RESEARCH ARTICLE

Blockchain Technology in Smart Cities and Photovoltaic Power Generation: Opportunities and Challenges from a Computer Science Perspective

Shan Wong[1], **Chen Chen**[2] **and Peishi Wu**[*]

[1] Shen Wai International School, Shenzhen, 518053, China

[2] Xi'an Kedagaoxin University, Xi'an, Shanxi, 710109, China

Abstract: This study presents a review of the applications, challenges, and development trends of blockchain technology in the context of smart cities and photovoltaic power generation. Blockchain technology possesses extensive applicability in the realms of government administration, public services, industrial development, and ecological environment, while simultaneously demonstrating immense potential within the photovoltaic power generation sector. Computer technology plays a pivotal role in blockchain applications, ensuring data security, compliance, and efficiency. However, the employment of blockchain technology in smart cities and photovoltaic power generation faces numerous challenges, including security, privacy protection, integration with other advanced technologies, and legal and regulatory issues. To surmount these obstacles, the adoption of corresponding technologies and strategies, reinforced education and training, and enhanced technological maturity and regulatory standards are requisite. By integrating blockchain technology with other technologies, one may anticipate its influential role across various domains and application scenarios, engendering a more extensive impact on the field of computing.

Keywords: Smart Cities; Photovoltaic Power; Computer Science; Data Security; Privacy Protection; Legal and Regulatory Issues; Technological Maturity

Citation: Shan Wong, Chen Chen and Peishi Wu, 2023. Blockchain Technology in Smart Cities and Photovoltaic Power Generation: Opportunities and Challenges from a Computer Science Perspective. *Journal of Smart Cities,* 8(1): 1-12. http://doi.org/10.26789/JSC.2023.01.001

Copyright: Blockchain Technology in Smart Cities and Photovoltaic Power Generation: Opportunities and Challenges from a Computer Science Perspective. © 2023 Shan Wong, Chen Chen and Peishi Wu. This is an Open Access article published by Urban Development Scientific Publishing Company. It is distributed under the terms of the Creative Commons.

1. Introduction

1.1 Overview of Blockchain Technology

Blockchain technology constitutes a distributed ledger system that employs cryptographic techniques to ensure data security and immutability [1]. According to the definition provided by the National Institute of Standards and Technology (NIST), a blockchain is a distributed, generally decentralized authoritative digital ledger that records transactions among community users [1]. Its salient features encompass decentralization, traceability, immutability, and security [2]. Blockchain technology operates on the concept of consensus mechanisms for transaction validation and maintaining the integrity of the blockchain [3], with consensus mechanisms responsible for ensuring that all nodes in the network concur with the state of the blockchain [4]. Furthermore, smart contracts represent a crucial component of blockchain technology, facilitating transaction automation and code execution on the blockchain [5, 6]. Smart contracts enable the creation of decentralized applications capable of autonomous operation without the necessity of intermediaries [5, 6]. Lastly, the security of blockchain technology is achieved through cryptographic techniques, such as public key encryption, digital signatures, and zero-knowledge proofs; its decentralized nature renders it resilient to attacks and eliminates the presence of single points of failure [7]. The application scope of blockchain technology has expanded far beyond the financial sector, encompassing various other industries, including the Internet of Things, supply chain management, and energy [2].

1.2 Background and Significance of Smart Cities and Photovoltaic Power Generation

Smart cities and photovoltaic power generation are vital components of future urban development. Smart cities employ information and communication technologies to improve key urban infrastructure and enhance the efficiency of public services [8, 9]. Simultaneously, photovoltaic power generation systems, as a focal point in the development of the Industry 4.0 smart grid, bring cleaner and greener energy to people [10]. With the advancement of 5G technology, foundational support is provided for the underlying framework of smart cities such as the Internet of Things [11]. Moreover, novel power generators as sustainable energy sources and self-powered sensors contribute to smart city applications, including smart transportation and smart healthcare [11].

Computer technology can promote the development of smart cities and photovoltaic power generation by enabling automation, ensuring security, and improving efficiency on the blockchain [12]. Blockchain technology can ensure data security and immutability in smart cities and photovoltaic power generation systems [13]. In the construction of smart cities, data security and privacy protection face numerous challenges, and blockchain technology can provide solutions for data protection [13]. Urban computing has essential applications in addressing the challenges brought by smart cities in the planning, environment, energy consumption, transportation, government policies, and business processes of sustainable smart cities [12].

Thus, computer technology drives the development of smart cities and photovoltaic power generation by empowering automation, ensuring security, and enhancing efficiency. With continuous technological innovation, we can expect future smart cities to better meet people's needs and provide long-term social support for economic development [9].

1.3 Research Objectives and Structure

The core objective of smart cities is to achieve sustainable development in areas such as environmental protection, resource management, economic development, and social welfare. As the cornerstone of urban development, the utilization efficiency and consumption of energy have become critical issues. Photovoltaic power generation, as a clean and renewable energy source, holds significant importance for the development of smart cities in realizing environmentally sustainable development, improving energy utilization efficiency, and achieving intelligent management of energy systems.

The application of blockchain technology in smart cities and photovoltaic power generation provides new possibilities for efficient and sustainable development. These mainly manifest in establishing decentralized energy trading platforms, ensuring the secure storage and sharing of energy data, utilizing smart contracts for automated collaboration and optimization, and achieving traceability and anti-counterfeiting of energy equipment. Although challenges such as technological maturity, data privacy protection, and policy regulations still exist, future research needs to explore areas like deep integration, real-world case analyses, and policy support and supervision to achieve efficient and sustainable urban energy systems and provide support for constructing green and intelligent future cities.

Hence, the present investigation primarily explores the applications, challenges, and solutions of blockchain technology in the realm of smart cities and photovoltaic power generation. The structure of this study is divided into several sections: initially offering an overview of the four aspects of blockchain technology applications in smart cities, encompassing governance and administration, public services, industrial development, and ecological environment; subsequently deliberating upon the potential and application scenarios of blockchain technology within the photovoltaic power generation domain; followed by an analysis of the pivotal role of computer technology in addressing the challenges and solutions of blockchain applications; the fifth section delves into the challenges and developmental directions of blockchain in smart cities, as well as the applications and opportunities of blockchain technology in smart cities and photovoltaic power generation sectors. In conclusion, the applications of blockchain technology in areas such as smart cities and photovoltaic power generation, alongside the pertinent challenges and solutions, offer opportunities and impacts for the field of computer science. The entire study revolves around the value and challenges of blockchain technology in different application scenarios, demonstrating the essential role of computer technology in resolving practical issues.

2. Blockchain Technology in Smart City Applications

2.1 Governance and Administration

Blockchain technology exhibits numerous applications in the governance and administration of smart cities. Primarily, it offers a secure and transparent platform for government data sharing [14]. Through such a platform, governments can collaborate more effectively, enhancing administrative efficiency. Furthermore, blockchain technology can improve supply chain management via distributed ledger technology, thereby augmenting transparency, reliability, traceability, and efficiency [15, 16]. In terms of environmental protection, social equity, and governance efficiency, blockchain-based supply chain management can bolster sustainability performance [15].

Smart contracts, another key application of blockchain technology, enable transaction automation [17]. Research indicates a positive relationship between smart contracts and supply chain transparency, while the impact on supply chain resilience remains inconclusive [17]. Nevertheless, blockchain-driven supply chain transparency exerts a positive influence on blockchain-driven supply chain resilience [17]. These findings can assist supply chain managers and other stakeholders in devising strategies to maximize the utilization of blockchain technology for enhancing supply chain transparency and resilience. This will contribute to the rapid restoration of supply chains to their original state when faced with disruptive events [17].

2.2 Livelihood Services

Blockchain technology has extensive applications in livelihood services, such as identity verification [18], privacy protection [19, 20], and property registration and transfer [16]. In the realm of identity verification, blockchain technology can provide a secure, transparent, and immutable platform for electronic health records, facilitating the sharing of sensitive data between patients and medical institutions [18]. Furthermore, blockchain technology harbours considerable potential in privacy protection. Despite the open and transparent design of blockchain potentially compromising user privacy, researchers have developed effective privacy-preserving techniques to satisfy the security requirements of privacy-related information in blockchain applications [19].

Property registration and transfer constitute another application scenario for blockchain technology in livelihood services [16]. Owing to the transparency, traceability, and security of blockchain technology, it yields significant economic benefits in logistics and supply chain management [16]. Specifically, blockchain technology proves particularly valuable for high-value goods [16].

Computational technology plays a pivotal role in these applications, facilitating transaction automation and code execution on the blockchain [21]. For instance, in electronic voting and event registration, blockchain technology can establish a more secure, transparent, and decentralized system [21]. These applications render livelihood services more convenient and efficient under the support of blockchain technology.

2.3 Industrial Development

In terms of industrial development, blockchain technology possesses the potential to innovate financial services and smart contract applications [22, 23]. The fintech industry has already begun leveraging the advantages of blockchain technology, and applying it to financial transactions and services [22]. Within financial transactions, blockchain technology can provide a secure and transparent platform, rendering the banking sector more convenient, efficient, secure, and user-friendly [22]. Smart contracts enable transaction automation [22], automatically executing when both parties fulfil specific conditions, reducing intermediary involvement and lowering transaction costs.

Computational technology plays a crucial role in these developments by facilitating transaction automation and code execution on the blockchain, enhancing application efficiency and accuracy [23]. Blockchain technology can provide reliable data exchange channels for various industries, gradually integrating into daily life. The fintech sector, in particular, demonstrates extensive applications [23]. Observing the process of digital trust reveals the true value and advantages of blockchain technology [23]. Transaction parties no longer require reliance on legal central institutions, reducing occurrences of distrust issues.

However, numerous unexplored application scenarios in the financial field remain, and the technology itself possesses considerable room for improvement [23]. As blockchain technology remains unregulated and in its early stages, its future applications in the financial domain retain significant potential and developmental opportunities [23].

2.4 Ecological Environment

In terms of the ecological environment, blockchain technology has multiple applications, including energy management, transactions, carbon emission trading, and monitoring [24-26]. Blockchain technology can create decentralized energy trading platforms, facilitating sustainable energy transitions and peer-to-peer energy transactions [24]. This distributed technology contributes to reducing transaction costs, accelerating the adoption of renewable energy, and providing fair prices for energy providers and users [24].

Furthermore, blockchain technology can enhance the efficiency of carbon emission trading [24]. During the carbon emission trading process, blockchain technology assists in calculating energy usage and carbon emissions to assess their economic benefits [24]. Simultaneously, blockchain technology can promote ecological embedding, such as tracking by-products and recyclable waste in the production process within coffee supply chains, supporting the ecological circular economy [25].

Computational technology plays a key role in these applications, supporting transaction automation and code execution, thereby improving application efficiency and accuracy [27]. For example, through customized blockchain service performance analysis tools, blockchain performance can be automatically deployed and optimized in different cloud environments, further enhancing system efficiency [27].

3. Applications and Opportunities of Blockchain Technology in Photovoltaic Power Generation

3.1 Photovoltaic Green Certificate Trading and Environmental Monitoring

Photovoltaic green certificate trading represents a market-driven instrument designed to achieve renewable energy generation targets [28]. Green certificates monetize the environmental value of renewable energy sources, functioning as tradable securities [29]. The fundamental concept behind the green certificate system involves determining the degree of support for renewable energy generation through market forces, creating incentives for renewable power production, and promoting the establishment of sustainable electricity systems [28].

Blockchain technology demonstrates extensive potential in photovoltaic green certificate trading. Firstly, it enhances the efficiency and transparency of green certificate transactions [29]. The utilization of smart contracts facilitates transaction automation, ensuring accountability for all parties. In practical applications, the green certificate trading market encourages virtual power plants to procure more renewable energy sources, such as wind, photovoltaic, and hydroelectric power, reducing reliance on carbon-intensive gas-fired power generation and thereby diminishing the carbon emissions of the entire power system [29].

Secondly, blockchain technology can monitor and trace environmental data, such as carbon emissions, augmenting the accuracy and reliability of environmental monitoring [28, 29]. By recording environmental data on the blockchain, data integrity can be maintained, bolstering the credibility of monitoring results. Additionally, carbon emission trading can be implemented with the aid of blockchain technology by limiting carbon emission allowances and considering excess carbon emissions as commodities. This market-driven approach enhances the competitiveness of low-carbon industries, fostering renewable energy generation development [29].

Therefore, blockchain technology exhibits widespread application prospects in photovoltaic green certificate trading and environmental monitoring, effectively increasing the prevalence of renewable energy generation, reducing carbon emissions, and promoting green economic development.

3.2 Blockchain-Based Green Certificate Trading Platform

A blockchain-based green certificate trading platform employs a peer-to-peer (P2P) energy trading model, offering an innovative approach to facilitate green certificate trading and circulation [30]. On this trading platform, renewable energy power plants receive a green certificate for every certified megawatt-hour (MWh) of renewable energy produced, which can then be transferred, purchased, sold, or cancelled [31]. However, the existing green certificate trading process is cumbersome and opaque, presenting considerable potential for the adoption of blockchain technology [31].

Implementing blockchain technology on a green certificate trading platform ensures certificate authenticity, increases system transparency, and reduces transaction costs [31]. Blockchain technology permits the creation of decentralized and distributed trading systems, providing a more transparent, reliable, and secure foundation for P2P trading environments [30]. Within this blockchain-based P2P energy trading platform, smart contracts are embedded into the blockchain as energy labels. These energy labels establish conditions for future energy transactions, rendering transactions more cost-effective while maintaining optimal high-quality energy choices [30].

Utilizing blockchain technology, green certificate transactions become more streamlined and transparent, eliminating the need for third-party regulatory agencies to manage the trading process, thus reducing transaction costs [31]. Moreover, in energy trading applications, blockchain provides a reliable verification process without the necessity for third-party authentication [31]. Implementing a blockchain-based green certificate trading platform is anticipated to create a sustainable energy trading ecosystem, offering a trustworthy, sustainable, secure, and energy-efficient environment for energy transactions between consumers and power producers [30].

3.3 Computer Technology and Photovoltaic Green Certificate Trading

Computer technology plays an instrumental role in photovoltaic green certificate transactions, providing a secure, transparent, and efficient trading platform while optimizing green future development prediction models [32]. Research indicates that implementing a blockchain-based green certificate trading platform can address green certificate tracking issues [32]. Moreover, the literature further examines the calculation and allocation methods of green certificates [32].

In the realm of market impact assessment, scholarly inquiry presents a conjoined framework for delineating carbon commerce, electrical energy exchange, and the trading of environmentally-conscious certification, while concurrently dissecting the interdependence amongst the triad [32]. Concurrently, academic investigation establishes an optimization paradigm for electrical energy transactions, taking into account both the environmentally-conscious certification and carbon commerce markets, and simulating the ramifications of carbon allotment coefficients and environmentally-conscious certification ratios on the carbon emission abatement consequences of power production enterprises [32].

The employment of virtual power installations engenders the facilitation of coordination and optimization of carbon commerce and environmentally-conscious certification transactions amid the procurement and vending termini, thereby maximizing the amalgamated benefits of virtual power installations [29]. In the context of a scenario encompassing carbon commerce and environmentally-conscious certification transactions, renewable energy production surpasses the aggregate of the remaining three scenarios, with gas turbine power generation yielding the nadir output. This insinuates that both carbon commerce and environmentally-conscious certification markets possess the capacity to render virtual power plant electricity procurement schemes more pristine and diminished in carbon emissions [29]. By instituting environmentally-conscious certification and carbon emission trading mechanisms, governing bodies may utilize market-oriented approaches to augment the competitiveness of low-carbon industries and bolster the proliferation of renewable energy power generation .

3.4 Blockchain Technology Applications in Carbon Trading

Blockchain technology possesses significant value in carbon trading applications, with carbon trading serving as a market-based mechanism aimed at reducing greenhouse gas emissions [33]. Blockchain technology can augment the transparency, security, and efficiency of carbon trading [24]. This nascent technology exhibits immense potential in P2P energy transactions, delivering substantial benefits and innovation for sustainable energy transitions and P2P trading [24].

Albeit recent apprehensions have emerged regarding the environmental repercussions and concomitant expenses of blockchain technology [24], it is imperative to delve further into this matter. By appraising energy consumption and carbon emissions during blockchain validation procedures and ascertaining the economic advantages of blockchain technology within peer-to-peer (P2P) energy trading contexts, the nexus between blockchain technology and energy systems may be more thoroughly scrutinized [24].

Experiential data gleaned from peer-to-peer (P2P) energy trading infrastructures evince the myriad perspicacity acquired through the employment of diverse blockchain augmentation techniques for energy transaction metamorphosis [24]. Examination divulges that the expenditure incurred in harnessing blockchain for transaction processing is inferior to extant coordination costs [24]. Moreover, blockchain-facilitated energy trading allows for higher-frequency transactions than those presently sanctioned by regulations, thereby optimizing the boons conferred by renewable energy sources [24]. An impregnable, blockchain-based P2P trading milieu ensures equitable pricing for energy purveyors and end-users, fostering expansion in the renewable energy sector [24].

The employment of smart contracts automates transactions, holding all parties accountable for their actions [24]. As trade openness reaches particular thresholds, environmental quality gradually improves, subsequently reducing carbon emissions [33]. Therefore, the application of blockchain technology in carbon trading plays a crucial role in lowering carbon emissions, enhancing energy transition efficiency, and fostering renewable energy development.

3.5 Applications of Blockchain Technology in the Energy Internet

Blockchain technology offers extensive applications and advantages within the energy internet, such as distributed energy trading and microgrid management [34]. Blockchain facilitates decentralized energy trading platforms, allowing direct energy exchange between producers and consumers [34]. This technological innovation empowers participants to promote distributed or wholesale energy trading and create virtual grids [34]. Consumers can trade amongst their devices and resources, with neighbours, and with the grid [34].

In this process, the use of smart contracts automates transactions, ensuring accountability among all parties [34]. Smart contracts simplify transaction processes, improve transaction efficiency, and reduce intermediary costs [34].

In several exemplary applications within this field, the extensive use of blockchain technology in the energy industry is evident [34]. For instance, blockchain technology can provide real-time data sharing for electricity markets, ensuring transparency and efficient operations. Moreover, blockchain enhances traceability within the renewable energy sector, assisting regulatory authorities in effectively implementing policies and regulatory measures.

Hence, the application of blockchain technology in the energy internet not only facilitates distributed energy trading and microgrid management but also improves transparency and efficiency in energy transactions, promoting sustainable development in the energy sector.

4. Challenges and Potential Solutions for Blockchain Technology Applications

4.1 Security Challenges and Solutions for Blockchain Technology in Smart Cities and Photovoltaic Power Generation

Security issues that may be encountered in blockchain technology applications within smart cities and photovoltaic power generation include cyberattacks, data breaches, and unauthorized access to sensitive information, posing risks [35]. These issues may affect the trust mechanisms carried out by blockchain technology, consequently impacting the authenticity and accuracy of data [35]. To address these issues, encryption, trust mechanisms, multifactor authentication and access control can be employed.

Firstly, encryption can protect sensitive data by converting it into codes that can only be decrypted by authorized parties [36]. This process involves recording and storing information generated by multiple entities participating in the consensus mechanism into data blocks using encryption algorithms, and creating a unique password for each data block to connect the data chain [35]. Consequently, even if data is intercepted, attackers cannot decrypt it, ensuring information security.

Secondly, trust mechanisms, such as digital signatures and public key infrastructure, can be employed to ensure the authenticity and integrity of data and transactions on the blockchain [36]. Cross-validation by each entity mutually verifies the authenticity of the information, ensuring the reliability of data on the blockchain [35]. This mechanism effectively mitigates the risk of forgery and tampering, maintaining the credibility of the blockchain system.

Lastly, multifactor authentication and access control can further enhance the security of blockchain-based systems [36]. By authenticating users, only verified users are granted access to sensitive data, preventing unauthorized access. Access control can limit specific users' access to certain data, effectively preventing data leaks and malicious attacks.

Therefore, encryption, trust mechanisms, and multifactor authentication and access control can ensure the security of blockchain technology applications in smart cities and photovoltaic power generation, reducing the risks of cyberattacks, data breaches, and unauthorized access to sensitive information. These measures contribute to maintaining the status of blockchain technology as a disruptive core technology for the next generation, providing greater security and trustworthiness to the fields of smart cities and photovoltaic power generation.

4.2 Selection and Challenges of Consensus Mechanisms

In choosing an appropriate consensus mechanism, it is vital to consider the specific requirements and application scenarios thoroughly [37]. The consensus mechanism is the core of blockchain networks, playing a crucial role in security, integrity, and performance [37]. Common consensus mechanisms include Proof of Work (PoW) and Proof of Stake (PoS).

Initially, Proof of Work (PoW) is renowned for its security and reliability but is energy-intensive and may lead to mining power centralization [37]. PoW consensus mechanisms achieve consensus through miners engaging in an intensive mining process [37]. However, this mechanism faces limitations such as low energy efficiency, significant latency, and susceptibility to security threats [37]. Consequently, with the development of blockchain technology, PoW may no longer be the optimal choice in certain application scenarios.

Subsequently, Proof of Stake (PoS) is recognized for its energy efficiency and scalability but may lead to validator power concentration [38, 39]. PoS consensus mechanisms achieve consensus by proving the stakeholder's interest [37]. Compared to PoW, PoS reduces environmental impact and lowers energy consumption [38]. Nevertheless, a potential issue with PoS is the concentration of stake, as validators with more significant stakes may more easily obtain consensus power, thus affecting the entire network's decentralization characteristic [39].

When selecting a consensus mechanism, it is necessary to balance various factors, including energy consumption, latency, security, and power distribution [37]. Additionally, the characteristics and requirements of the application scenario must be considered. For instance, in the field of internet-connected vehicles, a consensus mechanism with high security, low energy consumption, and rapid response should be chosen [37]. Moreover, alternative consensus mechanisms, such as Proof of Authority (PoA), can be explored, which maintain security and reliability while offering higher transaction speeds [39].

Hence, selecting an appropriate consensus mechanism is crucial for thoroughly considering application scenarios and specific system requirements, ensuring the security, integrity, and performance of blockchain networks are satisfied. Comparing the features and limitations of different consensus mechanisms can provide more suitable solutions for various application scenarios.

4.3 Legal and Regulatory Challenges and Their Solutions

To address legal and regulatory issues, such as data privacy and compliance, computing technology can support compliance and regulation by implementing smart contracts [40]. Smart contracts are self-executing contracts with the agreement terms directly written into lines of code [40]. Smart contracts can be utilized for automating compliance and regulation [40], ensuring adherence to laws and policies by all parties.

Blockchain technology plays a significant role in ensuring data privacy. Its distributed system can secure data privacy by encrypting sensitive data and providing secure access control [41]. Furthermore, blockchain technology can enhance compliance by providing transparent and auditable records of all transactions, ensuring adherence [35]. This endows blockchain with immense potential in various application scenarios, such as the Internet of Things (IoT) and cloud computing fields [41].

To further enhance privacy, security, and service support in business applications, cloud services can be integrated with blockchain technology into a unified system, improving network control, task scheduling, data integrity, resource management, pricing, equitable payment, and resource allocation [41]. At present, numerous blockchain-as-a-service (BaaS) platforms are available in the market, such as Alibaba, Oracle, Azure, Amazon, and IBM, integrating blockchain with cloud services [41]. A comprehensive assessment of these platforms can help understand the application value of BaaS platforms in cloud computing.

Therefore, computer technology possesses immense potential for addressing legal and regulatory issues. Smart contracts can enable automated compliance and regulation, while blockchain technology can ensure data privacy and enhance compliance. By combining blockchain technology with other technologies, such as cloud computing, privacy, security, and service support in business applications can be further improved.

5. Discussion and Analysis

5.1 Challenges and Development Directions of Blockchain in Smart Cities

First, in blockchain technology applications, although significant progress has been made in multiple domains, its maturity remains to be improved, and it is not yet fully regulated. To ensure its widespread application in smart cities, strengthening popularization and education is crucial. Simultaneously, safeguarding the security and attack resistance of blockchain becomes particularly important; researchers and developers need to pay attention to the latest developments in this area to address potential threats. Second, regarding privacy protection, although the open and transparent design of the blockchain can enhance the security and transparency of data sharing, it may also lead to user privacy leakage. To meet the security requirements of applications for privacy-related information, researchers need to continue developing effective privacy protection technologies.

Next, in smart city applications, blockchain technology needs to be combined with other advanced technologies (such as the Internet of Things and artificial intelligence) to achieve more efficient solutions. In the future, cross-domain technology integration and interoperability research need to be strengthened.

In promoting the application of blockchain in the photovoltaic power generation field, interoperability and coordination issues between different systems should be considered, strengthening cooperation with other relevant technologies and domains to achieve mutual benefits. Finally, in terms of law and regulation, governments and regulatory agencies need to formulate corresponding policies and regulations to promote the competitiveness of low-carbon industries and the development of renewable energy power generation. At the same time, regulatory agencies need to strengthen supervision of blockchain technology applications to ensure their compliance and security. Thus, overcoming these challenges requires adopting appropriate technologies and strategies to ensure the security, reliability, and compliance of blockchain technology.

5.2 Applications and Opportunities of Blockchain Technology in Smart Cities and Photovoltaic Power Generation

Blockchain technology presents numerous opportunities in the realms of governance and management, public services, industrial development, and ecological environments in smart cities. These opportunities encompass enhancing the security and transparency of government data sharing, facilitating secure identity authentication and property registration transfer services, promoting innovative financial services in the fintech industry, and supporting the establishment and optimization of distributed energy trading platforms. Furthermore, blockchain technology holds extensive applications and prospects in the photovoltaic power generation sector, such as elevating the efficiency and transparency of green photovoltaic certificate transactions, environmental monitoring, green certificate trading platform construction, and carbon trading, thereby playing a crucial role in reducing carbon emissions, heightening energy transition efficiency, and advancing renewable energy development.

However, challenges abound in the application of blockchain technology in smart cities and photovoltaic power generation, including security, consensus mechanisms, and legal and regulatory aspects. To ensure data security and reliability, measures such as encryption, trust mechanisms, multi-factor authentication, and access control can be employed. When selecting an appropriate consensus mechanism, careful consideration of application scenarios and specific system requirements, such as energy consumption, latency, security, and power distribution, is necessary. Smart contracts can support compliance and regulation, achieving automated compliance and supervision.

Integrating blockchain technology with other technologies, such as cloud services, can further enhance privacy, security, and service support in business applications. Numerous Blockchain as a Service (BaaS) platforms incorporate blockchain as part of cloud services; through comprehensive assessments of these platforms, the application value of BaaS platforms in cloud computing can be ascertained. As blockchain technology continually develops and matures, its significant role in various fields and application scenarios can be anticipated, including the Internet of Things, cross-border payments, healthcare, and intellectual property, where blockchain technology can provide secure, efficient, and decentralized solutions.

To fully harness the potential of blockchain technology, close attention must be paid to relevant technological advancements, such as zero-knowledge proofs, sidechains, and cross-chain technologies, which can further improve blockchain system scalability, security, and interoperability, thereby offering more research and application opportunities in the computing field. Concurrently, education and training are vital factors in implementing widespread blockchain technology applications. Strengthening the cultivation of computer professionals equipped with relevant blockchain knowledge and skills is necessary for better addressing future challenges and opportunities. This may require incorporating blockchain-related content into computer science curricula and encouraging collaboration between enterprises and academia to jointly promote blockchain technology development and application.

6. Conclusions

The present study demonstrates that blockchain technology possesses substantial potential and extensive applicability in the domains of smart cities and photovoltaic power generation. Within smart cities, blockchain technology has broad application scenarios, encompassing government and administration, public services, industrial development, and ecological environment. Owing to computer technology support, transaction automation is achieved, enhancing the efficiency and accuracy of applications. Concurrently, blockchain technology holds significant value in the realm of photovoltaic power generation, such as improving the efficiency and transparency of photovoltaic green certificate trading, reducing carbon emissions, augmenting the competitiveness of low-carbon industries, and promoting the development of renewable energy generation. Meanwhile, computer technology plays a pivotal role in addressing the challenges and solutions associated with blockchain applications, such as ensuring encryption and trust mechanisms, selecting suitable consensus mechanisms, implementing automated compliance and regulation through smart contracts, and safeguarding data privacy while enhancing compliance. Nonetheless, numerous challenges persist, including increasing the maturity of blockchain technology, enhancing security and attack resistance, protecting privacy, and integrating with other advanced technologies. Corresponding techniques and strategies should be employed to surmount these challenges.

Therefore, this research indicates that blockchain technology harbours immense potential in smart cities and photovoltaic power generation, offering numerous research and application opportunities within the computer science field. Challenges should be addressed through technological innovation and strategic adjustments to ensure the security, reliability, and compliance of blockchain technology. It is reasonable to believe that, with the continuous advancement of blockchain technology, its significance will extend to even more domains and application scenarios in the future. To fully exploit its potential, attention must be given to technological advancements, bolstering education and training to confront future challenges and opportunities. It’s my great honor to have Mr. Georgios Tsakmakis, our DP Computer Science / MYP Design Teacher, to work with me in the critical logic and methodology part of the essay.

Conflict of Interest

All authors reported no conflict of interest.

References

[1] Yaga, D., Mell, P., Roby, N., et al. Nistir 8202 blockchain technology overview [J]. National Institute of Standards and Technology, US Department of Commerce, Washington, USA, 2018.

[2] Wang, W., Hoang, D. T., Hu, P., et al. A survey on consensus mechanisms and mining strategy management in blockchain networks [J]. IEEE Access, 2019, 7: 22328-70.

[3] Tahir, U. M., Sardaraz, M., Aziz, U. Critical Review of Blockchain Consensus Algorithms: challenges and opportunities [J]. International Journal of Innovations in Science & Technology, 2022, 4(5): 52-64.

[4] Kingslin, S., Zahra, R. An effective randomization framework to pow consensus algorithm of blockchain (RPoW) [J]. International Journal of Engineering and Advanced Technology, 2019, 8(6): 1793-7.

[5] Siris, V. A., Dimopoulos, D., Fotiou, N., et al. Interledger smart contracts for decentralized authorization to constrained things; proceedings of the IEEE INFOCOM 2019-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), F, 2019 [C]. IEEE.

[6] Chen, J., Bu, F., Wang, Y., et al. Demand-side Response User Selection Based on Improved BPSO; proceedings of the Journal of Physics: Conference Series, F, 2022 [C]. IOP Publishing.

[7] Anwar, F., Khan, B. U. I., Kiah, M. L. B. M., et al. A Comprehensive Insight into Blockchain Technology: Past Development, Present Impact and Future Considerations [J]. International Journal of Advanced Computer Science and Applications, 2022, 13(11): 878-907.

[8] Prasad, G. PUBLIC TRANSPORTATION PORTAL

FOR COMMUTERS [J]. International Journal of Engineering Applied Sciences and Technology, 7(2): 108-13.

[9] Wang, S., Chen, D., Liu, L. The practice and prospect of smart cities in China's urbanization process [J]. Frontiers of Urban and Rural Planning, 2023, 1(1): 7.

[10] Niu, S., Ke, X., Shen, Q., et al. Research on transient overvoltage suppression measures for photovoltaics connected to the DC sending end in the smart power system for industry 4.0 [J]. Mathematical Problems in Engineering, 2020, 2020: 1-13.

[11] Xu, Y., Li, W., Tai, J., et al. A Bibliometric-Based Analytical Framework for the Study of Smart City Lifeforms in China [J]. International Journal of Environmental Research and Public Health, 2022, 19(22): 1-17.

[12] Hashem, I. A. T., Usmani, R. S. A., Almutairi, M. S., et al. Urban Computing for Sustainable Smart Cities: Recent Advances, Taxonomy, and Open Research Challenges [J]. Sustainability, 2023, 15(5): 1-32.

[13] Xihua, Z., Goyal, S. Security and privacy challenges using IoT-blockchain technology in a smart city: critical analysis [J]. IJEER, 2022, 10(2): 190-5.

[14] Saberi, S., Kouhizadeh, M., Sarkis, J., et al. Blockchain technology and its relationships to sustainable supply chain management [J]. International Journal of Production Research, 2019, 57(7): 2117-35.

[15] Park, A., Li, H. The effect of blockchain technology on supply chain sustainability performances [J]. Sustainability, 2021, 13(4): 1726.

[16] Berneis, M., Bartsch, D., Winkler, H. Applications of Blockchain Technology in Logistics and Supply Chain Management—Insights from a Systematic Literature Review [J]. Logistics, 2021, 5(3): 43.

[17] Mashud, A., Khan, M., Uddin, M., et al. A non-instantaneous inventory model having different deterioration rates with stock and price dependent demand under partially backlogged shortages [J]. Uncertain Supply Chain Management, 2018, 6(1): 49-64.

[18] Karmakar, S., Bhaduri, A., Kumari, P., et al. Blockchain Technology for Securing Electronic Health Records: A Comprehensive Review and Future Directions [J]. International Journal for Research in Applied Science & Engineering Technology, 2023, 11(III): 2266-71.

[19] Lai, Z. Comparison of current blockchain privacy protection technologies and prospects for future trends; proceedings of the Second International Conference on Green Communication, Network, and Internet of Things (CNIoT 2022), F, 2023 [C]. SPIE.

[20] Manzoor, A. Privacy and Security Under Blockchain Technology: Challenges and Solutions [M]. Fraud Prevention, Confidentiality, and Data Security for Modern Businesses. IGI Global. 2023: 176-95.

[21] Dash, S., Parida, P., Sahu, G., et al. Artificial Intelligence Models for Blockchain-Based Intelligent Networks Systems: Concepts, Methodologies, Tools, and Applications [M]. Handbook of Research on Quantum Computing for Smart Environments. IGI Global. 2023: 343-63.

[22] Taherdoost, H. Blockchain: a catalyst in fintech future revolution [J]. Future Technology (FUTECH), 2023, 2(2): 25-31.

[23] Trivedi, S., Mehta, K., Sharma, R. Systematic literature review on application of blockchain technology in E-finance and financial services [J]. Journal of technology management & innovation, 2021, 16(3): 89-102.

[24] Coutinho, K., Wongthongtham, P., Abu-Salih, B., et al. Carbon emission and cost of blockchain mining in a case of peer-to-peer energy trading [J]. Machine Learning Applications in Civil Engineering, 2022, 8: 1-13.

[25] Trollman, H., Garcia-Garcia, G., Jagtap, S., et al. Blockchain for ecologically embedded coffee supply chains [J]. Logistics, 2022, 6(3): 43.

[26] Wang, X., Yao, F., Wen, F. Applications of Blockchain Technology in Modern Power Systems: A Brief Survey [J]. Energies, 2022, 15(13): 4516.

[27] Xin, R., Mohazzab, J., Shi, Z., et al. CBProf: Customisable Blockchain-as-a-Service Performance Profiler in Cloud Environments; proceedings of

the Blockchain–ICBC 2021: 4th International Conference, Held as Part of the Services Conference Federation, SCF 2021, Virtual Event, December 10–14, 2021, Proceedings, F, 2022 [C]. Springer.

[28] Plumb, I., Zamfir, A. I. A comparative analysis of green certificates markets in the European Union [J]. Management of Environmental Quality: An International Journal, 2009, 20(6): 684-95.

[29] Hongliang, W., Benjie, L., Daoxin, P., et al. Virtual power plant participates in the two-level decision-making optimization of internal purchase and sale of electricity and external multi-market [J]. IEEE Access, 2021, 9: 133625-40.

[30] Park, L. W., Lee, S., Chang, H. A sustainable home energy prosumer-chain methodology with energy tags over the blockchain [J]. Sustainability, 2018, 10(3): 1-18.

[31] Khatoon, A., Verma, P., Southernwood, J., et al. Blockchain in energy efficiency: Potential applications and benefits [J]. Energies, 2019, 12(17): 1-14.

[32] Xu, Q., Qiao, S., Zhou, H., et al. Mechanism design and consumption certification of differentiated green electricity trading: A Zhejiang experience [J]. Frontiers in Energy Research, 2022, 10: 58.

[33] Byaro, M., Mafwolo, G., Mayaya, H. Keeping an eye on environmental quality in Tanzania as trade, industrialization, income, and urbanization continue to grow [J]. Environmental Science and Pollution Research, 2022, 29(39): 59002–12.

[34] Wu, J., Zhou, Y., Zhang, Y., et al. Application of Blockchain Energy [J]. International Journal of Engineering Technologies and Management Research, 2023, 10(4): 32–40.

[35] Chen, S., Tian, J. Research on Information Sharing Application of Collaborative Government Affairs System Based on Blockchain; proceedings of the 2022 2nd International Conference on Public Management and Intelligent Society (PMIS 2022), F, 2022 [C]. Atlantis Press.

[36] Kumar, M. V., Iyengar, N. A framework for Blockchain technology in rice supply chain management [J]. Advanced Science and Technology Letters, 2017, 146: 125-30.

[37] Nguyen, C. T., Hoang, D. T., Nguyen, D. N., et al. Proof-of-stake consensus mechanisms for future blockchain networks: fundamentals, applications and opportunities [J]. IEEE Access, 2019, 7: 85727-45.

[38] Budish, E. The economic limits of bitcoin and the blockchain [R]: National Bureau of Economic Research, 2018.

[39] Shynkarenko, D., Kopp, A. Towards the approach to building smart contracts based on business rules using natural language processing [J]. Grail of Science, 2022, (22): 144-50.

[40] Matura, R., Kunal. A Brief Analysis of Smart Contracts and Applications of Blockchain Technology [J]. Journal of Artificial Intelligence and Capsule Networks, 2023, 5(1): 39-51.

[41] Song, J., Zhang, P., Alkubati, M., et al. Research advances on blockchain-as-a-service: Architectures, applications and challenges [J]. Digital Communications and Networks, 2022, 8(4): 466-75.