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Review article

Blockchain-based management of demand response in electric energy grids: A systematic review

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ABSTRACT

The complexities associated with modern energy grids, including high penetration levels of renewable energy sources at the end use customers, the proliferation of electric vehicles (EVs), as well as decentralized energy management systems and energy data portals and services, require secure, reliable and cost-effective new platforms to administer such systems in a transparent manner. Blockchain technology can address such challenging complexities efficiently. This paper presents a thorough literature review of all potential blockchain applications in electric energy systems. First, all potential blockchain application possibilities and constraints in electric energy systems have been identified. Then, the implementations of blockchain technology in power systems are divided into various categories, such as demand response (DR), EVs, decentralized energy management, energy trading and distributed renewable energy. A detailed literature analysis is conducted by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines in a systematic approach using credible and reliable database systems such as IEEE Xplore, ScienceDirect, and Scopus to highlight current advancements in blockchain technology uses in electric energy systems particularly in DR, as well as future potential and existing problems. The paper is divided into three parts. The first part lists the important publications that have delved into the implementation of Blockchain in demand response. Trends of Blockchain applications in other electric energy system areas are detailed in the second section. The final part highlights the evolution and advancement of blockchain-based electric energy systems including favourable attributes of structures and designs, as well as the challenges and future trends.

Contents

Abbreviations: EVs, Electric Vehicles; DR, demand response; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; IEEE, The Institute of Electrical and Electronics Engineers; BC, Blockchain; SG, Smart grid; DL, Distributed ledger; CEC, California Energy Commission; TOU, Time of Use; RTP, real-time pricing; CPP, Critical Peak Pricing; BP, Based-Program; DLC, Direct load control; VOLL, value of the lost load; DSM, Demand side management; IET, Institution of Engineering and Technology; DRE, distributed renewable energy; EMS, Energy management system; PBFT, Practical Byzantine Fault Tolerance; DP, Delegated Proof of Stake; BFT, Byzantine Fault Tolerance; ADR, Automated demand response; ELN, energy local network; SP, service provider; P2P, peer-to-peer; V2G, Vehicles to grid; PHEV, plug-in hybrid electric vehicles; P2PEBT, P2P Electricity Blockchain Trading; PoB, Proof of Burn; TEF, transactive energy framework; TEM, transactive energy market; IDR, Integrated Demand Response; DN, distribution network; SPB, Secure Private Blockchain-based; SDN, software defined networking; ETS, Emission Trading Scheme; EPSDN, energy power supply and demand network; DLT, distributed ledger technology; AMI, automatic metering infrastructure; MG, microgrid; DAG, Directed Acyclic Graph; DPMP, Decentralized Permissioned Market Place; IoT, Internet of Things; TE, transactive energy; DER, distributed energy resource; VPP, virtual power plants; ADN, active distribution network; PoW, Proof-of-Work; PoS, Proof-of-Stake; AI, Artificial Intelligence; HVAC, Heating, ventilation, and air conditioning; FF-DNN, Feed Forward deep neural network; ANN, artificial neural network; POU, prediction-of-use; RL, Reinforcement Learning; VCG, Vickrey–Clarke–Groves; BTC, Bitcoin; ID, Identification; RQ, Research Questions; IDE, Integrated Development Environment; IIoT, Industrial internet of things; ESCO, energy service companies; DETF, decentralized electricity trading framework; FPA, Flexible Permission Ascription; MQTT, Message Queuing Telemetry Transport; COCO, Confidential Consortium Blockchain; PoET, Proof of Elapsed Time; SMES, superconductive magnetic energy storage; BSI, Blockchain Secure Interface; IT, Information Technology

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1. Introduction

Different political, economic, and technological motivations have driven the energy system towards the smart grid paradigm recently. Not only the architecture of the power system is changing dramatically as a result of this transformation, but also the planning and operation of the system are being revamped (Pilo et al., 2013; Siano et al., 2019). More specifically, the power system is transforming from a centralized to a decentralized architecture. This comes as a result of the execution of strategic rules and regulations, also including economic liberalization and emission reductions plans, that promote the removal of massive oil and coal-powered energy plants and the implementation of local grid management systems (Bruinenberg et al., 2012), which can better enhance the deployment of renewable energy sources. Consequently, to acquire a stable and affordable supply of energy, the future power system will need to fully use such adaptability provided by all the parties involved (Pilo et al., 2013; Shayeghi et al., 2019; Kazmi et al., 2017). A fundamental shift in the management of the electricity system from a top-down to a bottom-up approach, on the other hand, entails a change in duties from centralized authorities to decentralized entities, enabling grid users for further engagement. Decentralized energy systems are desirable because they boost the effectiveness of the entire electricity system by allowing scattered resources to be used locally (Wolfe, 2008). In this context, unique ways that allow grid users to actively participate in ensuring a secure and dependable electric power supply have recently been presented in the literature (Walker and Devine-Wright, 2008; Van Der Schoor and Scholtens, 2015; Jamil et al., 2021; Zeng et al., 2021).

Balancing supply and demand is one of the most difficult aspects of managing energy grids, especially during peak hours. Demand response (DR) programs are crucial instruments for resolving this issue, as they reward users to lower their electricity consumption during peak demand periods (Albadi and El-Saadany, 2008). Such a centralized management model of DR is typically challenged by a number of issues, including the credibility of the centralized database, the transparency of measurement data, the privacy leakage of demand-side users, the delay of DR subsidy settlement, and the high cost of business management (Wang et al., 2019; Yu et al., 2020). Hence, a blockchain-based solution can address this issue by providing a transparent and tamper-resistant record of all DR actions, including the amount of energy savings achieved and the reimbursement delivered to clients. This can boost customers' confidence in the DR program and encourage their participation.

Besides that, due to the sharp increase in cyber-attacks, that could disrupt networking in various ways, such as financial fraud, fake data injection, data manipulation, and many more, network security has recently been reckoned as a significant concern. The energy requests made by the consumers, the cost information given by the market participants, and the quantity of energy delivered to every user, on the other hand, are all transferred over the smart grid (SG) among the prosumers and the consumers. As a result, security vulnerabilities in SG outfitted by a range of sensors, miners, renewable energy systems, and smart gadgets, regarded as susceptible nodes in the network, should be properly addressed. Among the most effective methods for improving SG's security is to use blockchain technology that has the potential to stop frauds and enable secure transactions (Hassan et al., 2022; Kumari and Tanwar, 2022; Kavousi-Fard et al., 2021; Samuel and Javaid, 2021a; Van Cutsem et al., 2020; Dorri et al., 2019; Li et al., 2019b; Yapa et al., 2021).

A further difficulty in administering DR projects is the lack of standardization and interoperability among various platforms. Blockchain-based system can address this issue by providing a multi-system-compatible, centralized platform for DR activities (Tsolakis et al., 2018; Liu et al., 2020). Enhanced coordination and communication between grid operators, utilities, and customers can facilitate more efficient and effective DR initiatives.

According to the published studies, the most viable solution for constructing P2P frameworks is the upcoming Distributed Ledger (DL) technology coupled with the well-known application, *i.e.,* Blockchain (White Paper, 2022; Dick and Praktiknjo, 2019; Noor et al., 2018b). Decentralized data systems or ledgers, such as blockchains, make it possible for safe storage of digital transactions without a centralized body. Furthermore, blockchains allow P2P networks to carry out smart contracts automatically (Hatziargyriou, 2013). They might also be viewed as repositories to let several users to simultaneously edit the ledger, leading to different chain variations. Every network member keeps a duplicate of the data chain instead of letting one single trusted centre handle the ledger and uses consensus to determine the ledger's legitimate status. Blockchain technologies are durable and secure due to the cryptography, which connects new transactions to previous ones. All users on the network may verify whether transactions are genuine for themselves, which, in turn, ensures transparency and tamper-proof records (Andoni et al., 2019).

Several other review articles exploring the current state and potential of blockchain technology in the energy sector have been published. These articles give an in-depth study of the current literature, identify the primary obstacles, and propose viable solutions for the implementation of blockchain technology in the energy sector. Firstly, article (Ante et al., 2021) offers a bibliometric analysis of the research on blockchain and energy, including DR management. It identifies trends in research topics, nations, and publications pertaining the topic. Also, the article includes a critical overview of the available literature, identifying research gaps and suggested future study areas. Nevertheless, no extensive examination of specific blockchain-based DR management systems is provided. The study's primary limitation is that it is based on a bibliometric analysis of the available publications, which may not reflect the full scope of activities and advancements in the subject. In addition, the study lacked a systematic evaluation of the quality of the analysed papers.

Ref. Hasankhani et al. (2021) gives a complete overview of the current state of blockchain technology in the context of smart grids and suggests a number of potential use cases. However, the article's limitations include a lack of actual evidence to back some of the assertions stated and a limited examination of the challenges and constraints associated with utilizing blockchain technology in smart grids.

Article (Bao et al., 2020) provides a comprehensive review of the numerous blockchain applications in the energy sector and how they might be utilized to address the industry's difficulties. It also emphasizes the potential efficiency, transparency, and security benefits of blockchain technology. However, it provides only a high-level overview of blockchain applications in the energy industry and does not get into the technical elements of these applications. In addition, the report lacks a critical evaluation of the limitations and potential downsides of blockchain technology in the energy industry.

This paper was motivated by the increasing interest in DR management as a crucial instrument for balancing supply and demand in electric energy grids. With the rising use of renewable energy sources and the electrification of transportation, the significance of DR management is projected to increase. While DR programs have existed for decades, current technological advancements have led to the development of new and novel ways to DR management. Particularly, blockchain technology has been recommended as a possible alternative for controlling DR efforts, since it offers enhanced transparency, security, and efficiency.

Given the fast-changing nature of DR management and the revolutionary potential of blockchain technology, we deemed it important to perform a complete analysis of the present state of the art in DR in energy systems, with an emphasis on blockchain-based solutions. Our analysis intends to provide an up-to-date and comprehensive summary of the various methodologies and technologies utilized in energy systems, as well as their benefits and drawbacks.

In addition, our evaluation aims to identify gaps and obstacles in the existing state-of-the-art in energy systems, particularly in DR management in order to identify the potential for future research and innovation. By providing a comprehensive review of the current literature on electric energy systems and blockchain technology, hence contributing to the development of more effective and efficient DR programs, which will be crucial in ensuring the future reliability, stability, and sustainability of electric energy grids.

2. Background

A precise real-time balance between supply and demand is needed for the power system to operate reliably. This equilibrium is difficult to attain since supply and demand levels can fluctuate quickly and unpredictably for a variety of reasons, including forced outages of generating units, transmission and distribution line failures, and sudden changes in load. Demand side (load) response is among the least expensive options needed to operate the system such that the supply and demand are adequately balanced.

An overview of DR is provided in this section as well as DR programs, followed by the benefits of these DR programs. The application of DR in energy systems is also included herein.

2.1. Overview of demand response

Demand response is the modification of end-user customers' usual patterns of energy consumption in response to fluctuations in the price of electricity across time. Additionally, DR may be described as the incentive rewards intended to promote reduced energy usage during periods when wholesale prices are increasing or once system dependability is at risk (Federal Energy Regulatory Commission - FERC, 2006). Other definitions represent the emergence of demand-side flexible applications. In fact, demand is viewed as a resource that can be dispatched in response to operators of transmission and distribution systems, flexible aggregators, and utility companies in general. DR is defined by the California Energy Commission (CEC) as "a reduction in consumers power usage during a specific interval of time, comparative to what might normally happen in responding to a pricing signal, other financial benefits, or even a reliability signal".

DR programs aim to alter the energy use in response to price changes or incentives, in order to smooth out the demand curve. There are two main types of DR programs: price-based and incentive-based. Price-based programs can be further classified into Time of Use (TOU), real-time pricing (RTP), and critical peak pricing (CPP) (Albadi and El-Saadany, 2008). TOU rates vary over time blocks, with higher rates during peak hours and lower rates during off-peak hours. RTP refers to a pricing model where the cost of energy is adjusted regularly, usually on an hourly basis (Paterakis et al., 2017). CPP programs are similar to TOU plans, but with higher charges in response to reliability issues or high wholesale power costs (Losi et al., 2015). Incentive-based programs allow operators, aggregators, or utilities to limit customer loads in return for credits or incentives, rather than altering the retail electricity rate (Losi et al., 2015). A common element of incentive-based programs is direct load control (DLC), in which the utility or aggregator directly manages customer loads by turning them off or transferring them to a reduced demand period.

DR and demand side management (DSM) programs offer a range of economic and environmental benefits (Losi et al., 2015). The economic benefits include reducing peak demand, providing auxiliary services, and reducing transmission and distribution losses. These benefits can lower energy costs, reduce the need for high-cost energy plants and expansions, as well as minimize the transmission losses. The environmental benefits of DSM include reducing peak demand, which reduces the need for power plants and the pollution they produce and using fast-start units that emit less greenhouse gases. DR programs can also improve the operating safety of energy systems by offering ancillary services more quickly and widely than traditional generation. In addition, DR programs can reduce greenhouse gas emissions by encouraging energy efficiency and conservation and can provide social benefits by reducing the risk of blackouts and brownouts.

2.2. Demand response in energy systems

The following articles, listed in Table 1, discussed mainly the use of simulation, optimization, and artificial intelligence techniques for demand response in smart grid systems, particularly in the areas of peak demand forecasting, HVAC system energy efficiency, load pattern elasticity, and load learning models (Basnet et al., 2016; Lee and Horesh, 2015; Paterakis et al., 2016; Singh et al., 2017; Ninagawa et al., 2016; MacDougall et al., 2017; Klaassen et al., 2016; Ponocko and Milanovic, 2018). The integration of distributed energy resources (DER) and the internet of things (IoT) into demand response systems is also highlighted in the articles. Refs. Robu et al. (2018) and Nishiyama et al. (2017) explore different ways to integrate DR into energy markets as well as payment plans for program participants. Some of the papers concentrate on contract design and negotiation methods for DR (Meir and Robu, 2017), while others concentrate on techniques for figuring out what participants in DR should be paid fairly, including utilizing the Shapley value or reward bidding (O'Brien et al., 2015; Bakr and Cranefield, 2015; Ma et al., 2017). In several articles, it is suggested to use cooperative DR structures, prediction-of-use tariffs, and market techniques for aggregators based on payoff allocation (Lopes et al., 2013; Haring et al., 2016). According to these studies, demand response in energy markets can result in improved dependability and resource efficiency. However, it is also crucial to think about the technical and financial viability of implementing DR initiatives, as well as to establish contracts and pay plans that are fair for all participants. The design and optimization of demand response systems and market strategies, as well as the use of mathematical and computational models to estimate fair remuneration policies for participants and enhance the effectiveness of energy markets, appear to be the primary focus of the articles mentioned.

Nonetheless, security precautions were not specifically brought up in these articles, which would be a problem if these systems are used in the real world. The security of the system and the data it handles is a crucial factor to be taken into account, since improper security measures might result in vulnerabilities that bad actors can exploit. It is suggested that future studies in this field should concentrate on addressing the security issues of these systems, for example, by using secure communication protocols and encryption, to guarantee the protection of sensitive data and the integrity of the system.

The security of the system in these research endeavours can be increased using blockchain technology. Blockchain can provide clear and secure records of all transactions, preventing data theft and illegal access. Additionally, the demand response process can be automated to make it more secure and efficient using smart contracts, which are self-executing contracts in which the terms of the agreement between the buyer and seller are directly encoded into lines of code. For example, smart contracts can be used to automate the process of billing and compensating participants in demand response programs. Smart contracts can be implemented in the system to enhance the security and automation of transactions between different parties. Because smart contracts can be designed to abide by all rules and regulations established by authorities, they also make compliance and regulatory concerns automatable.

Blockchain's distributed architecture also increases the resistance to attacks and outages, adding another layer of protection to the system. Considering all these aspects, integrating blockchain technology into the demand response systems can assist to ensure the accuracy and dependability of the data and improve the security and effectiveness of the system.

2.3. Blockchain technologies

2.3.1. Overview of blockchain

Blockchain (BC) technologies creates a decentralized, secure, and tamper-resistant digital ledger of transactions. In order to create the decentralized money known as Bitcoin, an unknown person or group of people going by the name of Satoshi Nakamoto first proposed the idea of a blockchain in 2008 (Nakamoto, 2008). Since then, blockchain technology has been used for a wide range of applications beyond only bitcoin.

A blockchain is fundamentally a database that is controlled by a network of computers that collaborate to verify and record transactions (Kuo Chuen, 2015). The blockchain's individual blocks each have a record of several transactions and a distinctive cryptographic signature that validates their authenticity. A block that has been added to the chain cannot be altered, making it a tamper-proof log of all transactions that have occurred on the network. Fig. 1 illustrates an example of a blockchain. A block only has one parent block when the block header contains a preceding block hash. The initial block in a blockchain without a parent block is known as the "genesis block". A block is composed of a block header and a block body, as seen in Fig. 2. The block header specifically includes the following details:

2.3.2. Architecture of blockchain

The architecture of a blockchain can be divided into five layers as seen in Fig. 3. The application layer, contract layer, the data layer, the consensus layer, and the network layer. Decentralized applications (dApps) that function on top of the blockchain are included in the application layer. These dApps might be everything from simple programs like wallets to intricate ones like supply chain management systems. The smart contracts are stored in the contract layer. Smart contracts streamline agreement negotiation and implementation by acting as self-executing contracts.

The transactions are logged and saved in the data layer. All transactions on a public blockchain are available to all, however on a private blockchain, only persons with permission can see the transactions. The distributed ledger technology, on which the data layer is based, makes sure that the transactions are accurately and impenetrably recorded.

Table 1
Summary of studies of DR in energy systems.

Article	Method	Objective	AI
Basnet et al. (2016)	FF-DNN	Peak demand forecasting for DR.	Artificial Neural Network (ANN)
Lee and Horesh (2015)	ANN (1 hidden layer)	Model thermal behaviour of HVAC system.	
Paterakis et al. (2016)	ANN and wavelet decomposition	Load pattern forecasting considering DR price signals	
Singh et al. (2017)	Autoregressive ANN	Load forecasting	
Ninagawa et al. (2016)	ANN (1 hidden layer)	Prediction of aggregated power curtailment in DR	
MacDougall et al. (2017)	ANN (1 hidden layer)	Estimation of available flexibility of a heterogeneous VPP	
Klaassen et al. (2016)	ANN (1 hidden layer), multiple regression	Estimation of the DR potential of residential heating systems for DR	
Ponocko and Milanovic (2018)	ANN (1 hidden layer)	Load forecasting for DR	
Robu et al. (2018)	Cooperative game theory	Propose a prediction-of-use (POU) tariff	Multi agent system
Nishiyama et al. (2017)	Shapley value, core concept	Analysis of cooperative DR structure	
O'Brien et al. (2015)	Cooperative game theory,	RL Fair rewarding of DR participants, approximate Shapley value with RL.	
Bakr and Cranefield (2015)	Shapley value (weighted voting game)	Fair rewarding of DR participants.	
Meir and Robu (2017)	VCG auction	Contract design for DR	
Ma et al. (2017)	Mechanism design	Selection of agents for DR	
Lopes et al. (2013)	Automated negotiation in DR	Creation of tool to support bilateral contracting in electricity market	
Haring et al. (2016)	Cooperative game theory, Q-learning	Contract design for DR	

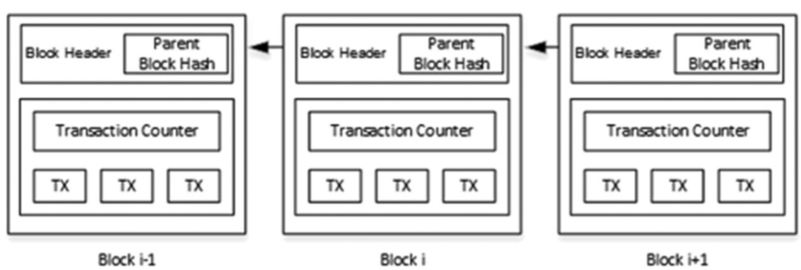

Fig. 1. Example of a blockchain.

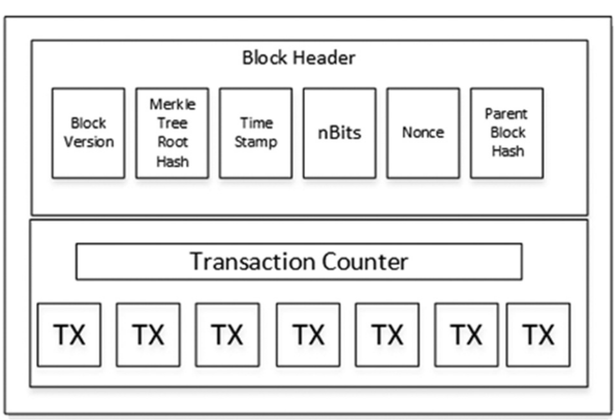

Fig. 2. Structure of a block.

The core of a blockchain is the consensus layer; where a network of computers collaborates to validate and approve transactions. This layer is in charge of making sure that only valid transactions are added to the blockchain. Several blockchain platforms use a variety of consensus mechanisms, including Proof of Work (PoW), Proof of Stake (PoS), Delegated Proof of Stake (DPoS) and Practical Byzantine Fault Tolerance (PBFT).

Communication between the various network nodes is handled by the network layer. A P2P network connects the nodes on a blockchain network, allowing for decentralized communication and information sharing. All nodes must have access to the most recent data, hence the network layer is also in charge of propagating transactions and blocks throughout the network.

In conclusion, a blockchain's architecture is built to make sure that transactions are documented in a way that cannot be altered, verified and approved by the network, and transmitted in a decentralized way. As a result, the blockchain is guaranteed to be secure and reliable, making it a solid foundation for a variety of applications. The consensus layer is where the network of computers collaborates to validate and approve transactions. The network layer is in charge of facilitating communication between the various network nodes.

2.3.3. Blockchain's operation

A blockchain's operation can be divided into five main phases: transaction broadcast, transaction collection and broadcast, consensus protocol execution, acceptance of blocks and chain upgrades, and incentive-based rewards.

A transaction is broadcast to the whole network for authentication in a transaction broadcast. Direct transactions are not allowed between the source and the destination. A transaction is gathered into a block with other validated transactions once it has been verified. Then, nodes pool their resources and begin

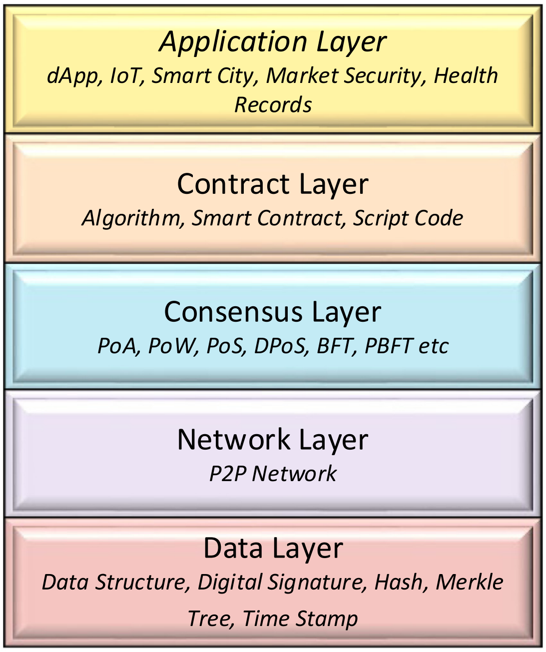

Fig. 3. Blockchain architecture.

mining to find a proof-of-work solution in order to add this block to the blockchain. The block is distributed over the network if the proof-of-work is valid. After including a block in their copy of the ledger, nodes signal their approval of it. They then move on to find the next valid block by using that block as a predecessor and using its hash as the previous hash for the following block.

2.3.4. Consensus mechanisms

A consensus mechanism is the method by which a blockchain network comes to an understanding regarding the ledger's present state. It ensures that all network nodes have a similar understanding of the blockchain and that all transactions are legitimate. Consensus mechanisms are used in blockchains to ensure that the network is secure and transactions are valid.

A blockchain network can use a variety of consensus techniques. The more prominent ones include PoW, PoS, and DPoS. Blockchain's most popular consensus mechanism is called PoW. To add new blocks to the blockchain, network users known as miners must solve challenging mathematical puzzles. The block is added to the blockchain, producing a permanent record of the transaction, and the first miner to solve the challenge and add the block is rewarded with new cryptocurrency.

The PoS consensus process is another popular one. In a PoS system, network users–known as validators–are selected to validate transactions depending on how much cryptocurrency they own. Validators demonstrate their dedication to the network by using their own bitcoin as collateral, which serves as an incentive to assure their honesty. The network then selects a validator to verify the following block using a random selection procedure.

DPoS is a modification of PoS where cryptocurrency holders vote on a set of delegates who are then responsible for validating transactions and adding new blocks to the blockchain. The delegates are incentivized to remain honest as they can be voted out of their position if they are found to be acting against the interests of the network. Proof of Authority (PoA), Byzantine Fault Tolerance (BFT), and Practical Byzantine Fault Tolerance (PBFT) are additional ways for achieving consensus.

The choice of consensus mechanism is frequently influenced by the particular requirements of the network. Each consensus method has advantages and disadvantages of its own. Decentralization may be given top priority in some networks, while transaction speed or energy efficiency may be given priority in others.

2.3.5. Mining and block validation

The act of dedicating computer resources to a cryptographic puzzle in order to validate a block of transactions is known as mining. A block is added to the blockchain once it has been verified, and the miner is paid in cryptocurrency.

Each transaction within a block is verified as part of the block validation process. The chronological order of the transactions is then confirmed in accordance with their occurrences and references after individual inspection. The time stamp's precision is examined, and the proof-of-work for the most recent block is confirmed.

2.3.6. Network operation

The network operation includes the stages that specify the sequence in which they are defined and how they are carried out. For authentication, every transaction is broadcasted to the whole network. Nodes verify transactions before collecting them into blocks. The nodes start mining to solve the cryptographic puzzle by pooling their resources. The block is distributed around the network once the issue has been resolved. After including a block in their copy of the ledger, nodes signal their approval of it. They then move on to find the next valid block by using that block as a predecessor and using its hash as the previous hash for the succeeding block. For successfully accepting blocks, miners receive rewards.

3. Method

3.1. Research questions

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021) were implemented to help with the review structure and systematic presentation. This includes the procedures employed to carry out the systematic review as well as a number of the steps in the review process with a step-by-step explanation, such as locating pertinent studies, screening titles and abstracts with review inclusion and exclusion criteria, manually determining eligibility, evaluating study quality, and data extraction and analysis before integrating the results (Mohamed Shaffril et al., 2020). The research questions for this study are formed using the key components of the review: types of demand response and blockchain and its application. The review was conducted using a set of research questions (RQs) as shown in Table 2.

3.2. Retrieving and selecting records

The approach for retrieving articles relating to blockchain-based applications in electric energy systems is covered in this section. The reviewers employed the PRISMA approach, which includes resources (Web of Science, Scopus, and IEEE Xplore) that were used to conduct the systematic review, eligibility and exclusion criteria, review process steps (identification, screening, and eligibility), and data abstraction and analysis.

3.2.1. PRISMA

To design this SLR for the engineering domain, the review was led by the PRISMA Statement (Preferred Reporting Items

Table 2
Set of Research Questions (RQs).

RQ	RQ statement	Motivation
RQ#1	What is the statistical distribution of the pertinent publications spanning from 2016 to 2022?	
RQ#1.1	How many papers were published between 2016 and 2022 that discuss the use of blockchain in demand response applications?	Identify the most significant publications in the search for the use of blockchain in demand response applications.
RQ#2	What are the current research trends in blockchain applications in energy systems?	
RQ#2.1	What types of platforms and consensus of blockchain were used in the studies?	Identify different types of platforms and consensus algorithms used in blockchain-based electric energy systems and the specific field of their applications.
RQ#2.2	What is the subject matter elaborated upon throughout the studies?	
RQ#3	What are the practical projects implemented using blockchains in energy system applications?	Identify the practical aspects of implemented projects using blockchains in energy systems.
RQ#4	What are the challenges and future trends of blockchain-based demand response studies?	Identify challenges, upcoming trends, and research directions of blockchain-based demand response studies.

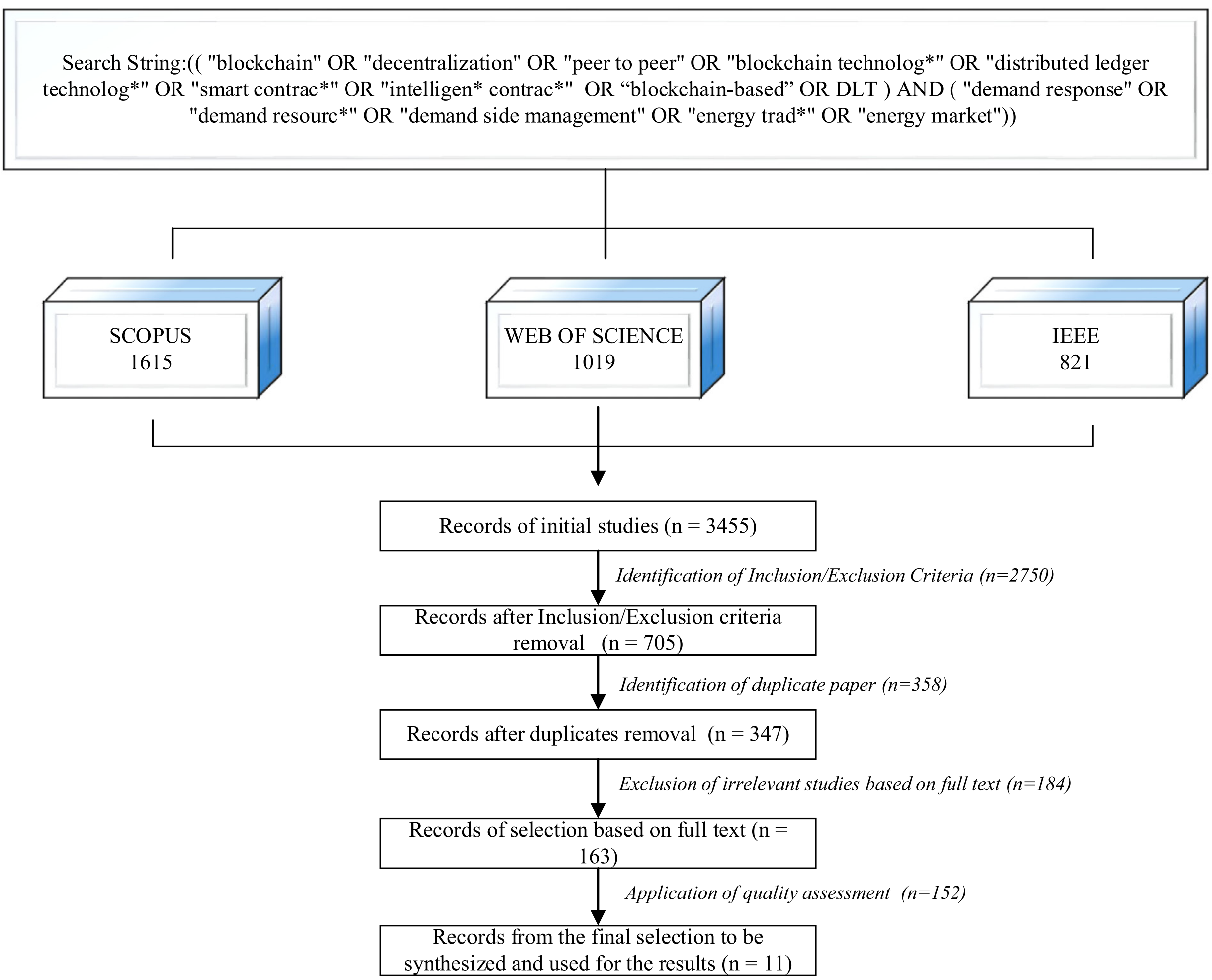

Fig. 4. Article selection process.
Source: Adapted from Page et al. (2021).

for Systematic Reviews and Meta-Analyses) and merged with the standard guidelines established by Kitchenham and Brereton (2013). In accordance with Sierra-Correa and Cantera Kintz (2015), it has three key advantages: (1) it establishes specific research questions that permit systematic study, (2) it establishes inclusion and exclusion standards, and (3) it seeks to review a sizable database of scientific literature in a given period of time. The PRISMA Statement enables a comprehensive investigation for phrases related to blockchain-based demand response applications. The methodology can be used to increase cyber security in the power system and develop new demand response tools. The Preferred Reporting Items for SLRs and Meta-Analyses (PRISMA) statement was applied to perform this evaluation. The procedure is depicted in Fig. 4.

Table 3
The inclusion and exclusion criteria.

Criteria	Eligibility	Exclusion
Timeline	2016–2022	<2016
Literature type	Journal (research articles)	Review, magazine, book series, book, chapter in book, conference proceeding
Subject area	Power system, demand response or demand side management	Other than power system, demand response or demand side management
Language	English	Non-English

3.2.2. Resources

Scopus, Web of Science (WoS), and IEEE Xplore were the three main journal databases used in the study. WoS is a comprehensive database that contains more than 33,000 articles from more than 256 different categories, such as engineering studies, multidisciplinary engineering fields, social issues, and development and planning. It integrates more than 100 years' worth of complete files and citation data produced by Clarivate Analytics and ranks them based on three independent metrics: citations, papers, and citations per-paper.

The second database considered in the review is Scopus. With N22,800 journals from 5000 publications globally, this is one of the largest abstract and citation repositories of peer-reviewed literature. Engineering studies, multidisciplinary engineering topics such as electrical, mechanical, civil, and chemical engineering, and information technology are all covered by Scopus. IEEE Xplore contains N5,110,535 journal articles, conference proceedings, technical standards, and related materials in computer science, electrical engineering, and electronics, as well as related subjects. The Institute of Electrical and Electronics Engineers (IEEE) and the Institution of Engineering and Technology (IET) collaborate to create it.

3.2.3. Eligibility and exclusion criteria

There are set inclusion and exclusion standards. Review articles, book series, novels, book chapters, and conference proceedings were all discarded. Only journal articles containing empirical data were selected. Second, the search efforts eliminated non-English publications and concentrated only on English-language information to prevent any ambiguity or difficulty in translation. Lastly, a five-year window (between 2016 and 2022) has been selected as an appropriate time frame for tracking the development of research and associated publications. Because the review process focused on the use of blockchain technology in demand response, only publications indexed in electrical engineering-based indexes were considered, excluding works published in fields other than electrical engineering. Finally, only publications focusing on demand response or demand side management are included, to keep with the SLR goal of focusing on demand response in power systems (Refer to Table 3).

3.2.4. Systematic review process

The procedure of a systematic review involves four steps. The evaluation was finished in March 2022. The terms that will be used in the search were defined in the first stage. Keywords linked to blockchain and demand response were chosen based on existing research and a thesaurus (Table 4). After meticulous screening, 358 redundant articles were deleted at this level. The screening stage came next. A total of 358 articles were removed from the 705 items that were qualified for scrutiny at this stage. The eligibility stage is where the complete articles are accessed. A total of 140 articles were eliminated after a thorough review since some did not focus on the use of Blockchain technologies in demand response. After the final round of screening, a total of 11 articles were chosen for qualitative data analysis.

3.2.5. Quality of appraisal

The remaining papers underwent evaluation and analysis. An emphasis was placed on certain research that provided answers to the problems that had been raised. In order to uncover pertinent topics and sub-themes, the information was acquired by reading the abstracts first, followed by the whole articles. To uncover themes relevant to blockchain applications in demand response, content analysis was used to carry out a qualitative analysis. Sub-themes were then organized around the themes specified by the field of application by the authors.

3.2.6. Data abstraction and analysis

At this stage, each report was given a quality rating. The remaining reports were examined by two specialists to ensure that the reports chosen were of high quality. This technique focused on methodology and results to choose reports that were labelled as high and moderate rank. Seven (7) reports were categorized as high, and four (4) reports were categorized as moderate during this process. As a result, the total number of papers under consideration for review was reduced to 11.

3.2.7. Result

The review resulted in eight main themes related to the broad application of blockchain in various demand response technologies and applications. The eight main themes are: EV, energy trading, demand response, microgrid, smart grid, demand side management, renewable energy and energy management. The findings gave a detailed analysis of how blockchain technology are currently being employed in demand response. A total of sixty three (63) studies concentrated on implementation of blockchain technologies in energy trading or electricity market (Siano et al., 2019; Dang et al., 2019; Hou et al., 2019; Li et al., 2018a; Lin et al., 2019; Lu et al., 2019; Son et al., 2020; Tan et al., 2019; Zhao et al., 2018; Wang et al., 2022c; Abdella et al., 2021; Saxena et al., 2021; Xu et al., 2021; Doan et al., 2021; Alashery et al., 2021; Yahaya et al., 2021; Cioara et al., 2021; Ali et al., 2021; Said, 2021; Yang and Wang, 2021b; S. for T.E. et al., 2021; Yan et al., 2021; Pradhan et al., 2022; Michael and Hardle, 2019; Gough et al., 2022; Bouachir et al., 2022; Zhang et al., 2022b; Couraud et al., 2022; Onyeka and Kim, 2022; Wongthongtham et al., 2021; Wang et al., 2021b; Khorasany et al., 2021; Yao et al., 2021; Wang et al., 2021c; Khalid et al., 2020; Karandikar et al., 2021; Gaybullaev et al., 2021; Song et al., 2021; Wang et al., 2022a; Yahaya et al., 2022; Chen et al., 2021; Zhang and Shi, 2021; Baig et al., 2021b,a; Yuvaraj et al., 2021; Khorasany et al., 2020; Wang et al., 2021a; Zhang and Hou, 2021; Wang et al., 2021d; Pradhan et al., 2021; Bose et al., 2021; Samuel and Javaid, 2021b; Wu et al., 2022a; R et al., 2022; Strepparava et al., 2022; Shukla et al., 2022; Hu et al., 2019; Mishra et al., 2022; Aitzhan and Svetinovic, 2018; Truong et al., 2018; Gai et al., 2019; Han et al., 2020). Twenty three (23) studies focused on the application of blockchain in EVs (Kang et al., 2017; Duan et al., 2020; Iqbal et al., 2021; Sadiq et al., 2021; Baza et al., 2021; Debe et al., 2021; Kaur et al., 2021; Saha et al., 2021; Danish et al., 2021; Abishu et al., 2022; Luo et al., 2022; Huang et al., 2021; Liu et al., 2021; Acharya et al., 2021; Wu et al., 2022b; Ferreira and Martins, 2018; Sheikh et al., 2020; Zhang et al., 2018; Zhou et al., 2020; Zielińska, 2019; Jindal et al., 2019; Silva et al., 2019; Li et al., 2021). Nineteen (19) studies focused

Table 4
The search string.

Database search string	
Scopus	TITLE-ABS-KEY ((“blockchain” OR “decentralization” OR “peer to peer” OR “blockchain technolog*” OR “distributed ledger technolog*” OR “smart contrac*” OR “intelligen* contrac*” OR “blockchain-based” OR DLT) AND (“demand response” OR “demand resourc*” OR “demand side management” OR “energy trad*” OR “energy market”))
Web of Science	TS = ((“blockchain” OR “decentralization” OR “peer to peer” OR “blockchain technolog*” OR “distributed ledger technolog*” OR “smart contrac*” OR “intelligen* contrac*” OR “blockchain-based” OR DLT) AND (“demand response” OR “demand resourc*” OR “demand side management” OR “energy trad*” OR “energy market”))
IEEE	“blockchain” OR “decentralization” OR “peer to peer” OR “blockchain technolog*” OR “distributed ledger technolog*” OR “smart contrac*” OR “intelligent contract” OR “blockchain-based” OR DLT) AND (“demand response” OR “demand resourc*” OR “demand side management” OR “energy trad*” OR “energy market”

on the application of blockchain in microgrid (Coll-Mayor and Notholt, 2019; Xu et al., 2019; Hamouda et al., 2021; Dabbaghjamanesh et al., 2021; Ledwaba et al., 2021; Tsao et al., 2021; Zhang et al., 2021; Šarac et al., 2021; Vieira and Zhang, 2021; Tsao and Van Thanh, 2021; Yang et al., 2021; Mengelkamp et al., 2018; van Leeuwen et al., 2020; Li et al., 2018b, 2019a; El-Baz et al., 2019; Li et al., 2019c; Jung et al., 2019; Thakur and Breslin, 2018), twelve (12) studies on application of blockchain technologies in smart grid (Jamil et al., 2021; Zeng et al., 2021; Hassan et al., 2022; Kumari and Tanwar, 2022; Kavousi-Fard et al., 2021; Samuel and Javaid, 2021a; Van Cutsem et al., 2020; Dorri et al., 2019; Li et al., 2019b; Park and Kim, 2019; Foti and Vavalis, 2019; Meeuw et al., 2019), eleven (11) studies on application of blockchain in the dispatch of system demand (Liu et al., 2020; Truong et al., 2018; Pop et al., 2018; Troncia et al., 2019; Yang et al., 2020; Aggarwal and Kumar, 2021; Zhang et al., 2022a; Bokkisam et al., 2022; Mao et al., 2022; Wang et al., 2022b), three (3) studies on application of blockchain in energy management system (Yang and Wang, 2021a; Mathew et al., 2022; Afzal et al., 2020), three (3) studies on application of blockchain in renewable energy (Mayer et al., 2021; Kwak et al., 2022; Che et al., 2019; Li et al., 2019c), and one (1) study on application of blockchain technologies in demand side management (Noor et al., 2018a).

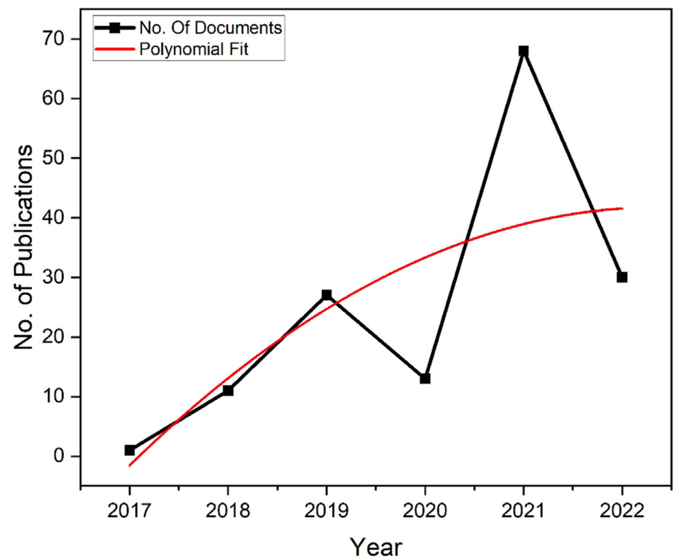

Fig. 5. Distribution of study-related publications by year.

4. Classification of the literature

This section of the literature review aims to organize and summarize the findings in accordance with the research questions outlined in Section 3.1. As seen in Table 2, the findings are divided into four subtopics. The most relevant literature on blockchain applications in demand response is thoroughly examined in the first subtopic, together with its key findings and contributions. The second subtopic examines the most recent research on blockchain technology's application in energy systems, as well as the most recent developments and trends in this area. The third section includes practical projects implemented using blockchain-based energy system applications. The final paragraph then analyses the constraints and prospects for additional research in this area while outlining the difficulties and potential advancements of blockchain-based demand response studies. In conclusion, this section provides a complete assessment of the present status of research on blockchain applications in the energy sector, with a focus on demand response important publications based on selected literature.

For 11 reports arising from the quality of assessment based on the RQs, data extraction was performed. According to the nations where the research was conducted, the majority of reports come from countries in Asia, mainly China. China had 7 studies out of the 12 selected reports, followed by India (2 studies) and Romania and Italy had one study respectively. Fig. 5 depicts a graph of chosen studies from the literature, organized by field of applications of Blockchain in energy systems. This subsection also presents 136 studies in terms of how individual publications were distributed across the years, as shown in Fig. 5, in an exponential fashion. These studies were chosen based on evaluations of the targeted research topic following the application of the quality assessment technique. The graph shows how blockchain application in energy systems have become much more popular over time, particularly in the last two years. Apparently, this came as a result of the 2016 technical advancements and growing implementation of blockchain, which made academics aware of the potential of this technology.

4.1. Research trends of BC-based electric energy systems

RQ#2 outlines the patterns of researchers' publications during the previous six years. This subsection describes the platforms and consensus employed in BC as well as various fields of BC applications in energy systems, particularly in Demand Response.

Energy decision-makers, utility firms, and industry stakeholders are all very interested in blockchain technology. This section gives a basic summary of how blockchains are currently being used in the energy sector that have resulted from the technology's application. Over 151 blockchain innovative projects and research activities in the energy sector have been found throughout our study. We explicitly divide blockchain application in energy systems into eight field of applications based on their objective and domain of application as depicted in Fig. 6. Energy trading is at the top of the list, followed by EVs (EV). The implementation of blockchain technology is also popular in microgrids. Demand response, as well, is getting more attention by the researchers according to our research. Then other fields such as smart grid (SG) and Demand Side Management (DSM), which account for 8.3 and 5.1 percent of all studies, respectively, come in fifth and sixth.

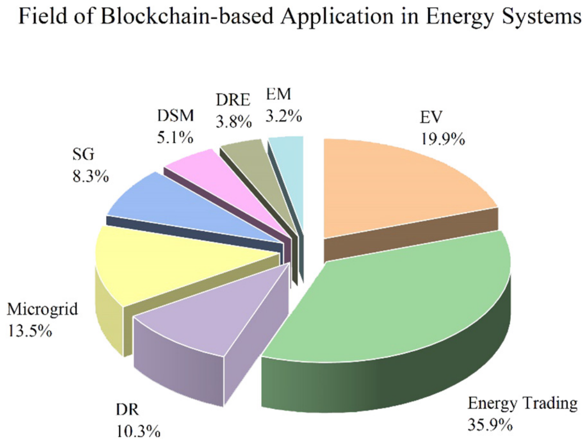

Fig. 6. Distribution number of selected reports grouped according to the field of application in electric energy system.

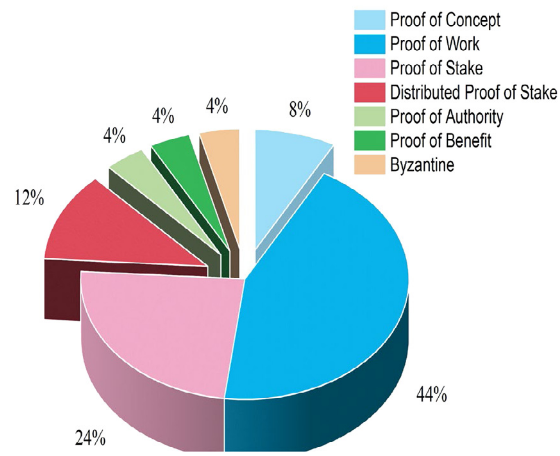

Fig. 8. Types of consensuses used in blockchain.

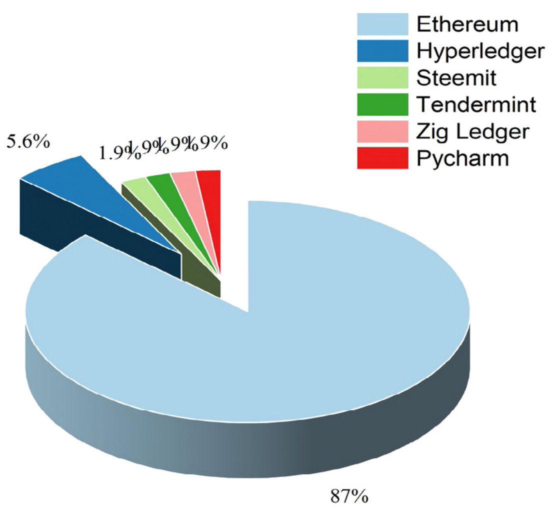

Fig. 7. Various platforms used in blockchain.

About 7% of the total is made up from Distributed Renewable Energy (DRE) and Energy Management field. Additionally, we categorize blockchain activities based on the platforms and consensus techniques employed, whenever information has been made accessible to the general public (see Figs. 7 and 8 respectively). 44% have employed PoW techniques, while 87% are beginning to create solutions based on Ethereum. It should be mentioned that Ethereum intends to move to PoS and other consensus techniques in 2018, including DPoS and PBFT (Consortium Chain Development, 2021). Additionally, the bulk of developers focus on private permissioned platforms since they are the most desirable for businesses (Blockchain-an opportunity, 2022). 5.6% of the studies, who have publically shared information on the platforms of their choice, are exploring Hyperledger Fabric. PoS consensus, is another preferred option for energy utility providers. Zig Ledger, Tendermint, Pycharm and Steemit are four further well-known systems. Future development initiatives may shift to blockchains that are more energy-efficient, quicker, and more scalable as they explore DPoS or BFT-type solutions.

4.1.1. BC in demand response

Liu et al. (2020) proposed a blockchain-based technique to facilitate bidirectional selection between DR users and aggregators based on reputation values, which increases the DR's success rate and reduces the DR's influence from user behaviour. The authors of Pop et al. (2018) studied the application of decentralized blockchain technologies for offering transparent, secure, reliable, and timely energy flexibility to all parties participating in the flexibility markets, in the form of adaption of Distributed Energy Prosumer energy demand profiles (Distribution System Operators primarily, retailers, aggregators, etc.). In article (Troncia et al., 2019), the authors introduced a new, completely autonomous platform for energy and auxiliary service markets in distribution networks that could function in a decentralized fashion. There is a significant potential for controlling local ancillary service markets in various-sized local energy communities using the proposed platform, which might serve as a Virtual Decentralized Market Authority. Truong et al. (2018) proposed a fundamental model for multi-use of stationary battery storage systems with different stakeholders to increase the economic value of stationary battery storage systems by incorporating blockchain technology. An ADR framework for decentralized scheduling and secure P2P trade among energy storage devices in ELNs is presented in Yang et al. (2020). Authors in Aggarwal and Kumar (2021) suggested a P2P energy trading system between EVs (EVs) and service providers (SPs) to handle demand response in a Vehicle to Grid (V2G) system. By contrasting the suggested approach to existing state-of-the-art ideas, security and privacy research revealed that it significantly increases transaction security. The study in Zhang et al. (2022a) examined the issues with demand-response management in P2P energy trading and suggests a blockchain-based P2P energy trading system. Two noncooperative games were used to construct the suggested demand-response system, which applies dynamic pricing to suppliers. The suggested demand-response games have a substantial impact in lowering the net peak load, according to the results of experiments with the prototype. In addition, the off-chain processing method offers lower latency and costs than the on-chain mode despite maintaining the same level of system reliability as the on-chain mode. Authors in Bokkisam et al. (2022) suggested a transactive energy framework (TEF) that uses auction theory, includes a system of agents, and used an auctioneer to assist a transactive energy market (TEM). P2P energy trading between residential buildings in a community microgrid is also made feasible, with the potential for financial gain. The results of simulation demonstrate that there will be considerable financial benefits for each market member as well as a rise in communal self-sufficiency, self-consumption, and reduction in reliance on the utility grid. In Mao et al. (2022), a blockchain-based structure for the DR program is suggested in order to address issues such as data credibility, privacy protection and transaction efficiency. On this foundation, the repeated verification mechanism-based bidding transaction process is created, and the use of blockchain in DR is examined. Then, the smart contract features related to DR bidding and subsidy payment are adjusted. The simulation results in this study which is done on the Remix IDE platform provide as an example of the viability of the DR bidding process. Authors in Wang et al. (2022b), integrate the information interaction network created by blockchain with the energy management network created by energy management system. This article has created a hierarchical framework that allows the exchange of Integrated Demand Response (IDR) resources between users. Finally, another blockchain-based model for China's demand response programs is presented in Yan et al. (2022), whereby the demand response process of invitation, bidding, and settlement is applied to the blockchain's consensus mechanism, encryption algorithm, and smart contract.

The studies discussed the consideration for the use of blockchain technology to increase the economic value of stationary battery storage systems, facilitate bidirectional selection between DR users and aggregators, and provide transparent, secure, reliable, and timely energy flexibility to all parties participating in the flexibility markets. These research undertakings demonstrate that blockchain technology can strengthen transaction security in P2P energy trading, decrease the influence of user behaviour on DR success rates, and give financial rewards for market participants. The research implies that blockchain technology can be applied to DR programs to address problems including data credibility, privacy protection, and transaction efficiency.

Although these studies, listed in Table 5, show the potential of blockchain technology in the energy sector, it is vital to emphasize that they also have significant limits. For instance, many of the suggested techniques are still in development and have not been put to use or thoroughly evaluated yet. Nevertheless, scalability, interoperability, and regulatory frameworks must be addressed prior to the broad implementation of blockchain-based demand response management. Overall, the research indicates that blockchain technology could transform demand response programmes and create a more efficient and sustainable energy system.

4.1.2. BC in energy trading

Decentralized energy trade has drawn the greatest amount of blockchain activity by far. Among the applications being investigated are energy market systems which allow consumers to have accessibility into bulk power markets and P2P energy trading systems among market participants.

Blockchains might reduce the price of transactions in wholesale energy trading while also providing transparent data that is accessible to many parties, including authorities who can check for regulatory compliance. By cutting away the intermediary and lowering transaction costs while potentially increasing trade volume, blockchains might provide an opportunity for local consumers to participate in power market.

A double auction-based game theoretic model for P2P energy trading in smart grids using blockchain is presented in Doan et al. (2021). The paper suggests a double auction-based consensus algorithm and applies game theory to assess the stability and effectiveness of the suggested method. The proposed method is stable and effective, and the research concludes that it can be applied to support P2P energy trading in smart grids. A smart contract architecture for decentralized energy trading and management based on blockchains is presented in Han et al. (2020). The article suggests a smart contract architecture that makes use of blockchain technology to enable decentralized P2P energy trade and administration. The article's conclusion states that additional study is required to assess the suggested architecture's practical performance, even though it is ideal for decentralized energy trading and management. Authors in Hou et al. (2019) introduces a local energy storage system for blockchain-based energy trading. In order to facilitate P2P energy trading in the Industrial Internet of Things (IIoT), the article offers a local electricity storage system that makes use of blockchain. The proposed system is appropriate for P2P energy trading in the IIoT, but more studies are required to assess how well it performs in actual use, according to the article's conclusion. A consortium blockchain for safe energy trade in the IIoT is presented in Li et al. (2018a). In order to facilitate P2P energy trading in IIoT, the study suggests a consortium blockchain-based energy trading system. While, the authors in Lin et al. (2019) evaluate several bidding tactics and auction systems for P2P solar energy markets. They assess the effectiveness of various processes and methods in terms of efficiency, equity, and revenue using simulations. However, the paper only considers P2P solar transactive energy marketplaces and ignores other types of energy trade.

The authors (Lu et al., 2019) suggest a software-defined networking (SDN)-based distributed energy trading system for the energy internet. They use simulations to assess the performance of the suggested system. The research's limitation is that it only addresses one sort of energy trading and ignores security and privacy concerns. A functionally encrypted P2P energy trading mechanism in blockchain-enabled smart grids is proposed by Son et al. (2020). They use simulations to assess the performance of the suggested system. The shortcoming is that it just examines one type of energy trading without taking complexity and scalability into account. Authors in Tan et al. (2019) suggest an energy scheduling system for energy service companies (ESCOs) that protects privacy and is built on an energy blockchain network. They use simulations to assess the performance of the suggested system. The limitation is that it solely considers energy scheduling for ESCOs and ignores other types of energy trading. A blockchain-based integrated energy transaction system is proposed by Zhao et al. (2018). They use simulations to assess the performance of the suggested mechanism. The limitation is that it just examines one type of energy trading and skips over the privacy and security concerns.

A decentralized P2P transactive energy trading system based on blockchain technology is presented in Wang et al. (2022c). This system aims to balance the supply and demand of energy in distribution systems. A consensus algorithm built on proof of authority is employed by the authors. The proposed approach is specific to distribution systems and cannot be generalized to bigger systems, which is one of the drawbacks. A blockchain-based P2P energy trading system that aims to increase the efficiency and security of energy trading is presented in article (Abdella et al., 2021). The proposed approach is not generalized to bigger systems, and the research is restricted to a particular design and performance assessment. A blockchain-based P2P energy trading system for large industrial energy users is presented in Dang et al. (2019). The system aims to increase the effectiveness and security of energy trading. Authors in Saxena et al. (2021) presented a permissioned blockchain-based P2P energy trading system for residential communities that aims to reduce peak demand.

A blockchain-based framework for P2P energy trading is described in Alashery et al. (2021). This framework enables multiple settlements between various participants. A two-stage approach for P2P energy trading that leverages blockchain technology for security and privacy preservation is described in Yahaya et al. (2021). A blockchain-based decentralized virtual power plant system for small prosumers is presented in Cioara et al. (2021). The suggested system above has not been tested in a real-world setting, and its scalability and security have not been properly assessed. A system dubbed Synergychain, which employs blockchain technology to enable adaptive cyber–physical

Table 5
Summary of articles related to blockchain in demand response based on our survey.

No	Article	Purpose of BC	Type	Platform	Consensus algorithm	Method
1.	Liu et al. (2020)	Reliable and efficient interoperation	N/A	N/A	N/A	Simulation
2.	Truong et al. (2018)	Secure and transparent transaction	N/A	N/A	N/A	Case studies
3.	Pop et al. (2018)	Autonomous, transparent and secure system	Public	Ethereum	PoS	Simulation
4.	Troncia et al. (2019)	Decentralized, efficiency, reliability and cost-effectiveness of the system	Public	Ethereum	N/A	Case studies/Simulation
5.	Yang et al. (2020)	Secure, efficient and transparent data management	N/A	N/A	N/A	Case studies
6.	Aggarwal and Kumar (2021)	Distributed V2G energy trading, autonomous DR process, energy costs reduction and improving system efficiency	Consortium	Ethereum	N/A	Simulation
7.	Zhang et al. (2022a)	P2P energy trading, improve the energy utilization efficiency and reduce energy costs	N/A	Hyperledger Fabric	BFT	Simulation and hardware
8.	Bokkisam et al. (2022)	Transparent and secure energy trading, improve the stability of the system and increase the revenue of prosumers	N/A	N/A	N/A	Simulation and hardware
9.	Mao et al. (2022)	Reduce information asymmetry, secure and transparent bidding, efficient, cost reduction	Public	Ethereum	N/A	Simulation
10.	Wang et al. (2022b)	Secure and transparent energy trading, cost-effectiveness, efficiency	N/A	N/A	N/A	Simulation
11.	Yan et al. (2022)	Transparent and secure energy trading, improve the accuracy and reliability of DR programs	Consortium	N/A	N/A	Conceptual

P2P energy trading, is proposed in Ali et al. (2021). In order to demonstrate how well the suggested approach works, the authors undertake a simulation exercise. A decentralized electricity trading framework (DETF) for connected EVs (EVs) that uses blockchain technology and machine learning for profit margin optimization is presented in Said (2021). The effectiveness of the suggested DETF was tested by simulation. Authors in Yang and Wang (2021b) proposed a blockchain-enabled transactive energy system with the goal of achieving social optimality. The authors run simulations to gauge how well the suggested system works. A blockchain-based authentication method for energy trading in vehicle-to-grid (V2G) networks is proposed in S. for T.E. et al. (2021). Simulations were carried out to test the performance of the proposed approach.

An innovative blockchain system is presented in Yan et al. (2021). Smart contracts are used in the proposed framework to speed up transactions and lower their costs. In addition, authors in Pradhan et al. (2022) proposed a Flexible Permission Ascription (FPA) based blockchain framework for P2P energy trading. Smart contracts are used in the proposed framework to enable P2P energy trading. Besides, smart contracts are also used in Xu et al. (2021) and Gough et al. (2022) which proposed a blockchain-based marketplace for trading power and a blockchain-based transactive energy framework for linked virtual power plants. In the suggested framework, smart contracts are used to speed up transactions and lower transaction costs.

In order to enable P2P energy sharing among local communities, the authors in Bouachir et al. (2022) introduces a novel concept called FederatedGrids. The FederatedGrids strategy, according to the authors, can lower energy prices and increase energy efficiency in local communities. Another innovative privacy-preserving method for energy trading based on consortium blockchain is presented in Zhang et al. (2022b). The system uses a private blockchain called consortium, which is owned and managed by a number of dependable players. The authors discovered that the suggested plan might increase energy trading's privacy without reducing its effectiveness. In Couraud et al. (2022), an innovative blockchain-based market model for real-time control of distributed batteries is presented. The authors discovered that the suggested market model might decrease energy expenses and increase battery control efficiency. Ref. Onyeka and Kim (2022) provides a study that tries to improve transaction time management in distributed energy markets built on blockchain technology. The "Developed Optimized Algorithm", which the authors proposed, enhances the market's ability to manage transaction times. Then, a study to create a blockchain-enabled P2P energy trading system is presented (Wongthongtham et al., 2021). A study by Wang et al. (2021b) proposed a double-layer blockchain network for P2P energy trading in distributed power markets. The disadvantage of the above studies is that the authors did not disclose any information regarding the experimental findings, making it challenging to assess how well the suggested method would operate.

A new framework for location-aware P2P energy trading using blockchain technology is presented in Khorasany et al. (2021). A location-aware methodology is employed on the platform, which is a lightweight blockchain foundation, to increase the effectiveness of energy trading. Authors in Yao et al. (2021) proposed a new model for trading distributed electric energy based on prospect theory. Ref. Wang et al. (2021c) presented a new design for a privacy-preserving decentralized energy trading scheme utilizing blockchain technology. Authors in Michael and Hardle (2019) covered the use of blockchain technology to allow local energy markets, with a focus on forecasting energy demand and supply. The authors presented a blockchain-based platform that takes into consideration the constraints of energy demand

and supply forecasts and enables users and producers to purchase and sell energy in a decentralized manner. While a study by Karandikar et al. (2021) suggested using fungible and non-fungible tokens in a blockchain-based transaction system for community-based energy infrastructure. According to the authors, this technology can support decentralized transactions that are both secure and efficient. A study written by Gaybullaev et al. (2021) suggested a blockchain-based energy trading platform that uses dual binary encoding for inner product encryption to guarantee privacy and efficiency. According to the authors, this technology can facilitate decentralized, secure, and effective energy trade.

The authors of Song et al. (2021) suggested a smart contract-based P2P energy trading system for use on the Ethereum blockchain. The cost of the energy that will be traded is determined by dynamic pricing, and according to the developers, the system is user-friendly. In addition, a study written by Wang et al. (2022a) suggested an integrated energy market cloud service platform that is based on blockchain smart contracts. The platform's goal is to give a 5G-deployed smart community a secure and effective energy trading paradigm. The authors in Yahaya et al. (2022) proposed an energy trading model using blockchain for a 5G-deployed smart community. A framework for energy trading based on blockchain and optimization is presented therein. To ensure the security and reliability of the energy trading system, the authors suggest a consensus algorithm based on the practical byzantine fault tolerance (PBFT) algorithm. The authors also demonstrate a simulation of the suggested framework, and the outcomes point to the potential for their strategy to improve the efficiency and security of energy trading. A study by Zhang and Shi (2021) provided a transaction model for energy blockchain that considers the variety of subjects involved in energy trade. For permissioned blockchain networks, the authors suggest a consensus method based on the proof of authority (PoA) algorithm. While Baig et al. (2021b) presented a P2P energy trading system based on IoT and blockchain PoW algorithm, a popular consensus algorithm in many blockchain networks, provides the foundation for the algorithm the authors have suggested. A study by Baig et al. (2021a) suggested a P2P energy trading platform using IoT and blockchain technology. The platform's foundations include ESP32-S2, Node-Red, and the Message Queuing Telemetry Transport (MQTT) protocol. Then, a comparative analysis of various compensating devices in energy trading radial distribution systems using blockchain technology and the Bat algorithm is presented in Yuvaraj et al. (2021). The study focused on voltage management and loss mitigation. A blockchain-based load balancing system for decentralized hybrid P2P energy trading in smart grids presented in Khalid et al. (2020) has suggested a load balancing algorithm for the system. Another blockchain-based trading platform for collaboration and sharing within a multi-agent energy internet is presented in Wang et al. (2021a) and a model of decentralized cross-chain energy trading for power systems is presented in Zhang and Hou (2021). A P2P energy sharing community is shown in Wang et al. (2021d). Overall, these studies illustrate the potential of blockchain technology to improve the efficiency, security, and collaboration of energy trade in smart grids and communities.

For P2P energy trading, the study by Pradhan et al. (2021) presented a revolutionary Confidential Consortium Blockchain structure. The Confidential Consortium Blockchain (COCO) consensus algorithm was suggested by the authors and utilized a platform based on the Ethereum blockchain for safe and private energy exchange between peers. The benefit of this strategy is that it permits safe and private transactions, but the drawback is that it may not be completely interoperable with other blockchain platforms already in use. Ref. Bose et al. (2021) suggested employing distributed energy trading to improve the resilience of electrical power markets. The authors created a consensus technique dubbed the PoA, which enables quicker transaction times and energy trading among peers. Faster transaction times are advantageous in this strategy, but a drawback is that PoA is thought to be less secure than alternative consensus algorithms like PoW or PoS. A safe blockchain-based demurrage mechanism for energy trade in smart communities was suggested by Samuel and Javaid (2021b). The benefit of this strategy is that it enables P2P energy trading that is secure and effective, but a drawback is that it could not be completely compatible with other blockchain platforms already in use.

A paper by Wu et al. (2022a) proposed a blockchain-based P2P (P2P) energy trading system that enables the integration of multi-scale flexibility services. The system's essential elements, such as the smart contracts and the user interface, were thoroughly described by the authors. The suggested system's key benefit is that it enables the integration of various flexibility services, which can assist to increase the effectiveness and dependability of the P2P energy trading process. Moreover, a blockchain-based P2P energy trading system was suggested in R et al. (2022) which enables direct energy trade between prosumers and consumers. The latter is a key benefit that can assist to lower costs and improve the effectiveness of the energy trading process. Authors in Strepparava et al. (2022) presented a local energy market based on blockchain that enables energy trading between prosumers and consumers. Similar to the previous paper, the main advantage is that it enables energy trading between prosumers and consumers, which can aid in boosting the effectiveness and dependability of the energy trading process. However, all of these studies are lacking the practical testing or real-world applications of the suggested solution.

A system for trading energy on the blockchain is proposed in Shukla et al. (2022) for an autonomous distribution network (ADN) with the goal of enhancing the load profile, distribution capability, and loadability margin. The study done by Khorasany et al. (2020) proposed a decentralized bilateral energy trading system for P2P power markets which makes use of blockchain technology to assure safe and open transactions. The suggested system is thoroughly described in the report, along with its benefits such as security, openness, and decentralization.

In Mishra et al. (2022), a smart contract-based energy trading system employing blockchain technology is suggested for a virtual power plant (VPP). The proposed approach is thoroughly described in the paper, along with its benefits like flexibility and openness. Authors in Aitzhan and Svetinovic (2018) outlined a framework for decentralized energy trading that makes use of these three technologies. For the P2P energy trading system, they have employed a consensus algorithm that provides security and privacy. The authors have highlighted the benefits of their suggested architecture for safe and private energy trade using the blockchain as the platform. The study's weaknesses, however, stem from the fact that it is a theoretical framework that needs to be put to the test through actual application. A blockchain-based smart contract trading mechanism for an energy power supply and demand network was proposed by Hu et al. (2019). For a P2P energy trading system, they have employed a consensus method that guarantees the accuracy of the data kept on the blockchain. The authors have discussed about the benefits of their suggested mechanism for safe and effective energy trading. Authors (Truong et al., 2018) suggest a blockchain-based market system for the multi-use of stationary battery storage systems in their study. In order to facilitate the participation of multiple market actors, such as grid operators, prosumers, and aggregators in the energy trading process, they recommend using blockchain technology. Additionally, the authors noted that their system can handle a variety of energy storage system use cases, including frequency regulation, peak shaving, and load balancing. The suggested system has not yet been deployed, and the authors hinted that additional research is required to assess the system's performance and scalability. Ref. Gai et al. (2019) proposed a privacy-preserving energy trading system using consortium blockchain in smart grid. The authors proposed a novel consensus algorithm called "Practical Byzantine Fault Tolerance" (PBFT) that enables a group of nodes to achieve consensus on the content of the blockchain. The advantages of this approach include privacy preservation, security, and transparency in energy trading. The limitation of this study is that the proposed system is a simulation and not a real-world implementation.

The mentioned papers discuss various suggestions for incorporating blockchain technology into energy trading. They all examine the potential of blockchain technology to support P2P energy trading, boost security and transparency, and enhance the overall effectiveness of the energy markets, encourage the use of renewable energy sources, and lower transaction costs. PoA and PoS algorithms are the consensus algorithms that are employed in the majority of the articles. Ethereum and Hyperledger are the platforms most employed by the articles. Many various blockchain-based energy trading platforms, including based on smart contracts, decentralized autonomous organizations (DAOs), and consortium blockchain, have been developed and implemented.

These studies do, however, have a number of drawbacks. The scalability of the proposed systems is one of their drawbacks, as many of the solutions might not be able to manage the large number of transactions needed in a real-world energy market. The suggested systems' lack of privacy and security is another drawback because they might not effectively safeguard sensitive data and might be open to hacking and other types of harmful attacks.

The use more effective consensus methods like PoW and DPoS, which can handle enormous volume of transactions, to get over these restrictions. The security and privacy of the suggested systems can be improved by incorporating privacy-preserving techniques as differential privacy, homomorphic encryption, and zero-knowledge proofs. Further testing and assessment should be done to confirm the viability and feasibility of suggested solutions, as well as taking the regulatory environment into account and ensuring compliance with any applicable rules and regulations.

Overall, the implementation of blockchain technology in energy trading has the potential to revolutionize the industry and promote the move towards a more decentralized and sustainable energy system (see Table 6).

4.1.3. BC in EVs

A decentralized energy trading system for plug-in hybrid electric cars (PHEVs) using consortium blockchains is presented in Kang et al. (2017). The technology, which is built on smart contracts and guarantees safe and open transactions, enables PHEVs to trade electricity among themselves. Duan et al. (2020) suggested an optimal dispatching method for EVs (EVs) using a platform based on smart contracts that takes into account the EVs' current state of charge and the cost of electricity. Iqbal et al. (2021) proposed a secure and decentralized Blockchain based EV energy trading model using smart contract in V2G Network, which describes a decentralized energy trading system for EVs. With the help of a vehicle-to-grid (V2G) network, the technology enables EVs to exchange energy both with one another and with the grid. An energy trading model for EVs in the internet of things (IoT) environment is presented in Sadiq et al. (2021). For the purpose of ensuring safe and effective energy trading among the EVs, they suggested a consensus mechanism termed "Proof of Authority" (PoA).

A privacy-preserving blockchain-based energy trading scheme for EVs is discussed in the second article, "Privacy-Preserving Blockchain-Based Energy Trading Schemes for EVs", by M. Baza et al. The "Proof of Elapsed Time" (PoET) consensus technique is used to assure safe and effective energy trading among the EVs. Hyperledger Fabric served as the study's platform. The absence of a practical implementation and scalability concerns were cited by the authors as study limitations. Debe et al. (2021) presented a blockchain-based energy trading scheme for EVs using an auctioning and reputation system. They employed "Proof of Stake" (PoS) consensus method to enable safe and effective energy exchange among the EVs. A blockchain-based method for preserving the security of an electrical vehicle-aided smart grid ecosystem is presented in Kaur et al. (2021). For managing and tracking the data and transactions inside the ecosystem, the authors suggest employing blockchain technology to build a safe and open system. While authors in Saha et al. (2021) proposed a blockchain-based approach to assuring the security of the Internet of Energy and Electric Vehicle Interface. The authors suggest utilizing blockchain technology to give ecosystem managers and transaction trackers a safe and open platform for maintaining and monitoring data and transactions. Furthermore, Ref. Danish et al. (2021) has also presented a blockchain-based method for effectively and securely choosing charging stations for EVs. In order to manage and track the data and transactions inside the ecosystem, the authors suggest employing blockchain technology to build a safe and open platform.

The article written by Abishu et al. (2022) presented a consensus mechanism for blockchain-enabled vehicle-to-vehicle energy trading in the internet of EVs. The authors proposed a consensus mechanism based on PoW and PoS and evaluate it through simulation. A two-way auction mechanism for power trading in the internet of EVs is presented in Luo et al. (2022). The authors suggest a smart contract-based two-way auction mechanism and simulate its performance. An innovative power market mechanism based on blockchain for electric car charging stations is presented in Huang et al. (2021). The authors suggested a blockchain-based power market mechanism and simulate its performance.

Authors in Liu et al. (2021) suggested a P2P electricity trading system that employs smart contracts and a proof-of-benefit consensus protocol. Acharya et al. (2021) suggested a decentralized market for ancillary services using smart contracts in order to make it easier for EVs to participate in the grid. According to Wu et al. (2022b), a decentralized transactive energy community using blockchain technology is suggested as a way to control the energy use of positive buildings and interactive EVs. A blockchain-based energy trading system for EVs employing a Byzantine-based consensus algorithm is presented in Sheikh et al. (2020). According to the study, a blockchain technology should be used to facilitate safe and open energy trade among EVs. Also, authors in Zhang et al. (2018) proposed a system for offering real-time incentives for EVs to charge with renewable energy. Article (Zhou et al., 2020) suggested a system that makes use of edge computing and blockchain to enable secure and effective energy trading between vehicles and the grid. The Byzantine consensus algorithm is employed in this system. Ref. Zielińska (2019) provides a model for financing and settling electric vehicle charging and infrastructure using blockchain technology. A blockchain-based framework for secure energy trading in a software-defined network (SDN)-enabled vehicle-to-grid environment is proposed in Jindal et al. (2019). Apart from that, authors in Silva et al. (2019) proposed a blockchain-based energy trading platform for EVs in smart campus parking lots. Finally, a P2P energy trading model for EVs based on superconductive magnetic energy storage (SMES) and blockchain is suggested in Li et al. (2021).

Table 6
Summary of articles related to blockchain in energy trading based on our survey.

No	Article	Purpose of BC	Type	Platform	Consensus algorithm	Method
1.	Doan et al. (2021)	Decentralized energy trading, cost-effectiveness and efficiency	N/A	N/A	N/A	N/A
2.	Han et al. (2020)	Decentralized energy trading and management, integrity and security of the transactions	N/A	N/A	N/A	N/A
3.	Hou et al. (2019)	Distributed energy storage, efficient system	N/A	N/A	N/A	N/A
4.	Li et al. (2018a)	Secure, efficient, fair and transparent transactions, automate the energy trading	Consortium	N/A	N/A	N/A
5.	Lin et al. (2019)	Market efficiency	N/A	N/A	N/A	Case study/simulation
6.	Lu et al. (2019)	P2P, secure and efficient energy trading	N/A	Ethereum	PoS	Experimental
7.	Son et al. (2020)	Privacy-preserving P2P, decentralized and autonomous energy trading	N/A	N/A	N/A	N/A
8.	Tan et al. (2019)	Privacy-preserving, efficient and secure energy scheduling	N/A	N/A	N/A	N/A
9.	Zhao et al. (2018)	Efficient. secure and reliable energy transactions	N/A	N/A	N/A	N/A
10.	Wang et al. (2022c)	Secure and transparent transactions	N/A	N/A	PoA	Simulation
11.	Abdella et al. (2021)	Decentralized, secure and automated the energy trading	N/A	N/A	PoS	Simulation
12.	Dang et al. (2019)	Decentralized energy management platform, transparent and secure transactions, efficient and cost effective trading	N/A	N/A	PoS	Simulation
13.	Saxena et al. (2021)	Effective in reducing peak demand and improving energy efficiency	Permis-sioned	Ethereum	PoS	Real-world Case study
14.	Alashery et al. (2021)	Efficient and reliable P2P energy trading, stable and secure system	N/A	N/A	N/A	N/A
15.	Yahaya et al. (2021)	Privacy-preserving, secure, and efficient P2P energy trading	N/A	N/A	N/A	N/A
16.	Cioara et al. (2021)	Transparent, immutable, autonomous and secure energy trading	N/A	N/A	N/A	Simulation
17.	Ali et al. (2021)	Secure and transparent energy transactions	N/A	N/A	N/A	Simulation
18.	Said (2021)	Secure and transparent transactions	N/A	N/A	N/A	Simulation
19.	Yang and Wang (2021b)	Cost-effective and efficient system	N/A	N/A	N/A	Simulation
20.	S. for T.E. et al. (2021)	Secure and private energy trading	N/A	N/A	N/A	N/A
21.	Yan et al. (2021)	Transparent, secure, and efficient energy trading	N/A	N/A	N/A	N/A
22.	Pradhan et al. (2022)	Efficient and scalable system, secure and privacy-preserving energy trading	N/A	N/A	N/A	Simulation
23.	Xu et al. (2021)	Decentralized, transparent, and secure energy trading	N/A	N/A	N/A	N/A
24.	Gough et al. (2022)	Secure and transparent P2P energy trading	N/A	N/A	N/A	N/A
25.	Bouachir et al. (2022)	Privacy-preserving, efficient and secure energy sharing	N/A	N/A	N/A	Simulation
26.	Zhang et al. (2022b)	Privacy-preserving and accurate data aggregation	Consortium	N/A	N/A	Simulation
27.	Couraud et al. (2022)	Cost savings and improved grid stability	N/A	N/A	N/A	Simulation
28.	Onyeka and Kim (2022)	Efficient and autonomous energy trading	N/A	Ethereum	N/A	Experimental
29.	Wongthongtham et al. (2021)	Autonomous, secure and transparent energy trading	N/A	Ethereum	PoS	Experimental
30.	Wang et al. (2021b)	Credible and efficient peer-to-peer energy trading.	N/A	Ethereum	PoW	Experimental
31.	Khorasany et al. (2021)	Efficient and secure energy trading	N/A	N/A	N/A	Simulation

(continued on next page)

Table 6 (*continued*).

No	Article	Purpose of BC	Type	Platform	Consensus algorithm	Method
32.	Yao et al. (2021)	Efficient and fair energy trading and reduce transactions cost	N/A	N/A	N/A	Conceptual
33.	Wang et al. (2021c)	Privacy-preserving, decentralized and secure energy trading	N/A	N/A	N/A	Simulation
34.	Michael and Hardle (2019)	Transparent and secure energy trading	N/A	N/A	N/A	Simulation
35.	Karandikar et al. (2021)	Decentralized, automated transparent and secure energy trading	N/A	N/A	N/A	Simulation
36.	Gaybullaev et al. (2021)	Privacy-preserving, secure and efficient P2P energy trading.	N/A	N/A	N/A	Simulation
37.	Song et al. (2021)	Secure, transparent, tamper-proof P2P transactions and resistant to cyber-attacks.	N/A	Ethereum	N/A	Simulation
38.	Wang et al. (2022a)	Flexible and scalable energy trading, secure transactions.	N/A	N/A	N/A	Simulation
39.	Yahaya et al. (2022)	Secure and privacy-preserving energy trading	N/A	N/A	N/A	Simulation
40.	Chen et al. (2021)	Secure and efficient P2P energy trading	N/A	Ethereum	PBFT	Simulation
41.	Zhang and Shi (2021)	Efficient and cost-efficient system	Permis-sioned	Hyperledger	PoA	Conceptual
42.	Baig et al. (2021b)	Secure, automated and transparent energy trading	N/A	Ethereum	PoW	Simulation
43.	Baig et al. (2021a)	Secure and transparent transactions	N/A	N/A	N/A	Simulation
44.	Yuvaraj et al. (2021)	Efficient system	N/A	N/A	N/A	Simulation
45.	Khalid et al. (2020)	Secure and transparent transactions	N/A	N/A	N/A	Simulation
46.	Wang et al. (2021a)	Efficient and reliable transactions	N/A	N/A	N/A	Simulation
47.	Zhang and Hou (2021)	Reliable and automated energy trading	N/A	N/A	N/A	Simulation
48.	Wang et al. (2021d)	P2P energy sharing	N/A	N/A	N/A	Simulation
49.	Pradhan et al. (2021)	Private, decentralized and secure energy trading	Consortium	Ethereum	Confidential Consortium Blockchain (COCO	Simulation
50.	Bose et al. (2021)	Electricity markets resilience	N/A	N/A	PoA	Simulation
51.	Samuel and Javaid (2021b)	Stable, automated and fair energy trading	N/A	N/A	PoS	Simulation
52.	Wu et al. (2022a)	Secure and transparent transactions	N/A	Ethereum	PoA	Simulation
53.	R et al. (2022)	Transparent, secure, and efficient energy trading	N/A	Ethereum	PoW	Simulation
54.	Strepparava et al. (2022)	Secure, automated and transparent P2P energy trading	N/A	Ethereum	PoS	Simulation
55.	Shukla et al. (2022)	Automated P2P energy trading	N/A	N/A	N/A	Simulation
56.	Khorasany et al. (2020)	Efficient and fair energy trading in a decentralized manner	N/A	N/A	N/A	Simulation
57.	Mishra et al. (2022)	Automate the energy service negotiation and agreement	N/A	N/A	N/A	Simulation
58.	Aitzhan and Svetinovic (2018)	Secure and private for decentralized energy trading	N/A	N/A	N/A	Theoretical
59.	Hu et al. (2019)	P2P trading, secure and transparent system	N/A	Ethereum	N/A	Simulation
60.	Truong et al. (2018)	Transparent, secure and fair energy market transactions.	N/A	Ethereum	N/A	Simulation
61.	Gai et al. (2019)	Privacy-preserving, automated, ensures integrity energy trading	Consortium	N/A	PBFT	Simulation

Based on the studies presented above, it is apparent that there is a growing interest in utilizing block-chain to promote secure and efficient energy trade and management in the context of EVs. The articles address a variety of EV-related subjects, such as energy trading, cybersecurity, auctioning and reputation schemes, smart contracts, and decentralized energy communities. The usage of blockchain technology in EV-related applications has numerous advantages, including enhanced security,

Table 7
Summary of articles related to blockchain in EVs based on our survey.

No	Article	Purpose of BC	Type	Platform	Consensus algorithm	Method
1.	Kang et al. (2017)	Decentralized energy trading	Consortium	N/A	N/A	Simulation
2.	Duan et al. (2020)	Reliable and effective system, cost effectiveness	N/A	N/A	N/A	Simulation
3.	Iqbal et al. (2021)	Secure and automated energy transactions	N/A	N/A	N/A	Simulation
4.	Sadiq et al. (2021)	Secure and automated data and energy trading	Public	Ethereum	PoA	Simulation
5.	Baza et al. (2021)	Privacy-preserving, efficient and secure system	N/A	Hyperledger Fabric	PoET	Simulation
6.	Debe et al. (2021)	Efficient and secure system	Public	Ethereum	PoS	Simulation
7.	Kaur et al. (2021)	Secure and authenticate the communication and data transfer, automate transaction	N/A	N/A	N/A	Simulation
8.	Saha et al. (2021)	Security, decentralized, immutable, and tamper-proof data storage	N/A	N/A	N/A	Simulation
9.	Danish et al. (2021)	Secure and efficient charging station selection	N/A	N/A	N/A	Simulation
10.	Abishu et al. (2022)	Security and high transaction throughput and low transaction latency	N/A	Ethereum	PoW/PoS	Simulation
11.	Luo et al. (2022)	Reliability of transactions, protects the privacy of users, efficient electricity trading	N/A	Ethereum	N/A	Simulation
12.	Huang et al. (2021)	Secure, autonomous and efficient transactions in electric vehicle charging stations	N/A	N/A	N/A	Simulation
13.	Liu et al. (2021)	Decentralized, cost effective, transparent, secure electricity trading	N/A	Ethereum	PoB	Simulation
14.	Acharya et al. (2021)	Decentralized, reliable and efficient	N/A	Ethereum	N/A	Simulation
15.	Wu et al. (2022b)	Efficient, stability, and reliable of the edge grid	N/A	Ethereum	N/A	Simulation
16.	Sheikh et al. (2020)	Secure, high transaction throughput and low latency	N/A	N/A	Byzantine	Simulation
17.	Zhang et al. (2018)	Transparency and security in energy trading.	N/A	N/A	N/A	Simulation
18.	Zhou et al. (2020)	Efficient, secure and transparent transactions	N/A	N/A	Byzantine	Simulation
19.	Zielińska (2019)	Automated and transparent payment processes	N/A	N/A	N/A	Simulation
20.	Jindal et al. (2019)	Secure and efficient energy trading	N/A	N/A	N/A	Simulation
21.	Silva et al. (2019)	Secure and transparent transactions	N/A	N/A	N/A	Simulation
22.	Li et al. (2021)	Secure and transparent transactions	N/A	N/A	N/A	Simulation

transparency, efficiency, and decentralization. Blockchain technology allows for the secure and efficient exchange of data and energy between electric vehicles, charging stations, and the power grid. Moreover, blockchain-based solutions give a mechanism to overcome the obstacles associated with EV adoption, such as range issue, charging infrastructure, and the incorporation of renewable energy.

The publications indicate that blockchain technology has the potential to change EV sector by enabling secure and efficient energy management and trade. However, additional research is required to develop and evaluate blockchain-based solutions for EVs in real-world situations and to overcome the technological and practical obstacles to their deployment. Furthermore, the studies do not offer a comprehensive assessment of the suggested blockchain-based systems' scalability, security, and interoperability. The EV business is predicted to grow in the upcoming years, and it is possible that the suggested systems would not be able to handle the growing volume of transactions and data (see Table 7).

4.1.4. BC in microgrids

The application of blockchain technology in microgrid systems has been explored in a number of studies. We summarize some of the most main findings and methods for implementing DLT for microgrid management and energy trading in this section.

Enhancing the security and transparency of energy transactions is one way to use blockchain technology for microgrid systems. Blockchain technology has the potential to make microgrids more financially viable and reduce their energy costs, as shown by studies such as Coll-Mayor and Notholt (2019) and Xu et al. (2019). However, some studies, like (Hamouda et al., 2021), have proposed a centralized blockchain-based platform for selling electricity, which may raise concerns about the scalability and reliability of large-scale microgrids.

Dabbaghjamanesh et al. provide a priory list for efficient energy tradeoff in interconnected microgrids in Dabbaghjamanesh et al. (2021). They suggest an incentive contract to encourage increased electricity purchases from a sub-microgrid. The paper examines the uncertainties associated with hourly load demands and renewable energy sources in a stochastic context and solves them by means of mixed-integer linear programming (MILP) using the BC algorithm. Authors in Ledwaba et al. (2021) examine the utilization of DLT for remote and restricted microgrid deployments. In Tsao et al. (2021), the authors offer a microgrid architecture that employs blockchain technology for real-time price-based demand response systems.

The study in Zhang et al. (2021) offers a peer-to-peer energy trading system for a microgrid that utilizes iterative double auction and blockchain technology to enable secure and transparent transactions. Moreover, Šarac et al. (2021) advocates integrating a Blockchain Secure Interface (BSI) into an Internet of Things (IoT) device security gateway architecture in order to improve privacy and security. The authors of Vieira and Zhang (2021) offer a P2P energy trading system for a microgrid that leverages smart contracts to promote secure and transparent transactions. A strategy for creating sustainable microgrids using blockchain technology and a fuzzy meta-heuristic methodology is presented in Tsao and Van Thanh (2021). To improve the effectiveness and adaptability of microgrids, the authors propose a blockchain-based P2P energy trading system.

Authors in Yang et al. (2021) describes a blockchain-based PoS consortium solution for compensating microgrid power loss. The authors offer a PoS-based consensus method to assure the security and dependability of the microgrid. In addition, they propose a smart contract-based power loss compensation system to ensure participant fairness. The authors of Mengelkamp et al. (2018) describe the Brooklyn Microgrid, a blockchain-based energy market case study. They propose a decentralized and transparent energy market utilizing blockchain technology to promote participant-to-participant energy transaction.

Authors in van Leeuwen et al. (2020) propose a blockchain-based framework for microgrid community energy management. They presented a bilateral trading system that enables P2P energy trading via smart contracts. Furthermore, Li et al. (2018b) proposes a decentralized energy management solution for active distribution networks employing IoT devices, utilizing blockchain technology for safe and decentralized energy management.

The study in Li et al. (2019a) explores a blockchain-based transactive energy management system for networked microgrids, proposing blockchain technology as part of a decentralized energy management approach that enables peer-to-peer energy exchange and billing. In El-Baz et al. (2019), the authors describe a two-sided auction strategy for integrating microgrid energy markets. In addition, they propose an algorithm that employs Device-Oriented Bidding Strategies. The management of a distributed hybrid energy system utilizing smart contracts and blockchain technology is covered in Li et al. (2019c). Finally, authors of Thakur and Breslin (2018) suggested a P2P energy trading system for microgrids utilizing blockchain technology and a distributed coalition formation method. The system makes it possible for microgrids to band together to trade electricity. According to the authors, this system can increase the microgrids' energy trading's effectiveness and dependability.

However, most of the above studies have limitations which include its emphasis on modelling the suggested approach rather than actually putting it into practice. The studies, however, are also constrained to a small scale, and additional investigation is required to assess the scalability and robustness of the suggested approach. It is quite challenging to determine the viability and scalability of the suggested solutions because some studies do not provide enough information on the testbeds and simulations used to examine the suggested methods. The lack of testing and application in the actual world is one of the weaknesses, and additional research is required to examine the scalability and potential difficulties of the suggested methods.

Based on the studies done above, it can be inferred that blockchain technology has the potential to facilitate peer-to-peer energy trade in microgrid situations. Using blockchain technology can provide a safe, transparent, and decentralized energy trading platform that enables customers to generate and consume their own energy, as well as sell excess energy to other consumers within the microgrid (see Table 8).

4.1.5. BC in smart grid

A P2P energy trading mechanism based on blockchain and machine learning for sustainable electrical power supply in smart grids is presented in Jamil et al. (2021). The authors propose using machine learning to optimize energy use, and blockchain technology to enable safe and open P2P energy trading. A data-driven method for blockchain-based smart grid systems is presented in Zeng et al. (2021). The authors suggest utilizing blockchain technology to control the smart grid's data coordination and flow, as well as to guarantee data security and privacy. Additionally, they suggest applying machine learning algorithms to examine the data and come to systemic judgements. A directed acyclic graph (DAG) based distributed ledger for low-latency smart grid network is proposed in Park and Kim (2019). The authors contend that because of its low latency, high scalability, and affordable characteristics, DAG is a better data format than blockchain for smart grid networks. A blockchain-based uniform price double auction system for the energy markets is suggested in Foti and Vavalis (2019). The authors contend that by ensuring the appropriate price signals are communicated to market participants, their suggested approach can increase the effectiveness of the energy markets.

A study on the application of blockchain technology in smart grid auctions to optimize energy trading is detailed in Hassan et al. (2022). The authors provide a framework for blockchain-based smart grid auctions with the goal of increasing energy trading effectiveness and lowering the negative environmental effects of the electricity industry. Through simulation, they put their framework to the test and demonstrate how it can boost energy trading effectiveness while lowering the sector's environmental impact.

Kumari and Tanwar (2022) describes a reinforcement learning-based scheme for secure demand response in smart grid systems. The proposed plan makes use of a blockchain infrastructure to enable safe data exchange between utility companies and their customers. One of the study's drawbacks is that it only takes into account the interactions between a single agent in a reinforcement learning framework. A study proposed by Kavousi-Fard et al. (2021), describes such a market for interconnected microgrids and smart grids. The study however, only takes the economic element of the proposed market into account; technological or regulatory aspects are left out. A privacy-preserving system for smart grid customers using blockchain is presented in the Samuel and Javaid (2021a). The suggested system, known as GarliChain, combines blockchain technology and genetic algorithms to give users of smart grids anonymity and security.

The article by Van Cutsem et al. (2020) proposed an approach that makes use of a blockchain to enable safe and transparent communication between the buildings in the neighbourhood, enabling them to efficiently share and exchange energy. A secure private blockchain-based solution for distributed energy trading is suggested in the study by Dorri et al. (2019). Finally, a blockchain-based design for a reliable smart grid is suggested in Li et al. (2019b).

All of the solutions proposed by the researchers are intended to protect the privacy and security of energy transactions, enhancing energy efficiency, and facilitate the adoption of renewable energy sources. To assure the accuracy and transparency

Table 8
Summary of articles related to blockchain in microgrids based on our survey.

No	Article	Purpose of BC	Type	Platform	Consensus algorithm	Method
1.	Coll-Mayor and Noholt (2019)	Secure communication and autonomous transaction	Public	Ethereum	N/A	Experimental
2.	Xu et al. (2019)	Secure, transparent and efficient energy trading	N/A	N/A	BFT	Simulation
3.	Hamouda et al. (2021)	Transparent, secure, efficient and automated trading process	Public	Ethereum	N/A	Simulation
4.	Dabbaghjamanesh et al. (2021)	Operating cost reduction	Public	Ethereum	BFT	Simulation
5.	Ledwaba et al. (2021)	Efficient energy transactions and reduce the need for central authorities	Public	Ethereum	PBFT	Simulation
6.	Tsao et al. (2021)	Effectiveness of the system	Public	Ethereum	PoA	Simulation
7.	Zhang et al. (2021)	Secure, transparent, and tamper-proof transactions	N/A	N/A	N/A	Simulation
8.	Šarac et al. (2021)	Secure communication and prevent cyber attack	N/A	N/A	N/A	Simulation
9.	Vieira and Zhang (2021)	Decentralized and autonomous trading	N/A	N/A	N/A	Simulation
10.	Tsao and Van Thanh (2021)	Efficiency of the system	N/A	N/A	N/A	Theoretical
11.	Yang et al. (2021)	Security and reliability	Consortium	N/A	PoS	Theoretical
12.	Mengelkamp et al. (2018)	P2P energy trading	N/A	N/A	N/A	Case Study
13.	van Leeuwen et al. (2020)	P2P energy trading and reduce energy cost	Public	Ethereum	N/A	Simulation
14.	Li et al. (2018b)	Decentralized transactive energy management system	N/A	N/A	N/A	Simulation
15.	Li et al. (2019a)	Reducing energy costs	N/A	N/A	N/A	Simulation
16.	El-Baz et al. (2019)	P2P energy trading and reducing energy costs	N/A	N/A	N/A	Simulation
17.	Li et al. (2019c)	P2P trading, and provide a transparent and trustworthy platform for energy transactions	N/A	N/A	N/A	Simulation
18.	Thakur and Breslin (2018)	Ensure secure and automated payment settlement	N/A	N/A	N/A	Simulation

of transactions, these blockchain-based solutions usually employ consensus processes and smart contracts. In addition, the integration of edge computing and blockchain technology is on the rise, since it may improve the speed and efficiency of energy trading and sharing in the smart grid ecosystem.

While these studies offered suggested remedy based on simulation, they have not been proven to work in the actual world. The studies have some limitations, such as the fact that it is merely a simulation and does not account for the real-world difficulties in putting the recommended method into practice. Additionally, the proposed solution's security and scalability have not been thoroughly examined. Therefore, more investigation is required to validate the suggested framework in a real-world environment (see Table 9).

4.1.6. BC in distributed renewable energy

The design and management of a distributed hybrid energy system utilizing smart contracts and blockchain technology are covered in the work by Li et al. (2019c). The system's goal is to promote the integration of renewable energy sources while optimizing energy generation and consumption in a dispersed setting. The authors suggest an energy trading system based on smart contracts that enables real-time energy trading between producers and consumers. A blockchain-based energy management module is also part of the system, which makes it easier to track and control energy production and consumption. The research gives a thorough explanation of how the system was designed and put into operation, including how smart contracts were used to make energy trading easier and how blockchain technology was incorporated to guarantee safe and open energy management. The study does, however, have certain drawbacks. Firstly, the suggested system is not experimentally validated; instead, the study concentrates on the theoretical component of the system. Second, the study does not take into account the suggested system's scalability or how it would function in a large-scale implementation. Finally, the research makes no mention of the proposed system's economic viability or how it may affect energy pricing for both consumers and producers.

A study by Kwak et al. (2022) makes a platform suggestion for solar energy generation and trading in edge-based IoT systems utilizing blockchain technology. The platform is evaluated by the authors using actual data after they have given an overview of its design and implementation. In addition, Che et al. (2019) proposed a distributed energy trade authentication system based on a consortium blockchain, which describes such a mechanism. The proposed method is thoroughly explained by the authors, who then use actual data to assess it. The lack of a thorough explanation of the consensus process and the necessity for additional testing and evaluation of the suggested mechanism in practical situations are some of this research's drawbacks (see Table 10).

4.1.7. BC in energy management

A research of privacy-preserving transactive energy management for IoT-aided smart houses via blockchain is presented

Table 9
Summary of articles related to blockchain in smart grid based on our survey.

No	Article	Purpose of BC	Type	Platform	Consensus algorithm	Method
1.	Jamil et al. (2021)	Secure and transparent energy transactions	N/A	N/A	N/A	Simulation
2.	Zeng et al. (2021)	Efficient, secure, and privacy of energy management	N/A	N/A	N/A	Simulation
3.	Hassan et al. (2022)	Fair and efficient auction	N/A	Ethereum	N/A	Simulation
4.	Kumari and Tanwar (2022)	Secure communication	N/A	N/A	N/A	Simulation
5.	Kavousi-Fard et al. (2021)	Effective and autonomous, secure peer-to-peer energy market	N/A	N/A	DPoS	Simulation
6.	Samuel and Javaid (2021a)	Privacy-preserving and secure transactions	N/A	N/A	N/A	Simulation
7.	Van Cutsem et al. (2020)	Secure, transparent, immutable transactions and decentralized and autonomous decision-making	N/A	N/A	N/A	Simulation
8.	Dorri et al. (2019)	Secure and private distributed energy trading	N/A	Ethereum	PoS	Conceptual
9.	Li et al. (2019b)	Scalability and security	N/A	N/A	N/A	Conceptual
10.	Park and Kim (2019)	Low-latency and high-throughput	N/A	N/A	N/A	Simulation
11.	Foti and Vavalis (2019)	Efficient, transparent, secure and automated auction process	N/A	N/A	N/A	Simulation

Table 10
Summary of articles related to blockchain in distributed renewable energy based on our survey.

No	Article	Purpose of BC	Type	Platform	Consensus algorithm	Method
1.	Li et al. (2019c)	Efficient and secure distributed hybrid energy system	N/A	Ethereum	N/A	Simulation
2.	Kwak et al. (2022)	Automate transactions and ensure secure and transparent energy trading	N/A	N/A	N/A	Experimental
3.	Che et al. (2019)	Secure, transparent, and traceable energy transactions	Consortium	N/A	N/A	Experimental

Table 11
Summary of articles related to blockchain in energy management based on our survey.

No	Article	Purpose of BC	Type	Platform	Consensus algorithm	Method
1.	Yang and Wang (2021a)	Privacy-preserving	N/A	N/A	N/A	Simulation
2.	Mathew et al. (2022)	P2P trading	N/A	N/A	N/A	Simulation
3.	Afzal et al. (2020)	Secure and transparent transactions, distributed consensus mechanism	N/A	N/A	N/A	Simulation

in Yang and Wang (2021a). The authors provided a privacy-preserving approach for a blockchain-based transactive energy management system for smart homes. The system attempts to maintain energy management and trade while preserving the privacy of the consumers' energy consumption data. The authors in Mathew et al. (2022) presented a study of a blockchain-based decentralized power management solution for home distributed generation within a virtual power plant. A blockchain-based approach is suggested by the authors to enable safe and open power management in a virtual power plant. The system facilitates P2P energy trading and allows for the effective management of dispersed energy resources. Finally, the authors in Afzal et al. (2020) suggested a blockchain-based method for distributed demand side management in community energy systems with smart homes in their article. The authors outline a system architecture that makes use of blockchain technology to facilitate safe and open communication between smart houses and the neighbourhood energy grid. Real-time monitoring of energy use and dynamic pricing are also made possible by the system. All of these studies have limitations that include the absence of a thorough evaluation of the suggested system in actual use (see Table 11).

4.1.8. BC in demand side management

The application of blockchain technology to enhance energy demand side management in microgrid networks is covered in Noor et al. (2018a). The authors suggest a decentralized, blockchain-based strategy that permits secure and effective energy trade between microgrid participants. The suggested method is tested through simulation, and the findings indicate that, when compared to conventional centralized systems, the blockchain-based system can significantly cut energy expenditures and boost energy efficiency. Nonetheless, one of the study limitations is that the suggested solution is only assessed through simulation, not through actual deployment. The authors also point out that when the volume of transactions rises, scalability of the suggested system is an issue (see Table 12).

5. Blockchain-based implementation in energy systems around the world

There are more projects that are being developed and tested in various countries around the world. These are only a few instances of the practical projects that have been executed using blockchain-based energy systems. Some examples include:

Table 12
Summary of articles related to blockchain in demand side management based on the survey.

No	Article	Purpose of BC	Type	Platform	Consensus algorithm	Method
1.	Noor et al. (2018b,a)	Efficient, transparent, and secure Energy DSM in microgrids.	N/A	Ethereum	PoA	Simulation

- Brooklyn Microgrid: This initiative, carried out by LO3 Electricity, enables people of Brooklyn, New York, to exchange energy utilizing blockchain technology. As a result of the system's P2P energy trading capabilities, residents can obtain energy from their neighbours rather than from centralized utilities (Mengelkamp et al., 2018).
- Exergy: The goal of this project, which was created by the Australian start-up Power Ledger, is to establish a decentralized energy market that will allow customers to exchange extra energy among themselves. The platform makes use of blockchain technology to monitor the movement of energy and guarantee the accuracy of transactions (LO3 Energy, 2017).
- Enerchain: Using blockchain technology, this German concept aims to build a decentralized energy trading platform that enables direct energy trades between customers and producers (Home, 2023).
- LO3 Energy's TransActive Grid project intends to build a blockchain-based platform for the administration of distributed energy resources. The software enables users to control their energy usage in real-time and purchase and sell energy among themselves (The Future of Energy, 2023).
- PowerPeer: Developed by the Dutch start-up Powerpeers, this project attempts to build a P2P energy trading platform that enables customers to resell extra energy to the grid. Blockchain technology is used by the platform to track the flow of energy and ensure the integrity of the transactions (Powerpeers, 2023).
- Sun Exchange: Developed by the start-up of the same name, this initiative seeks to provide a blockchain-based platform for the financing and administration of solar energy projects. The platform enables investors to buy solar cells and partake in the energy those cells produce (Earn with Purpose, 2023).
- The project, called Grid Singularity, attempts to develop a blockchain-based platform for the administration of energy infrastructure. The platform will make it possible to incorporate renewable energy sources like solar and wind power and will let users control their energy consumption in real time (Grid Singularity, 2023).
- Power Ledger: This project uses blockchain technology to develop a decentralized energy trading platform that enables direct energy trades between customers and producers (Power Ledger Whitepaper, 2023).
- This project, called Energi Mine, attempts to build a blockchain-based platform for the administration of energy systems. The platform will make it possible to incorporate renewable energy sources like solar and wind power and will let users control their energy consumption in real time (Energi Mine Launches Blockchain, 2023).

In conclusion, the management and operation of energy systems could be completely transformed by blockchain technology. Blockchain technology is being used in a number of real-world projects that allow for the development of decentralized energy markets, P2P energy trade, and the incorporation of renewable energy sources. These initiatives could lower consumer costs, stimulate the use of renewable energy sources, and improve the efficiency and dependability of energy systems. To fully exploit the potential of blockchain technology in the energy industry, it is crucial to keep in mind that these initiatives are still in the early phases and that additional research and development are necessary.

6. Issues and upcoming trends

Blockchain initiatives and studies efforts presented in this article demonstrate that blockchains are a viable solution for a variety of services in the energy sector. The interest of investors and the significant involvement of well-known utilities and energy companies in DLT efforts show the significant potential of this technological advancement for the power sector. Though, the genuine, long-term benefit needs to be proven, particularly as the majority of efforts have only used the technologies in very small-scale works which are currently at the initial phases of development.

Since blockchain technology is still in its early stages, there are a number of issues that must be resolved before it can be completely used in the energy sector. To ensure that blockchain-based energy systems can manage significant volumes of data and transactions in real-time and maintain the security of the system against malicious assaults, concerns relating to scalability, security, and interoperability need to be incorporated.

The scalability, speed, and security needed for such suggested studies must first be made evident by blockchain technology. The development of distributed consensus algorithms, that is essential in fulfilling such objectives, is currently in progress, but there are still many trade-offs to be made before a complete solution can be found. On the other hand, PoW algorithms are slow and consume considerable amount of energy despite being more developed and secure. As a result, PoS systems that seem to be speedier, more energy-efficient, and scalable are becoming more popular among blockchain developers. Techniques that enable parallel processing, such as "partitioning", are among other intriguing possibilities. These solutions might, however, frequently come at the sacrifice of security and decentralization. Without a solid long-term view on the benefits and drawbacks that every strategy has to offer, early users of blockchain technology encounter the issue of choosing the best consensus method and system design. In addition, suitable consensus method should be selected and developed in order to prevent incurring unnecessary costs during implementation.

The implementation of blockchain technology to the power sector additional issues like regulation and standardization needs further attention. The implementation of blockchain technology in the highly regulated energy sector lacks defined guidelines and standards. Developers and businesses find it challenging to verify that their solutions are compatible with current systems and to understand how to adhere to existing rules as a result. Besides, the energy industry is quite complicated and has a wide range of participants, such as utilities, generators, and consumers. Energy systems built on blockchains must be able to smoothly interact with existing systems and allow for participation from all participants. Moreover, implementing blockchain technology in the energy sector has the potential to be expensive, especially in the beginning. The existing blockchain platforms have significant transaction costs as compared to traditional information technology (IT)-based trading systems. Small and medium-sized firms and organizations can be discouraged from implementing the technology and will be unable to participate in decentralized energy market due as a result.

Furthermore, appropriate design and construction of smart contracts in the trading process should also be focused on enhancing the distributed market system so that it can carry out all of the functions of a traditional marketplace. It must be noted, however, that using a smart contract in an energy project does not automatically make the project "intelligent". Machine learning techniques for effective use of data sources and control, energy systems/smart grid methods for considering local imbalances, voltage excursions, power quality issues, and network management, and automated negotiation and smart market techniques for effective trading and clearing are all still needed in such systems. Instead of the actual smart contract implementation, these other areas frequently drive innovation. Nonetheless, when correctly implemented and combined smart contracts have the potential to be a very robust technology that might enable completely decentralized and transactive energy systems in the long run when combined with other technologies like Artificial Intelligence (AI).

These are some of the key obstacles that must be ironed out for blockchain technology to be successfully implemented in the energy sector. In order to develop solutions that are both technically sound and compliant with current regulations, industry players, policymakers, and researchers will need to work together. By addressing these challenges, blockchain technology has the potential to revolutionize the way energy systems are managed and operated, increasing the efficiency and reliability of energy systems, reducing costs for consumers, and promoting the use of renewable energy sources.

7. Conclusions

There is an overwhelming interest recently in employing Blockchain (BC) technologies in secure data transmission and decentralization. This paper's main contribution is to keep the reader abreast of the latest and most recent advances in Blockchain applications in electric energy systems in general, as well as to highlight the problems and prospects of Blockchain technology aspects in Demand Response, in particular. The application of Blockchain technologies to the energy sector is exhibiting promising outcomes. A total of 136 publications were evaluated and assessed in terms of BC research trends in Energy Systems, notably in Demand Response, as well as the types of BC employed, and platforms used. The majority of the studies have concluded that the system's security and efficacy have improved. Nevertheless, the data extraction technique may be one of this review's imperfections. Although the data gathering process adopted herein is acceptable, yet it is limited to responding to just a few RQs. As a result, there is a potential that some crucial information may have been, unintentionally, overlooked in this evaluation. Finally, by synthesizing the obtained data, new study fields have been uncovered. Future demand response studies in BC technologies must address the following issues:

i. There has not been a full investigation of BC-based demand response. It is vital to assess their performance either in a lab setting or via simulation as well as a realizing it in a real-world environment.
ii. Another suggestion is to include AI into smart contracts to facilitate decision-making throughout the trading process. Self-executing contracts known as smart contracts make it possible to buy and sell energy without relying on intermediaries. However, these smart contracts use pre-defined rules and parameters to guide their decision-making. To enable dynamic decision making based on real-time data, AI-based decision making can be embedded into the smart contract. Energy trading will become more effective and optimal as a result.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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