. Xuan, J. Zhu, Y. Wu, X. Li and J. Zou, "Conceptual Framework of Blockchain-based Electricity Trading for Neighborhood Renewable Energy," *2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2),* 2018.

[32] W. Hua and H. Sun, "A Blockchain-Based Peer-to-Peer Trading Scheme Coupling Energy and Carbon Markets," *2019 international conference on smart energy systems and technologies (SEST),* 2019.

[33] C. Plaza, J. Gil, F. d. Chezelles and K. A. Strang, "Distributed Solar Self-Consumption and Blockchain Solar Energy Exchanges on the Public Grid Within an Energy Community," *2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 2018.

[34] B. Teufel, A. Sentic and M. Barmet, "Blockchain energy: Blockchain in future energy systems," *Journal of Electronic Science and Technology,* vol. 17, no. 4, p. 100011, 2019.

[35] S. Zhu, M. Song, M. K. Lim, J. Wang and J. Zhao, "The development of energy blockchain and its implications for China's energy sector," *Resources Policy,* vol. 66, p. 101595, 2020.

[36] J. Duchenne, "Blockchain and Smart Contracts: Complementing Climate Finance, Legislative Frameworks, and Renewable Energy Projects," in *Transforming Climate Finance and Green Investment with Blockchains,* 2018, pp. 303-317.

[37] M. Mihaylov, I. Zapata and A. Nowé, "NRGcoin—A Blockchain-based Reward Mechanism for Both Production and Consumption of Renewable Energy," in *Transforming Climate Finance and Green Investment with Blockchains*, 2018, pp. 111-131.

[38] A. Meeuw, S. Schopfer, A. Wörner, V. Tiefenbeck, L. Ableitner, E. Fleisch and F. Wortmann, "Implementing a blockchain-based local energy market: Insights on communication and scalability," *Computer Communications*, p. Article in Press, 2020.

[39] J. Hwang, M.-i. Choi, T. Lee, S. Jeon, S. Kim, S. Park and S. Park, "Energy Prosumer Business Model Using Blockchain System to Ensure Transparency and Safety," *Energy Procedia,* vol. 141, pp. 194-198, 2017.

[40] E. S. Kang, S. J. Pee, J. G. Song and J. W. Jang, "A Blockchain-Based Energy Trading Platform for Smart Homes in a Microgrid," *2018 3rd International Conference on Computer and Communication Systems (ICCCS),* 2018.

[41] F. Bosco, V. Croce and G. Raveduto, "Blockchain Technology for Financial Services Facilitation in RES Investments," *2018 IEEE 4th International Forum on Research and Technology for Society and Industry (RTSI)*, 2018.

[42] P. Siano, G. D. Marco, A. Rolan and V. Loia, "A Survey and Evaluation of the Potentials of Distributed Ledger Technology for Peer-to-Peer Transactive Energy Exchanges in Local Energy Markets," *IEEE Systems Journal,* vol. 13, no. 3, pp. 3454-3466, 2019.

[43] E. Mengelkamp, B. Notheisen, C. Beer, D. Dauer and C. Weinhardt, "A blockchain-based smart grid: Towards sustainable local energy markets," *Computer Science - Research and Development,* vol. 33, no. 1/2, pp. 207-214, 2018.

[44] A. Toor, S. u. Islam, N. Sohail, A. Akhunzada, J. Boudjadar, H. A. Khattak, I. U. Din and J. J. Rodrigues, "Energy and performance aware fog computing: A case of DVFS and green renewable energy," *Future generation computer systems,* vol. 101, pp. 1112-1121, 2019.

[45] A. Ahl, M. Yarime, K. Tanaka and D. Sagawa, "Review of blockchain-based distributed energy: Implications for institutional development," *Renewable and Sustainable Energy Reviews,* vol. 107, pp. 200-211, 2019.

[46] M. U. Hassan, M. H. Rehmani and J. Chen, "DEAL: Differentially Private Auction for Blockchain based Microgrids Energy Trading," *IEEE Transactions on Services Computing,* p. Early Access, 2019.

[47] S. Cui, Y.-W. Wang, C. Li and J.-W. Xiao, "Prosumer Community: A Risk Aversion Energy Sharing Model," *IEEE transactions on sustainable energy,* p. To be published, 2019.

[48] A. Sheikh, V. Kamuni, U. Asfia, S. Wagh, N. Singh and D. Patel, "Secured Energy Trading using Byzantine based Blockchain Consensus," *IEEE Access,* p. To be published, 2019.

[49] A. Ahl, M. Yarime, M. Goto and S. S. Chopra, "Exploring blockchain for the energy transition: Opportunities and challenges based on a case study in Japan," *Renewable and sustainable energy reviews,* vol. 117, 2020.

[50] T. Zhang, H. Pota, C.-C. Chu and R. Gadh, "Real-time renewable energy incentive system for electric vehicles using prioritization and cryptocurrency," *Applied Energy,* vol. 226, pp. 582-594, 2018.

[51] J. Kang, R. Yu, X. Huang, S. Maharjan, Y. Zhang and E. Hossain, "Enabling Localized Peer-to-Peer Electricity Trading Among Plug-in Hybrid Electric Vehicles Using Consortium Blockchains," *IEEE Transactions on Industrial Informatics,* vol. 13, no. 6, pp. 3154-3164, 2017.

[52] K. Christidis and M. Devetsikiotis, "Blockchains and Smart Contracts for the Internet of Things," *IEEE Access,* vol. 4, pp. 2292 - 2303, 2016.

[53] X. Wu, B. Duan, Y. Yan and Y. Zhong, "M2M Blockchain: The Case of Demand Side Management of Smart Grid," *2017 IEEE 23rd International Conference on Parallel and Distributed Systems (ICPADS),* pp. 810-813, 2017.

[54] C. Pop, T. Cioara, M. Antal, I. Anghel, I. Salomie and M. Betoncini, "Demand Response Programs in Smart Energy Grids," *Sensors,* vol. 18, no. 1, 2018.

[55] Z. Zhou, B. Wang, Y. Guo and Y. Zhang, "Blockchain and Computational Intelligence Inspired Incentive-Compatible Demand Response in Internet of Electric Vehicles," *IEEE tranactions on emerging topics in computational intelligence,* vol. 3, no. 3, pp. 205-216, 2019.

[56] A. Jindal, G. S. Aujla, N. Kumar and M. Villari, "GUARDIAN: Blockchain-based Secure Demand Response Management in Smart Grid System," *IEEE transactions on service computing,* p. To be published, 2019.

[57] Y. Li, W. Yang, P. He, C. Chen and X. Wang, "Design and management of a distributed hybrid energy system through smart contract and blockchain," *Applied Energy,* vol. 248, pp. 390-405, 2019.

[58] X. Yang, G. Wang, H. He, J. Lu and Y. Zhang, "Automated Demand Response Framework in ELNs: Decentralized Scheduling and Smart Contract," *IEEE transactions on systems, man, and cybernetics: systems,* vol. 50, no. 1, pp. 58-72, 2020.

[59] C. Dang, J. Zhang, C.-P. Kwong and L. Li, "Demand Side Load Management for Big Industrial Energy Users Under Blockchain-Based Peer-to-Peer Electricity Market," *IEEE transactions on smart grid,* vol. 10, no. 6, pp. 6424-6435, 2019.

[60] N. Z. Benisi, M. Aminian and B. Javadi, "Blockchain-based decentralized storage networks: A survey," *Journal of Network and Computer Applications,* vol. 162, p. 102656, 2020.

[61] M. Foti, D. Greasidis and M. Vavalis, "Viability Analysis of a Decentralized Energy Market Based on Blockchain," *2018 15th International Conference on the European Energy Market (EEM),* 2018.

[62] N. M. Kumar, "Blockchain: Enabling wide range of services in distributed energy system," *Beni-Suef University Journal of Basic and Applied Sciences,* vol. 7, no. 4, pp. 701-704, 2018.

[63] G. Leeuwen, T. AlSkaif, M. Gibescu and W. Sark, "An integrated blockchain-based energy management platform with bilateral trading for microgrid communities," *Applied Energy,* vol. 263, p. 114613, 2020.

[64] M. H. Amini, "Decentralized operation of interdependent power and energy networks: Blockchain and security," in *Blockchain-based Smart Grids*, 2020, pp. 61-73.

[65] A. Hajizadeh and S. M. Hakimi, "Blockchain in decentralized demand-side control of microgrids," in *Blockchain-based Smart Grids*, 2020, pp. 145-167.

[66] H. Khajeh, M. Shafie-khah and H. Laaksonen, "Blockchain-based demand response using prosumer scheduling," in *Blockchain-based Smart Grids*, 2020, pp. 131-144.

[67] T. Morstyn, N. Farrell, S. J. Darby and M. D. McCulloch, "Using peer-to-peer energy trading platforms to incentivize prosumers to form federated power plants," *Nature Energy,* vol. 3, no. 2, pp. 94-101, 2018.

[68] X. Lu, L. Shi, Z. Chen, X. Fun, Z. Guan, X. Du and M. Guizani, "Blockchain-Based Distributed Energy Trading in Energy Internet: An SDN Approach," *IEEE Access,* vol. 7, pp. 173817-173826, 2019.

[69] M. Foti and M. Vavalis, "Blockchain based uniform price double auctions for energy markets," *Applied Energy,* vol. 254, 2019.

[70] Z. Li, S. Bahramirad, A. Passo, M. Yan and M. Shahidehpour, "Blockchain for decentralized transactive energy management system in networked microgrids," *The Electricity Journal,* vol. 32, no. 4, pp. 58-72, 2019.

[71] B. Wang, M. Dabbaghjamanesh, A. Kavousi-Fard and S. Mehraeen, "Cybersecurity Enhancement of Power Trading Within the Networked Microgrids Based on Blockchain and Directed Acyclic Graph Approach," *IEEE transactions on Industry Applications,* vol. 55, no. 6, pp. 7300-7309, 2019.

[72] X. Kong, J. Zhang, H. Wang and J. Shu, "Decentralized multi-chain data management framework for power systems," *CSEE journal of power and energy systems,* vol. early access, pp. 1-11, 2019.

[73] S. Noor, W. Yang, M. Guo, K. H. v. Dam and X. Wang, "Energy Demand Side Management within micro-grid networks enhanced by blockchain," *Applied Energy,* vol. 228, pp. 1385-1398, 2018.

[74] J. Li, Z. Zhou, J. Wu, J. Li, S. Mumtaz, X. Lin and H. Gacanin, "Decentralized On-Demand Energy Supply for Blockchain in Internet of Things: A Microgrids Approach," *IEEE transactions on computational social systems,* vol. 6, no. 6, pp. 1395-1406, 2019.

[75] M. L. D. Silvestre, P. Gallo, M. G. Ippolito and E. R. Sanseverino, "A Technical Approach to the Energy Blockchain in Microgrids," *IEEE transactions on industrial informatics,* vol. 14, no. 11, pp. 4792-4803, 2018.

[76] O. V. Cutsem, D. H. Dac, P. Boudou and M. Kayal, "Cooperative energy management of a community of smart-buildings: A Blockchain approach," *International Journal of electrical power & energy systems,* vol. 117, 2020.

[77] S. Wang, A. F. Taha, J. Wang, K. Kvaternik and A. Hahn, "Energy Crowdsourcing and Peer-to-Peer Energy Trading in Blockchain-Enabled Smart Grids," *IEEE transactions on systems, man, and cybernetics: systems,* vol. 49, no. 8, pp. 1612-1623, 2019.

[78] M. L. D. Silvestre, P. Gallo, M. G. Ippolito, R. Musca, E. R. Sanseverino, Q. T. T. Tran and G. Zizzo, "Ancillary Services in the Energy Blockchain for Microgrids," *IEEE transactions on industry applications*, vol. 55, no. 6, pp. 7310-7319, 2019.

[79] A. R. Rao and D. Clarke, "Perspectives on emerging directions in using IoT devices in blockchain applications," *Internet of Things*, p. To be published, 2019.

[80] F. Imbault, M. Swiatek, R. d. Beaufort and R. Plana, "The green blockchain: Managing decentralized energy production and consumption," *2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, 2017.

[81] N. Z. Aitzhan and D. Svetinovic, "Security and Privacy in Decentralized Energy Trading Through Multi-Signatures, Blockchain and Anonymous Messaging Streams," *IEEE Transactions on Dependable and Secure Computing*, vol. 15, no. 5, pp. 840-852, 2018.

[82] Z. Li, M. Shahidehpour and X. Liu, "Cyber-secure decentralized energy management for IoT-enabled active distribution networks," *Journal of Modern power system and clean energy*, vol. 6, pp. 900-917, 2018.

[83] C. Pop, T. Cioara, M. Antal, I. Anghel and I. B. M. Salomie, "Blockchain Based Decentralized Management of Demand Response Programs in Smart Energy Grids," *Sensors*, vol. 18, no. 1, p. 162, 2018.

[84] E. Mengelkamp, B. Notheisen, C. Beer, D. Dauer and C. Weinhardt, "A blockchain-based smart grid: towards sustainable local energy markets," *Computer Science-Research and development*, vol. 33, pp. 207-214, 2018.

[85] M. Pichler, M. Meisel, A. Goranovic, K. L. G. C. G. Leonhartsberger, H. Vallant, S. Marksteiner and H. Bieser, "Decentralized Energy Networks Based on Blockchain: Background, Overview and Concept Discussion," *International Conference on Business Information Systems*, pp. 244-257, 2018.

[86] M. Stephant, K. Hassam-Ouari, D. Abbes, A. Labrunie and B. Robyns, "A survey on energy management and blockchain for collective self-consumption," *2018 7th International Conference on Systems and Control (ICSC)*, 2018.

[87] J. Struker, S. Albrecht and S. Reichert, "Blockchain in the Energy Sector," in *Business Transformation through Blockchain*, Cham, Springer, 2019, pp. 23-51.

[88] K. Tanaka, K. Nagakubo and R. Abe, "Blockchain-based electricity trading with Digitalgrid router," *2017 IEEE International Conference on Consumer Electronics - Taiwan (ICCE-TW)*, 2017.

[89] K. N. Khaqqi, J. J. Sikorski, K. Hadinoto and M. Kraft, "Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application," *Applied Energy*, vol. 209, pp. 8-19, 2018.

[90] J. Lin, M. Pipattanasomporn and S. Rahman, "Comparative analysis of auction mechanisms and bidding strategies for P2P solar transactive energy markets," *Applied Energy*, vol. 225, 2019.

[91] S. Rahmadika, D. R. Ramdania and M. Harika, "Security Analysis on the Decentralized Energy Trading System Using Blockchain Technology," *Journal online Informatika*, vol. 3, no. 1, 2018.

[92] D. Han, C. Zhang, J. Ping and Z. Yan, "Smart contract architecture for decentralized energy trading and management based on blockchains," *Energy*, vol. 199, p. 117417, 2020.

[93] M. Mylrea and S. N. Gupta Gourisetti, "Blockchain for smart grid resilience: Exchanging distributed energy at speed, scale and security," *2017 Resilience Week (RWS)*, 2017.

[94] D. Vangulick, B. Cornelusse and D. Ernst, "Blockchain for Peer-to-Peer Energy Exchanges: Design and Recommendations," *2018 Power Systems Computation Conference (PSCC)*, 2018.

[95] K. Gai, Y. Wu, L. Zhu, M. Qui and M. Shen, "Privacy-Preserving Energy Trading Using Consortium Blockchain in Smart Grid," *IEEE Transactions on Industrial Informatics*, vol. 15, no. 6, pp. 3548-3558, 2019.

[96] M. E. Peck and D. Wagman, "Energy trading for fun and profit buy your neighbor's rooftop solar power or sell your own-it'll all be on a blockchain," *IEEE Spectrum*, vol. 54, no. 10, pp. 56-61, 2017.

[97] S.-C. Oh, M.-S. Kim, Y. Park, G.-T. Roh and C.-W. Lee, "Implementation of blockchain-based energy trading system," *Asia Pacific Journal of Innovation and Entrepreneurship*, vol. 11, no. 3, 2017.

[98] M. Sabounchi and J. Wei, "Towards resilient networked microgrids: Blockchain-enabled peer-to-peer electricity trading mechanism," *2017 IEEE Conference on Energy Internet and Energy System Integration (EI2)*, 2017.

[99] N. Wang, X. Zhou, X. Lu, Z. Guan, L. Wu, X. Du and M. Guizani, "When Energy Trading Meets Blockchain in Electrical Power System: The State of the Art," *Applied sciences*, vol. 9, no. 8, p. 1561, 2019.

[100] K. Mannaro, A. Pinna and M. Marchesi, "Crypto-trading: Blockchain-oriented energy market," *2017 AEIT International Annual Conference*, 2017.

[101] S. J. Pee, E. S. Kang, J. G. Song and J. W. Jang, "Blockchain based smart energy trading platform using smart contract," *2019 International Conference on Artificial Intelligence in Information and Communication (ICAIIC)*, 2019.

[102] V. Hassija, V. Chamola, S. Garg, N. G. Krishna Dara, G. Kaddoum and D. N. K. Jayakody, "A Blockchain-based Framework for Lightweight Data Sharing and Energy Trading in V2G Network," *IEEE Transactions on Vehicular Technology*, p. Early access, 2020.

[103] C. Zhnag, J. Wu, C. Long and M. Cheng, "Review of Existing Peer-to-Peer Energy Trading Projects," *Energy Procedia*, vol. 105, pp. 2563-2568, 2017.

[104] S. Wang, A. F. Taha and J. Wang, "Blockchain-Assisted Crowdsourced Energy Systems," *2018 IEEE Power & Energy Society General Meeting (PESGM)*, 2018.

[105] K. Gai, Y. Wu, L. Zhu, M. Qiu and M. Shen, "Privacy-preserving energy trading using consortium blockchain in smart grid," *IEEE Transactions on Industrial Informatics*, vol. 15, no. 6, pp. 3548-3558, 2019.

[106] S. Aggarwal, R. Chaudhary, G. S. Aujla, A. Jindal, A. Dua and N. Kumar, "Energychain: Enabling energy trading for smart homes using blockchains in smart grid ecosystem," *In Proceedings of the 1st ACM MobiHoc Workshop on Networking and Cybersecurity for Smart Cities*, pp. 1-6, 2018.

[107] A. Jindal, G. S. Aujla and N. Kumar, "SURVIVOR: A blockchain based edge-as-a-service framework for secure energy trading in SDN-enabled vehicle-to-grid environment," *Computer Networks*, vol. 153, pp. 36-48, 2019.

[108] Z. Liu, D. Wang, J. Wang, X. Wang and H. Li, "A Blockchain-enabled Secure Power Trading Mechanism for Smart Grid Employing Wireless Networks," *IEEE Access*, 2020.

[109] X. Lu and Z. Guan, "A Blockchain-based Trading Matching Scheme in Energy Internet," *In Proceedings of the 2nd ACM International Symposium on Blockchain and Secure Critical Infrastructure*, pp. 142-150, 2020.

[110] K. TAKAI and N. SHINOMIYA, "Small scale peer-to-peer electricity trading through Ethereum Blockchain," *35th International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC)*, pp. 126-130, 2020.

[111] M. B. Niasar, E. K. R., A. R. and M. Mozaffari-Kermani, "Fast, Small, and Area-Time Efficient Architectures for Key-Exchange on Curve25519," *IEEE 27th Symposium on Computer Arithmetic (ARITH)*, pp. 72-79, 2020.

[112] M. Jo, S. Jangirala, A. K. Das, X. Li and M. K. Khan, "Designing Anonymous Signature-Based Authenticated Key Exchange Scheme for IoT-Enabled Smart Grid Systems," *IEEE Transactions on Industrial Informatics*, 2020.

[113] D. Sikeridis, A. Bidram, M. Devetsikiotis and M. J. Reno, "A blockchain-based mechanism for secure data exchange in smart grid protection systems," *17th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 2020*, pp. 1-6, 2020.

[114] J. Guruprakash and S. Koppu, "EC-ElGamal and Genetic Algorithm-Based Enhancement for Lightweight Scalable Blockchain in IoT Domain," *IEEE Access*, vol. 8, 2020.

[115] J. Moradi, H. Shahinzadeh, H. Nafisi, G. B. Gharehpetian and M. Shaneh, "Blockchain, a Sustainable Solution for Cybersecurity Using Cryptocurrency for Financial Transactions in Smart Grids," *2019 24th Electrical Power Distribution Conference (EPDC)*, pp. 47-53, 2019.

[116] Y. Xu, P. Ahokangas, S. Yrjölä and T. Koivumäki, "The fifth archetype of electricity market: The blockchain marketplace," *Wireless Networks*, pp. 1-17, 2019.

[117] A. Aderibole, A. Aljarwan, M. H. Ur Rehman, H. H. Zeineldin, T. Mezher, K. Salah, E. Damiani and D. Svetinovic, "Blockchain Technology for Smart Grids: Decentralized NIST Conceptual Model," *IEEE Access,* vol. 8, pp. 43177-43190, 2020.

[118] F. Bosco, V. Croce and G. Raveduto, "Blockchain technology for financial services facilitation in RES investments," *In 2018 IEEE 4th International Forum on Research and Technology for Society and Industry (RTSI),* pp. 1-5, 2018.

[119] P. Xie, W. Yan, P. Xuan, J. Zhu, Y. Wu, X. Li and J. Zou, "Conceptual Framework of Blockchain-based Electricity Trading for Neighborhood Renewable Energy," *In 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2),* pp. 1-5, 2018.

[120] D. Orazgaliyev, Y. Lukpanov, I. A. Ukaegbu and H. S. K. Nunna, "Towards the application of blockchain technology for smart grids in kazakhstan," *In 2019 21st International Conference on Advanced Communication Technology (ICACT),* pp. 273-278, 2019.

[121] M. Ghorbanian, S. H. Dolatabadi, P. Siano, I. Kouveliotis-Lysikatos and N. D. Hatziargyriou, "Methods for Flexible Management of Blockchain-based Cryptocurrencies in Electricity Markets and Smart Grids," *IEEE Transactions on Smart Grid.,* 2020.

[122] F. A. Khan, M. Asif, A. Ahmad, M. Alharbi and H. Aljuaid, "Blockchain technology, improvement suggestions, security challenges on smart grid and its application in healthcare for sustainable development," *Sustainable Cities and Society,* vol. 55, p. 102018, 2020.

[123] H. A. Khattak, K. Tehreem, A. Almogren, Z. Ameer, I. U. Din and M. Adnan, "Dynamic pricing in industrial internet of things: Blockchain application for energy management in smart cities," *Journal of Information Security and Applications,* vol. 55, p. 102615, 2020.

[124] B. Bhushan, A. Khamparia, K. M. Sagayam, S. K. Sharma, M. A. Ahad and N. C. Debnath, "Blockchain for smart cities: A review of architectures, integration trends and future research directions," *Sustainable Cities and Society,* vol. 61, p. 102360, 2020.

[125] M. B. Mollah, J. Zhao, D. Niyato, K.-Y. Lam, X. Zhang, A. M. Ghias, L. H. Koh and L. Yang, "Blockchain for future smart grid: A comprehensive survey," *IEEE Internet of Things Journal,* 2020.

[126] Z. Su, Y. Wang, Q. Xu, M. Fei, Y.-C. Tian and N. Zhang, "A Secure Charging Scheme for Electric Vehicles With Smart Communities in Energy Blockchain," *IEEE internet of things journal,* vol. 6, no. 3, pp. 4601-4613, 2019.

[127] A. Jindal, G. S. Aujla and N. Kumar, "SURVIVOR: A blockchain based edge-as-a-service framework for secure energy trading in SDN-enabled vehicle-to-grid environment," *Computer Networks,* vol. 153, pp. 36-48, 2019.

[128] Y. Wang, Z. Su and N. Zhang, "BSIS: Blockchain-Based Secure Incentive Scheme for Energy Delivery in Vehicular Energy Network," *IEEE transactions on industrial informatics,* vol. 15, no. 6, pp. 3620-3631, 2019.

[129] H. Liu, Y. Zhang and T. Yang, "Blockchain-Enabled Security in Electric Vehicles Cloud and Edge Computing," *IEEE Network,* vol. 32, no. 3, pp. 78-83, 2018.

[130] Z. Zhou, B. Wang, M. Dong and K. Ota, "Secure and Efficient Vehicle-to-Grid Energy Trading in Cyber Physical Systems: Integration of Blockchain and Edge Computing," *IEEE transactios on systems, man, and cybernetics: systems,* vol. 50, no. 1, pp. 43-57, 2020.

[131] C. Liu, K. K. Chai, X. Zhang, E. T. Lau and Y. Chen, "Adaptive Blockchain-Based Electric Vehicle Participation Scheme in Smart Grid Platform," *IEEE Access,* vol. 6, pp. 25657-25665, 2018.

[132] H. Liu, Y. Zhnag, S. Zheng and Y. Li, "Electric Vehicle Power Trading Mechanism Based on Blockchain and Smart Contract in V2G Network," *IEEE Access,* vol. 7, pp. 160546-160558, 2019.

[133] Z. Jin, R. Wu, X. Chen and G. Li, "Charging Guiding Strategy for Electric Taxis Based on Consortium Blockchain," *IEEE Access,* vol. 7, pp. 144144-14153, 2019.

[134] X. Huang, Y. Zhang, D. Li and L. Han, "An optimal scheduling algorithm for hybrid EV charging scenario using consortium blockchains," *Future Generation Computer Systems,* vol. 91, pp. 555-562, 2019.

[135] W. Hu, W. Yao, Y. Hu and H. Li, "Collaborative Optimization of Distributed Scheduling Based on Blockchain Consensus Mechanism Considering Battery-Swap Stations of Electric Vehicles," *IEEE Access*, vol. 7, pp. 137959-137967, 2019.

[136] Q. He, Y. Xu, Y. Yan, J. Wang, Q. Han and L. Li, "A consensus and incentive program for charging piles based on consortium blockchain," *CSEE journal of power and energy systems*, vol. 4, no. 4, pp. 452-458, 2018.

[137] X. Huang, C. Xu, P. Wang and H. Liu, "LNSC: A Security Model for Electric Vehicle and Charging Pile Management Based on Blockchain Ecosystem," *IEEE Access*, vol. 6, pp. 13565-13574, 2018.

[138] S. Guo, X. Hu, Z. Zhou, X. Wang, F. Qi and L. Gao, "Trust access authentication in vehicular network based on blockchain," *China Communications*, vol. 16, no. 6, pp. 18-30, 2019.

[139] T. Jiang, H. Fang and H. Wang, "Blockchain-Based Internet of Vehicles: Distributed Network Architecture and Performance Analysis," *IEEE internet of things journal*, vol. 6, no. 3, pp. 4640-4649, 2019.

[140] W. Hu, Y. Hu, W. Yao and H. Li, "A Blockchain-Based Byzantine Consensus Algorithm for Information Authentication of the Internet of Vehicles," *IEEE Access*, vol. 7, pp. 139703-139711, 2019.

[141] T. A. Butt, R. Iqbal, K. Salah, M. Aloqaily and Y. Jararweh, "Privacy Management in Social Internet of Vehicles: Review, Challenges and Blockchain Based Solutions," *IEEE Access*, vol. 7, pp. 79694-79713, 2019.

[142] F. Gao, L. Zhu, M. Shen, K. Sharif, Z. Wan and K. Ren, "A Blockchain-Based Privacy-Preserving Payment Mechanism for Vehicle-to-Grid Networks," *IEEE network*, vol. 32, no. 6, pp. 184-192, 2018.

[143] Z. Yang, K. Yang, L. Lei, K. Zheng and V. C. Leung, "Blockchain-Based Decentralized Trust Management in Vehicular Networks," *IEEE ineternet of things journal*, vol. 6, no. 2, pp. 1495-1505, 2019.

[144] R. Shrestha and S. Y. Nam, "Regional Blockchain for Vehicular Networks to Prevent 51% Attacks," *IEEE Access*, vol. 7, pp. 95033-95045, 2019.

[145] P. Fraga-Lamas and T. M. Fernandez-Carames, "A Review on Blockchain Technologies for an Advanced and Cyber-Resilient Automotive Industry," *IEEE Access*, vol. 7, pp. 17578-17598, 2019.

[146] X. Chen and X. Zhnag, "Secure Electricity Trading and Incentive Contract Model for Electric Vehicle Based on Energy Blockchain," *IEEE Access*, vol. 7, pp. 178763-178778, 2019.

[147] Z. Lu, W. Liu, Q. Wang, G. Qu and Z. Liu, "A Privacy-Preserving Trust Model Based on Blockchain for VANETs," *IEEE Access*, vol. 6, pp. 45655-45664, 2018.

[148] S. Kim, "Impacts of Mobility on Performance of Blockchain in VANET," *IEEE Access*, vol. 7, pp. 68646-68655, 2019.

[149] L. Li, J. Liu, L. Cheng, S. Qiu, W. Wang, X. Zhnag and Z. Zhang, "CreditCoin: A Privacy-Preserving Blockchain-Based Incentive Announcement Network for Communications of Smart Vehicles," *IEEE transactions on intelligent transportation systems*, vol. 19, no. 7, pp. 2204-2220, 2018.

[150] C. Chen, T. Xiao, T. Qiu, N. Lv and Q. Pei, "Smart-Contract based Economical Platooning in Blockchain Enabled Urban Internet of Vehicles," *IEEE Transactions on Industrial Informatics*, p. To be published, 2019.

[151] F. Knirsch, A. Unterweger and D. Engel, "Privacy-preserving blockchain-based electric vehicle charging with dynamic tariff decisions," *Computer Science - Research and Development*, vol. 33, pp. 71-79, 2018.

[152] H. Song, Z. Ence, P. Bingfeng, S. Jun, N. Yoshihide and K. Hidetoshi, "Apply blockchain technology to electric vehicle battery refueling," *Blockchain and Fintech*, 2018.

[153] S. Jeong, N.-N. Dao, Y. Lee, C. Lee and S. Cho, "Blockchain Based Billing System for Electric Vehicle and Charging Station," *2018 Tenth International Conference on Ubiquitous and Future Networks (ICUFN)*, 2018.

[154] C. Liu, K. K. Chai, E. T. Lau and Y. Chen, "Blockchain Based Energy Trading Model for Electric Vehicle Charging Schemes," in *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering* , Springer, 2018, pp. 64-72.

[155] M. Pustisek, A. Kos and U. Sedlar, "Blockchain Based Autonomous Selection of Electric Vehicle Charging Station," *2016 International Conference on Identification, Information and Knowledge in the Internet of Things (IIKI)*, 2016.

[156] A. R. Pedrosa and G. Pau, "ChargeltUp: On Blockchain-based technologies for Autonomous Vehicles," *Proceedings of the 1st workshop on cryptocurrencies and blockchains for distributed systems,* pp. 87-92, 2018.

[157] A. Dorri, M. Steger, S. S. Kanhere and R. Jurdak, "BlockChain: A Distributed Solution to Automotive Security and Privacy," *IEEE Communications Magazine,* vol. 55, no. 12, pp. 119-125, 2017.

[158] M. K. Kim, K. Pak, S. Yu, J. Y. Lee, Y. Park, S.-W. Lee and B. Chung, "A Secure Charging System for Electric Vehicles Based on Blockchain," *Sensors,* vol. 19, no. 13, p. 3028, 2019.

[159] J. Pajic, J. Rivera, K. Zhang and H.-A. Jacobsen, "EVA: Fair and Auditable Electric Vehicle Charging Service using Blockchain," *Proceedings of the 12th ACM International Conference on Distributed and Event-based Systems,* pp. 262-265, 2018.

[160] L. a. K. D.-H. Huang, "Design and Implementation of an Integrated IoT Blockchain Platform for Sensing Data Integrity," *Sensors,* vol. 19, no. 10, p. 2228, 2019.

[161] A. Dorri, S. S. Kanhere, R. Jurdak and P. Gauravaram, "Blockchain for IoT security and privacy: The case study of a smart home," *2017 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops),* 2017.

[162] Z. Guan, X. Lu, N. Wang, J. Wu, X. Du and M. Guizani, "Towards secure and efficient energy trading in IIoT-enabled energy internet: A blockchain approach," *Future Generation Computer Systems,* p. To be published, 2019.

[163] Z. Li, J. Kang, R. Yu, D. Ye, Q. Deng and Y. Zhang, "Consortium Blockchain for Secure Energy Trading in Industrial Internet of Things," *IEEE transactions on industrial informatics,* vol. 14, no. 8, pp. 3690-3700, 2018.

[164] O. Novo, "Blockchain Meets IoT: An Architecture for Scalable Access Management in IoT," *IEEE internet of things journal,* vol. 5, no. 2, pp. 1184-1195, 2018.

[165] A. Miglani, N. Kumar, V. Chamola and S. Zeadally, "Blockchain for Internet of Energy management: Review, solutions, and challenges," *Computer Communications,* p. To be published, 2020.

[166] H. Shahinzadeh, J. Moradi, G. B. Gharehpetian, H. Nafisi and M. Abedi, "IoT architecture for smart grids. .," *2019 International Conference on Protection and Automation of Power System (IPAPS),* pp. 22-30, 2019.

[167] K. Valtanen, J. Backman and S. Yrjola, "Blockchain-Powered Value Creation in the 5G and Smart Grid Use Cases," *IEEE Access,* vol. 7, pp. 25690-25707, 2019.

[168] W. Liang, M. Tang, J. Long, X. Peng, J. Xu and K.-c. Li, "A Secure FaBric Blockchain-Based Data Transmission Technique for Industrial Internet-of-Things," *IEEE transactions on industrial informatics,* vol. 15, no. 6, pp. 3582-3592, 2019.

[169] M. A. Ferrag and L. Maglaras, "DeepCoin: A Novel Deep Learning and Blockchain-Based Energy Exchange Framework for Smart Grids," *IEEE transactions n engineering management,* vol. Early Access, pp. 1-13, 2019.

[170] I. Makhdom, M. Abolhasan, H. Abbas and W. Ni, "Blockchain's adoption in IoT: The challenges, and a way forward," *Journal of network and computer applications,* vol. 125, pp. 251-279, 2019.

[171] X. Wang, X. Zha, W. Ni, R. P. Liu, Y. J. Guo, X. Niu and K. Zheng, "Survey on blockchain for Internet of Things," *Computer Comunications,* vol. 136, pp. 10-29, 2019.

[172] J. Sengupta, S. Ruj and S. D. Bit, "A Comprehensive Survey on Attacks, Security Issues and Blockchain Solutions for IoT and IIoT," *Journal of Network and Computer Applications,* vol. 149, p. 102481, 2020.

[173] Z. Davoody-Beni, N. Sheini-Shahvand, H. Shahinzadeh, M. Moazzami, M. Shaneh and G. B. Gharehpetian, "Application of IoT in Smart Grid: Challenges and Solutions," *2019 5th Iranian Conference on Signal Processing and Intelligent System,* pp. 1-8, 2019.

[174] S. Huh, S. Cho and S. Kim, "Managing IoT devices using blockchain platform," *2017 19th International Conference on Advanced Communication Technology (ICACT),* 2017.

[175] M. Ahamad Khan and K. Salah, "IoT security: Review, blockchain solutions, and open challenges," *Future Generation Computer Systems,* vol. 82, pp. 395-411, 2018.

[176] A. Reyna, C. Martin, J. Chen, E. Soler and M. Diaz, "On blockchain and its integration with IoT. Challenges and opportunities," *Future generation computer systems,* vol. 88, pp. 173-190, 2018.

[177] A. Dorri, S. S. Kanhere and R. Jurdak, "Towards an Optimized BlockChain for IoT," *2017 IEEE/ACM Second International Conference on Internet-of-Things Design and Implementation (IoTDI),* 2017.

[178] M. Samaniego, U. Jamsrandorj and R. Deter, "Blockchain as a Service for IoT," *2016 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),* 2016.

[179] Y. Zhang and J. Wen, "The IoT electric business model: Using blockchain technology for the internet of things," *Peer-to-Peer Networking and Applications,* vol. 10, pp. 983-994, 2017.

[180] H. Shafagh, L. Burkhalter, A. Hithnawi and S. Duquennoy, "Towards Blockchain-based Auditable Storage and Sharing of IoT Data," *Proceedings of the 2017on cloud computing security workshop,* pp. 45-50, 2017.

[181] A. Panarello, N. Tapas, G. Merlino, F. Longo and A. Puliafito, "Blockchain and IoT Integration: A Systematic Survey," *Sensors,* vol. 18, no. 8, p. 2575, 2018.

[182] B. Liu, X. L. Yu, S. Chen, X. Xu and L. Zhu, "Blockchain Based Data Integrity Service Framework for IoT Data," *2017 IEEE International Conference on Web Services (ICWS),* 2017.

[183] A. Ouaddah, A. A. Elkalam and A. A. Ouahman, "Towards a Novel Privacy-Preserving Access Control Model Based on Blockchain Technology in IoT," in *Advances in Intelligent Systems and Computing*, Springer, 2016, pp. 523-533.

[184] A. Boudguiga, N. Bouzerna, L. Granboulan, Olivereau, F. Quesnel, A. Roger and R. Sirdey, "Towards Better Availability and Accountability for IoT Updates by Means of a Blockchain," *2017 IEEE European Symposium on Security and Privacy Workshops (EuroS&PW),* 2017.

[185] M. T. Hammi, B. Hammi, P. Bellot and A. Serhrouchni, "Bubbles of Trust: A decentralized blockchain-based authentication system for IoT," *Computers & Security,* vol. 78, pp. 126-142, 2018.

[186] A. D. Dwivedi, G. Srivastava, S. Dhar and R. Singh, "A Decentralized Privacy-Preserving Healthcare Blockchain for IoT," *Sensors,* vol. 19, no. 2, p. 326, 2019.

[187] A. Dorri, S. S. Kanhere, R. Jurdak and P. Gauravaram, "LSB: A Lightweight Scalable BlockChain for IoT Security and Privacy," *Cryptography and Security,* 2017.

[188] R. Casado-Vara, F. d. l. Prieta, J. Prieto and J. Corchado, "Blockchain framework for IoT data quality via edge computing," *Proceedings of the 1st Workshop on Blockchain-enabled Networked Sensor Systems,* pp. 19-24, 2018.

[189] J. Moradi, H. Shahinzadeh, H. Nafisi, M. Marzband and G. B. Gharehpetian, "Attributes of Big Data Analytics for Data-Driven Decision Making in Cyber-Physical Power Systems," *14th International Conference on Protection and Automation of Power Systems,* pp. 83-92, 2020.

[190] N. Kshetri, "Can Blockchain Strengthen the Internet of Things?," *IT professional,* vol. 19, no. 4, pp. 68-72, 2017.

[191] H. Zhang, J. Wang and Y. Ding, "Blockchain-based decentralized and secure keyless signature scheme for smart grid," *Energy,* vol. 180, pp. 955-967, 2019.

[192] Y. Yuan and F. Y. Wang, "Blockchain: The state of the art and future trends," *Acta Automatica. Sinica,* vol. 42, no. 4, pp. 481-494, 2016.

[193] D. C. Nguyen, P. N. Pathairana, M. Ding and A. Senevirante, "Blockchain for 5G and beyond networks: A state of the art survey," *Journal of Network and Computer Applications,* vol. 166, p. 102693, 2020.

[194] Q. Feng, D. He, S. Zeadally, M. Khurram Khan and N. Kumar, "A survey on privacy protection in blockchain system," *Journal of Network and Computer Applications,* vol. 126, pp. 45-58, 2019.

[195] B. Hu, C. Zhou, Y.-C. Tian, Y. Qin and X. Junping, "A Collaborative Intrusion Detection Approach Using Blockchain for Multimicrogrid Systems," *IEEE Transactions on Systems, Man, and Cybernetics: Systems,* vol. 49, no. 8, pp. 1720-1730, 2019.

[196] G. Liang, S. R. Weller, F. Luo, J. Zhao and Z. Y. Dong, "Distributed Blockchain-Based Data Protection Framework for Modern Power Systems Against Cyber Attacks," *IEEE transactions on smart grid,* vol. 10, no. 3, pp. 3162-3173, 2019.

[197] Y. Liu, D. He, M. S. Obaidat, N. Kumar, M. Khrram Khan and K.-k. Raymond Choo, "Blockchain-based identity management systems: A review," *Journal of network and computer applications,* p. 102731, 2020.

[198] S. Singh and N. Singh, "Blockchain: Future of financial and cyber security," *2016 2nd International Conference on Contemporary Computing and Informatics (IC3I),* 2016.

[199] P. J. Taylor, T. Dargahi, A. Dehghantanha, R. M. Parizi and K.-K. Raymond Choo, "A systematic literature review of blockchain cyber security," *Digital Communications and Networks,* p. Corrected proof, 2019.

[200] T. Ahram, A. Sagolzaei, S. Sargolzaei, J. Daniels and B. Amaba, "Blockchain technology innovations," *2017 IEEE Technology & Engineering Management Conference (TEMSCON),* 2017.

[201] C. Esposito, A. De Santis, G. Tortora, H. Chang and K.-K. Raymond Choo, "Blockchain: A Panacea for Healthcare Cloud-Based Data Security and Privacy?," *IEEE Cloud Computing,* vol. 5, no. 1, pp. 31-37, 2018.

[202] Q. Xia, E. B. Sifah, A. Smahi, S. Amofa and X. Zhang, "BBDS: Blockchain-Based Data Sharing for Electronic Medical Records in Cloud Environments," *Information,* vol. 8, no. 2, p. 44, 2017.

[203] L. S. Sankar, M. Sindhu and M. Sethumadhavan, "Survey of consensus protocols on blockchain applications," *2017 4th International Conference on Advanced Computing and Communication Systems (ICACCS),* 2017.

[204] D. Puthal, N. Malik, S. P. Mohanty, E. Kougianos and C. Yang, "The Blockchain as a Decentralized Security Framework [Future Directions]," *IEEE Consumer Electronics Magazine,* vol. 7, no. 2, pp. 18-21, 2018.

[205] I.-C. Lin and T.-C. Liao, "A Survey of Blockchain Security Issues and Challenges," *International Journal of Network Security,* vol. 19, no. 5, pp. 653-659, 2017.

[206] P. Sajana, M. Sindhu and M. Sethumadhavan, "On Blockchain Applications: Hyperledger Fabric and Ethereum," *International Journal of Pure and Applied Mathematics,* vol. 118, no. 18, pp. 2965-2970, 2018.

[207] M. Banerjee, J. Lee and K.-K. Raymond Choo, "A blockchain future for internet of things security: a position paper," *Digital Communications and Networks,* vol. 4, no. 3, pp. 149-160, 2018.

[208] D. K. Tosh, S. Shetty, X. Liang, C. A. Kamhoua, K. A. Kwiat and L. Njilla, "Security Implications of Blockchain Cloud with Analysis of Block Withholding Attack," *2017 17th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGRID),* 2017.

[209] A. Lei, H. Cruickshank, Y. Cao, P. Asuquo, C. P. A. Ogah and Z. Sun, "Blockchain-Based Dynamic Key Management for Heterogeneous Intelligent Transportation Systems," *IEEE Internet of Things Journal,* vol. 4, no. 6, pp. 1832-1843, 2017.

[210] X. Liang, J. Zhao, S. Shetty and D. Li, "Towards data assurance and resilience in IoT using blockchain," *MILCOM 2017 - 2017 IEEE Military Communications Conference (MILCOM),* 2017.

[211] X. Liang, S. Shetty, D. Tosh, C. Kamhoua, K. Kwait and L. Njilla, "ProvChain: A Blockchain-Based Data Provenance Architecture in Cloud Environment with Enhanced Privacy and Availability," *2017 17th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGRID),* 2017.

[212] R. Rivera, J. G. Robledo, V. M. Larios and J. M. Avalos, "How digital identity on blockchain can contribute in a smart city environment," *2017 International Smart Cities Conference (ISC2),* 2017.

[213] M. J. Burer, M. d. Lapparent, V. Pallotta, M. Capezzali and M. Capita, "Use cases for Blockchain in the Energy Industry Opportunities of emerging business models and related risks," *Computers & Industrial Engineering,* vol. 137, 2019.

[214] Y. Zhao, K. Peng, B. Xu, Y. Liu, W. Xiong and Y. Han, "Applied engineering programs of energy blockchain in US," *Energy Procedia,* vol. 158, pp. 2787-2793, 2019.

[215] T. Mcghin, K.-K. Raymond Choo, C. Z. Liu and D. He, "Blockchain in healthcare applications: Research challenges and opportunities," *Journal of Network and Computer Applications,* vol. 135, pp. 62-75, 2019.

[216] H. Jianchao, W. Che and L. Sai, "How to improve the competiveness of distributed energy resources in China with blockchain technology," *Technological forecasting and social challenge,* vol. 151, 2020.

[217] W. M. Shbair, M. Steichen, J. Francois and R. State, "BlockZoom: Large-Scale Blockchain Testbed," *2019 IEEE International Conference on Blockchain and Cryptocurrency (ICBC),* 2019.

[218] X. Wang, G. Yu, X. Zha, W. Ni, R. P. Liu, Y. J. Guo, K. Zheng and X. Niu, "Capacity of blockchain based Internet-of-Things: Testbed and analysis," *Internet of Things,* vol. 8, p. 100109, 2019.

[219] A. Goranovic, M. Meisel, S. Wilker and T. Sauter, "Hyperledger Fabric Smart Grid Communication Testbed on Raspberry PI ARM Architecture," *2019 15th IEEE International Workshop on Factory Communication Systems (WFCS),* 2019.

[220] M. Buth, A. Wieczorek and G. Verbong, "The promise of peer-to-peer trading? The potential impact of blockchain on the actor configuration in the Dutch electricity system," *Energy Research & Social Science,* vol. 53, pp. 194-205, 2019.

[221] D. Zhang, "Application of Blockchain Technology in Incentivizing Efficient Use of Rural Wastes: A case study on Yitong System," *Enegry Procedia,* vol. 158, pp. 6707-6714, 2019.

[222] Y. Pan, X. Zhang, Y. Wang, J. Yan, S. Zhou, G. Li and J. Bao, "Application of Blockchain in Carbon Trading," *Energy Procedia,* vol. 158, pp. 4286-4291, 2019.

[223] J. Truby, "Decarbonizing Bitcoin: Law and policy choices for reducing the energy consumption of Blockchain technologies and digital currencies," *Energy Research & Social Scienece,* vol. 44, pp. 399-410, 2018.

[224] C. Stoll, L. Klaasen and U. Gallersdorfer, "The Carbon Footprint of Bitcoin," *Joule,* vol. 3, no. 7, pp. 1647-1661, 2019.

[225] U. W. Chohan, "Blockchain and Environmental Sustainability: Case of IBM's Blockchain Water Management," *Notes on the 21st Century (CBRI),* 2019.

[226] "https://futurethinkers.org/blockchain-environment-climate-change/," 11 September 2017. [Online]. [Accessed 03 06 2020].