Critical success factor blockchain technology in renewable energy: systematic literature review

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ABSTRACT

In recent years, blockchain technology has garnered considerable interest in the renewable energy sector. Nonetheless, scholars have yet to investigate the comprehensive assessment of critical success factors (CSFs) for the implementation of blockchain technology in renewable energy. Furthermore, the current research lacks a stage framework or a standardized set of CSFs for blockchain technology. This review study seeks to establish a stage framework and identify a set of common CSFs for the effective adoption of blockchain technology by examining published materials pertinent to the topic under investigation. This evaluation employs a systematic literature review and scientific mapping methodology to objectively ascertain a collection of CSFs. We examined 65 journal articles from the Scopus database and Google Scholar, concentrating on prominent journals, keywords, countries/regions, and documents within the CSF domain of blockchain technology in renewable energy. The findings indicate that nations including China, Australia, the United States, and Germany have made the most significant contributions to this field. Among the 20 CSFs, the foremost five are regulation, integration with current systems, scalability, and security. The proposal delineates four principal research gaps and prospective research trajectories: environmental effect assessment, standardization, user experience and interface design, and management control. The insights and CSF checklist for blockchain technology will facilitate successful exploration and implementation in renewable energy.

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1. INTRODUCTION

The global development of renewable energy has accelerated in tandem with the growing demand for clean energy. Renewable energy includes various sources such as solar, wind, air, geothermal, biomass, and biofuels [1], [2]. The development of technology allows the use of energy from these sources more efficiently and widely. Innovations in technologies such as solar panels, wind turbines, and energy storage systems (batteries) continue to develop, making renewable energy more affordable and reliable. This contributes to the global shift toward clean energy [3]. Consumption of biofuels and other renewable energy continues to increase. The renewable energy industry creates millions of jobs, from manufacturing to maintenance, and makes a major contribution to reducing greenhouse gas emissions [4]. Renewable energy is the primary solution for reducing reliance on fossil fuels, addressing climate change, and safeguarding the environment [5]. Overall, renewable energy not only provides an environmentally friendly alternative energy but also supports economic development and global sustainability [6].

Recently, blockchain technology has been recognized as a sophisticated database mechanism capable of revolutionizing numerous worldwide industries, including renewable energy [7], [8]. Consequently, it is imperative to implement blockchain technology in the renewable energy sector to improve information dissemination and database administration [9]. Blockchain is a decentralized framework and an innovative distributed computing paradigm that employs linked data structures for verification, storage, and distributed consensus methods to create and modify data [10]. Blockchain technology has introduced innovative and sophisticated capabilities for the business and industrial sectors. The decentralization and openness of blockchain technology enhance data security, ultimately augmenting user trust. It integrates multiple mechanisms to facilitate a shared ledger among users (e.g., organizations and people), hence ensuring consensus, stability, and secure transactions [11]. Blockchain technology can facilitate the advancement of businesses like renewable energy due to its numerous critical success factors (CSFs) [12]. CSFs include domains and actions that proficiently incorporate blockchain technology into renewable energy. These domains/activities pertain to the principal attributes and/or advantages of blockchain technology, including decentralization, autonomy, peer-to-peer (P2P) interactions, and immutability. The characteristics of blockchain technology significantly enhance time efficiency, reduce expenses, bolster user confidence, ensure data security and transparency, and facilitate international project development. Prior research on blockchain technology in renewable energy has depended on manual evaluations, which may be prone to subjectivity or prejudice.

The research investigates the obstacles and prospects associated with blockchain technology and presents a comprehensive conceptual model to improve its utilization in renewable energy. This review article examines the present state of blockchain technology in renewable energy. Currently, there is no research about the application of CSFs for the implementation of blockchain technology in renewable energy. The current literature has not synthesized methodological approaches utilizing comprehensive literature reviews and scientific mapping techniques. Furthermore, the current literature has not investigated the identification of a set of common CSFs. This review study aims to assist researchers in comprehending the essential variables necessary for advancing blockchain technology research and to guide practitioners in prioritizing crucial success factors that enhance information sharing and database management in renewable energy. This review study utilizes a systematic literature analysis and a science mapping technique to address this gap, examining current research on CSFs for blockchain technology deployment in renewable energy, and proposing future research directions. This review study seeks to provide a stage framework, define a set of shared CSFs for the effective deployment of blockchain technology in renewable energy, and propose research gaps and future research goals. The study aims to achieve the following objectives: i) identify the annual trends of CSFs for the implementation of blockchain technology in renewable energy; ii) employ a science mapping methodology to analyze significant journals, keywords, countries/regions, and documents within the field; iii) discuss a compilation of essential common CSFs for the successful implementation of blockchain technology; and iv) propose future research avenues for the application of blockchain technology in renewable energy. This review study structures the subsequent sections as follows. Section 2 examines prior evaluation studies on blockchain technology across multiple sectors, including its utilization in renewable energy. Section 3 delineates the study methodologies grounded in the systematic literature review and scientific mapping review. Section 4 outlines the findings of annual publication trends, selection of peer-reviewed journals, keyword co-occurrence analysis, co-occurrence analysis by country/region, document analysis, and presents the conclusions of this review study.

2. RESEARCH METHOD

This review study adopts a “mixed-methods approach,” which consists of a science mapping review (i.e., quantitative approach) and a systematic literature review (i.e., qualitative approach). This systematic review was conducted following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. The literature search was conducted from November 2024 using three primary databases: Scopus, IEEE Xplore, and Google Scholar. The keywords used included:

- "Blockchain" AND "Renewable" AND " Success " AND “Factor”
- "Blockchain" AND " Impact "
- "Blockchain" AND "Influence"

2.1. Inclusion and exclusion criteria

2.1.1. Inclusion criteria

The following criteria were used to select relevant studies for this review:

- Articles discussing the application of blockchain technology in renewable energy.
- Published in an indexed international journal or proceedings.
- Published between 2015 and 2025.
- Written in English.

2.1.2. Exclusion criteria

Studies were excluded based on the following criteria:

- Articles that only discuss the blockchain conceptually without implementation or case studies.
- Non-academic reports, news, or blogs.
- Duplicate publications.

2.2. Study selection process

The study selection process was conducted in four stages according to the PRISMA diagram in Figure 1: identification–a total of 285 publications were found from three databases and additional searches. Screening–based on the title and abstract, 73 articles were removed for irrelevance. Eligibility–of the 78 articles read in full, 36 were removed for not meeting the inclusion criteria. Included studies–a total of 36 articles were eligible for further analysis.

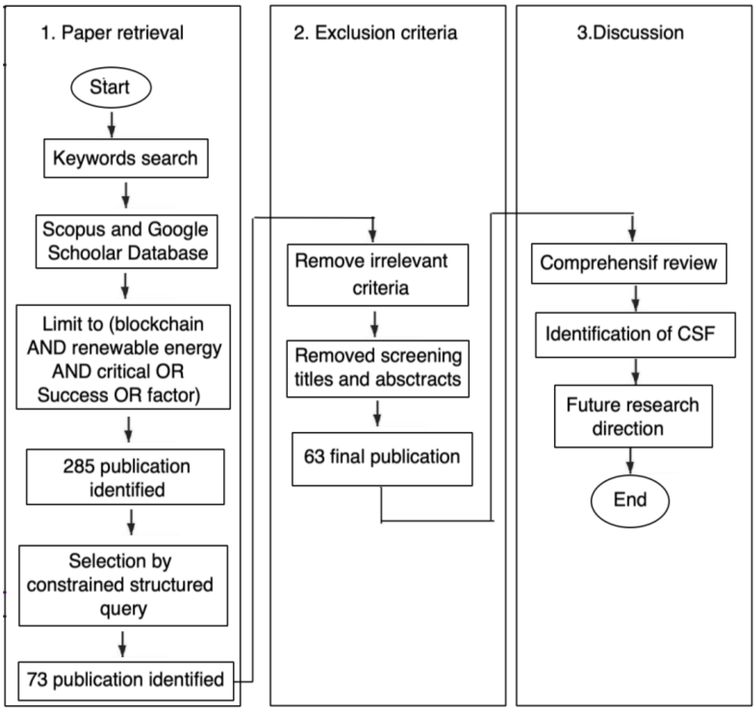

Figure 1. The research methods

3. RESULTS AND DISCUSSION

This section breaks down the research results into several parts, including annual publication trends, country/region co-emergence analysis, CSFs for blockchain technology implementation in renewable energy, and future aspects research.

3.1. Annual article publication trends

The studies we looked at were picked because they were done between 2019 and 2024. Figure 2 shows that 2021 will be the year with the most studies on blockchain and renewable energy. But over time, studies on these topics have changed. In 2019, there was a drop because blockchain research into clean energy had just started. It became more common to study blockchain in 2022–2024, when new topics like smart cities and building management came up. So far, only parts of the latest study from 2024 have been made public. However, the number kept going up until the middle of the year. Trade in green energy is what blockchain-based research on renewable energy primarily focuses on. It also investigates smart cities, smart grids, and building control.

Figure 2. Annual article publication trends

3.2. Country/region co-emergence analysis

We identified countries and regions to investigate the distribution of articles on blockchain technology in renewable energy. Figure 3 displays the geospatial distribution of the selected articles. The results show that researchers from 21 countries and regions have conducted relevant studies and published papers in this field. Among these, China has published the highest number of research articles (19). Australia has the second-largest number, with 14 articles. Germany and the US are tied with 13 articles each, followed by the United Kingdom with eight articles, and Indonesia with five.

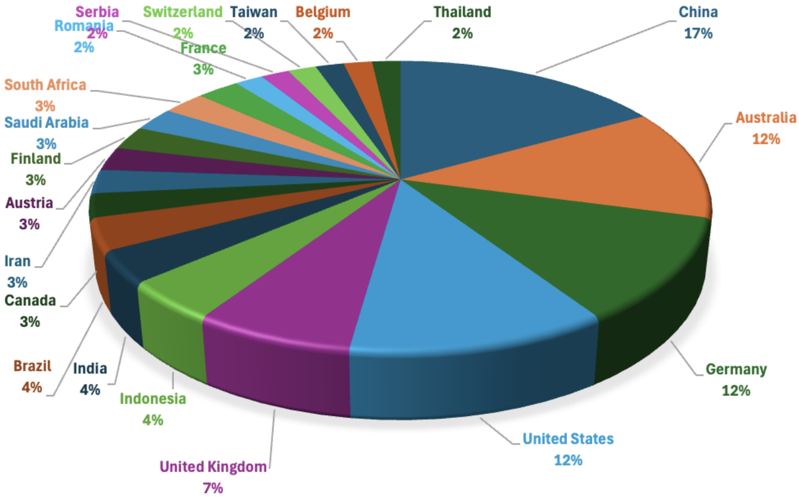

Figure 3. Country co-emergence analysis

3.3. Critical success factors for blockchain technology implementation in renewable energy

Key activity areas known as CSFs typically yield favorable outcomes. CSFs for blockchain technology implementation in renewable energy are essential for managers to achieve their goals. CSFs are also powerful project management tools to minimize project failures. CSFs for blockchain technology in renewable energy can be defined as a set of key characteristics and areas that drive rapid progress in the industry. In this study, CSFs for blockchain technology refer to areas or activities in renewable energy companies or projects that drive updates, information sharing, iteration, and database management. To successfully implement blockchain technology, researchers and practitioners must identify the CSFs and take necessary steps to ensure its effective implementation in these key areas. Figure 4 presents a complete list of all 20 CSFs and describes at the bottom of the table. Table 1 shows the 20 CSFs that had three or more occurrences/citations taken from the 65 included articles. Table 1 does not display the remaining CSFs with one or two occurrences.

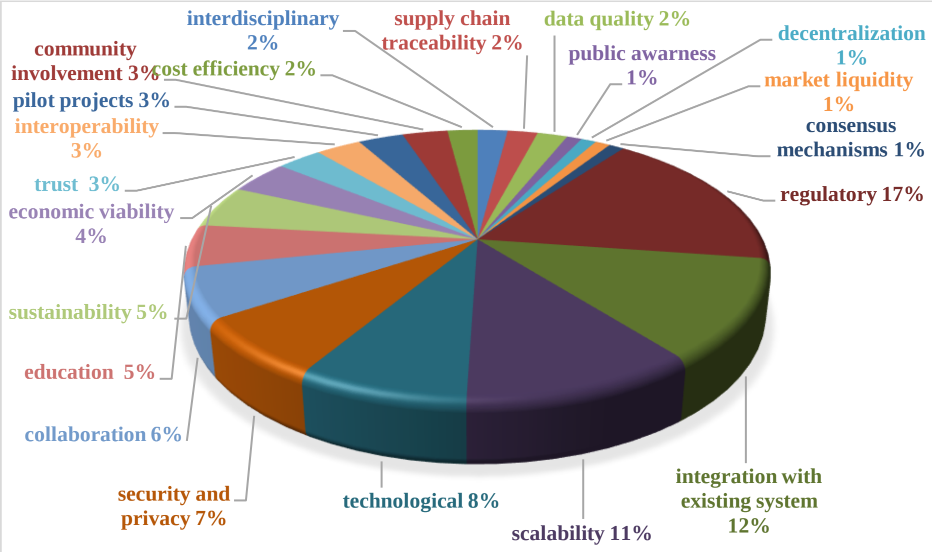

Figure 4. CSFs for blockchain technology implementation in renewable energy

Table 1. CSF implementation of blockchain technology in renewable energy

No	CSF	Reference
1	Regulatory	All paper [13]-[72].
2	Integration with existing system	[1]-[9], [11]-[16], [21]-[23], [28]-[33], [35]-[42], [46]-[61].
3	Scalability	[7]-[9], [11]-[14], [16], [17], [19]-[35], [48], [51]-[54], [56]-[58], [60], [71].
4	Technological	[1]-[4], [18], [22], [28], [29], [31], [34], [35], [38], [39], [43], [49], [50], [52]-[55], [57], [59], [60], [62], [68], [72].
5	Security and privacy	[11]-[14], [17], [18], [20]-[25], [28], [29], [41], [44], [46], [48], [49], [55], [56], [60], [62], [65], [69].
6	Collaboration	[13], [15], [16], [18], [28], [31]-[39], [41], [56], [61], [64], [66], [68], [70].
7	Education and training	[14]-[16], [19], [22], [39], [41], [46]-[49], [52], [53], [55], [60], [65], [66], [68], [71].
8	Sustainability	[13], [18], [19], [21], [24], [26], [29], [35], [39], [41], [42], [44], [49], [50], [57], [58], [64].
9	Economic viability	[15], [21], [31], [34], [36], [39], [40], [46], [49], [52], [55], [56], [59], [61].
10	Trust	[17], [19]-[21], [23], [26], [28], [33], [40], [42], [58], [64].
11	Pilot projects	[15], [18], [21], [24], [27], [32], [35], [37], [39], [49].
12	Community and stakeholder involvement	[13], [15], [16], [28], [31]-[33], [37], [38], [52].
13	Cost efficiency	[15], [16], [23], [34], [63], [65], [71].
14	Interdisciplinary approach	[13], [20], [47], [50], [58], [64], [72].
15	Supply chain traceability	[42], [50], [51], [57], [69], [72].
16	Data quality	[13], [47], [53], [56], [60], [61].
17	Public, consumer awareness and acceptance	[13], [23], [28], [34], [35].
18	Decentralization	[26], [30], [36], [37], [54].
19	Market liquidity	[22], [29], [30], [33].
20	Consensus mechanisms	[26], [37], [55].

3.3.1. Regulatory

Establishing clear regulatory frameworks is necessary to support the adoption of blockchain technology in renewable energy. These frameworks can help address legal and operational challenges, facilitating smoother implementation and acceptance of blockchain solutions [13]. Establishing clear regulatory guidelines and frameworks is necessary to support the adoption of blockchain technology in the energy sector. This includes addressing data privacy concerns and ensuring compliance with existing laws [14]. Adhering to relevant regulations and standards is necessary to ensure that the decentralized trading system operates within legal frameworks. This can help in gaining acceptance from stakeholders and regulatory bodies [21]. Regulatory framework: a robust regulatory system is essential for the widespread adoption of blockchain in renewable energy. Without clear legal guidance and supportive policies, the implementation of blockchain solutions may face significant barriers, particularly for larger companies [28].

3.3.2. Integration with existing systems

Investigating how blockchain can be effectively integrated with existing energy management systems and infrastructure is crucial. This includes exploring hybrid models that combine traditional and blockchain-based approaches [14]. Ensuring that the platform adheres to existing renewable energy systems and regulations is crucial for gaining acceptance and legitimacy in the market 4. The ability to integrate with existing energy management systems and smart metering infrastructure is essential for seamless operation and user adoption [17]. The successful implementation of blockchain in renewable energy systems requires the integration of various technologies, such as smart grids and artificial intelligence (AI). This integration enhances the overall efficiency and sustainability of energy systems, making it a critical factor for success [13]. The ability to integrate blockchain technology with existing energy management systems and building information modeling (BIM) is essential for enhancing efficiency and ensuring seamless operations [15]. The blockchain model in renewable energy must effectively incorporate various forms of existing renewable energy systems, such as wind and solar power, to ensure a clean and sustainable energy supply. Addressing the uncertainties associated with these energy sources is crucial for the model's success [26].

3.3.3. Scalability

Addressing scalability challenges is crucial for the effective operation of blockchain in smart grids. As the number of transactions and users increases, the system must handle higher data volumes and processing demands without compromising performance [63]. Continued advancements in blockchain technology, including the development of more efficient consensus mechanisms and scalability solutions, are vital for overcoming current limitations and enhancing the performance of blockchain applications in renewable energy [59]. The ability of blockchain systems to scale and adapt to the evolving needs of the renewable energy sector is vital [69]. The ability to scale the solution to accommodate larger communities and diverse customer profiles is crucial. Future simulations and field validations should explore various community sizes and configurations to optimize performance [52]. The platform must be designed to handle increasing transaction volumes and user demands without compromising performance. Scalability ensures that the system can grow alongside the expanding renewable energy market [44]. The blockchain solution must be scalable to accommodate a growing number of users and transactions. Addressing scalability issues and ensuring efficient transaction processing are necessary for the long-term viability of P2P energy trading systems [38]. As the system expands to support larger renewable energy communities, ensuring scalability and interoperability becomes crucial. Future research should focus on developing protocols that facilitate seamless integration of various communities and compatibility with existing energy market infrastructures [25].

3.3.4. Technological

Technological integration of blockchain technology for governance and management of energy communities is highlighted as a critical factor. Blockchain can facilitate transparent and secure transactions, enabling efficient load balancing and self-consumption without the need for a trusted third party [31]. The development and maturity of blockchain technology and microgrid systems are essential. As these technologies advance, they will enable more efficient and reliable trading mechanisms [34]. The availability of a robust technological infrastructure, including internet connectivity and mobile technology, is essential for the successful implementation of blockchain solutions. The document notes the rapid adoption of mobile technology in Pakistan, which can facilitate blockchain applications in energy management [35].

3.3.5. Security and privacy

Implementing robust security protocols to protect against cyber threats and ensure the integrity of transactions is critical. This includes encryption, access controls, and regular security assessments [44]. Ensuring the security of transaction data and building trust among participants is fundamental. Blockchain technology can address issues related to data security and privacy, which are significant concerns in traditional centralized energy management models [49]. Ensuring the security of transactions and the reliability of the blockchain network is critical. This includes protecting against malicious nodes and ensuring that the system can handle the expected load without failures [44]. Addressing security concerns and ensuring user privacy through cryptographic measures and smart contracts are essential for building trust among users [65].

3.3.6. Collaboration

Collaboration with practitioners: engaging with industry practitioners and experts in blockchain technology can provide practical insights and facilitate the development of user-friendly applications. Collaborative research efforts can help bridge the gap between theoretical frameworks and real-world applications [15]. Engaging stakeholders, including consumers and organizations, is essential for fostering collaboration and ensuring that the energy market operates effectively [63]. Successful adoption of blockchain requires strong collaboration between industry stakeholders, regulators, and technology developers. This cooperation is essential to build trust and facilitate the transition to blockchain-based solutions [59].

3.3.7. Education and training

Raising awareness about the benefits of participating in energy communities and educating members about renewable energy and blockchain technology can drive engagement and participation [68]. Increasing awareness and understanding of blockchain technology among stakeholders is vital. Training and educational programs can help stakeholders grasp the benefits and functionalities of blockchain in renewable energy management [15]. Engaging consumers and educating them about the benefits and functionalities of blockchain-based energy systems can drive adoption. Increased consumer awareness can lead to greater participation in decentralized energy markets [14]. Educating stakeholders about the benefits and functionalities of blockchain technology can drive adoption and encourage participation in the renewable energy dertificate (REC) market [18]. There is a need for adequate resources and educational opportunities to harness the human capital in the region. This includes training and support to help stakeholders understand and implement blockchain solutions effectively [26]. Raising awareness and understanding of blockchain technology among stakeholders is critical. Education initiatives can help demystify the technology, highlight its benefits, and encourage adoption within the renewable energy sector [39]. Training programs and educational initiatives can help build the necessary skills and knowledge to utilize blockchain solutions [41] effectively. Raising awareness and educating consumers about the benefits and functionalities of blockchain technology in renewable energy trading is critical. Informed consumers are more likely to participate in blockchain-based trading systems, which can drive demand and adoption [56].

3.3.8. Sustainability

Emphasizing sustainable practices and renewable energy sources is crucial. The integration of blockchain should align with the goals of increasing the share of renewable energy and reducing emissions, which can enhance the overall acceptance and success of the technology [35]. Addressing the high energy consumption associated with blockchain mining and ensuring that renewable energy sources are utilized effectively [64]. Derived from organic materials, biomass energy can be produced from plant and animal waste, providing a sustainable alternative to fossil fuels [64].

3.3.9. Economic viability

Demonstrating the economic benefits of using blockchain in renewable energy projects, such as cost savings and improved efficiency, can encourage adoption. The document mentions that blockchain-BIM applications can improve cost performance in green buildings [15]. Economic viability assessments: conducting studies to evaluate the financial impacts of blockchain-based trading systems on the renewable energy market. This includes analyzing cost-benefit scenarios and the long-term sustainability of such systems [15].

3.3.10. Trust

Building trust among stakeholders is vital. Blockchain's inherent characteristics, such as decentralization and data immutability, can help enhance trust in energy transactions. However, ensuring the security of these transactions against cyber threats is also a critical factor [28]. The integrity of the data and transactions must be maintained to build trust among users. This includes ensuring that energy measurements are tamper-proof and that user identities are protected [17]. Ensuring that all transactions are transparent and verifiable on the blockchain is crucial for building trust among participants, especially prosumers who may be wary of market manipulation [19]. Ensuring robust security measures, such as authorized access and encryption, is essential for gaining user trust and protecting sensitive transaction data [23]. Ensuring that the blockchain system provides clear and accessible information about the origin of renewable energy can help build trust among consumers and organizations [68]. Enhancing consumer trust through the use of blockchain for guarantees, anti-fraud measures, and transparency in energy transactions [64]. Involvement of all relevant stakeholders, including government bodies, energy producers, consumers, and trading centers, is crucial. Collaborative efforts can enhance trust and ensure that the system meets the needs of all parties involved [60]. The use of Consortium blockchain is emphasized for its advantages in transaction efficiency and security, which are critical for building trust among participants in the trading system [53].

3.3.11. Pilot projects

Conducting pilot projects and detailed case studies can provide valuable insights into the practical applications of blockchain in renewable energy, helping to identify best practices and potential challenges [61]. There is a lack of empirical studies that provide concrete evidence of the benefits and challenges associated with implementing blockchain in the REC market. More case studies and pilot projects are needed to validate theoretical frameworks [71].

3.3.12. Community and stakeholder involvement

The active involvement of prosumers—individuals who both consume and produce energy—is crucial. Encouraging participation from all stakeholders, including tenants, is vital for optimizing energy systems and achieving renewable energy targets [31]. Involvement of all relevant stakeholders, including government bodies, energy producers, consumers, and trading centers, is crucial. Collaborative efforts can enhance trust and ensure that the system meets the needs of all parties involved [60].

3.3.13. Cost efficiency

Demonstrating the economic benefits of using blockchain in renewable energy projects, such as cost savings and improved efficiency, can encourage adoption. The document mentions that blockchain-BIM applications can improve cost performance in green buildings [15]. The current expense of energy storage solutions impacts the viability of specific trading configurations. As energy storage technology improves and costs decrease, it will enhance the feasibility of decentralized trading models [34]. Managing operational and capital costs associated with blockchain implementation is critical. This includes addressing the expenses related to technology, storage, and cybersecurity, which can impact the overall feasibility and attractiveness of blockchain solutions for energy providers and consumers [64]. Demonstrating the cost savings associated with blockchain technology, such as reduced transaction costs and improved efficiency, can drive its adoption [65]. The current expense of energy storage solutions impacts the viability of specific trading configurations. As energy storage technology improves and costs decrease, it will enhance the feasibility of decentralized trading models [34].

3.3.14. Interdisciplinary approach

The necessity for more interdisciplinary research is emphasized, integrating insights from economics, sociology, and environmental science to develop a holistic understanding of blockchain's role in renewable energy [13]. The integration of various disciplines, such as energy systems, technology, and environmental protection, is vital. This interdisciplinary focus allows for comprehensive research that addresses the complexities of energy management and blockchain applications [50].

3.3.15. Supply chain traceability

Blockchain can enhance the traceability of renewable energy sources, providing consumers with information about the origin and sustainability of the energy they are using [61]. The potential for blockchain applications in biomass energy systems is implied, particularly in tracking the supply chain and ensuring the sustainability of biomass sources [13].

3.3.16. Data quality

Ensuring high-quality, accurate, and real-time data is essential for the successful operation of blockchain systems. Reliable data input is crucial for effective decision-making and transaction processing [14]. Ensuring the accuracy and tamper-proof nature of data collected from smart meters is critical for maintaining trust in the system [16]. Ensuring that data transmitted between distributed entities is secure and tamper-proof is essential. Blockchain technology provides a transparent and immutable ledger, which helps maintain the integrity of data related to energy generation and consumption [24].

3.3.17. Public, consumer awareness and acceptance

Investigating consumer attitudes towards blockchain technology in energy management could provide insights into how to enhance public acceptance and trust, which is critical for successful implementation [62]. Increasing public awareness about renewable energy technologies and their benefits is essential for driving adoption and participation in sustainable energy initiatives [71].

3.3.18. Decentralization

Analyzing the broader implications of decentralized energy trading on traditional energy markets, including economic impacts and shifts in consumer behavior [19]. The ability to create a fully decentralized system is crucial. This reduces the risk of third-party misconduct, enhances data transparency, and eliminates the costs associated with maintaining a trusted central authority [30].

3.3.19. Market liquidity

Research could investigate the impact of blockchain-enabled RECs on local energy markets, including how these communities can influence energy pricing, trading, and overall market dynamics [31]. The ability of the system to adapt to changing market conditions and user behaviors is crucial. Future research and development should focus on incorporating adaptive strategies that can respond to fluctuations in transaction volumes and market dynamics [33].

3.3.20. Consensus mechanisms

Continued advancements in blockchain technology, including the development of more efficient consensus mechanisms, are vital for overcoming current limitations and enhancing the performance of blockchain applications in renewable energy [30]. Implementing robust consensus algorithms is essential to ensure that all nodes in the blockchain network can agree on the state of the system. This enhances the reliability and security of the data being processed and shared among participants [26].

3.4. Future research

This review study aims to conduct state-of-the-art research on the CSFs for implementing blockchain technology in renewable energy, identifying a set of common CSFs and future research directions. This study adopted a mixed-methods approach, consisting of a science mapping review (i.e., a quantitative approach) and a systematic literature review (i.e., a qualitative approach). Based on the science mapping review, the impact of keywords, countries/regions, and documents related to the CSFs for blockchain technology in renewable energy was quantitatively analyzed. Furthermore, the systematic literature review reported five sets of common CSFs.

Following the reported results of the co-occurring keyword analysis and the set of common CSFs, it is essential to identify and explore relevant future research directions that will expand the research domain within the CSFs for blockchain technology in renewable energy. This study highlights five key future research directions for the successful implementation of blockchain technology in renewable energy: environmental impact analysis, standardization, user experience and interface design, management control, and knowledge and skill development.

3.4.1. Environmental impact analysis

Future research should also focus on assessing the environmental impacts of blockchain technology in renewable energy applications. This includes evaluating the carbon footprint of blockchain operations and exploring ways to mitigate any adverse effects [28]. Conducting comprehensive studies to assess the economic, social, and environmental impacts of implementing blockchain technology in the energy sector, particularly in rural areas [35]. While blockchain can enhance transparency in renewable energy, there is limited research on the environmental impact of blockchain technology itself, particularly concerning energy consumption in consensus mechanisms like proof of work [39].

3.4.2. Standarization

There is a need for established standards and protocols for integrating diverse renewable energy data sources with blockchain technology. Research is required to address issues of data accuracy, compatibility, and privacy to ensure the integrity and consistency of the data used in the RETP [43]. This includes developing standards and protocols that facilitate seamless data exchange between various platforms [56].

3.4.3. User experience and interface design

Developing intuitive and user-friendly interfaces for stakeholders to interact with the blockchain system can enhance adoption rates. Simplifying the user experience is essential for encouraging participation from various market players [60]. Researching user experience and interface design to improve the usability of the blockchain platform for multiple stakeholders, including electricity generators, utility companies, and consumers [16].

3.4.4. Management and control

There is a lack of in-depth research on robust methods for managing this uncertainty. Developing advanced predictive models and strategies for flexible load management in the face of variable energy supply is a potential for future research [32]. It is essential to concentrate on the practical application of the suggested dynamic energy management model utilizing blockchain technology. It is necessary to validate the benefits of enhancing management energy systems, ensuring economic viability, and achieving emission reduction through a thorough investigation [43].

3.4.5. Knowledge and skill

Many stakeholders in the energy industry lack the technical knowledge required to implement blockchain solutions effectively, which inhibits the adoption of innovative practices [68]. There is a significant gap in knowledge, skills, and expertise between developed nations and sub-Saharan Africa regarding the implementation and benefits of blockchain technology. This disparity hinders the effective adoption of such innovations in the region, so there is a need for future research [27].

4. CONCLUSION

Despite the existing literature discussing the current state of blockchain technology, there is a lack of recent research on common security frameworks (CSFs) for blockchain technology in renewable energy, which aims to summarize a set of common CSFs and provide implications and directions for both practice and theory. The current review study aims to identify a set of common CSFs for the successful implementation of blockchain technology in renewable energy by analyzing research articles from 2019 to 2024. We used a systematic literature review and a science mapping review to retrieve 65 relevant articles for analysis in this study.

Publications on CSFs for blockchain technology in renewable energy have significantly increased over the past five years, particularly since 2022. The co-occurrence analysis of keywords reveals key topics in this domain, including smart contracts, IoT, supply chain, building management, and smart cities. Among countries/regions, China makes the most significant contribution by publishing the most research. The number of articles published in developed countries such as the US, Australia, and the UK also accounts for a large proportion. The main findings propose 20 CSFs for successful blockchain technology implementation and discuss five standard sets of the most frequently cited CSFs: regulation, integration with existing systems, scalability, security/privacy, and technology.

We expect the findings to serve as valuable references for academics and practitioners, enabling them to comprehend the research and development trends in blockchain technology implementation and to enhance their comprehension of CSFs in renewable energy applications. This review study contributes to theory and practice. From a theoretical perspective, future researchers should focus on environmental impact analysis to assess the economic, social, and environmental impacts of implementing blockchain technology in the energy sector. Future research also needs to focus on standardizing blockchain implementation in renewable energy because it involves many different systems. Future research holds the potential to develop a practical user experience. The renewable energy industry, which utilizes blockchain technology, is a relatively new sector, necessitating the development of its management control and knowledge.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Inayatulloh	✓	✓		✓					✓	✓				
Thoyyibah T.	✓	✓					✓	✓						

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Open data and contributors are available at https://doi.org/10.5281/zenodo.16814418.

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