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A systematic review of blockchain for energy applications

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ABSTRACT

The increasing penetration of distributed energy resources and the growing electrification of end-use consumption complicate energy management. Current strategies, which rely on centralized systems for peer-to-peer interactions, face issues of scalability, security, traceability, single points of failure, and privacy. Blockchain, with its decentralized nature, offers immutability, transparency, automation, and scalability as potential solutions. However, practical implementation remains challenging. This study systematically reviews 156 studies published since 2021 using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology to explore these limitations. Results highlight that selecting the appropriate blockchain platform and consensus mechanism is crucial. Observations show that 42% of studies proposing new consensus methods and 46% developing new platforms or using simulations struggle with practical implementation. In contrast, leveraging existing standard blockchain platforms and consensus mechanisms enhances practicality and scalability. Additionally, seamless interoperability with Internet of Things (IoT) remains a significant challenge due to the high costs associated with the few platforms that offer this feature. Standardization of blockchain methodology, interoperability, performance measurement, and governance remains a major issue despite several parallel efforts by multiple stakeholders, including blockchain platform providers. Consolidation of these efforts into a common framework, together with the utilization of existing blockchain components, is key to resolving current limitations and fostering wider adoption. Among the various blockchain components suited for different applications, this study provides key criteria for selection, guiding the development of practical and scalable blockchain-based energy applications.

List of abbreviations

BFT	Byzantine Fault Tolerance
CFT	Crash Fault Tolerance
EU	European Union
EV	Electric Vehicle
EVM	Ethereum Virtual Machine
IoT	Internet of Things
PoA	Proof of Authority
PoW	Proof of Work
P2P	Peer-to-Peer
PoS	Proof of Stake
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RES	Renewable Energy Source
TPS	Transactions Per Second
ZKP	Zero Knowledge Proof

Introduction

Growing challenges with centralized management

Advancements in Information and Communication Technology (ICT), especially the growth of Internet of Things (IoT) technology in smart grids, coupled with initiatives to mitigate climate change, have continued to stimulate energy distributed generation at the consumer level using renewable energy sources (RES). As the number of active consumers participating in generation increases, the power system

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dynamics in terms of management and controls become more challenging. For example, the study presented in [1] reports that with consumers participating in renewable generation, power and data exchanges become bi-directional, which tremendously increases the amount of data available to be processed. Moreover, according to [2], some RES like wind and solar are non-dispatchable, meaning they cannot be controlled or scheduled to generate energy on demand. Such RES potentially increase the stress on the management and control of networks, as they may cause complicated situations such as local grid congestion.

Attempts to address the challenges of smart grids with high penetration of generation using renewable sources are leading to several research efforts exploring demand-side management techniques. One such technique is demand flexibility management, which adapts demand response operations of end-user appliances to patterns in renewable generation and energy storage. According to [3] and [4], unfortunately, some of these techniques themselves pose challenges as they involve processes that require substantial computing resources to ensure secure data exchange for management and control purposes. These challenges are exacerbated by scalability problems associated with centralized coordination of dispersed and distributed resources. The urgency to solve these scalability problems is currently driving the exploration of decentralized architectures like blockchain in several research studies [5,6].

Brief introduction to blockchain fundamentals

Blockchain is a decentralized technology of distributed data storage ledgers across nodes with a peer-to-peer (P2P) system for data validation, integrity, and verification [7]. A distributed ledger is a system of validated data of digital assets grouped into blocks and connected using hashed pointers, making them difficult to alter [8]. Data validation is performed on new data blocks through a consensus mechanism involving a rigorous proof protocol, and then broadcasted to all nodes in the network. Several consensus mechanisms exist, but Proof of Work (PoW), which involves solving an expensive and energy-intensive computational puzzle, is the most widely used [5]. Proof of Stake (PoS) is another consensus mechanism that uses an algorithm to randomly select validator nodes based on staked ownership [9]. The Byzantine Fault Tolerant (BFT) consensus mechanism is maturing and uses a leader-follower system to select a leader node that can add new blocks, requiring validation from two-thirds of the follower nodes [5].

A blockchain network can be provisioned to be permissioned, where actions can only be performed by authorized participant nodes, or permissionless, where no authorization is required. Additionally, the distributed ledger of the blockchain can operate in a private mode, where only designated nodes participate in consensus, or in a public mode, where any node can participate.

Blockchain technology offers transparency through its system of distributed ledgers and trust due to its immutable data blocks [10,11]. The immutability of blockchain transactions, combined with transparency and a distributed ledger, are key features leveraged in many applications and use-cases. While primitive blockchain focused on transactions, the advent of Blockchain 2.0 introduced smart contracts, which offer much more. A smart contract is an autonomous and self-executing script deployed on the blockchain to automate transactions [12]. It resides in the distributed ledger of every node in a blockchain network, from where it can automatically disseminate, verify, and execute transaction contracts in a sequential and informational manner. Smart contracts can automate complex transaction processes using a series of simple rules. Their key attributes are autonomy, self-execution, and decentralization [13]. These attributes enable blockchain to automate systems at scale.

Blockchain application and use-cases

Blockchain has found application in many sectors. In the health sector, where privacy and security are top concerns, blockchain has been employed in authenticating access to health records, securing IoT devices used in remote monitoring of vulnerable people, and in the verification of prescriptions [14,15]. For example, blockchain can store managed policies with encryption algorithms to grant authorization, preventing unauthorised access and corruption of medical data. Additionally, blockchain provides a secure channel and storage for data generated from IoT devices used for monitoring patients. For instance, [14] reviewed the use of blockchain to secure IoT data for monitoring the compliance of the elderly with prescriptions, monitoring the behavioral patterns of people with specific needs to promptly detect anomalies, and providing personalized healthcare from multiple sources of expert advice.

Blockchain has also been applied in life-cycle analysis (LCA) of various products, establishing a decentralized platform for tracking the recycling and disposal of waste materials to ensure transparency and compliance with regulations. The authors in [16] and [17] reviewed various applications of blockchain for waste management, employing different components of the technology. Blockchain-based tracking systems in these applications can guarantee the origin of materials and transparently record performance metrics. Blockchain also has applications in cybersecurity for secure device authentication using distributed and secured data exchanges, as described in [18]. Authors in [19] also employed blockchain in logistics and supply chain management for product certification and tracing the origin of materials. Government bodies are adopting blockchain for security and transparency, such as for identity management using cryptographic signatures and distributed storage to reduce identity theft and privacy risks [20]. Other governance applications include electronic voting transparency and enhancing public trust in tender evaluations for projects [21].

In the energy sector, blockchain has found significant relevance. Many use cases have been recorded in the last five years as companies leverage the technology to drive innovation [22-24]. According to [22], investment in blockchain and other energy sector digitization projects in 2017 was 40% higher than the overall investment in gas-fired generation in the same year. Initially, most blockchain use cases were for peer-to-peer (P2P) energy trading [25]. However, the technology is now being used in other areas such as managing energy assets (end-user appliances, electric vehicles, RES) in smart grids, guaranteeing energy origin, managing IoTs, carbon trading, waste management, LCA, and energy project financing [11,15,17,25,26]. Blockchain applications have the potential to increase transparency, reduce operational and investment costs, secure data transmission, enhance privacy, increase energy savings, reduce emissions, and improve trust.

Blockchain for energy management has been demonstrated for grouping, monitoring, and control. For example, a blockchain-based system named SynergyChain was developed to improve energy trading among prosumers [27]. It uses smart contracts and reinforcement learning (RL) to create geographically distributed virtual groups of prosumers for efficient matching with consumers. Another system developed in [28] ensures a secure and transparent energy trading platform between agents (prosumers, consumers, and grid operators) using a decentralized optimization algorithm for matching prosumers and consumers, with a central control from the grid operator to track available energy. The system employs a proof of location consensus algorithm to group end users based on proximity and allows agents to select trading partners.

In [29], a blockchain-based system was developed to facilitate high-throughput energy transactions efficiently. It implements a bidding system combining blockchain and off-chain optimization models using Alternating Direction Method of Multipliers and Fast Iterative Shrinkage Thresholding Algorithms, reducing the amount of private data transferred to the public blockchain to protect participants' privacy. Authors in [30] developed a blockchain-based system for electric vehicle (EV) energy trading in day-ahead and real-time markets using a double auction mechanism for matching EVs and a charging token system for value exchange. In [31], a framework using blockchain was proposed to improve trust and cooperation among partner stakeholders participating in the renewable energy supply chain. The system enabled data sharing and decision-making under uncertainties using fuzzy logic techniques and inter-criteria correlation. In [32], blockchain was employed in the Internet of Energy with limited available computing resources for processing sensor data. The architecture allowed for the implementation of algorithms for the efficient scheduling of sensor data.

Several pilot projects have advanced significantly, exploring blockchain for energy applications. Examples include PowerLedger on the Solana blockchain, deployed in Australia for local trading of renewable energy and now with partner clients across 12 countries [4,24]; the Sunchain Hyperledger implemented in France for solar energy trading [33]; and the Power-ID platform deployed in Switzerland for offsetting carbon emissions [26,34]. Some blockchain projects are in the early stages of market adoption, such as Quorum by Ethereum, an open-source blockchain for security management [8]; Avalanche, with fast smart contracts for developing distributed apps [35]; and Energy Web Chain (EWC), which connects grid operators, energy consumers, and energy assets [36,37]. Some other initiatives include EFFORCE, which provides a blockchain-based platform for projects aimed at promoting energy efficiency and mitigating climate change by making these projects accessible to funding and creating business value [38,39]. Another project is Block-Z, a blockchain platform for energy trading that introduces a token system to facilitate transactions for carbon-free energy matching [40].

Blockchain challenges overview

Despite extensive research and significant investments, the use of blockchain for energy and other applications still faces several setbacks. Many of these setbacks are related to technological concerns and regulatory policies [41,42]. On the technology side, there are numerous concerns around the cost of implementation [11]. Many blockchain networks still employ the Proof of Work (PoW) consensus mechanism. Unfortunately, PoW relies on substantial computing power [5], which increases with the number of transactions, driving up costs. Additionally, the enormous data generated by IoT devices exponentially increases the storage needs of the blockchain. This issue is further complicated by the requirement for every blockchain node to maintain a full copy of all transactions.

Scalability is another significant concern for many blockchain implementations. The scalability of any implementation is typically influenced by the consensus mechanisms utilized. For example, Bitcoin, the largest blockchain network for cryptocurrency using PoW, can only process between 7 and 10 transactions per second [43]. Another large blockchain network, Ethereum, can process between 15 and 30 transactions per second using PoW. Currently, with PoS, Ethereum supports between 10 and 20 transactions per second, with the prospect of reaching 100,000 transactions per second using a technique called sharding, which is still under development. Until Ethereum and other networks achieve the ability to process thousands of transactions per second, their current capacities will remain major limitations for applications requiring the processing of several hundred transactions in a short time. Standardization and interoperability with legacy systems are also technical limitations that have been identified [15,44,45].

Even if technical challenges are resolved, the lack of substantial governmental policies and frameworks will still pose a major hindrance. In the area of policy, [22,42,46] and [47] emphasize the need for enabling policy frameworks, local market structures, taxation, and other regulatory actions by the government to foster blockchain technology adoption. Governments of many countries are now beginning to address this challenge. For example, in the health sector, the Russian government has officially signed into law the use of blockchain for managing health records [15]. Similarly, the United States has constituted blockchain initiatives for authenticating and managing access to patient records [15]. The Netherlands has also initiated a blockchain project for the procurement of medical equipment. In the energy sector, China has developed an inclusive 2025 strategic plan that encourages the development of emerging technologies like blockchain [48]. In the United States, there are numerous government fundings and policy frameworks to foster the adoption of blockchain for energy applications [48,49]. One such initiative is the blockchain project in the state of Illinois to create a marketplace for trading carbon credits [15].

Previous review works

The use of blockchain for energy applications is still an emerging concept despite extensive research and numerous pilot projects. It has not yet been scaled for larger use due to unresolved technical concerns regarding scalability, efficiency, and standardization. Therefore, despite the existence of several publications that broadly identify these challenges, a detailed review is necessary to concisely identify current patterns, possible future trends, and limitations that have been stumbling blocks to wider adoption and application. Table 1 presents an analysis of some previous review studies.

In the review study by [50], the authors examined 783 publications on energy and blockchain between 2014 and 2020. The objective of the review was to understand blockchain evolution and areas of application. It indicates that there is a growing interest in developing countries in the application of blockchain for energy solutions and shows an increasing trend in the use of blockchain for energy applications, especially for catalyzing energy transition. However, the review is limited in scope as the application areas were drawn from a few identified pilot projects.

In another review study [47], the authors presented an overview of the fundamental principles of blockchain technology. Additionally, the publication traces the evolution of blockchain solutions for energy applications through business cases. The authors also reviewed 140 industrial reports from companies and research organizations to identify the potentials of blockchain, classifying them by use-cases, consensus approaches, and platforms. From the business use-cases, the authors concluded that despite the potential of blockchain and several business use-cases, significant barriers still need to be resolved for market adoption. Unfortunately, many of these potential business use-cases are still not implemented or have failed to scale.

The authors in [51] applied co-citation, exploratory factor, and social network analysis to summarize the main characteristics of 166 studies published until 2019. By using these data analysis approaches, the review identified broader research focus areas encountered in the papers applying blockchain for energy solutions, including their interdependencies. However, the scope of the review was limited to macro-level pattern recognition of blockchain application areas. In [52], the authors reviewed the potential of applying blockchain to solve problems in the Internet of Energy (IoE) domain. This review primarily focused on identifying the suitability of blockchain for the domain and the possible implications of not leveraging blockchain technology. In [53], the authors performed a review to identify causes of delayed progress in the widespread adoption of blockchain-based energy solutions from 89 academic publications between 2018 and 2022, 42 industrial reports, and 45 interviews with experts executing blockchain projects. This review grouped these causes into organizational, regulatory, and technological categories but focused mainly on the first two causes.

In [54], the review of studies published until 2021 focused specifically on architectural patterns in the use of blockchain combined with IoT for energy P2P trading enabled by smart contracts. In [55], the review examined the prospects of combining blockchain and machine learning for smart grids. The authors reviewed 100 publications focusing on security, energy trading, and demand management to highlight

Table 1
Comparison of previous review studies.

Author	Database	Start	End	Publications	Methodology	Scope	Key Outcomes
[50]	Scopus	2014	2020	783	Bibliometric Analysis	Pilot projects	Blockchain application areas
[47]	–	–	–	140	–	Business use-cases from industrial report	Blockchain application from projects business use-cases
[51]	Web of Science	–	2019	166	Data analyis (co-citation, exploratory factor and social network)	Research publications	Blockchain application pattern analysis
[52]	–	–	–	–	–	Pilot projects	Blockchain suitability and integration with Internet of Energy (IoE)
[53]	IEEE Xplore, Scopus, Science Direct, Taylor & Francis, and SAGE Journals	2018	2022	131 (excluding interviews)	Kitchenham's five-step approach, PRISMA	Research publications, Industrial report, Expert report	Blockchain application areas and challenges focusing on organizational and regulatory issues
[54]	IEEE Xplore, Scopus, Ebscohost, Science Direct, MDPI	–	2021	54	PRISMA	Research publications	Blockchain architectures with IoT for P2P energy trading
[55]	–	–	–	100	–	Research publications	Blockchain potentials with machine learning for Energy applications
[45]	Scopus, Web of Science, IEEE Xplore, ScienceDirect, Google Scholar	1997	2024	2000	PRISMA	Research Publications	Potentials of blockchains and challenges of quantum and digital twin
[38]	Web of Science	–	–	33	PRISMA	Review publications and application publications	Blockchain application, general evaluation guidelines, open issues

challenges in research and future directions regarding the integration of both technologies. It emphasized the need for more detailed studies to identify and resolve hindrances, including scalability issues, that are preventing the wider adoption of blockchain for energy solutions.

In [45], the authors reviewed 2000 studies to identify the potential of advanced technologies, including blockchain, AI, quantum computing, and digital twin technology, in achieving a net-zero future. Using the PRISMA protocol, the review highlights the need for more research to promote the adoption of these advanced technologies. It specifically focuses on identifying the challenges of implementing quantum computing and digital twin technology in the energy sector. Additionally, in the review study [38], the authors conducted a systematic review of other review papers on blockchain applications in smart grids. This review was guided by five questions to provide a high-level perspective on: the applications of blockchain, the role of blockchain in smart grids, guidelines for assessing the usefulness of blockchain solutions, the maturity of blockchain applications, and issues in blockchain application development.

Highlight of research relevance

Despite previous review papers, a research gap still exists in identifying the current limitations inhibiting the wider adoption of blockchain and suitable approaches for implementing blockchain-based energy solutions to overcome these limitations. In this regard, this research aims to carry out a systematic review of existing works applying blockchain for energy applications, addressing the limitations of previous review studies. Unlike [47], which focuses on business use-cases; [38] which performs and umbrella review of reviews; and [50,51] and [53], which identify the evolution of application areas from a perspective of potential opportunities, this review performs a detailed analysis of the methodologies of implementations of applications from research works to identify barriers.

Furthermore, unlike [47,52] and [55], this review applies a systematic review approach using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to provide a comprehensive overview of existing research publications. While [54] focused on the interaction between blockchain and IoT, and [55] on the interplay between blockchain and machine learning, this paper focuses on the general use of blockchain applications for energy. This review work identifies core technological barriers differently from [53], which focused on organizational and regulatory barriers. Unlike many previous review studies that draw main conclusions mainly from pilot projects, this review tends to have a wider coverage as it considers studies even in development stages but with actual implementations or simulations.

Additionally, besides including more recent studies, this work contributes a concise and detailed requirement checklist deduced from learnings in existing studies for making critical decisions, especially in the selection of appropriate components of the blockchain system and suitable approaches for implementation to build scalable and innovative solutions. The checklist will be an important component in developing a standardization approach, which is currently lacking in blockchain solution implementation for energy applications, hence bridging this research gap. The output will provide a clear path to overcoming existing barriers, useful for industry experts and future developments.

This paper is structured into four more sections. The second section briefly presents the systematic review objective, criteria for data extraction, and the process of data extraction following the PRISMA protocol methodology. In the third section, the data extracted from studies are presented and analyzed. In the fourth section, a checklist useful for selecting blockchain components is discussed based on the review outcome. In the fifth section, conclusions regarding the results and limitations of the review are briefly presented.

Methodology

Systematic review objectives

The overall objective of this review is to identify why many blockchain-based energy applications suffer from the lack of wider adoption by analyzing how research works are exploring the use of blockchain. The review uses key criteria to characterize research works in a bid to precisely understand the blockchain components employed and the rationale for their use, thereby identifying specific limitations. Specifically, the key objectives of this review are to:

- Understand the purpose(s) for using blockchain in energy applications.
- Extract the specification(s) of the blockchain employed in energy applications.
- Deduce possible rationale for the use of various components of the blockchain employed in energy applications from the alternatives available.

- Identify specific positive and negative trends in the development of energy applications.
- Identify current technical challenges and limitations.

Criteria selection

In line with the key objectives of the systematic review, a list of criteria was elicited as a common base point for data extraction. The process of elicitation involved an initial proposal of the criteria by the main reviewer (the first author), followed by deliberation with the entire 4-member review team. The final criteria selected upon reaching a consensus are as follows:

- Interest and Acceptance Across Countries: Using the number of studies from different countries as an indicator to identify countries with enabling policies that promote blockchain adoption.
- Consensus Mechanisms: Examining the consensus mechanisms employed in each study and the approach of usage to understand the blockchain specifications.
- Implementation Platform or Blockchain: Identifying the platforms or blockchains where solutions proposed in studies are tested to deduce the feasibility of such solutions.
- Blockchain Application: Analyzing the areas of use of blockchain in each study to provide pointers for the rationale behind the selection of blockchain components.
- Objective for Use of Blockchain: Understanding the primary specific feature of the blockchain that each study aims to take advantage of the most.

Selection methodology

For this review, the PRISMA 2020 protocol was employed [56,57]. This protocol provides guidance for reporting a review in a transparent and systematic manner. It comprises a categorized 27-item checklist with guidelines on steps to conduct the review, allowing for reproducibility. Full details about the protocol are described by [56]. The PRISMA protocol was selected for this research because it has been reported by a vast body of literature as being evidently viable, having a comprehensive evaluation list, applicable to several domains of research, endorsed by many journals, and enjoying continuous improvement [53,57,58].

For the review, the Scopus database was selected due to its proven efficacy in indexing and presenting research works from several high-impact journals relevant to the subject matter under review [13,59-61]. The initial query used for the search on the database consisted of the keywords “Energy” and “Blockchain”. However, considering that “Distributed Ledger” and “Digital Ledger” are synonymous terms often used in place of “Blockchain”, these words were also included. Consequently, the final query was “Energy” AND (“Blockchain” OR “Distributed Ledger” OR “Digital Ledger”).

The search on the Scopus database was conducted on October 15, 2023. Records considered were restricted to those published from 2021 onwards, as preliminary investigation indicated that viable publications utilizing blockchain for other applications in energy began to emerge following the introduction of smart contracts [13,22,62]. Furthermore, Ethereum, the largest reference platform, launched the Beacon chain in 2020 in preparation for its official launch of Blockchain 2.0 and migration to the PoS consensus [63]. This launch was a major catalyst

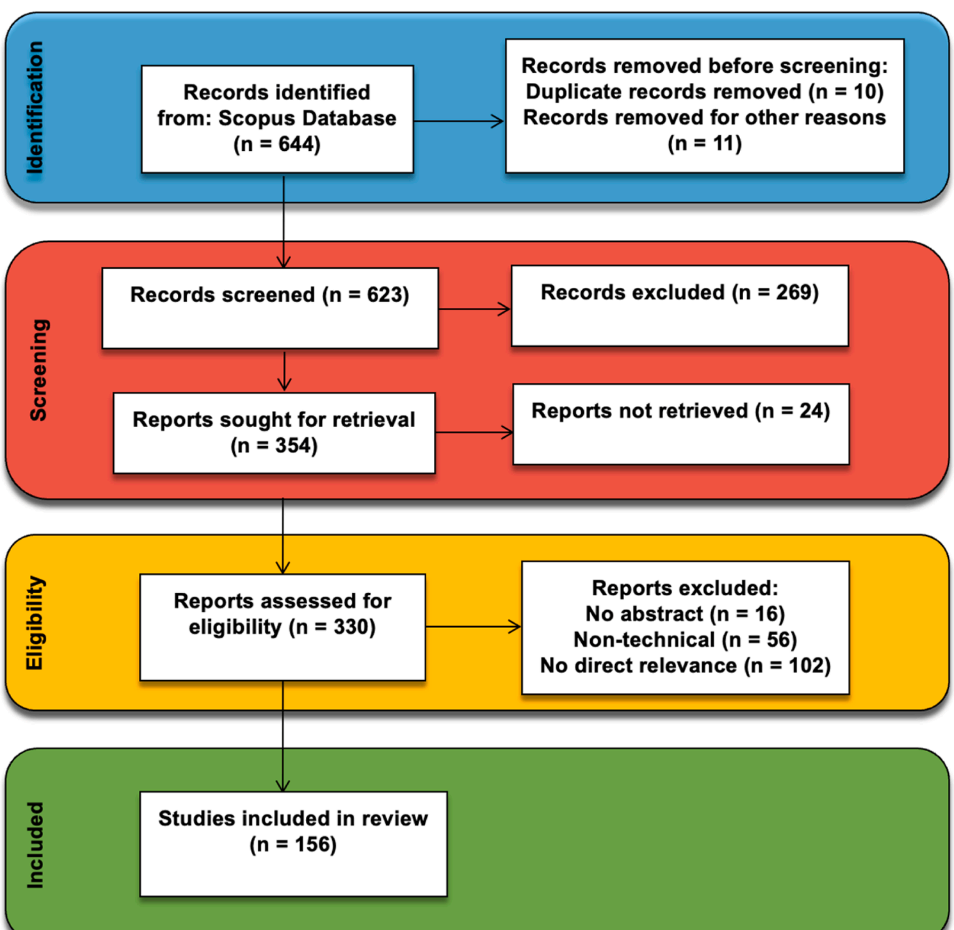

Fig. 1. Flowchart of systematic review process based on PRISMA protocol.

for widespread research into viable solutions in the subsequent years.

In Fig. 1, the block diagram of the review process with the number of publications (n) at each stage is presented. As shown in the figure, after the search using the query string explained earlier, 644 records were identified. From these records, 10 duplicate records were detected and removed. Similarly, 11 records in languages other than English were also removed, as English was the common language understood by the reviewers.

Following the identification of suitable records, 623 records remained and were screened. During the initial screening, 269 records with less than two (2) citations were removed. The remaining 354 records were then sought for retrieval, out of which 24 records could not be retrieved. These records were either inaccessible due to broken links, had been retracted, or required additional subscriptions outside of personal and institutional coverage.

The 330 reports retrieved were assessed for eligibility for inclusion in the review, but only 156 were considered eligible. The high number of 174 ineligible records was due to the broad initial search query on the database and few restrictions, which allowed for the inclusion of many publications not directly relevant to the review. Records in this category that were removed belonged to one or more of the following groups:

- Records focused only on improving the blockchain technology itself and not on its application. For example, records on improving encryption and consensus mechanisms of the blockchain.
- Records focusing mainly on non-technical implementation that are not of interest for the review. For example, records mainly on regulation, policy, business models, reviews, concepts, and surveys.
- Records applying blockchain to some energy-related operations but not of actual interest for the review. For example, records applying blockchain to manage computing infrastructures.
- Records without an abstract.

Results of systematic review

At the end of the exclusion process, 156 studies were selected for review. In the Appendix, the data extracted from each study using the criteria presented earlier is shown. In the following subsections, the results of the review are discussed in the same order of presentation. Thereafter, a discussion about the results is provided.

Interest and acceptance across countries

The exploration of blockchain for energy applications is rapidly gathering momentum across several continents. However, due to varying conditions, including government policies, energy situations, and technology maturity, the level of adoption of blockchain technology varies significantly across countries. In [47] and many other studies, the relevance of government policies and frameworks to drive blockchain adoption has been emphasized. Fig. 2 presents the distribution of countries of the studies included in this review. For each study, countries were categorized based on the institution of the first author.

As shown in Fig. 2, China has the highest number of studies, followed by India, the United States, Canada, and Australia in decreasing order. Due to its stable and favorable government policies, it is no surprise that China tops the list, following its 2025 strategic plan with mandates that clearly support innovation and experimentation using emerging

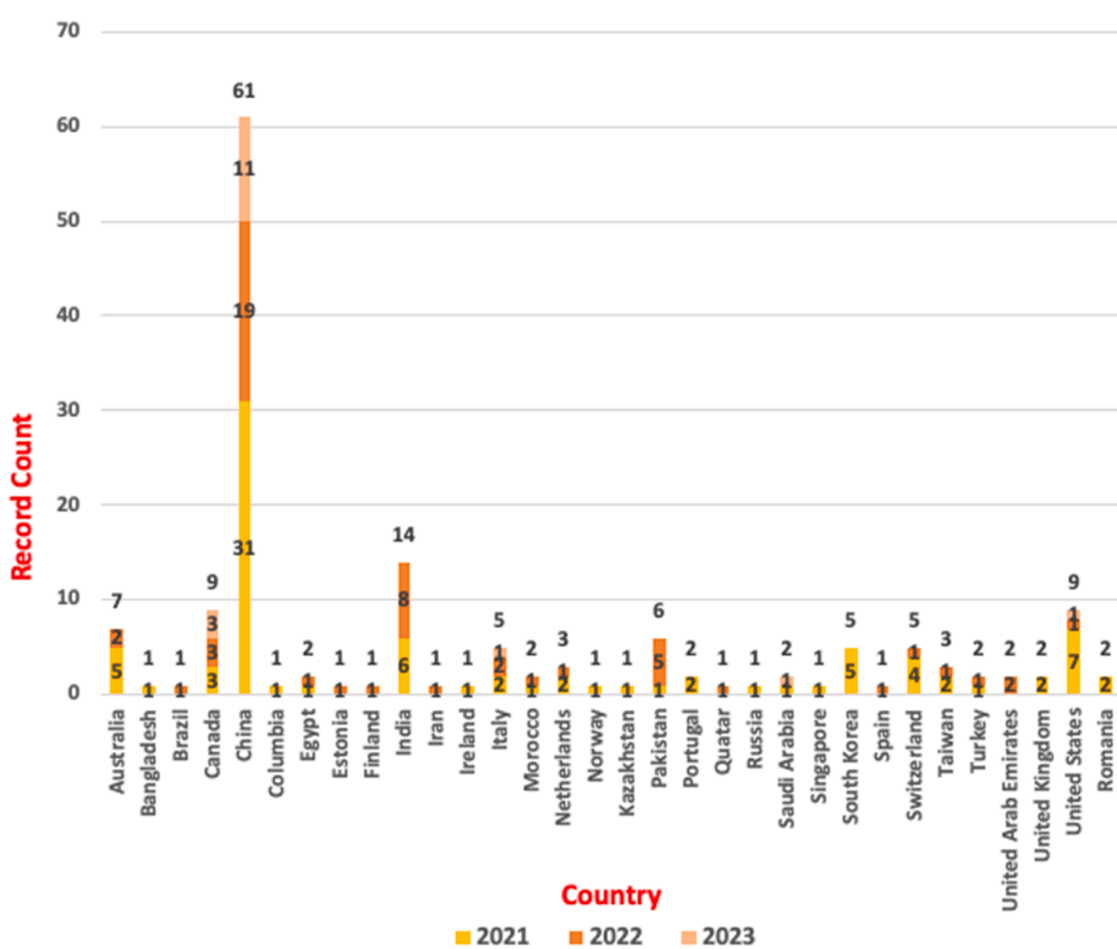

Fig. 2. Record distribution by of studies by country.

technologies like blockchain. Moreover, the country's 13th five-year plan for the electricity sector, which ended in 2020, encouraged distributed generation and self-consumption, paving the way for decentralized solutions like blockchain. In the case of India, even though its government, like other countries, frowns upon cryptocurrency, it has promoted blockchain technology for other uses. In Australia, the government developed a national roadmap for blockchain in 2021 and has continued to invest heavily in blockchain innovations [64].

In Europe, though few studies were encountered from individual member states, collectively as the European Union (EU), the records sum up to a significant value. The EU council operates a global policy across its member states, and most of the investments in blockchain research are through central funding like Horizon 2020 [65]. Moreover, the EU has had several policies since 2015 to support blockchain adoption [49]. It is striving to take the lead with its clear policies on blockchain strategy for security, identity, and interoperability. This strategy was expected to lead to the development of the European Blockchain Services Infrastructure in 2021 to pioneer several blockchain solutions and services.

Aside from government funding, blockchain research has received significant funding from venture capitalists at various levels. A report from [66] shows that blockchain companies received over 2.75 billion USD in investment funding in 2020, compared to 1.28 billion USD in 2017. North America, Asia, and Europe top the list of highest investments, which may account for the higher number of studies encountered from countries in these continents. Since 2022, studies from new countries absent in 2021 have emerged, possibly due to recovery from the COVID-19 pandemic. The pandemic period saw developing economies struggling to survive compared to developed economies that were better positioned to cope [67]. With COVID-19 now largely under control, activities are returning to normal in these countries, leading to higher participation in research and development.

However, compared to 2021, the number of studies in 2022 decreased, especially in developed countries, and declined further in 2023. Several reasons may account for this decline. One possible reason is the reduction of online transactions in the post-COVID-19 period compared to the surge during the pandemic, which recorded an increase in online transactions and remote activities [68]. This surge burdened existing cloud computing infrastructures, impacting the quality of some services. Many believed that these services were impacted due to inadequate preparedness and because of their central architecture, which failed to cope with the surge. Additionally, these centralized systems raised significant security and privacy concerns [69]. The increased research in vertical and horizontal scaling of cloud infrastructures using decentralized technologies like blockchain during this period has declined after the pandemic.

Another possible reason for the reduction in studies in 2022 is the collapse of the cryptocurrency market in mid-2022 [70]. Though the crypto market has always been volatile, the drastic drop in the valuation of crypto assets in 2022 had a long-lasting impact. The reduction in the value of Bitcoin from above 65,000 USD per BTC to less than 20,000 USD impacted the amount of investment funds available and reduced the hype of cryptocurrency [70], which had been a major advertising agent driving investments to blockchain-related research. The significant cybercrime during this period, resulting in the hacking of many cryptocurrency platforms, also caused a decline in investor confidence [71]. This led to the collapse of many startups and huge losses for many investors. Additionally, the forecasted recession of 2022 following the pandemic led to a general reduction in economic activities and financial investments [72].

Consensus mechanism

Several blockchain technology variants have continued to emerge since the advent of blockchain 2.0. These variants usually introduce their own consensus approaches with the promise of being better than existing ones. For example, a commonly employed consensus approach, Byzantine Fault Tolerance (BFT), particularly uses a leader-follower consensus rule that makes it adaptable to various use cases. Another similar consensus approach, Crash Fault Tolerance (CFT), also uses a leader-follower rule but with a simpler algorithm [73]. Newer consensus mechanisms like Proof of Authority (PoA) employ a limited set of trusted nodes to validate transactions in private blockchains. PoA uses a simple algorithm to select a leader node from the trusted set that generates new transaction blocks. As such, it can achieve high transaction throughput with minimal computing resources [74]. Avalanche is another new consensus mechanism that has begun to gain adoption following its release in the last quarter of 2020 [75]. The consensus is said to be highly scalable with high throughput. Unlike many other consensus mechanisms, it leverages multi-core processing of computing infrastructure to allow parallel processing of transactions [75].

Consensus is one of the core features of blockchain as it is the main determinant for scalability [11]. The table of the distribution of the consensus mechanisms employed by the studies reviewed is presented in Table 2. Consensus determines the rate at which transactions can be processed and hence is a fundamental requirement to guarantee efficiency in any blockchain-based solution.

Almost 60% of the studies encountered in this review adopted widely known consensus approaches, leveraging existing standards to bootstrap their solutions. However, the remaining studies, classified as "Custom", developed custom consensus methodologies. This category, which is the largest single group, accounts for over 40% of the total studies. Studies in this class have at least one of the following attributes:

- Developed or applied entirely new consensus algorithms not widely known.
- Utilized experimental setups to simulate consensus in a manner different from standardized approaches.
- Had no identifiable consensus approach because it was not stated or not deducible.

Developing a consensus approach is not an easy task as it involves implementing a consensus algorithm. A consensus algorithm must guarantee a solution that is timely, secure, and consumes minimal computing resources [9]. These criteria are only ascertained through rigorous processes, including demo simulations and real deployments. The consensus approaches developed by studies in the "Custom" group do not meet these criteria to guarantee the feasibility of scalable implementation. For example, in [76], a consortium blockchain framework with a custom proof-of-function consensus mechanism to audit the data sharing process for secure data sharing in smart grid was proposed. The framework, which utilizes four role-based entities, was simulated in a MATLAB environment. The implementation involves a series of iterations for authentication and an expensive audit process for verifying data authenticity. Deploying such a system for real applications directly is impractical or very costly.

Even worse are studies proposing frameworks but with inadequate details of implementation for evaluating performance and reproducibility. In this category, the authors in [77] proposed a blockchain-based system employing a mathematical model that uses quote prices and power demands to execute energy contracts for matching energy prosumers and consumers. However, the solution proposed was not demonstrated, nor was there a mention of a suitable blockchain platform for implementation.

Leveraging existing consensus standards is vital to improving the chances of developing feasible application solutions, as it allows researchers to focus on the application use-case. Unfortunately, the trend followed by many researchers has been otherwise, as deduced from this review. A chart representation of Table 2 is presented in Fig. 3. A year-on-year comparison of studies employing custom consensus mechanisms shows an increase from 39% in 2021 to 41% in 2022 and eventually to 59% in 2023, indicating a worsening situation. On the other hand, among studies that employed standardized consensus approaches, Proof

Table 2
Record distribution of studies by consensus mechanism.

Year/Consensus	Avalanche	BFT	CFT	Custom	PoA	PoS	PoW	Solo
2021		14	10	33	2	6	18	2
2022	1	7	6	22	1	1	16	
2023		5	1	10		1		
Total	1	26	17	65	3	8	34	2

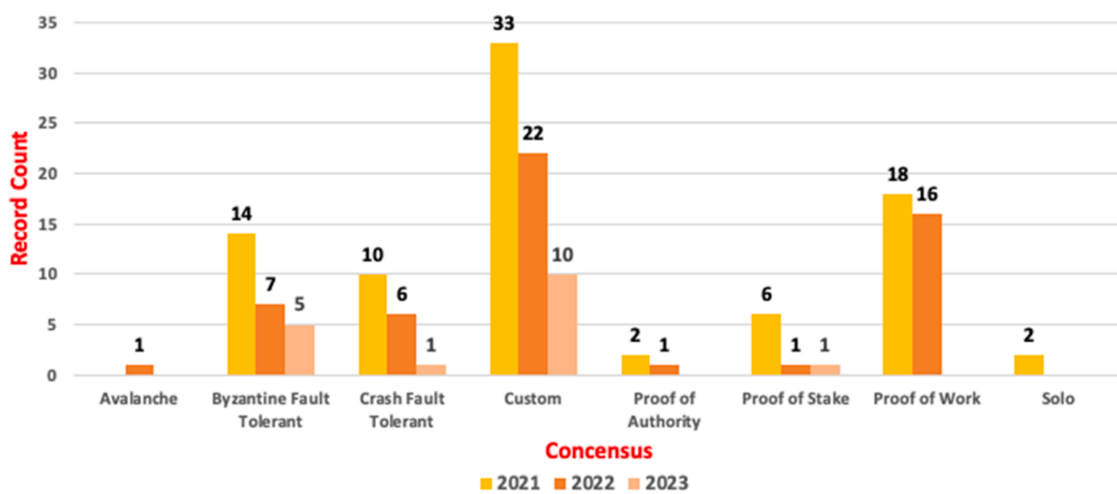

Fig. 3. Record distribution of studies by consensus mechanism.

of Work (PoW) accounts for over 37%, despite being identified as an energy-intensive consensus approach [15,24]. While PoW offers high security and decentralization, its application in the energy sector is limited due to its intensive energy consumption and substantial environmental impact. PoW is not suitable for energy applications in the era of energy efficiency and better energy utilization. Byzantine Fault Tolerance (BFT) and Crash Fault Tolerance (CFT), which account for 29% and 19% respectively, are better alternatives to PoW. Besides being less energy-intensive, these consensus approaches are at mature stages of development, like PoW.

BFT's adaptability to various use-cases was explored in some of the studies encountered, where it was customized for their applications with the promise of offering improved consensus. For example, in the work of [78], where a reputation and fairness indicator system for matching energy sellers and buyers was developed, a variant of BFT, named delegated BFT, was proposed to overcome the complexity in message broadcast problems faced in typical BFT. The result showed improved performance and the ability to achieve consensus even with greater than one-third faults, a known limitation of BFT. Some other studies employed the Raft consensus, which is CFT-based. Though CFT is less complicated than BFT, it is not able to withstand threats from malicious nodes. As such, CFT consensus approaches were mostly employed by studies where performance had higher priority than protection against malicious attacks. This was observed in [79], where high performance throughput had to be guaranteed on a unified platform that affords transparent and secure asset tracing between prosumers, EV owners, and energy storage providers. It achieved a performance of 448.3 transactions per second (TPS) with minimal computing infrastructure.

Some newer consensus approaches, like Proof of Authority (PoA) and Avalanche, that are now gaining maturity were also encountered in the studies. PoA is a suitable consensus for applications with constraints on computing resources and requirements for minimizing single points of failure where central coordination may be required from time to time. It allows assigning such roles to a participant from a pre-selected trusted group instead of always assigning them to the same participant. Avalanche is very important for applications that require fast settlement following the delivery of services, as it guarantees the immutability of transactions faster than most other consensuses. This is why the authors in [35] employed this consensus approach in their proposed blockchain-based system for trading energy across virtual power plants in an open market system, with the objective of maximizing profit while ensuring fast transaction completion.

Proof of Stake (PoS) is another slowly growing consensus mechanism that has been researched since the last decade [5]. Some blockchain platforms, like Solana and Cardano, have been using this consensus mechanism since 2020 and 2017, respectively [24]. Despite this, only about 5% of the studies encountered in this review employed the PoS consensus approach, even though it has been widely researched but was yet to be supported by larger blockchain platforms. However, it is anticipated that following the official merger of Ethereum's Beacon chain with its Mainnet chain in the last quarter of 2022, allowing PoS as the default consensus [80], many works utilizing Ethereum will begin to take advantage of it, allowing for more energy-efficient blockchain solutions. PoS has already begun to promote the acceptance of cryptocurrency among people with climate change concerns, being a better alternative to PoW [11]. Employing this standardized consensus mechanism allowed studies like [81] to focus on proposing feasible solutions that promote energy dispatch in smart building clusters using day-ahead forecasts. The solution, which employs a reputation system to incentivize participants, eliminates the need for an aggregator, which has been a major bottleneck in profit maximization during local energy trading. However, there are still concerns around transaction costs on PoS-based blockchain platforms for scalable and profitable energy applications.

Comparing 2021 to 2022, though studies employing new consensus approaches like Avalanche emerged in 2022, the percentage of studies employing each of the other consensus mechanisms remained relatively constant with minor variations. However, no study employed the Solo consensus in 2022, which coincidentally appears to have been officially deprecated on the Hyperledger Fabric. Solo consensus uses only one node and is suitable only for testing. In 2023, BFT was the most used among the studies employing standard consensus mechanisms.

Implementation platform of blockchain

While consensus is a determinant factor for the scalability of any blockchain-based solution, it is only a component of the whole blockchain ecosystem. The blockchain platforms where the solutions are implemented or deployed are the main promoters of blockchain adoption. Following the rise in the quest for decentralization, coupled with several investment fundings, numerous blockchain platforms have continued to emerge [82]. In Table 3, the distribution of implementation platforms employed by the studies in this review is shown.

Every blockchain platform offers its own set of features and functionalities that are crucial to the successful end-to-end implementation of any blockchain solution [44]. As such, the choice of platform is a vital decision in any blockchain project. The key factors for selecting a suitable platform for an application include [83]:

- Consensus Mechanisms: Type and maturity stage of consensus mechanisms, with options supported.
- Performance: Frequency of transaction block creation and transaction volume.
- Development Suite: Programming language, support system, ease of development and deployment.
- Smart Contract: Support, level of adaptation, ease of integration, and interoperability with external systems and other blockchains.
- Security: Support for authentication, data encryption, and data storage methods.
- Stage of Maturity: Stability and continuous improvement.
- Blockchain Class: Whether it is private, consortium, or public.
- Cost: Including development, deployment, and transaction fees

Developing a blockchain platform is not an easy feat, as different blockchain platforms are in constant competition to improve on these factors listed above. A chart of the distribution of implementation platforms employed by the studies is presented in Fig. 4. Like the consensus mechanisms discussed earlier, the "Custom" platform was attributed to studies with one of the following attributes:

- Instantiated local computing environments to develop and test implementations using scripts on standalone machines like Raspberry Pi.
- Utilized experimental setups to simulate implementation in a manner different from a standard blockchain. This includes studies that employed IEEE bus experimental setups and MATLAB environments.
- Had no identifiable platform because it was not stated or was not deducible.

The Custom platform group accounts for over 46% of the platforms, with many of the studies in this group utilizing experimental setups to simulate implementation. The problem with this approach is that experimental setups fail to consider cost implications, performance problems, limitations of smart contracts, and interoperability, which are key to achieving a feasible implementation. While simulations provide valuable insights, they often lack the practical depth necessary for real-world deployment. These types of studies focus on other aspects of their proposed framework, such as algorithms, rather than the practicality of the solution. For example, in [84], an efficient framework for energy trading on an IEEE 906 Bus is simulated, with the ability to handle all offers, bids, and settlements in large markets. The framework proposed collects data directly from IoTs, considers preferences from all participants, applies a uniform clearing price, and distributes losses. Unfortunately, deploying such a solution on an actual blockchain platform presents significant challenges because IoTs that integrate directly with blockchain do not yet exist off-the-shelf, smart contracts have limitations in the type of algorithms they can implement, and the system will incur high costs from several transaction iterations in the market clearing process.

The remaining studies, accounting for over 53%, employed standard blockchain platforms that have achieved some level of maturity. Though these platforms are at different stages of maturity and, depending on the use-case, may require adaptation, they generally tend to offer better security features, ease of implementation, and scalability. Studies utilizing these established platforms showed better prospects for real-world application due to the platforms' maturity.

Among studies employing known blockchain platforms, Ethereum accounts for over 45% of the platforms. Studies like [85] and [86] in this group include those implementing the Ethereum Virtual Machine (EVM) in test environments using the Truffle suite or Hardhat with Ganache blockchain. Others, like [87] and [88], used the Remix platform, which can be run on web browsers for quick prototyping. Some studies were implemented on actual Ethereum testnets like Sepolia and Goerli. Using these types of local setups and testnets allows for practical implementation and fast prototyping while avoiding actual transaction costs. The authors in [89] took advantage of this by implementing a test blockchain using Ganache to prototype their proposed system for energy trading in community markets, which promotes prosumers and uses a double auction mechanism for budget balancing of trades. The EVM also allows the use of other consensus mechanisms besides PoW and PoS, permitting researchers to adapt its development environment with other suitable consensus mechanisms for the needed application. An example of this was demonstrated by [90], who proposed a Practical BFT consensus in an EVM to implement an energy trading system for demand response. The BFT consensus was introduced as a suitable and fast consensus to distribute account rights to participants. Ethereum blockchain is likely to continue taking the highest share, especially now that PoS is its default consensus mechanism.

Hyperledger is also a widely employed blockchain platform, accounting for almost 35% of the studies employing standard blockchain platforms. Hyperledger is a group name for blockchains developed as open source under the Linux Foundation [91]. It has similar advantages to Ethereum in terms of adaptability. However, unlike the EVM, it offers different blockchains for different use cases. The most employed Hyperledger blockchain encountered in the studies reviewed is Fabric [92,93]. Hyperledger Fabric is a modular private blockchain that can be integrated with several consensus mechanisms [94]. Other Hyperledger blockchains, like Besu and Burrow, were also used by studies like [95] and [96] in the review. Each of these blockchains offers functionalities suited for different applications. In the Appendix, the specific Hyperledger platforms encountered in the studies are presented under the platform column.

Besides the blockchain, Hyperledger offers other systems. One such system is Hyperledger Caliper, a modular tool for measuring the performance of blockchain solutions [97,98]. Performance evaluation is key to determining the feasibility of any blockchain solution. This tool possibly influenced the choice of the Hyperledger platform for implementing the system proposed for unifying energy trading to promote efficient utilization of energy resources in [97]. In the study, several

Table 3
Record distribution of studies by blockchain platform.

Platform/Year	2021	2022	2023	Total
Avalanche		1	1	2
Cosmos	3	1		4
Custom	38	25	10	73
Ethereum	18	17	3	38
Hyperledger	19	7	3	29
Quorum	2			2
IOTA Tangle	1	1		2
Swarm	1			1
Binance	1			1
Energy Web Chain	1	1		2
Solar Coin	1			1
Monero		1		1

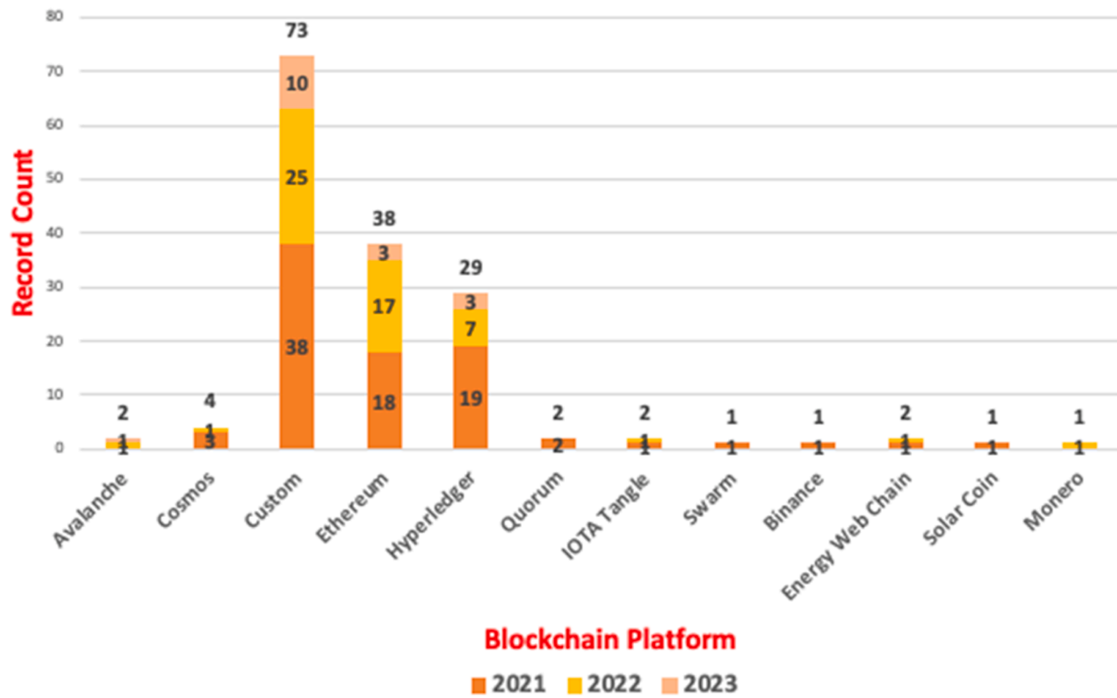

Fig. 4. Record distribution of studies by blockchain platform.

scenarios were presented, and performance evaluations were conducted. The Hyperledger ecosystem offers a wide range of tools and has a large community of support, making it the second most preferred platform. However, setting up a local test instance of the Hyperledger blockchain involves some technicalities. Additionally, the Hyperledger ecosystem experiences frequent deprecation of components aimed at improvement, which inadvertently causes uncertainty and poses risks of continuity for businesses using such components for the development of their blockchain solutions. For example, the deprecation of Hyperledger Composer in 2019 increased the complexity of API integration of the blockchain with business solutions [99,100]. The deprecation of Hyperledger Indy in 2023, which provided tools for identity management, also had a major impact on users [101,102]. Consequently, Hyperledger continues to fall behind Ethereum, which benefits from a wider audience, having been in existence for a longer time, a stable ecosystem, and being much easier to deploy locally for testing.

There are also other platforms like Avalanche, IOTA Tangle, Solar Coin, Cosmos, and Monero that are recently beginning to gain popularity [5,82,103]. Many of these platforms, which employ components from other existing larger platforms, are designed for more specific use cases. For example, Monero focuses on enhancing privacy using encryption techniques, while IOTA Tangle's main goal is to improve transaction speed and eliminate the need for miners. The Cosmos platform, launched in 2019, implements an Inter-Blockchain Communication Protocol (IBC) to facilitate interoperability among blockchain technologies [36]. Some of the studies encountered in this review have leveraged the specific features of these blockchains for their proposed applications, hence enhancing performance.

The review also tried to study the influence of the platform choice by the consensus mechanisms. In Table 4, the consensus mechanisms used in the studies are shown against the platforms.

In Fig. 5, a chart of Table 4 is presented. From the figure, most of studies employing custom consensus mechanisms mostly used custom blockchains. Likewise, most studies employing PoW and PoS preferred the Ethereum platform. Solo and CFT are only supported natively by Hyperledger Fabric and hence are the default selection for studies employing these consensus mechanisms. BFT has the highest spread of platform usage but was mostly employed on Hyperledger.

Consequently, an energy application developing a new consensus mechanism will most likely have to develop or simulate its own custom blockchain platform. On the other hand, energy applications using BFT as an existing consensus mechanism can take advantage of selecting a blockchain platform from several existing options. Meanwhile, since Ethereum, which constituted the highest count of platforms with PoW,

Table 4
Blockchain consensus mechanism vs platform.

Consensus/Platform	Avalanche	BFT	CFT	Custom	PoA	PoS	PoW	Solo
Avalanche	1			1				
Binance					1			
Cosmos		4						
Custom		7		59		2	5	
Energy Web Chain					2			
Ethereum		4		1		5	28	
Hyperledger		9	17	1				2
IOTA Tangle				2				
Monero							1	
Quorum		2						
Solar Coin						1		
Swarm				1				
Total	1	26	17	65	3	7	35	2

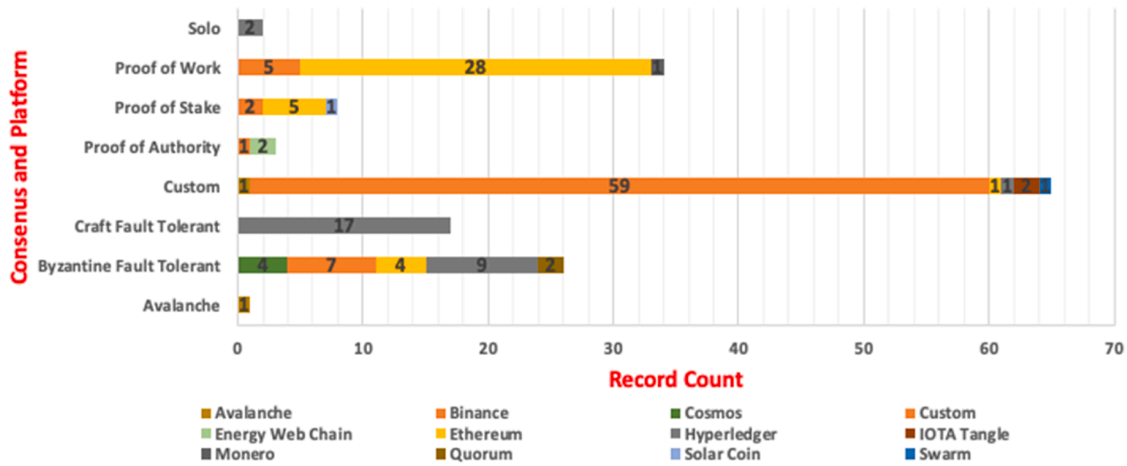

Fig. 5. Record distribution of studies by blockchain consensus and platform.

now employs PoS consensus, the number of studies employing Ethereum is expected to rise.

Blockchain application

Blockchain, as an enabling technology, has found usage for different purposes in energy applications. Consequently, several researchers are exploring the use of blockchain to solve various problems in the energy sector. Some studies, such as those presented in [42] and [47], have identified some of these uses, including billing, marketing, trading, data transfer, automation, energy tokens, and carbon trading, among others. In this review, studies are classified according to the following categories of application or uses:

- Trading: Involves energy generated from distributed sources and the flexible operation of end-user appliances in the form of demand response, including energy stored in batteries.
- Data: Encompasses storage, security, verification, authentication, and tracking for energy records.

In Fig. 6, the distribution of studies across the two application categories is presented for each of the years considered. The use of blockchain for trading energy accounts for the highest application among the studies encountered. Currency trading is the first and most widely known use of blockchain [104], and this has influenced the direction of many blockchain innovations in the energy domain towards energy trading. Moreover, blockchain continues to gain interest as a promoter of peer-to-peer (P2P) trading of distributed renewable energy sources in energy communities. Studies in the trading category have applied

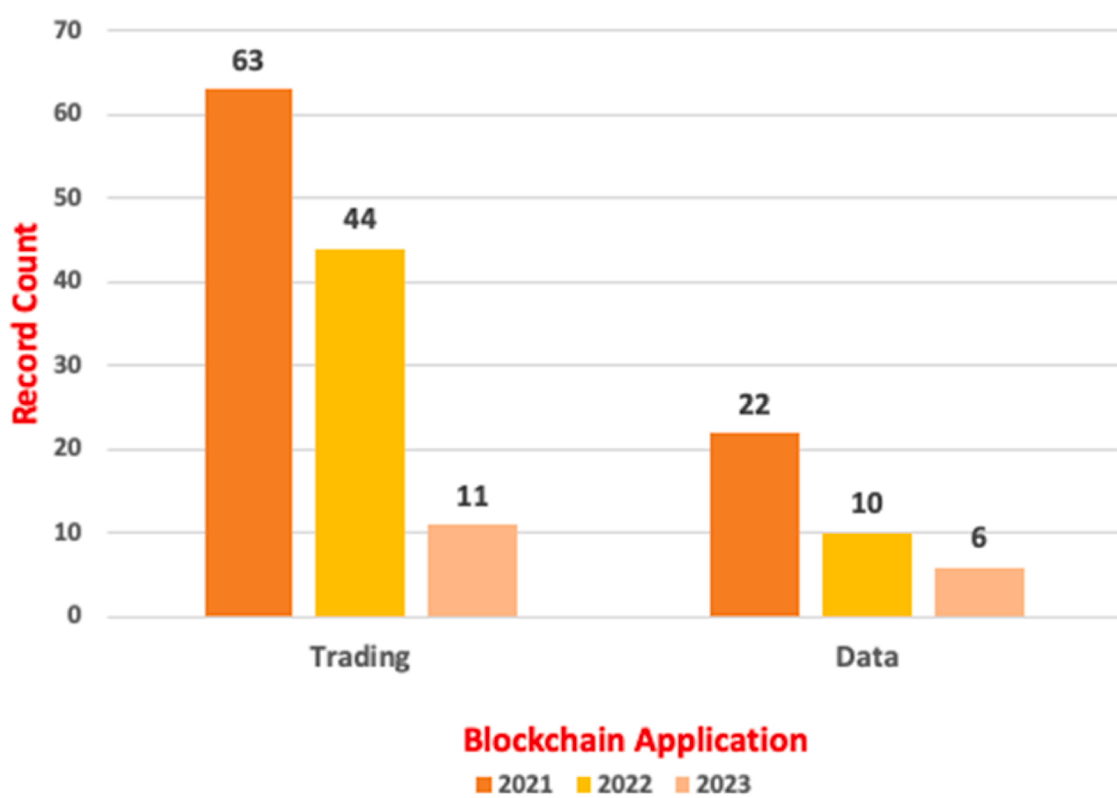

Fig. 6. Record distribution of studies by category of blockchain application purpose.

blockchain to address various issues and achieve different objectives in the energy trading process. For example, [78] deployed a reputation scoring system on blockchain to guarantee trust in energy trading between sellers and buyers, while [74] applied blockchain as a decentralized technology to address scalability problems during energy trading.

On the other hand, studies in the data category have employed blockchain for privacy protection, authentication, energy asset registration, energy origin tracking, and transaction verification. Unfortunately, blockchain for this application has continued to become less popular due to several limitations, including severe latency in data transfer on many blockchain platforms and data storage constraints [105]. Data storage constraints are particularly a serious concern in the energy space as the amount of data generated becomes exponentially larger in smart grids with the increasing number of connected IoT devices. For perspective, the size of the full raw data of the Bitcoin blockchain used for cryptocurrency trading surpassed 1.3 terabytes by the end of 2022. With far more connected IoT devices in energy applications, this data volume will be surpassed in a single year, imposing high demands on storage requirements [106].

Another limitation in the data application of blockchain, identified in several studies like [107] and [108], is the architecture often proposed, which introduces some form of central management with the possibility of increasing the risk of a single point of failure and information monopoly. Such architecture not only defeats the objective of true decentralization but also tends to be far more expensive to operate compared to existing centralized management. For example, [109] proposed a blockchain-based system for privacy protection for EVs in 5G networks using an identity-based encryption technique to protect transactions and users. However, it requires aggregator supervision to oversee the system. The authors in [107] also proposed the use of blockchain for sharing identification codes for verification purposes in energy transactions, but the system still requires a centralized system for participant registration.

Data exchange applications also suffer from integration bottlenecks with existing devices. This is because many devices transmitting data to the blockchain do not currently have the capacity to do so directly. Studies encountered in this review requiring such integration often implemented a custom approach that not only requires technical skills but also lacks standardization. In [110], a blockchain-based application was proposed to track the energy footprint of buildings. It uses a smart meter running a blockchain node to record and transmit energy consumption in buildings to a public distributed ledger. However, this type of meter does not readily exist off-the-shelf. Nevertheless, platforms like Chainlink now offer oracle connectors at a cost to provide integration between blockchain and external systems [111]. Implementations using such platforms can incur significant costs if not properly managed. Unfortunately, the wider adoption of blockchain for energy applications still greatly depends on leveraging its capabilities to drive innovations through data management rather than its ability to merely power transactions, but existing limitations must be resolved.

Objective for use of blockchain

Blockchain offers core features that drive its utilization to meet various application objectives. These features include immutability from rigorous validation processes and record chaining, transparency from the visibility of transactions in public ledgers, decentralization through the use of distributed ledgers and nodes, privacy through encryption, and automation afforded by smart contracts, among others [112]. These features form the premise for using blockchain as an enabling technology for other applications [42]. Using these features, the objectives for blockchain applications are grouped as follows in this review:

- Security: Enhancing data security using encryption to improve secure data transfer and address privacy concerns.
- Efficiency: Improving scalability in energy operations through decentralized management or process automation afforded by smart contracts.
- Trust: Ensuring record transparency, validation, and tracking to guarantee correctness and prove authenticity.

In Fig. 7, the distribution of the studies according to this group of objectives is presented. Over 55% of the studies employed blockchain to enhance efficiency in energy applications. Many of these studies focused on energy trading applications. Studies in this group aimed to increase the speed of completing energy transactions, automate energy trading while reducing the need for manual interventions, reduce the risk of single points of failure by providing redundancy through decentralization, eliminate bottlenecks in transactions due to middlemen, and enhance localized trading. The use of blockchain to enhance efficiency in this manner relies on the use of smart contracts and distributed nodes.

Smart contracts enable the deployment of various algorithms for different operations on the blockchain. These algorithms are executed automatically once preset conditions are met. Many studies have utilized smart contracts in this manner for settlement operations in energy trade contracts. For instance, [113] proposed using smart contracts to establish and fulfill contracts between prosumers and consumers in energy communities without the need for a middle agent. Such implementations have not only improved efficiency but also reduced transaction costs from fees that would otherwise have been imposed by middle agents, thus maximizing the profit of prosumers. Other studies have also employed smart contracts in this manner to match energy buyers and sellers, including the scheduling of energy trades. In [114], smart contracts were used to include prosumers' offers in a virtual power plant group once contract conditions were met. It also uses a selection algorithm deployed on the smart contract to rank and select prosumers that meet energy request conditions for the virtual power plant.

However, smart contracts are limited to the execution of simple code blocks with a known number of iterations. Unfortunately, many energy operations require more complex algorithms and models that cannot be executed on smart contracts. As such, studies in this situation, encountered in this review, often result in implementing an off-chain system capable of executing complex algorithms. For example, in [115], an efficient energy trading solution for future markets is proposed, which anonymizes trading data activity. However, it implements a CPLEX optimization algorithm on an off-chain system for matching trades. The challenge with such a setup is managing the architectural complexity and scaling the solution, especially as it introduces some central control that increases the chances of single points of failure. A more suitable approach would be to employ simple algorithms deployable on smart contracts alone or run a federated system of off-chain nodes where complex algorithms are unavoidable. Furthermore, when off-chain nodes are implemented, they should be designed such that, as much as possible, the operations executed on them are not critical to the overall solution.

On the other hand, studies leveraging blockchain to enhance security account for close to 28%, a value far less compared to those utilizing it to enhance efficiency. Many of these studies employed blockchain for data applications. Many of these studies focused on using cryptographic encryption to resolve privacy issues and secure data transfer among participants during energy trading. These studies either use the default encryption technique or introduce custom encryption techniques to improve the overall system security level. Zero Knowledge Proof (ZKP) was one of the most common techniques used in this regard. This technique allows participants to prove the validity of data without revealing its actual details [116]. For instance, the authors in [117] employed ZKP to design a blockchain-based roaming system for EV charging, allowing authentication of users at public charging stations while preserving their personal data. Generally, most of the studies in the security group, like [108] and [117], took advantage of private and

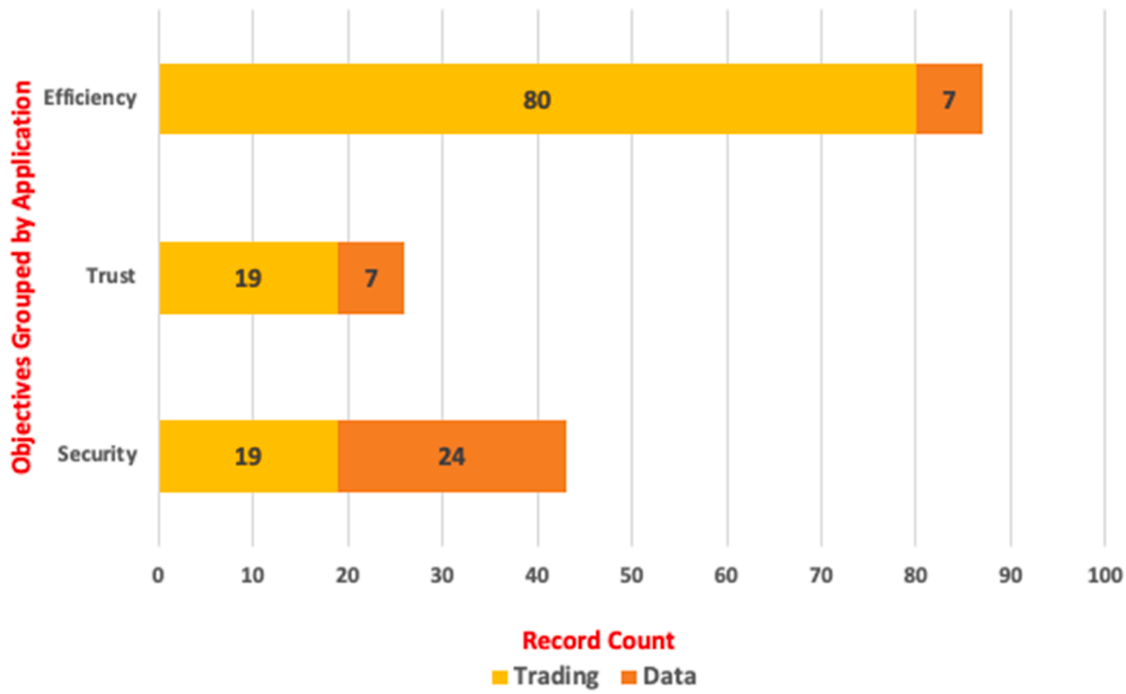

Fig. 7. Record distribution of studies by objectives grouped by application.

consortium blockchains to authenticate participants and ensure only authorized participants could engage in energy trading.

Unfortunately, blockchain to enhance security suffers from several limitations. This is because employing blockchain technology to achieve this objective requires an expert knowledge about the underlying principles of blockchain, cybersecurity, and cryptographic encryption. Additionally, stronger cryptographic encryption processes require high computing power, impact transaction throughput, and affect overall system performance [116,118]. Systems involving large or frequent volumes of data exchange, as is typical with IoT devices, are even more susceptible to these performance problems.

Studies employing blockchain to directly guarantee trust account for only about 17% of the total studies. These studies focused on purely using the immutability and transparency features of the blockchain. However, since the guarantee of trust usually comes with improving efficiency and security, other studies are invariably increasing trust levels in their solutions as a secondary objective. In this review, studies employing blockchain for trust include those utilizing it to verify the source of data, trace records or track chains of records, guarantee settlement, reduce the risk of defaulting, and increase confidence. For example, in [119], blockchain is employed to reduce the risk for investors financing RES projects. The proposed system increases confidence levels and makes investment funds available to promote the penetration of RES. On the other hand, in [120], blockchain is used for energy performance management. The performance system verifies the authenticity of energy certificates to assure participants in energy communities of their authenticity. However, the use of blockchain to guarantee trust may conflict with security objectives as it raises privacy concerns. For instance, the system proposed by [121] to track the usage of EVs could reveal private information directly linked to the EV user. Caution must therefore be taken in the careful design of blockchain applications for enhancing trust.

Though the selection of consensus mechanisms influences the choice of blockchain platform, ultimately, the selection of the consensus mechanisms is a direct result of the objective of the blockchain application. In Table 5, the blockchain consensus mechanisms are categorized against the objectives. In Fig. 8, this influence is evaluated using the spread of the objectives across the consensus mechanisms. Blockchain applications to improve efficiency are compatible with a wide range of consensus mechanisms. Ironically, PoW accounts for the highest number of consensus mechanisms with this application objective. This result casts some doubt on the feasibility of such solutions, especially since PoW is not only energy-intensive but also suffers from low transaction throughput. This could explain the rationale for the choice of a custom consensus approach in many of the studies instead of PoW. Nonetheless, other standardized alternative consensus mechanisms like BFT and PoS would have been more beneficial to take advantage of instead of the custom consensus approach. The application of blockchain to guarantee trust is compatible with a wide range of consensus mechanisms, as the default configuration of any blockchain system, irrespective of the consensus mechanisms, affords this.

On the other hand, almost 47% of the studies employing blockchain to enhance security resulted in using custom consensus approaches. This is because blockchain for this objective usually implies modifications to the consensus mechanisms, which is not easily achievable with the existing standard consensus mechanisms.

Discussion

Blockchain, as an enabling technology, can enhance various tasks in

Table 5
Blockchain objectives vs consensus.

Objective/Consensus	Avalanche	BFT	CFT	Custom	PoA	PoS	PoW	Solo
Security		7	4	20		4	7	1
Trust		4	5	8	2	2	5	
Efficiency	1	14	8	37	1	3	22	1

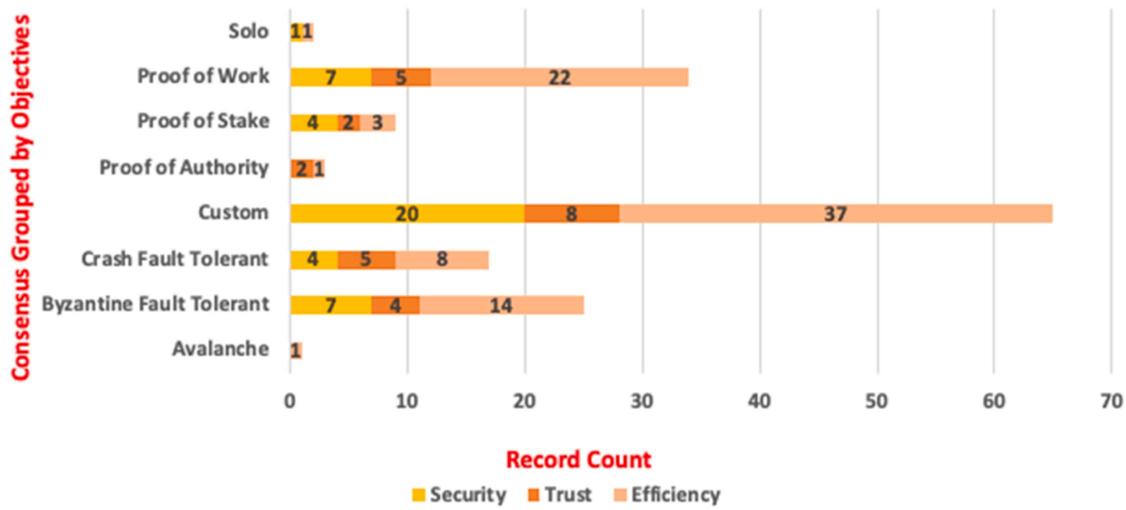

Fig. 8. Record distribution of studies by consensus grouped by objectives.

energy operations. However, to gain adoption, blockchain solutions for energy applications must be practical, cost-effective to implement, secure, and highly performant. Meeting all these requirements in equal measure is unlikely, and thus a compromise must be reached. This requires prioritizing the requirements that must be met depending on the specific application use case. Each of these requirements is fulfilled by various components of the blockchain, with several options to choose from. Identifying the key requirements and selecting appropriate components of the blockchain are therefore crucial to developing any feasible blockchain-based energy application. In Table 6, a comparison is made of major blockchain platforms encountered against key features.

Following this, a discussion on some important requirement checklists that can help select the appropriate blockchain components, especially regarding platform and consensus mechanisms, is provided below as synthesized from the table.

Identify the primary goal of the solution

The primary goal of any blockchain solution is the most critical decision to make. The goal can be to improve efficiency, enhance security, or ensure trust. For example, a blockchain solution for energy trading might prioritize efficiency to handle large transaction volumes quickly, whereas a solution for verifying renewable energy certificates might prioritize trust and transparency. Once the primary goal is determined, the next step is to classify the goal according to the application class. In this review, two broad application classes were adopted: trade and data. The interplay between the objective and the application will allow the creation of a requirement list, which will guide the best decisions for the choice of suitable platforms and consensus mechanisms.

Consensus mechanism

The choice of a consensus mechanism for any application is influenced by the requirements for security, scalability, and performance. As observed in studies like [78], applications requiring high security should consider consensus mechanisms like Practical Byzantine Fault Tolerance (PBFT) or Proof of Stake (PoS), which offer strong security features without the high energy consumption of Proof of Work (PoW). For instance, PBFT is used in Hyperledger Fabric to provide fault tolerance and ensure that the system can operate correctly even if some nodes are compromised. For high transaction volumes, mechanisms like PoS or sharding (offered by platforms like Ethereum 2.0) are more suitable due to their ability to handle larger throughput. Ethereum 2.0′s PoS mechanism, combined with sharding, aims to process thousands of transactions per second, significantly improving scalability compared to Ethereum 1.0. If transaction speed is critical, consider newer mechanisms like Avalanche or Raft, as employed in [35], which offer faster processing times. Avalanche, for example, is known for its high

Table 6
Comparison of major blockchain platforms against key features.

Feature/Platform	Ethereum	Hyperledger Fabric	Cosmos	Avalanche	Chainlink
Consensus Mechanisms	PoW, PoS, Sharding	PBFT, CFT	Tendermint, BFT	Avalanche Consensus	
Development Tools	Truffle, Hardhart, Remix	Frabric SDK, Composer (depreacted)	Cosmos SDK, IBC	Solidity, Other languages	
Interoperability	High, EVM Compatibility	Medium, Modular	High, IBC	Medium, Customizable	High, Oracles
Cost	High transaction fees	Customizable fees	Variable	Variable	Additonal cost for oracles
Maturity and Stability	High	High	Growing	Growing	Growing
Smart Contract Support	Robust (Solidity)	Flexible (Chaincode)	Multiple languages	Multiple languages	
Data Management	On-chain, off-chain	On-chain, off-chain	On-chain, off-chain	On-chain, off-chain	Off-chain via oracles
Security	High	High	High	High	High
Privacy	Medium	High	High	High	High
Integration with IoTs	Medium	Medium	Medium	High	High
Peformance Tools	Caliper (limited)	Caliper	Custom tools	Custom tools	
Country of Use	Global	Global	Global	Global	Global
Application Class	Trade, Data	Trade, Data	Trade, Data	Trade, Data	Data
Primary Objective	Efficiency, Security, Trust	Efficiency, Security, Trust	Efficiency, Security, Trust	Efficiency, Security, Trust	Efficiency, Security

throughput and low latency, making it suitable for applications requiring quick finality.

Blockchain platform

The choice of blockchain platform plays one of the most critical roles in the success of any blockchain solution. Platforms today offer multiple consensus mechanisms and support tool options, making the selection process more complex. Once the consensus mechanisms suitable for an application have been selected, factors like development tools, interoperability, and cost should influence the choice of platform. Platforms like Ethereum offer comprehensive development tools (e.g., Truffle, Hardhat) that simplify the creation and deployment of smart contracts. These tools provide a robust environment for testing and deploying smart contracts, enabling developers to build and iterate quickly. The Hyperledger platform also offers several tools within its ecosystem to simplify the development process.

Platforms that support interoperability, such as Cosmos with its Inter-Blockchain Communication Protocol (IBC), are ideal for applications requiring integration with other blockchains or external systems. Evaluating the cost implications of different platforms is also crucial. Ethereum, while widely used, may have higher transaction fees compared to platforms like Hyperledger, which are designed for enterprise use and may offer more cost-effective solutions. For example, Hyperledger Fabric allows businesses to set up private, permissioned blockchains with customizable transaction fees. Cosmos similarly provides integration with other blockchains. Avalanche focuses on the development of decentralized apps and boasts high adaptability for various use cases.

Support for smart contract

Smart contracts deploy algorithms to automate tasks. The level of automation and the complexity of algorithms vary from one use case to another. Therefore, being aware that smart contracts typically have limitations in supporting complex algorithms and that capabilities vary across platforms, careful choices and architectural designs need to be made. For applications requiring extensive automation, ensure the platform supports robust smart contract capabilities. Ethereum's EVM is well-known for its smart contract support, allowing for the automation of various processes in a trustless manner. For instance, smart contracts can be used to automate energy trading and settlement processes in real-time, as employed in [113,114]. If complex algorithms are needed, consider whether these can be executed on-chain or if an off-chain solution is required, as in [115]. Some platforms, like Hyperledger Fabric, offer more flexibility for integrating off-chain computation. For example, a complex energy optimization algorithm might be executed off-chain, with the results recorded on-chain for transparency and auditability.

Also, consider the ease of writing and deploying smart contracts. On Ethereum, smart contracts are written in Solidity, which has a syntax like JavaScript. Avalanche allows the development of smart contracts using multiple programming languages, with better support for complex algorithms. Cosmos allows the choice of consensus and smart contract platforms, thus not only providing support for complex algorithms but also affording future needs to integrate suitable smart contract platforms in case the algorithm improvements result in even more complex algorithms.

Data management

In energy systems, there are concerns about storage cost and capacity due to the high volume of time-series data being exchanged. Additionally, growing concerns about data privacy and security place higher demands on some use cases more than others. As employed in [29], blockchain-based energy applications should consider platforms that support off-chain storage solutions or have efficient data handling mechanisms while ensuring data integrity. For applications requiring high privacy, like [117], explore platforms that offer advanced cryptographic techniques like Zero-Knowledge Proofs (ZKP). For instance, ZKPs can be used to verify transactions without revealing sensitive information, enhancing privacy for participants in energy trading. In cases where restricted access is required, consider private blockchain platforms over public ones.

Maturity and stability

As more options for blockchain platforms and components continue to emerge, they undergo different levels of product stability until maturity. Some blockchain platforms that started off well no longer exist today. Choosing such platforms can potentially impact business continuity. For example, TradeLens, a blockchain platform launched in 2018 to digitize the global supply chain using blockchain technology, failed to attain commercial viability and was closed in 2023. Similarly, the approach of developing custom platforms is not a good option. For example, in this review, most of the studies that employed a custom approach to achieving consensus designed solutions that are either not feasible for practical implementation or very costly to implement. On the other hand, those studies leveraging standard and mature consensus mechanisms offered better solutions.

Regarding stability, care must be taken to study the development and update patterns even for mature platforms. Deprecated components of a platform heavily relied on by a business application or breaking changes may impact the sustainability of such solutions. For example, the deprecation of Hyperledger Composer, though intended for improvement, impacted many business solutions built around it. The maturity and stability of blockchain components in an application are major factors investors watch out for. Choose platforms with a track record of stability and continuous improvement. Ethereum and Hyperledger are both mature platforms with large support communities and are employed by many studies, such as [89,90,92,93]. Prefer platforms that adhere to industry standards and have clear protocols for implementation and governance. Standardized platforms ensure better interoperability and lower the risk of vendor lock-in.

Integration with IoTs

IoTs are the core of smart grids, and as such, energy applications must integrate with them seamlessly. Unfortunately, integration problems with IoTs are a major limitation, as observed in some studies like [84], which implemented solutions that connect IoTs directly to blockchain but rely on technologies that do not yet exist off the shelf. Until such technologies are available, consider platforms that provide connectors or links to IoTs and other external systems, such as Chainlink [111]. Chainlink's oracles can securely connect smart contracts with real-world data, enabling automated responses to external events. However, be aware of the extra costs associated with these connectors and aim for solution architectures that offer cost-effective integration. Proper planning and cost management can prevent budget overruns and ensure the economic viability of the blockchain solution.

Performance metric evaluation

The measure of performance of any blockchain-based solution is the premise for evaluating its scalability and, consequently, its feasibility. Select blockchain platforms that allow the ease of integration of tools for measuring performance. Use tools like Hyperledger Caliper to measure and evaluate the performance of blockchain solutions. Hyperledger Caliper can benchmark the transaction throughput, latency, and resource utilization of different blockchain implementations. Studies like [97] employed Hyperledger Caliper to benchmark configurations to optimize performance. Conduct scalability testing to ensure the chosen platform can handle the expected transaction load and data volume. Scalability testing helps identify potential bottlenecks and areas for improvement, ensuring that the solution can grow with increasing demand.

Conclusions and future directions

Blockchain, as a decentralized technology, offers significant potential for various applications. Despite extensive efforts and research funding, its adoption in energy applications remains low. This systematic review of 156 studies analyzed the implementation methods, examining use cases, blockchain components, and their evolution to identify trends and bottlenecks.

The findings indicate that consensus mechanisms and blockchain platforms are crucial for the feasibility of blockchain-based applications. Scalability remains a primary challenge, with custom consensus mechanisms and platforms often being costly and impractical. In contrast, standardized consensus mechanisms and platforms showed better outcomes and scalability potential for business use cases.

To handle high transaction volumes and data sizes, some studies employ sidechains and sharding. Integration with IoT devices is essential but challenging due to the lack of off-the-shelf solutions, necessitating the use of connectors like Chainlink, which increase costs. Standardization in implementation, testing, and governance remains a significant issue, making it difficult for business owners and investors to evaluate feasibility.

Selecting the right blockchain platform and components involves understanding the application's primary goal and requirements. Mature platforms like Ethereum and Hyperledger Fabric offer robust support, while emerging platforms like Cosmos and Avalanche provide innovative solutions. Platforms like Chainlink enhance data security and IoT integration but come with additional costs. The insights from this review guide researchers in selecting appropriate blockchain components, enhancing the development of practical solutions. Industries can use these findings to make informed technology choices, overcoming known limitations.

This review employed the PRISMA protocol, acknowledging potential biases during inclusion and exclusion stages. The studies were sourced from Scopus, which may have a time lag in indexing newer publications. Despite these limitations, the review offers valuable guidance for future blockchain implementations in the energy sector.

CRediT authorship contribution statement

O.O. Egunjobi: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **A. Gomes:** Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. **C.N. Egwim:** Writing – review & editing, Visualization, Validation, Investigation, Formal analysis. **H. Morais:** Writing – review & editing, Validation, Supervision, Investigation, Conceptualization.

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.

Appendix: Tables of studies reviewed and data extracted

Author	Country	Application	Objective	Consensus	Platform
[122]	China	Trading	Security	Custom	Custom
[78]	China	Trading	Trust	Byzantine Fault Tolerant (Delegated)	Custom
[123]	United States	Trading	Security	Custom (Relaxed Innovation)	Custom (IEEE 24-Bus)
[88]	China	Trading	Efficiency	Proof of Work	Custom
[27]	Turkey	Trading	Efficiency	Proof of Work	Ethereum (SynergyChain)
[124]	China	Trading	Security	Solo	Hyperledger (Fabric)
[125]	China	Data	Security	Custom (Linear)	Swarm
[126]	China	Trading	Efficiency	Proof of Stake (Delegated)	Custom
[113]	Saudi Arabia	Trading	Efficiency	Proof of Stake	SolarCoin
[127]	China	Data	Security	Byzantine Fault Tolerant (Istanbul)	Hyperledger (Fabric)
[79]	Norway	Data	Trust	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[128]	United Kingdom	Trading	Efficiency	Proof of Work	Ethereum
[129]	Romania	Trading	Efficiency	Proof of Work	Custom
[130]	India	Trading	Trust	Proof of Stake	Ethereum
[97]	Australia	Trading	Efficiency	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[131]	Russia	Trading	Efficiency	Custom	Custom
[28]	Australia	Trading	Trust	Custom (Karush-Kuhn-Tucker Algorithm)	Custom (IEEE 33-Bus)
[74]	Italy	Trading	Efficiency	Proof of Authority	Energy Web Chain
[84]	Egypt	Trading	Efficiency	Custom	Custom (IEEE 906-Bus)
[132]	China	Trading	Security	Byzantine Fault Tolerant	Quorum
[133]	India	Data	Security	Custom (Time Based)	Custom
[134]	China	Data	Security	Custom	Custom
[135]	China	Trading	Efficiency	Custom	Custom
[136]	Australia	Trading	Efficiency	Custom	Custom
[137]	China	Trading	Efficiency	Custom	Custom (IEEE 13-Bus)
[138]	China	Data	Security	Custom (Credibility Based Equity Proof)	Custom
[139]	China	Data	Security	Custom	Custom (Switch Board)
[140]	China	Trading	Security	Byzantine Fault Tolerant	Custom
[86]	United States	Data	Security	Proof of Work (Zero Knowledge)	Ethereum
[141]	Netherlands	Trading	Efficiency	Solo	Hyperledger (Fabric)
[142]	China	Trading	Security	Custom	Custom (MATLAB)
[143]	China	Data	Security	Proof of Work	Ethereum
[144]	Singapore	Trading	Efficiency	Proof of Work (Dynamic)	Custom
[33]	South Korea	Trading	Efficiency	Byzantine Fault Tolerant (Istanbul)	Hyperledger (Fabric)

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Author	Country	Application	Objective	Consensus	Platform
[119]	Taiwan	Trading	Trust	Custom	Custom (IEEE 30-Bus)
[145]	China	Trading	Trust	Custom	Custom
[146]	Korea	Trading	Efficiency	Proof of Work	Custom (Raspberry Pi)
[147]	Italy	Data	Trust	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[148]	South Korea	Trading	Efficiency	Proof of Work	Ethereum
[149]	Columbia	Trading	Efficiency	Custom	Custom
[150]	United States	Data	Efficiency	Proof of Work	Ethereum
[30]	Switzerland	Trading	Trust	Custom	Custom (MATLAB)
[151]	United States	Trading	Trust	Byzantine Fault Tolerant (Istanbul)	Hyperledger (Fabric)
[152]	United Kingdom	Trading	Security	Custom	Custom
[29]	China	Trading	Efficiency	Proof of Work	Ethereum
[90]	China	Trading	Efficiency	Byzantine Fault Tolerant	Ethereum
[153]	China	Trading	Efficiency	Custom	Custom
[154]	Kazakhstan	Trading	Efficiency	Custom	Custom (IEEE 34-Bus)
[103]	India	Trading	Efficiency	Custom (Fast Probabilistic)	IOTA Tangle
[96]	Australia	Trading	Efficiency	Byzantine Fault Tolerant (Istanbul)	Hyperledger (Besu)
[114]	Romania	Trading	Efficiency	Proof of Work	Ethereum
[6]	India	Trading	Efficiency	Proof of Work	Ethereum
[155]	China	Trading	Efficiency	Custom	Custom
[76]	India	Data	Security	Custom (Proof of Function)	Custom (MATLAB)
[95]	Netherlands	Trading	Efficiency	Byzantine Fault Tolerant (Istanbul)	Hyperledger (Burrow)
[156]	China	Trading	Efficiency	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[157]	Canada	Trading	Security	Proof of Work	Ethereum
[158]	South Korea	Trading	Efficiency	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[159]	South Korea	Trading	Efficiency	Custom	Custom
[160]	China	Data	Efficiency	Byzantine Fault Tolerant	Ethereum
[161]	China	Data	Security	Custom	Custom
[162]	United States	Trading	Trust	Crash Fault Tolerant	Hyperledger (Fabric)
[163]	China	Trading	Efficiency	Proof of Work (Credit Based Custom)	Custom
[164]	China	Data	Security	Proof of Stake	Ethereum
[165]	Switzerland	Data	Security	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[110]	Switzerland	Data	Trust	Custom	Custom
[166]	China	Trading	Efficiency	Byzantine Fault Tolerant (Proof of Clearance)	Custom
[117]	Portugal	Trading	Security	Byzantine Fault Tolerant (Zero Knowledge)	Hyperledger (Indy)
[167]	Canada	Trading	Efficiency	Custom	Custom (MATLAB)
[168]	Canada	Trading	Efficiency	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[92]	United States	Trading	Efficiency	Byzantine Fault Tolerant (Istanbul)	Hyperledger
[169]	China	Trading	Security	Byzantine Fault Tolerant (Modified)	Quorum
[107]	China	Data	Trust	Custom	Custom
[170]	China	Trading	Efficiency	Proof of Work	Ethereum
[171]	Portugal	Trading	Efficiency	Custom	Custom
[172]	Pakistan	Trading	Trust	Proof of Work	Ethereum
[173]	Bangladesh	Trading	Trust	Proof of Authority (Staked)	Binance
[174]	Taiwan	Trading	Efficiency	Custom	Custom
[175]	India	Data	Security	Proof of Work	Ethereum
[176]	Australia	Trading	Efficiency	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[115]	United States	Trading	Security	Proof of Stake	Ethereum
[177]	Switzerland	Data	Security	Custom	Custom
[126]	China	Trading	Security	Proof of Stake	Custom
[178]	Morocco	Data	Efficiency	Custom (Proof of Random Participation)	Custom
[120]	Ireland	Data	Trust	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[77]	India	Trading	Trust	Custom	Custom
[89]	China	Trading	Efficiency	Proof of Work	Ethereum
[85]	Canada	Trading	Trust	Proof of Work	Ethereum
[179]	United Arab Emirates	Trading	Trust	Proof of Authority	Energy Web Chain
[36]	Switzerland	Trading	Efficiency	Byzantine Fault Tolerant (Tendermint)	Cosmos
[180]	China	Trading	Trust	Byzantine Fault Tolerant	Custom
[181]	China	Trading	Efficiency	Custom	Custom
[182]	China	Trading	Efficiency	Custom (Fast Probabilistic)	IOTA Tangle
[183]	Italy	Trading	Security	Proof of Work	Ethereum
[184]	Pakistan	Trading	Efficiency	Proof of Work	Ethereum
[35]	Turkey	Trading	Efficiency	Avalanche (Snowball)	Avalanche
[185]	Pakistan	Trading	Security	Custom (Proof of Computational Closeness)	Custom
[186]	Iran	Trading	Efficiency	Custom	Custom
[187]	China	Trading	Efficiency	Byzantine Fault Tolerant (Fast)	Custom
[188]	Canada	Trading	Efficiency	Proof of Work	Ethereum
[189]	Spain	Trading	Efficiency	Proof of Work (Zero Knowledge)	Monero
[190]	Brazil	Trading	Trust	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[191]	India	Trading	Efficiency	Custom (Distributed Consensus)	Custom
[108]	China	Trading	Trust	Byzantine Fault Tolerant (Credit Delegated)	Hyperledger (Fabric)
[192]	India	Trading	Efficiency	Custom	Custom
[193]	China	Trading	Security	Custom	Custom
[81]	China	Trading	Efficiency	Proof of Stake	Ethereum
[109]	Pakistan	Data	Security	Proof of Work	Ethereum
[194]	Finland	Trading	Efficiency	Custom (Proof of Concept)	Custom
[195]	Egypt	Trading	Security	Custom (Zero Metric Weighted Average)	Custom

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Author	Country	Application	Objective	Consensus	Platform
[196]	China	Trading	Efficiency	Custom	Custom (MATLAB)
[87]	China	Trading	Trust	Proof of Work	Ethereum
[197]	China	Trading	Efficiency	Byzantine Fault Tolerant (Credit Based Custom)	Custom
[198]	Netherlands	Trading	Efficiency	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[199]	Pakistan	Trading	Trust	Proof of Work	Ethereum
[200]	United Arab Emirates	Data	Security	Custom	Custom (Omnet++)
[201]	China	Trading	Efficiency	Custom	Custom
[202]	Estonia	Trading	Efficiency	Custom (Profit Order)	Custom
[203]	India	Trading	Efficiency	Custom	Custom
[204]	Morocco	Trading	Efficiency	Custom	Custom
[205]	Quatar	Trading	Efficiency	Proof of Work	Ethereum
[206]	Australia	Trading	Efficiency	Byzantine Fault Tolerant	Ethereum
[207]	Taiwan	Trading	Efficiency	Byzantine Fault Tolerant	Custom
[208]	India	Trading	Efficiency	Proof of Work	Ethereum
[209]	Pakistan	Trading	Security	Proof of Work	Ethereum
[210]	Canada	Data	Efficiency	Custom	Custom
[93]	Italy	Data	Security	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[211]	China	Trading	Trust	Custom	Custom
[212]	China	Data	Security	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[213]	China	Trading	Efficiency	Proof of Work	Ethereum
[214]	China	Data	Security	Custom (Byzantine Fault Tolerance)	Custom (MATLAB)
[215]	China	Trading	Efficiency	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[216]	China	Trading	Efficiency	Custom	Custom (MATLAB)
[217]	Australia	Data	Efficiency	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[218]	India	Trading	Efficiency	Proof of Work	Ethereum
[219]	China	Data	Security	Custom	Custom
[220]	India	Data	Efficiency	Proof of Work	Ethereum
[221]	United States	Trading	Efficiency	Custom	Custom
[121]	India	Data	Trust	Proof of Work	Ethereum
[222]	China	Trading	Security	Crash Fault Tolerant (RAFT)	Hyperledger (Fabric)
[223]	Canada	Trading	Efficiency	Custom	Custom
[224]	Saudi Arabia	Trading	Efficiency	Custom	Custom
[225]	China	Trading	Efficiency	Custom	Custom
[226]	China	Trading	Security	Byzantine Fault Tolerant	Custom
[227]	USA	Trading	Efficiency	Custom	Custom
[98]	China	Trading	Efficiency	Byzantine Fault Tolerant	Hyperledger (Fabric)
[228]	China	Data	Trust	Byzantine Fault Tolerant	Ethereum
[229]	Italy	Data	Security	Proof of Stake	Ethereum
[230]	China	Trading	Efficiency	Custom	Custom
[231]	China	Trading	Efficiency	Custom (Power Utility Ration Function)	Ethereum
[232]	China	Trading	Efficiency	Byzantine Fault Tolerant	Custom
[233]	China	Trading	Efficiency	Custom (Blockchain Alliance Consensus)	Hyperledger (Fabric)
[214]	China	Data	Security	Byzantine Fault Tolerant	Custom (IEEE Bus)
[200]	Canada	Data	Security	Custom	Custom (OMNET++)
[234]	Canada	Data	Security	Custom (Proof of Energy Generation)	Avalanche
[235]	China	Data	Efficiency	Custom (Proof of Energy Contribution)	Custom

References

[1] R.G. Junker, et al., Characterizing the energy flexibility of buildings and districts, Appl. Energy 225 (2018) 175–182, https://doi.org/10.1016/j.apenergy.2018.05.037.

[2] M. Diesendorf, B. Elliston, The feasibility of 100% renewable electricity systems: a response to critics, Renew. Sustain. Energy Rev. 93 (May) (2018) 318–330, https://doi.org/10.1016/j.rser.2018.05.042.

[3] G. De Zotti, S.A. Pourmousavi, J.M. Morales, H. Madsen, N.K. Poulsen, A control-based method to meet TSO and DSO ancillary services needs by flexible end-users, IEEE Trans. Power Syst. 35 (3) (2020) 1868–1880, https://doi.org/10.1109/TPWRS.2019.2951623.

[4] M.B. Mollah, et al., Blockchain for future smart grid: a comprehensive survey, IEEE *Internet Things J.* (iv) (2020) 1, https://doi.org/10.1109/jiot.2020.2993601.

[5] W. Deng, T. Huang, H. Wang, A review of the key technology in a blockchain building decentralized trust platform, Mathematics 11 (1) (2023), https://doi.org/10.3390/math11010101.

[6] S. Bhowmik, M. Sarkar, D. Bose, and C.K. Chanda, "Distributed energy trading network: decentralized and secured," 2021, 10.1109/ICEPE50861.2021.9404481.

[7] Y. Xu, P. Ahokangas, S. Yrjölä, T. Koivumäki, The fifth archetype of electricity market: the blockchain marketplace, Wirel. Networks 9 (2019), https://doi.org/10.1007/s11276-019-02065-9.

[8] C. Pop, T. Cioara, M. Antal, I. Anghel, I. Salomie, M. Bertoncini, Blockchain based decentralized management of demand response programs in smart energy grids, Sensors 18 (1) (2018), https://doi.org/10.3390/s18010162.

[9] A.K. Yadav, K. Singh, A.H. Amin, L. Almutairi, T.R. Alsenani, A. Ahmadian, A comparative study on consensus mechanism with security threats and future scopes: blockchain, Comput. Commun. 201 (January) (2023) 102–115, https://doi.org/10.1016/j.comcom.2023.01.018.

[10] A.A. Khan, A.A. Laghari, Z.A. Shaikh, Z. Dacko-Pikiewicz, S. Kot, Internet of Things (IoT) security with blockchain technology: a state-of-the-art review, IEEE *Access.* 10 (November) (2022) 122679–122695, https://doi.org/10.1109/ACCESS.2022.3223370.

[11] T. Wang, H. Hua, Z. Wei, J. Cao, Challenges of blockchain in new generation energy systems and future outlooks, Int. J. Electr. Power Energy Syst. 135 (May 2021) (2022) 107499, https://doi.org/10.1016/j.ijepes.2021.107499.

[12] A.S. Yahaya, N. Javaid, M.U. Javed, M. Shafiq, W.Z. Khan, M.Y. Aalsalem, Blockchain-based energy trading and load balancing using contract theory and reputation in a smart community, IEEE *Access.* 8 (2020) 222168–222186, https://doi.org/10.1109/ACCESS.2020.3041931.

[13] H. Taherdoost, Smart contracts in blockchain technology: a critical review, Inf 14 (2) (2023), https://doi.org/10.3390/info14020117.

[14] U. Zaman, F.Mehmood Imran, N. Iqbal, J. Kim, M. Ibrahim, Towards secure and intelligent internet of health things: a survey of enabling technologies and applications, Electron 11 (12) (2022) 1–43, https://doi.org/10.3390/electronics11121893.

[15] S. Alam, et al., Blockchain-based Initiatives: current state and challenges, Comput. Networks 198 (2021), https://doi.org/10.1016/j.comnet.2021.108395.

[16] P. Jiang, et al., Blockchain technology applications in waste management: overview, challenges and opportunities, J. Clean. Prod. 421 (2023), https://doi.org/10.1016/j.jclepro.2023.138466.

[17] R. Karaszewski, P. Modrzyński, G.T. Müldür, J. Wójcik, Blockchain technology in life cycle assessment— new research trends, Energies 14 (24) (2021), https://doi.org/10.3390/en14248292.

[18] P. Bansal, R. Panchal, S. Bassi, A. Kumar, Blockchain for cybersecurity: a comprehensive survey, in: Proc. - 2020 IEEE 9th Int. Conf. Commun. Syst. Netw.

Technol. CSNT 2020, 2020, pp. 260–265, https://doi.org/10.1109/CSNT48778.2020.9115738.
[19] M. Berneis, D. Bartsch, H. Winkler, Applications of blockchain technology in logistics and supply chain management—insights from a systematic literature review, Logistics 5 (3) (2021), https://doi.org/10.3390/logistics5030043.
[20] A.C. Careja, N. Tapus, Digital identity using blockchain technology, Procedia Comput. Sci. 221 (2023) 1074–1082, https://doi.org/10.1016/j.procs.2023.08.090.
[21] A. Phadke, F.Antonio Medrano, S. Ustymenko, Applications of blockchain in E-government, in: Proc. - 2022 Int. Symp. Electr. Electron. Inf. Eng. ISEEIE 2022, 2022, pp. 157–164, https://doi.org/10.1109/ISEEIE55684.2022.00035.
[22] J. Wu, N.K. Tran, Application of blockchain technology in sustainable energy systems: an overview, Sustain 10 (9) (2018) 1–22, https://doi.org/10.3390/su10093067.
[23] World Energy Counsil, "World Energy Insights Brief 2018 IS blockchain in energy driving an evolution or a revolution?," p. 38, 2018, [Online]. Available: www.worldenergy.org.
[24] C. Burger, J. Weinmann, Blockchain platforms in energy markets—a critical assessment, J. Risk Financ. Manag. 15 (11) (2022) 516, https://doi.org/10.3390/jrfm15110516.
[25] A. Khatoon, P. Verma, J. Southernwood, B. Massey, P. Corcoran, Blockchain in energy efficiency: potential applications and benefits, Energies 12 (17) (2019), https://doi.org/10.3390/en12173317.
[26] N. Wang, et al., When energy trading meets blockchain in electrical power system: the state of the art, Appl. Sci. 9 (8) (2019), https://doi.org/10.3390/app9081561.
[27] F. Ö. Ö. Safdar Ali, S. Member, O. Bouachir, Ö. Özkasap, S. Member, M. Aloqaily, SynergyChain: blockchain-assisted adaptive cyber-physical P2P energy trading, IEEE Trans. Ind. Informatics 17 (8) (2021), https://doi.org/10.1109/TII.2021.3046744.
[28] M. Khorasany, A. Dorri, R. Razzaghi, R. Jurdak, Lightweight blockchain framework for location-aware peer-to-peer energy trading, Int. J. Electr. Power Energy Syst. 127 (2021), https://doi.org/10.1016/j.ijepes.2020.106610.
[29] B. Wang, et al., Design of a privacy-preserving decentralized energy trading scheme in blockchain network environment, Int. J. Electr. Power Energy Syst. 125 (2021), https://doi.org/10.1016/j.ijepes.2020.106465.
[30] Z. Huang, et al., A novel power market mechanism based on blockchain for electric vehicle charging stations, Electron 10 (3) (2021) 1–21, https://doi.org/10.3390/electronics10030307.
[31] S.J. Hosseini Dehshiri, M. Amiri, A. Mostafaeipour, T. Le, Integrating blockchain and strategic alliance in renewable energy supply chain toward sustainability: a comparative decision framework under uncertainty, Energy 304 (March) (2024) 132136, https://doi.org/10.1016/j.energy.2024.132136.
[32] A. Lakhan, et al., BEDS: blockchain energy efficient IoE sensors data scheduling for smart home and vehicle applications, Appl. Energy 369 (June) (2024) 123535, https://doi.org/10.1016/j.apenergy.2024.123535.
[33] F. Jamil, N. Iqbal, S.Ahmad Imran, D. Kim, Peer-to-peer energy trading mechanism based on blockchain and machine learning for sustainable electrical power supply in smart grid, IEEE *Access*. 9 (2021) 39193–39217, https://doi.org/10.1109/ACCESS.2021.3060457.
[34] X. Wang, W. Yang, S. Noor, C. Chen, M. Guo, K.H. Van Dam, Blockchain-based smart contract for energy demand management, Energy Procedia 158 (2019) 2719–2724, https://doi.org/10.1016/j.egypro.2019.02.028.
[35] S. Seven, et al., Energy trading on a peer-to-peer basis between virtual power plants using decentralized finance instruments, Sustain 14 (20) (2022), https://doi.org/10.3390/su142013286.
[36] D. Strepparava, L. Nespoli, E. Kapassa, M. Touloupou, L. Katelaris, V. Medici, Deployment and analysis of a blockchain-based local energy market, Energy Reports 8 (2022) 99–113, https://doi.org/10.1016/j.egyr.2021.11.283.
[37] S. Hartnett, et al., The energy web chain, Accel. Energy Transit. with an Open-Source, Decentralized Blockchain Platf. (October) (2018) [Online]. Available, http://www.energyweb.org/papers/the-energy-web-chain.
[38] W. Zhao, Q. Qi, J. Zhou, X. Luo, Blockchain-based applications for smart grids: an umbrella review, Energies 16 (17) (2023) 1–35, https://doi.org/10.3390/en16176147.
[39] "Energy Efficiency. Reinvented. | EFFORCE." https://www.efforce.io/ (accessed Jul. 16, 2024).
[40] "Blok-Z | 24/7 hourly CFE matching." https://www.blok-z.com/ (accessed Jul. 16, 2024).
[41] World EnergyCouncil and PwC, "The developing role of blockchain," p. 22, 2017, 10.1017/S0020818300023973.
[42] O. Juszczyk, K. Shahzad, Blockchain technology for renewable energy: principles, applications and prospects, Energies 15 (13) (2022), https://doi.org/10.3390/en15134603.
[43] L. Zhang, T. Wang, S.C. Liew, Speeding up block propagation in Bitcoin network: uncoded and coded designs, Comput. Networks 206 (October 2021) (2022) 108791, https://doi.org/10.1016/j.comnet.2022.108791.
[44] A. Yadlapalli, S. Rahman, P. Gopal, Blockchain technology implementation challenges in supply chains – evidence from the case studies of multi-stakeholders, Int. J. Logist. Manag. 33 (5) (2022) 278–305, https://doi.org/10.1108/IJLM-02-2021-0086.
[45] M.M. Ferdaus, T. Dam, S. Anavatti, S. Das, Digital technologies for a net-zero energy future: a comprehensive review, Renew. Sustain. Energy Rev. 202 (March 2023) (2024) 114681, https://doi.org/10.1016/j.rser.2024.114681.
[46] S. Edward, "The policy environment for blockchain innovation and adoption 2019 OECD global blockchain policy forum summary report OECD blockchain policy series," 2019.
[47] M. Andoni, et al., Blockchain technology in the energy sector: a systematic review of challenges and opportunities, Renew. Sustain. Energy Rev. 100 (2019) 143–174, https://doi.org/10.1016/j.rser.2018.10.014.
[48] C.C. Kuo, J.Z. Shyu, A cross-national comparative policy analysis of the blockchain technology between the USA and china, Sustain 13 (12) (2021), https://doi.org/10.3390/su13126893.
[49] Price Water House Coopers, "Establishing blockchain policy," 2019.
[50] Q. Wang, M. Su, Integrating blockchain technology into the energy sector - from theory of blockchain to research and application of energy blockchain, Comput. Sci. Rev. 37 (2020) 100275, https://doi.org/10.1016/j.cosrev.2020.100275.
[51] L. Ante, F. Steinmetz, I. Fiedler, Blockchain and energy: a bibliometric analysis and review, Renew. Sustain. Energy Rev. 137 (2021), https://doi.org/10.1016/j.rser.2020.110597.
[52] A. Miglani, N. Kumar, V. Chamola, S. Zeadally, Blockchain for internet of energy management: review, solutions, and challenges, Comput. Commun. 151 (2020) 395–418, https://doi.org/10.1016/j.comcom.2020.01.014.
[53] T. Roth, M. Utz, F. Baumgarte, A. Rieger, J. Sedlmeir, J. Strüker, Electricity powered by blockchain: a review with a European perspective, Appl. Energy 325 (August) (2022) 119799, https://doi.org/10.1016/j.apenergy.2022.119799.
[54] M. Casquiço, B. Mataloto, J.C. Ferreira, V. Monteiro, J.L. Afonso, J.A. Afonso, Blockchain and internet of things for electrical energy decentralization: a review and system architecture, Energies 14 (23) (2021) 1–26, https://doi.org/10.3390/en14238043.
[55] V.K. Mololoth, S. Saguna, C. Åhlund, Blockchain and machine learning for future smart grids: a review, Energies 16 (1) (2023), https://doi.org/10.3390/EN16010528.
[56] M.J. Page, et al., The PRISMA 2020 statement: an updated guideline for reporting systematic reviews, Syst. Rev. 10 (1) (2021), https://doi.org/10.1186/s13643-021-01626-4.
[57] C. Sohrabi, et al., PRISMA 2020 statement: what's new and the importance of reporting guidelines, Int. J. Surg. 88 (March) (2021) 39–42, https://doi.org/10.1016/j.ijsu.2021.105918.
[58] E. Kapassa, M. Themistocleous, Blockchain technology applied in IoV demand response management: a systematic literature review, Futur. Internet 14 (5) (2022), https://doi.org/10.3390/fi14050136.
[59] L.F. Cabeza, M. Chàfer, É. Mata, Comparative analysis of web of science and scopus on the energy efficiency and climate impact of buildings, Energies 13 (2) (2020), https://doi.org/10.3390/en13020409.
[60] B. Akash, A.M.A. Abdo, O. Akash, M.S. Mohsen, Scopus-based analysis of peer-reviewed literature related to solar energy in GCC countries, Procedia Comput. Sci. 83 (Seit) (2016) 750–757, https://doi.org/10.1016/j.procs.2016.04.163.
[61] S. Stahlschmidt, D. Stephen, Comparison of web of science, scopus and dimensions databases, in: Comp. Web Sci. Scopus Dimens. Databases - KB Forschungspoolprojekt 2020, 2020, p. 37 [Online]. Available, https://bibliometrie.info/downloads/DZHW-Comparison-DIM-SCP-WOS.PDF.
[62] M.A. Hisseine, D. Chen, X. Yang, The application of blockchain in social media: a systematic literature review, Appl. Sci. 12 (13) (2022), https://doi.org/10.3390/app12136567.
[63] F. Cassez, J. Fuller, A. Asgaonkar, Formal Verification of the Ethereum 2.0 Beacon Chain, Springer International Publishing, 2022, 13243 LNCS.
[64] Australian Government, The national blockchain roadmap, Aust. Gov. Dep. Ind. Sci. Energy Resour. (2020) [Online]. Available: INDUSTRY.GOV.AU/BLOCKCHAIN.
[65] European Commission, "Blockchain funding and investment Funding for research and innovation Funding for contracts to help build the European Blockchain," 2020.
[66] Coindesk, Blockchain Venture Capital, Coindesk, 2021 [Online]. Available, https://www.coindesk.com/bitcoin-venture-capital.
[67] N. Renu, Technological advancement in the era of COVID-19, SAGE Open Med. 9 (2021), https://doi.org/10.1177/20503121211000912.
[68] R. De', N. Pandey, A. Pal, Impact of digital surge during Covid-19 pandemic: a viewpoint on research and practice, Int. J. Inf. Manage. 55 (June) (2020) 102171, https://doi.org/10.1016/j.ijinfomgt.2020.102171.
[69] Z.R. Alashhab, M. Anbar, M.M. Singh, Y.B. Leau, Z.A. Al-Sai, S.A. Alhayja'a, Impact of coronavirus pandemic crisis on technologies and cloud computing applications, J. Electron. Sci. Technol. 19 (1) (2021) 25–40, https://doi.org/10.1016/j.jnlest.2020.100059.
[70] A. Jalan, R. Matkovskyy, Systemic risks in the cryptocurrency market: evidence from the FTX collapse, Financ. Res. Lett. 53 (December 2022) (2023) 103670, https://doi.org/10.1016/j.frl.2023.103670.
[71] Y.L. Chen, Y.T. Chang, J.J. Yang, Cryptocurrency hacking incidents and the price dynamics of Bitcoin spot and futures, Financ. Res. Lett. 55 (PB) (2023) 103955, https://doi.org/10.1016/j.frl.2023.103955.
[72] O. Taylan, A.S. Alkabaa, M.T. Yılmaz, Impact of COVID-19 on G20 countries: analysis of economic recession using data mining approaches, Financ. Innov. 8 (1) (2022), https://doi.org/10.1186/s40854-022-00385-y.
[73] J.S. Søgaard, P.W. Eklund, L. Herskind, J. Spasovski, Improving trust in a (trans) national invoicing system: the performance of crash vs. byzantine fault tolerance at scale, Appl. Sci. 13 (12) (2023) 6941, https://doi.org/10.3390/app13126941.
[74] A. Bischi, et al., Enabling low-voltage, peer-to-peer, quasi-real-time electricity markets through consortium blockchains, Appl. Energy 288 (2021), https://doi.org/10.1016/j.apenergy.2020.116365.

[75] T. Rocket, M. Yin, K. Sekniqi, R. van Renesse, and E.G. Sirer, "Scalable and probabilistic leaderless BFT consensus through metastability," 2019, [Online]. Available: http://arxiv.org/abs/1906.08936.
[76] G. Vasukidevi, T. Sethukarasi, BBSSE: blockchain-based safe storage, secure sharing and energy scheme for smart grid network, Wirel. Pers. Commun. (2021), https://doi.org/10.1007/s11277-021-08406-2.
[77] P. Sharma, R. Senapati, A. Swetapadma, Mathematical modeling for matching the prosumers in decentralized energy trading system, in: 11th IEEE International Conference on Renewable Energy Research and Applications, ICRERA 2022, 2022, pp. 502–507, https://doi.org/10.1109/ICRERA55966.2022.9922776.
[78] T. Wang, J. Guo, S. Ai, J. Cao, RBT: a distributed reputation system for blockchain-based peer-to-peer energy trading with fairness consideration, Appl. Energy 295 (2021), https://doi.org/10.1016/j.apenergy.2021.117056.
[79] N. Karandikar, A. Chakravorty, C. Rong, Blockchain based transaction system with fungible and non-fungible tokens for a community-based energy infrastructure, Sensors 21 (11) (2021), https://doi.org/10.3390/s21113822.
[80] E. Kapengut, B. Mizrach, An event study of the ethereum transition to proof-of-stake, Commodities 2 (2) (2023) 96–110, https://doi.org/10.3390/commodities2020006.
[81] S. Zhao, S. Zhu, Z. Wu, B. Jaing, Cooperative energy dispatch of smart building cluster based on smart contracts, Int. J. Electr. Power Energy Syst. 138 (2022), https://doi.org/10.1016/j.ijepes.2021.107896.
[82] Y. Chen, C. Bellavitis, Blockchain disruption and decentralized finance: the rise of decentralized business models, J. Bus. Ventur. Insights 13 (November 2019) (2020) e00151, https://doi.org/10.1016/j.jbvi.2019.e00151.
[83] S. Nanayakkara, M.N.N. Rodrigo, S. Perera, G.T. Weerasuriya, A.A. Hijazi, A methodology for selection of a blockchain platform to develop an enterprise system, J. Ind. Inf. Integr. 23 (January) (2021) 100215, https://doi.org/10.1016/j.jii.2021.100215.
[84] M.R. Hamouda, M.E. Nassar, M.M.A. Salama, A novel energy trading framework using adapted blockchain technology, IEEE Trans. Smart Grid 12 (3) (2021) 2165–2175, https://doi.org/10.1109/TSG.2020.3045662.
[85] M.F. Munoz, K. Zhang, and F. Amara, "ZipZap: a blockchain solution for local energy trading," 2022, 10.1109/ICBC54727.2022.9805486.
[86] M. Baza, R. Amer, A. Rasheed, G. Srivastava, M. Mahmoud, and W. Alasmary, "A blockchain-based energy trading scheme for electric vehicles," 2021, 10.1109/CCNC49032.2021.9369517.
[87] W. Tan, et al., Blockchain-based distributed power transaction mechanism considering credit management, Energy Rep. 8 (2022) 565–572, https://doi.org/10.1016/j.egyr.2022.02.240.
[88] Y. Yao, C. Gao, T. Chen, J. Yang, S. Chen, Distributed electric energy trading model and strategy analysis based on prospect theory, Int. J. Electr. Power Energy Syst. 131 (2021), https://doi.org/10.1016/j.ijepes.2021.106865.
[89] H. Lu, et al., A blockchain-based trading framework for community electricity market, in: I and CPS Asia 2022 - 2022 IEEE IAS Industrial and Commercial Power System Asia, 2022, pp. 1906–1911, https://doi.org/10.1109/ICPSAsia55496.2022.9949866.
[90] Y.X. Liu, F. Zhou, Electricity market transaction model design combining blockchain and machine learning, in: 2021 IEEE International Conference on Consumer Electronics and Computer Engineering, ICCECE 2021, 2021, pp. 458–464, https://doi.org/10.1109/ICCECE51280.2021.9342201.
[91] A. Augusto, R. Belchior, A. Vasconcelos, I. Kocsis, G. László, and M. Correia, "CBDC bridging between Hyperledger fabric and permissioned EVM-based blockchains," 2023, [Online]. Available: https://doi.org/10.36227/techrxiv.21809430.v2%0A https://ndownloader.figshare.com/files/39685807.
[92] K. Christidis, D. Sikeridis, Y. Wang, M. Devetsikiotis, A framework for designing and evaluating realistic blockchain-based local energy markets, Appl. Energy 281 (2021), https://doi.org/10.1016/j.apenergy.2020.115963.
[93] L. Bracciale, P. Loreti, E. Raso, G. Bianchi, P. Gallo, E.R. Sanseverino, A privacy-preserving blockchain solution to support demand response in energy trading, in: MELECON 2022 - IEEE Mediterranean Electrotechnical Conference, Proceedings, 2022, pp. 677–682, https://doi.org/10.1109/MELECON53508.2022.9843108.
[94] E. Androulaki, et al., Hyperledger fabric: a distributed operating system for permissioned blockchains, in: Proc. 13th EuroSys Conf. EuroSys 2018 2018-Janua, 2018, https://doi.org/10.1145/3190508.3190538.
[95] A. Esmat, M. de Vos, Y. Ghiassi-Farrokhfal, P. Palensky, D. Epema, A novel decentralized platform for peer-to-peer energy trading market with blockchain technology, Appl. Energy 282 (2021), https://doi.org/10.1016/j.apenergy.2020.116123.
[96] J. Abdella, Z. Tari, A. Anwar, A. Mahmood, F. Han, An architecture and performance evaluation of blockchain-based peer-to-peer energy trading, IEEE Trans. Smart Grid 12 (4) (2021) 3364–3378, https://doi.org/10.1109/TSG.2021.3056147.
[97] A. Lohachab, S. Garg, B.H. Kang, M.B. Amin, Performance evaluation of hyperledger fabric-enabled framework for pervasive peer-to-peer energy trading in smart Cyber–Physical Systems, Futur. Gener. Comput. Syst. 118 (2021) 392–416, https://doi.org/10.1016/j.future.2021.01.023.
[98] X. Wang, Y. Liu, Blockchain enabled smart community for bilateral energy transaction, SSRN Electron. J. 148 (2022), https://doi.org/10.2139/ssrn.4200144.
[99] "What are reasons for the deprecation of hyperledger composer? - stack overflow." https://stackoverflow.com/questions/57423380/what-are-reasons-for-the-deprecation-of-hyperledger-composer (accessed Jul. 13, 2024).
[100] D. Li, W.E. Wong, J. Guo, A survey on blockchain for enterprise using hyperledger fabric and composer, in: Proc. - 2019 6th Int. Conf. Dependable Syst. Their Appl. DSA 2019, 2020, pp. 71–80, https://doi.org/10.1109/DSA.2019.00017.
[101] "Hyperledger Indy — Hyperledger Indy 1.0 documentation." https://hyperledger-indy.readthedocs.io/en/latest/ (accessed Jul. 13, 2024).
[102] "2020 Q2 Hyperledger Indy - technical oversight committee - Hyperledger foundation." https://wiki.hyperledger.org/display/TSC/2020+Q2+Hyperledger+Indy (accessed Jul. 13, 2024).
[103] G. Lakshmi, G. Thiyagarajan, Decentralized energy to power rural homes through smart contracts and carbon credit, in: Proceedings of the 7th International Conference on Electrical Energy Systems, ICEES 2021, 2021, pp. 280–283, https://doi.org/10.1109/ICEES51510.2021.9383683.
[104] K. Christina, R. Kesavamoorthy, Evolution of blockchain and smart contracts: a state of the art review, in: Proc. 2023 Int. Conf. Intell. Syst. Commun. IoT Secur. ICISCoIS 2023, 2023, pp. 235–240, https://doi.org/10.1109/ICISCoIS56541.2023.10100456.
[105] M.A. Uddin, A. Stranieri, I. Gondal, V. Balasubramanian, A survey on the adoption of blockchain in IoT: challenges and solutions, Blockchain Res. Appl. 2 (2) (2021) 100006, https://doi.org/10.1016/j.bcra.2021.100006.
[106] P. Drakatos, Blockchain data management for IoT applications, in: Proc. - IEEE Int. Conf. Mob. Data Manag. 2022-June, 2022, pp. 337–339, https://doi.org/10.1109/MDM55031.2022.00076.
[107] H. Wang, J. Xuan, R. Qin, S. Han, Research on the application of identifier resolution and blockchain technology in the new energy field, in: IOP Conference Series: Earth and Environmental Science 632, 2021, https://doi.org/10.1088/1755-1315/632/3/032024.
[108] K. Zhou, J. Chong, X. Lu, S. Yang, Credit-based peer-to-peer electricity trading in energy blockchain environment, IEEE Trans. Smart Grid 13 (1) (2022) 678–687, https://doi.org/10.1109/TSG.2021.3111181.
[109] A.S. Yahaya, et al., A secure and efficient energy trading model using blockchain for a 5G-deployed smart community, Wirel. Commun. Mob. Comput. 2022 (2022), https://doi.org/10.1155/2022/6953125.
[110] M. Galici, et al., Energy blockchain for public energy communities, Appl. Sci. 11 (8) (2021), https://doi.org/10.3390/app11083457.
[111] S. Ellis, A. Juels, and S. Nazarov, "ChainLink: a decentralized oracle network," vol. 2017, no. September, pp. 1–38, 2017, [Online]. Available: https://link.smartcontract.com/whitepaper.
[112] S. Chen, J. Ping, Z. Yan, J. Li, Z. Huang, Blockchain in energy systems: values, opportunities, and limitations, Front. Energy 16 (1) (2022) 9–18, https://doi.org/10.1007/s11708-022-0818-8.
[113] S. Rehman, et al., Bi-directional mutual energy trade between smart grid and energy districts using renewable energy credits, Sensors 21 (9) (2021), https://doi.org/10.3390/s21093088.
[114] T. Cioara, M. Antal, V.T. Mihailescu, C.D. Antal, I.M. Anghel, D. Mitrea, Blockchain-based decentralized virtual power plants of small prosumers, IEEE *Access.* 9 (2021) 29490–29504, https://doi.org/10.1109/ACCESS.2021.3059106.
[115] S. Eisele, T. Eghtesad, K. Campanelli, P. Agrawal, A. Laszka, A. Dubey, Safe and private forward-trading platform for transactive microgrids, ACM Trans. Cyber-Physical Syst. 5 (1) (2021), https://doi.org/10.1145/3403711.
[116] E. Morais, T. Koens, C. van Wijk, A. Koren, A survey on zero knowledge range proofs and applications, SN Appl. Sci. 1 (8) (2019) 1–17, https://doi.org/10.1007/s42452-019-0989-z.
[117] J.C. Ferreira, C.F. da Silva, J.P. Martins, Roaming service for electric vehicle charging using blockchain-based digital identity, Energies 14 (6) (2021), https://doi.org/10.3390/en14061686.
[118] st Jun Wook Heo, Gowri Ramachandran, PPoS : practical proof of storage for blockchain full nodes, in: 2023 IEEE Int. Conf. Blockchain Cryptocurrency, 2023, pp. 1–9, https://doi.org/10.1109/ICBC56567.2023.10174897.
[119] Y.C. Tsao, V. Van Thanh, Toward blockchain-based renewable energy microgrid design considering default risk and demand uncertainty, Renew. Energy 163 (2021) 870–881, https://doi.org/10.1016/j.renene.2020.09.016.
[120] T. Ranathunga, R. Marfievici, A. McGibney, S. Rea, A distributed ledger based platform for automated energy performance assessment, in: 2021 3rd International Conference on Blockchain Computing and Applications, BCCA 2021, 2021, pp. 65–72, https://doi.org/10.1109/BCCA53669.2021.9657038.
[121] G. Subramanian and A.S. Thampy, "Blockchain consortium for electric vehicles to enhance the security," 2022, 10.1109/ICONAT53423.2022.9725887.
[122] H. Yi, W. Lin, X. Huang, X. Cai, R. Chi, Z. Nie, Energy trading IoT system based on blockchain, Swarm Evol. Comput. 64 (2021), https://doi.org/10.1016/j.swevo.2021.100891.
[123] A. Kavousi-Fard, A. Almutairi, A. Al-Sumaiti, A. Farughian, S. Alyami, An effective secured peer-to-peer energy market based on blockchain architecture for the interconnected microgrid and smart grid, Int. J. Electr. Power Energy Syst. 132 (2021), https://doi.org/10.1016/j.ijepes.2021.107171.
[124] L. Wang, et al., A permissioned blockchain-based energy management system for renewable energy microgrids, Sustain 13 (3) (2021) 1–19, https://doi.org/10.3390/su13031317.
[125] W. Xu, J. Li, M. Dehghani, M. GhasemiGarpachi, Blockchain-based secure energy policy and management of renewable-based smart microgrids, Sustain. Cities Soc. 72 (2021), https://doi.org/10.1016/j.scs.2021.103010.
[126] J. Li, A design of the settlement mode of the electric vehicles' shared private piles based on the energy block chain, in: E3S Web of Conferences 257, 2021, https://doi.org/10.1051/e3sconf/202125701053.
[127] W. Yang, Z. Guan, L. Wu, X. Du, M. Guizani, Secure data access control with fair accountability in smart grid data sharing: an edge blockchain approach, IEEE *Internet Things J.* 8 (10) (2021) 8632–8643, https://doi.org/10.1109/JIOT.2020.3047640.

[128] G. Vieira, J. Zhang, Peer-to-peer energy trading in a microgrid leveraged by smart contracts, Renew. Sustain. Energy Rev. 143 (2021), https://doi.org/10.1016/j.rser.2021.110900.
[129] S.V. Oprea, A. Bâra, Devising a trading mechanism with a joint price adjustment for local electricity markets using blockchain. Insights for policy makers, Energy Policy 152 (2021), https://doi.org/10.1016/j.enpol.2021.112237.
[130] A. Muzumdar, C. Modi, G.M. Madhu, C. Vyjayanthi, A trustworthy and incentivized smart grid energy trading framework using distributed ledger and smart contracts, J. Netw. Comput. Appl. (2021) 183–184, https://doi.org/10.1016/j.jnca.2021.103074.
[131] A. Belov and S. Slastnikov, "Blockchain technology to manage the energy supply of real estate," 2021, 10.1109/IEMTRONICS52119.2021.9422552.
[132] Q. Yang, H. Wang, Blockchain-empowered socially optimal transactive energy system: framework and implementation, IEEE Trans. Ind. Informatics 17 (5) (2021) 3122–3132, https://doi.org/10.1109/TII.2020.3027577.
[133] R. Premkumar, P.S. Sathya, A blockchain based framework for IoT security, in: Proceedings - 5th International Conference on Computing Methodologies and Communication, ICCMC 2021, 2021, pp. 409–413, https://doi.org/10.1109/ICCMC51019.2021.9418485.
[134] S. Wen, W. Xiong, J. Tan, S. Chen, Q. Li, Blockchain enhanced price incentive demand response for building user energy network in sustainable society, Sustain. Cities Soc. 68 (2021), https://doi.org/10.1016/j.scs.2021.102748.
[135] Y. Chang, et al., Research on nearby consumption of renewable energy and electric power user matching method based on energy blockchain technology, in: 2021 3rd Asia Energy and Electrical Engineering Symposium, AEEES 2021, 2021, pp. 1060–1069, https://doi.org/10.1109/AEEES51875.2021.9402964.
[136] J. Guerrero, B. Sok, A.C. Chapman, G. Verbič, Electrical-distance driven peer-to-peer energy trading in a low-voltage network, Appl. Energy 287 (2021), https://doi.org/10.1016/j.apenergy.2021.116598.
[137] Y. Wu, X. Zhang, H. Sun, A multi-time-scale autonomous energy trading framework within distribution networks based on blockchain, Appl. Energy 287 (2021), https://doi.org/10.1016/j.apenergy.2021.116560.
[138] Z. Guan, X. Lu, W. Yang, L. Wu, N. Wang, Z. Zhang, Achieving efficient and Privacy-preserving energy trading based on blockchain and ABE in smart grid, J. Parallel Distrib. Comput. 147 (2021) 34–45, https://doi.org/10.1016/j.jpdc.2020.08.012.
[139] F. Yin, et al., A secured social-economic framework based on PEM##grids, IEEE *Access.* 9 (2021) 40797–40810, https://doi.org/10.1109/ACCESS.2021.3065400.
[140] Y. Zhang, Q. Shi, An intelligent transaction model for energy blockchain based on diversity of subjects, Alexandria Eng. J. 60 (1) (2021) 749–756, https://doi.org/10.1016/j.aej.2020.10.005.
[141] T. Alskaif, J.L. Crespo-Vazquez, M. Sekuloski, G.V. Leeuwen, J.P.S. Catalao, Blockchain-based fully peer-to-peer energy trading strategies for residential energy systems, IEEE Trans. Ind. Informatics (2021), https://doi.org/10.1109/TII.2021.3077008.
[142] W. Hu, H. Li, A blockchain-based secure transaction model for distributed energy in Industrial Internet of Things, Alexandria Eng. J. 60 (1) (2021) 491–500, https://doi.org/10.1016/j.aej.2020.09.021.
[143] T. Gaybullaev, H.Y. Kwon, T. Kim, M.K. Lee, Efficient and privacy-preserving energy trading on blockchain using dual binary encoding for inner product encryption†, Sensors 21 (6) (2021) 1–26, https://doi.org/10.3390/s21062024.
[144] U. Javaid and B. Sikdar, "A lightweight and secure energy trading framework for electric vehicles," 2021, 10.1109/SeFet48154.2021.9375754.
[145] Y. Sun, et al., The research of source-load transaction mechanism based on blockchain, in: IOP Conference Series: Earth and Environmental Science 675, 2021, https://doi.org/10.1088/1755-1315/675/1/012142.
[146] J.G. Song, E.S. Kang, H.W. Shin, J.W. Jang, A smart contract-based p2p energy trading system with dynamic pricing on ethereum blockchain, Sensors 21 (6) (2021) 1–27, https://doi.org/10.3390/s21061985.
[147] A. Lucas, D. Geneiatakis, Y. Soupionis, I. Nai-Fovino, E. Kotsakis, Blockchain technology applied to energy demand response service tracking and data sharing, Energies 14 (7) (2021), https://doi.org/10.3390/en14071881.
[148] S. Kwak, J. Lee, Implementation of blockchain based P2P energy trading platform, in: International Conference on Information Networking 2021-Janua, 2021, pp. 755–757, https://doi.org/10.1109/ICOIN50884.2021.9333876.
[149] R. Moreno, C. Hoyos, S. Cantillo, A framework from peer-to-peer electricity trading based on communities transactions, Int. J. Energy Econ. Policy 11 (3) (2021) 537–545, https://doi.org/10.32479/ijeep.11077.
[150] C. Shah, J. King, R.W. Wies, Distributed ADMM using private blockchain for power flow optimization in distribution network with coupled and mixed-integer constraints, IEEE *Access.* 9 (2021) 46560–46572, https://doi.org/10.1109/ACCESS.2021.3066970.
[151] S. Saha, N. Ravi, K. Hreinsson, J. Baek, A. Scaglione, N.G. Johnson, A secure distributed ledger for transactive energy: the Electron Volt Exchange (EVE) blockchain, Appl. Energy 282 (2021), https://doi.org/10.1016/j.apenergy.2020.116208.
[152] J. Kalbantner, K. Markantonakis, D. Hurley-Smith, R.N. Akram, B. Semal, P2pedge: a decentralised, scalable p2p architecture for energy trading in real-time, Energies 14 (3) (2021), https://doi.org/10.3390/en14030606.
[153] X. Chen, T. Zhang, W. Ye, Z. Wang, H.H.C. Iu, Blockchain-based electric vehicle incentive system for renewable energy consumption, IEEE Trans. Circuits Syst. II Express Briefs 68 (1) (2021) 396–400, https://doi.org/10.1109/TCSII.2020.2996161.
[154] A. Kalakova, A. Zhanatbekov, A. Surash, H.S.V.S. Kumar Nunna, and S. Doolla, "Blockchain-based decentralized transactive energy auction model with demand response," 2021, 10.1109/TPEC51183.2021.9384958.
[155] M. Dabbaghjamanesh, B. Wang, A. Kavousi-Fard, N.D. Hatziargyriou, J. Zhang, Blockchain-based stochastic energy management of interconnected microgrids considering incentive price, IEEE Trans. Control Netw. Syst. 8 (3) (2021) 1201–1211, https://doi.org/10.1109/TCNS.2021.3059851.
[156] G. Yun, V. Zhygulin, Q.P. Zheng, Residential energy trading with blockchain technology, Energy Syst. 12 (3) (2021) 619–636, https://doi.org/10.1007/s12667-021-00426-y.
[157] K. Kaur, G. Kaddoum, S. Zeadally, Blockchain-based cyber-physical security for electrical vehicle aided smart grid ecosystem, IEEE Trans. Intell. Transp. Syst. 22 (8) (2021) 5178–5189, https://doi.org/10.1109/TITS.2021.3068092.
[158] H.T. Doan, J. Cho, D. Kim, Peer-to-peer energy trading in smart grid through blockchain: a double auction-based game theoretic approach, IEEE *Access.* 9 (2021) 49206–49218, https://doi.org/10.1109/ACCESS.2021.3068730.
[159] T. Ha, D. Lee, C. Lee, S. Cho, VCG auction mechanism based on block chain in smart grid, in: International Conference on Information Networking 2021-Janua, 2021, pp. 465–468, https://doi.org/10.1109/ICOIN50884.2021.9333885.
[160] Z. Zeng, M. Dong, W. Miao, M. Zhang, H. Tang, A data-driven approach for blockchain-based smart grid system, IEEE *Access.* 9 (2021) 70061–70070, https://doi.org/10.1109/ACCESS.2021.3076746.
[161] H. Fan, Y. Liu, and Z. Zeng, *Blockchain-based decentralized privacy-preserving data aggregation (BDPDA): scheme for SmartGrid*, vol. 344. 2021.
[162] S.N. Gowda, B.A. Eraqi, H. Nazaripouya, and R. Gadh, "Assessment and tracking electric vehicle battery degradation cost using blockchain," 2021, 10.1109/ISGT49243.2021.9372218.
[163] J. Guo, X. Ding, W. Wu, A blockchain-enabled ecosystem for distributed electricity trading in smart city, IEEE *Internet Things J.* 8 (3) (2021) 2040–2050, https://doi.org/10.1109/JIOT.2020.3015980.
[164] K. Li, Y. Yang, S. Wang, R. Shi, J. Li, A lightweight privacy-preserving and sharing scheme with dual-blockchain for intelligent pricing system of smart grid, Comput. Secur. 103 (2021), https://doi.org/10.1016/j.cose.2021.102189.
[165] M. Dehghani, et al., Blockchain-based securing of data exchange in a power transmission system considering congestion management and social welfare, Sustain 13 (1) (2021) 1–22, https://doi.org/10.3390/su13010090.
[166] M.K. Alashery, et al., A blockchain-enabled multi-settlement quasi-ideal peer-to-peer trading framework, IEEE Trans. Smart Grid 12 (1) (2021) 885–896, https://doi.org/10.1109/TSG.2020.3022601.
[167] A. Al-Obaidi, H. Khani, H.E.Z. Farag, M. Mohamed, Bidirectional smart charging of electric vehicles considering user preferences, peer to peer energy trade, and provision of grid ancillary services, Int. J. Electr. Power Energy Syst. 124 (2021), https://doi.org/10.1016/j.ijepes.2020.106353.
[168] S. Saxena, H.E.Z. Farag, A. Brookson, H. Turesson, H. Kim, A permissioned blockchain system to reduce peak demand in residential communities via energy trading: a real-world case study, IEEE *Access.* 9 (2021) 5517–5530, https://doi.org/10.1109/ACCESS.2020.3047885.
[169] Q. Yang, H. Wang, Privacy-preserving transactive energy management for IoT-aided smart homes via blockchain, IEEE *Internet Things J.* 8 (14) (2021) 11463–11475, https://doi.org/10.1109/JIOT.2021.3051323.
[170] H. Zhang, W. Zhu, C. Wang, Y. Wang, T. Li, Excessive consumption transaction of renewable energy based on blockchain smart contract, in: IOP Conference Series: Earth and Environmental Science 675, 2021, https://doi.org/10.1088/1755-1315/675/1/012119.
[171] H. Ko, I. Praca, Design of a secure energy trading model based on a blockchain, Sustain 13 (4) (2021) 1–11, https://doi.org/10.3390/su13041634.
[172] A. Sadiq, M.U. Javed, R. Khalid, A. Almogren, M. Shafiq, N. Javaid, Blockchain based data and energy trading in internet of electric vehicles, IEEE *Access.* 9 (2021) 7000–7020, https://doi.org/10.1109/ACCESS.2020.3048169.
[173] F.A. Niloy, A. Nayeem, M.M. Rahman, M.N.U. Dowla, Blockchain-based peer-to-peer sustainable energy trading in microgrid using smart contracts, in: International Conference on Robotics, Electrical and Signal Processing Techniques, 2021, pp. 61–66, https://doi.org/10.1109/ICREST51555.2021.9331007.
[174] Y.C. Tsao, V. Van Thanh, Toward sustainable microgrids with blockchain technology-based peer-to-peer energy trading mechanism: a fuzzy meta-heuristic approach, Renew. Sustain. Energy Rev. 136 (2021), https://doi.org/10.1016/j.rser.2020.110452.
[175] A. Kumari, S. Tanwar, A secure data analytics scheme for multimedia communication in a decentralized smart grid, Multimed. Tools Appl. (2021), https://doi.org/10.1007/s11042-021-10512-z.
[176] A. Dorri, F. Luo, S. Karumba, S. Kanhere, R. Jurdak, Z.Y. Dong, Temporary immutability: a removable blockchain solution for prosumer-side energy trading, J. Netw. Comput. Appl. 180 (2021), https://doi.org/10.1016/j.jnca.2021.103018.
[177] R. Mandaroux, C. Dong, G. Li, A European emissions trading system powered by distributed ledger technology: an evaluation framework, Sustain 13 (4) (2021) 1–21, https://doi.org/10.3390/su13042106.
[178] Z. Dlimi, A. Ezzati, S. Ben Alla, A lightweight blockchain for IoT in smart city (IoT-SmartChain, Comput. Mater. Contin. 69 (2) (2021) 2687–2703, https://doi.org/10.32604/cmc.2021.018942.
[179] V. Pangracious, Blockchain based energy trade, in: ACM International Conference Proceeding Series, 2022, pp. 278–283, https://doi.org/10.1145/3491003.3494122.
[180] L. Luo, J. Feng, H. Yu, G. Sun, Blockchain-enabled two-way auction mechanism for electricity trading in internet of electric vehicles, IEEE *Internet Things J.* 9 (11) (2022) 8105–8118, https://doi.org/10.1109/JIOT.2021.3082769.

[181] Z. Xu, Y. Wang, R. Dong, W. Li, Research on multi-microgrid power transaction process based on blockchain technology, Electr. Power Syst. Res. 213 (2022), https://doi.org/10.1016/j.epsr.2022.108649.
[182] N.R. Pradhan, et al., A blockchain based lightweight peer-to-peer energy trading framework for secured high throughput micro-transactions, Sci. Rep. 12 (1) (2022), https://doi.org/10.1038/s41598-022-18603-z.
[183] F. Buccafurri, G. Lax, L. Musarella, A. Russo, An Ethereum-based solution for energy trading in smart grids, Digit. Commun. Networks (2022), https://doi.org/10.1016/j.dcan.2021.12.004.
[184] M.U. Javed, et al., Blockchain based secure, efficient and coordinated energy trading and data sharing between electric vehicles, Cluster. Comput. 25 (3) (2022) 1839–1867, https://doi.org/10.1007/s10586-021-03435-9.
[185] O. Samuel, N. Javaid, T.A. Alghamdi, N. Kumar, Towards sustainable smart cities: a secure and scalable trading system for residential homes using blockchain and artificial intelligence, Sustain. Cities Soc. 76 (2022), https://doi.org/10.1016/j.scs.2021.103371.
[186] M. Mehdinejad, H. Shayanfar, B. Mohammadi-Ivatloo, Decentralized blockchain-based peer-to-peer energy-backed token trading for active prosumers, Energy 244 (2022), https://doi.org/10.1016/j.energy.2021.122713.
[187] J. Dong, C. Song, S. Liu, H. Yin, H. Zheng, Y. Li, Decentralized peer-to-peer energy trading strategy in energy blockchain environment: a game-theoretic approach, Appl. Energy 325 (2022), https://doi.org/10.1016/j.apenergy.2022.119852.
[188] M.J.A. Baig, M.T. Iqbal, M. Jamil, J. Khan, A low-cost, open-source peer-to-peer energy trading system for a remote community using the internet-of-things, blockchain, and hypertext transfer protocol, Energies 15 (13) (2022), https://doi.org/10.3390/en15134862.
[189] Y. Mezquita, A.B. Gil-González, A. Martín Del Rey, J. Prieto, J.M. Corchado, Towards a blockchain-based peer-to-peer energy marketplace, Energies 15 (9) (2022), https://doi.org/10.3390/en15093046.
[190] J. Westphall, J.E. Martina, Blockchain privacy and scalability in a decentralized validated energy trading context with hyperledger fabric, Sensors 22 (12) (2022), https://doi.org/10.3390/s22124585.
[191] H.R. Bokkisam, S. Singh, R.M. Acharya, and M.P. Selvan, "Blockchain-based peer-to-peer transactive energy system for community microgrid with demand response management," vol. 8, no. 1, pp. 198–211, 2022, 10.17775/CSEEJPES.2020.06660.
[192] M. Mehdinejad, H.A. Shayanfar, B. Mohammadi-Ivatloo, H. Nafisi, Designing a robust decentralized energy transactions framework for active prosumers in peer-to-peer local electricity markets, IEEE *Access.* 10 (2022) 26743–26755, https://doi.org/10.1109/ACCESS.2022.3151922.
[193] S. Ding, J. Zeng, Z. Hu, Y. Yang, A peer-2-peer management and secure policy of the energy internet in smart microgrids, IEEE Trans. Ind. Informatics 18 (8) (2022) 5689–5697, https://doi.org/10.1109/TII.2021.3133458.
[194] M. Nykyri, T.J. Kärkkäinen, S. Levikari, S. Honkapuro, S. Annala, P. Silventoinen, Blockchain-based balance settlement ledger for energy communities in open electricity markets, Energy 253 (2022), https://doi.org/10.1016/j.energy.2022.124180.
[195] H.A. Abdelsalam, A.K. Srivastava, A. Eldosouky, Blockchain-based privacy preserving and energy saving mechanism for electricity prosumers, IEEE Trans. Sustain. Energy 13 (1) (2022) 302–314, https://doi.org/10.1109/TSTE.2021.3109482.
[196] L. Wang, et al., Optimal dispatch of integrated energy system considering integrated demand response resource trading, IET Gener. Transm. Distrib. 16 (9) (2022) 1727–1742, https://doi.org/10.1049/gtd2.12389.
[197] J. Guo, X. Ding, W. Wu, An architecture for distributed energies trading in byzantine-based blockchains, IEEE Trans. Green Commun. Netw. 6 (2) (2022) 1216–1230, https://doi.org/10.1109/TGCN.2022.3142438.
[198] T. Alskaif, J.L. Crespo-Vazquez, M. Sekuloski, G. Van Leeuwen, J.P.S. Catalao, Blockchain-based fully peer-to-peer energy trading strategies for residential energy systems, IEEE Trans. Ind. Informatics 18 (1) (2022) 231–241, https://doi.org/10.1109/TII.2021.3077008.
[199] T. Ashfaq, et al., An efficient and secure energy trading approach with machine learning technique and consortium blockchain, Sensors 22 (19) (2022), https://doi.org/10.3390/s22197263.
[200] S. Otoum, I. Al Ridhawi, H. Mouftah, A federated learning and blockchain-enabled sustainable energy trade at the edge: a framework for industry 4.0, IEEE *Internet Things J.* 10 (4) (2023) 3018–3026, https://doi.org/10.1109/JIOT.2022.3140430.
[201] Q. Luo, Y. Zhou, W. Hou, L. Peng, A hierarchical blockchain architecture based V2G market trading system, Appl. Energy 307 (2022), https://doi.org/10.1016/j.apenergy.2021.118167.
[202] S. Mishra, C.J. Crasta, C. Bordin, J. Mateo-Fornés, Smart contract formation enabling energy-as-a-service in a virtual power plant, Int. J. Energy Res. 46 (3) (2022) 3272–3294, https://doi.org/10.1002/er.7381.
[203] S. Aggarwal, N. Kumar, PETS: P2P energy trading scheduling scheme for electric vehicles in smart grid systems, IEEE Trans. Intell. Transp. Syst. 23 (9) (2022) 14361–14374, https://doi.org/10.1109/TITS.2021.3127577.
[204] O. Laayati, H. El Hadraoui, M. Bouzi, A. El-Alaoui, A. Kousta, A. Chebak, Smart energy management system: blockchain-based smart meters in microgrids, in: Proceedings - 2022 IEEE 4th Global Power, Energy and Communication Conference, GPECOM 2022, 2022, pp. 580–585, https://doi.org/10.1109/GPECOM55404.2022.9815559.
[205] M. Aloqaily, O. Bouachir, Ö. Özkasap, F.S. Ali, SynergyGrids: blockchain-supported distributed microgrid energy trading, Peer-to-Peer Netw. Appl. 15 (2) (2022) 884–900, https://doi.org/10.1007/s12083-021-01199-y.
[206] T. Yu, F. Luo, C. Pu, Z. Zhao, G. Ranzi, Dual-blockchain-based P2P energy trading system with an improved optimistic rollup mechanism, IET Smart Grid 5 (4) (2022) 246–259, https://doi.org/10.1049/stg2.12074.
[207] Y.J. Lin, Y.C. Chen, J.Y. Zheng, D. Chu, D.W. Shao, H.T. Yang, Blockchain power trading and energy management platform, IEEE *Access.* 10 (2022) 75932–75948, https://doi.org/10.1109/ACCESS.2022.3189472.
[208] A. Kumari, et al., Blockchain-based peer-to-peer transactive energy management scheme for smart grid system, Sensors 22 (13) (2022), https://doi.org/10.3390/s22134826.
[209] O. Samuel, N. Javaid, A. Almogren, M.U. Javed, U. Qasim, A. Radwan, A secure energy trading system for electric vehicles in smart communities using blockchain, Sustain. Cities Soc. 79 (2022), https://doi.org/10.1016/j.scs.2022.103678.
[210] F. Mohammadi, M. Sanjari, and M. Saif, "A real-time blockchain-based state estimation system for battery energy storage systems," 2022, 10.1109/KPEC54747.2022.9814731.
[211] Q. Zhang, Y. Su, X. Wu, Y. Zhu, Y. Hu, Electricity trade strategy of regional electric vehicle coalitions based on blockchain, Electr. Power Syst. Res. 204 (2022), https://doi.org/10.1016/j.epsr.2021.107667.
[212] W. Qiu, X. Jiang, Z. Lin, L. Li, Y. Pei, Y. Tao, A contract-based, decentralized and privacy-preserving computation scheme of evaluation indices of shared energy storage market for renewable energy accommodation, IEEE Trans. Ind. Appl. 59 (2) (2023) 2546–2562, https://doi.org/10.1109/TIA.2022.3225783.
[213] Y. Xu, Z. Liu, C. Zhang, J. Ren, Y. Zhang, X. Shen, Blockchain-based trustworthy energy dispatching approach for high renewable energy penetrated power systems, IEEE *Internet Things J.* 9 (12) (2022) 10036–10047, https://doi.org/10.1109/JIOT.2021.3117924.
[214] J. Ping, Z. Yan, S. Chen, A privacy-preserving blockchain-based method to optimize energy trading, IEEE Trans. Smart Grid 14 (2) (2023) 1148–1157, https://doi.org/10.1109/TSG.2022.3198165.
[215] Y.T. Lei, C.Q. Ma, N. Mirza, Y.S. Ren, S.W. Narayan, X.Q. Chen, A renewable energy microgrids trading management platform based on permissioned blockchain, Energy Econ. 115 (2022), https://doi.org/10.1016/j.eneco.2022.106375.
[216] W. Hua, Y. Zhou, M. Qadrdan, J. Wu, N. Jenkins, Blockchain enabled decentralized local electricity markets with flexibility from heating sources, IEEE Trans. Smart Grid 14 (2) (2023) 1607–1620, https://doi.org/10.1109/TSG.2022.3158732.
[217] S. Karumba, S.S. Kanhere, R. Jurdak, S. Sethuvenkatraman, HARB: a hypergraph-based adaptive consortium blockchain for decentralized energy trading, IEEE *Internet Things J.* 9 (16) (2022) 14216–14227, https://doi.org/10.1109/JIOT.2020.3022045.
[218] A. Umar, D. Kumar, T. Ghose, Blockchain-based decentralized energy intra-trading with battery storage flexibility in a community microgrid system, Appl. Energy 322 (2022), https://doi.org/10.1016/j.apenergy.2022.119544.
[219] Q. Wang, L. Huang, S. Chen, Y. Xiang, Blockchain enables your bill safer, IEEE *Internet Things J.* 9 (16) (2022) 14162–14171, https://doi.org/10.1109/JIOT.2020.3016721.
[220] A. Kumari, S. Tanwar, A Reinforcement-Learning-Based Secure Demand Response Scheme for Smart Grid System, IEEE *Internet Things J.* 9 (3) (2022) 2180–2191, https://doi.org/10.1109/JIOT.2021.3090305.
[221] B.P. Rimal, C. Kong, B. Poudel, Y. Wang, P. Shahi, Smart electric vehicle charging in the era of internet of vehicles, emerging trends, and open issues, Energies 15 (5) (2022), https://doi.org/10.3390/en15051908.
[222] R. Ma, Z. Yi, Y. Xiang, D. Shi, C. Xu, H. Wu, A blockchain-enabled demand management and control framework driven by deep reinforcement learning, IEEE Trans. Ind. Electron. 70 (1) (2023) 430–440, https://doi.org/10.1109/TIE.2022.3146631.
[223] M.R. Hamouda, M.E. Nassar, M.M.A. Salama, Blockchain-based sequential market-clearing platform for enabling energy trading in interconnected microgrids, Int. J. Electr. Power Energy Syst. 144 (2023), https://doi.org/10.1016/j.ijepes.2022.108550.
[224] T.R. Alsenani, The participation of electric vehicles in a peer-to-peer energy-backed token market, Int. J. Electr. Power Energy Syst. 148 (2023), https://doi.org/10.1016/j.ijepes.2023.109005.
[225] B. Wang, et al., CE-SDT: a new blockchain-based distributed community energy trading mechanism, Front. Energy Res. 10 (2023), https://doi.org/10.3389/fenrg.2022.1091350.
[226] Y. Chen, Y. Li, Q. Chen, X. Wang, T. Li, C. Tan, Energy trading scheme based on consortium blockchain and game theory, Comput. Stand. Interfaces 84 (2023), https://doi.org/10.1016/j.csi.2022.103699.
[227] H.K. Lopez, A. Zilouchian, Peer-to-peer energy trading for photo-voltaic prosumers, Energy 263 (2023), https://doi.org/10.1016/j.energy.2022.125563.
[228] J. Gao, K.O. Asamoah, Q. Xia, E.B. Sifah, O.I. Amankona, H. Xia, A blockchain peer-to-peer energy trading system for microgrids, IEEE Trans. Smart Grid (2023) 1, https://doi.org/10.1109/tsg.2023.3237624.
[229] F. Buccafurri, G. Lax, L. Musarella, A. Russo, An Ethereum-based solution for energy trading in smart grids, Digit. Commun. Networks 9 (1) (2023) 194–202, https://doi.org/10.1016/J.DCAN.2021.12.004.
[230] T. Chu, X. An, W. Zhang, Y. Lu, J. Tian, Multiple virtual power plants transaction matching strategy based on alliance blockchain, Sustain 15 (8) (2023), https://doi.org/10.3390/SU15086939.
[231] J. Yu, J. Liu, Y. Wen, X. Yu, Economic optimal coordinated dispatch of power for community users considering shared energy storage and demand response under blockchain, Sustain 15 (8) (2023), https://doi.org/10.3390/su15086620.

[232] J. Ping, D. Li, Z. Yan, X. Wu, S. Chen, A trusted peer-to-peer market of joint energy and reserve based on blockchain, Electr. Power Syst. Res. 214 (2023), https://doi.org/10.1016/j.epsr.2022.108802.

[233] Y. Wang, et al., A fast and secured vehicle-to-vehicle energy trading based on blockchain consensus in the internet of electric vehicles, IEEE Trans. Veh. Technol. 72 (6) (2023) 7827–7843, https://doi.org/10.1109/TVT.2023.3239990.

[234] M. Moniruzzaman, A. Yassine, R. Benlamri, Blockchain and cooperative game theory for peer-to-peer energy trading in smart grids, Int. J. Electr. Power Energy Syst. 151 (2023), https://doi.org/10.1016/j.ijepes.2023.109111.

[235] L. Wang, et al., Blockchain-based dynamic energy management mode for distributed energy system with high penetration of renewable energy, Int. J. Electr. Power Energy Syst. 148 (2023), https://doi.org/10.1016/j.ijepes.2022.108933.