CHAPTER 11
Blockchain Enabled Peer-to-peer Renewable energy trading

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ABSTRACT

The rapid growth of renewable energy sources such as solar and wind has created opportunities for decentralized energy generation and consumption. Traditional centralized power grids, however, face challenges in efficiently managing distributed renewable energy resources and enabling direct energy exchange between producers and consumers. Blockchain-enabled peer-to-peer (P2P) renewable energy trading has emerged as a promising solution to address these limitations by enabling secure, transparent, and decentralized energy transactions among participants in a local energy market. Blockchain technology provides a distributed ledger that records energy transactions in a tamper-proof and transparent manner, eliminating the need for centralized intermediaries. In a blockchain-based P2P trading system, prosumers—individuals or organizations that both produce and consume energy—can sell surplus renewable energy directly to nearby consumers. Smart contracts automate the trading process by executing predefined rules for pricing, settlement, and verification of energy transactions. This decentralized framework enhances trust among participants, reduces transaction costs, and improves the efficiency of renewable energy utilization. Furthermore, the integration of Internet of Things (IoT) devices and smart meters enables real-time monitoring of energy generation and consumption, facilitating accurate measurement and automated trading. Advanced technologies such as artificial intelligence can also be incorporated to optimize pricing strategies and demand forecasting in the P2P energy market.Despite its advantages, blockchain-based energy trading systems face challenges related to scalability, regulatory frameworks, data privacy, and energy consumption of blockchain networks. Addressing these issues is essential for large-scale adoption. Overall, blockchain-enabled P2P renewable energy trading represents a transformative approach for building decentralized, resilient, and sustainable energy ecosystems that empower consumers and accelerate the transition toward clean energy systems..

Keywords: *renewable energy sources , blockchain-based P2P trading system, artificial intelligence, energy consumption of blockchain networks etc.*

INTRODUCTION

The inter-linkage between energy and sustainable development as per the sustainable development goals (SDGs) has been well established, with energy considered a cross-cutting issue as it is interwoven and key to achieving many of the SDG goals Research and practice aimed at promoting this important role of energy have, therefore, become a policy concern. Energy policies worldwide are underpinned mainly by the energy trilemma framework consisting of energy security, sustainability, and equity, which are pushing for a transition in which, amongst the three objectives, clean energy is delivered, and the energy systems become

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decarbonized. The shift towards decentralized energy systems, driven by renewable energy adoption, has created a need for innovative solutions like P2P energy trading as there is need to optimize energy distribution, reduce transmission losses, and empower consumers to actively participate in the energy market. This model offers significant benefits to deploying energy systems, including improved energy distribution and reduced transmission losses. However, it faces challenges like scalability, trust, and integrating intermittent renewable sources. Addressing these issues is crucial for the success and growth of P2P systems, which are key to achieving global sustainability goals. This challenge has necessitated the research need to explore how innovative solutions, such as blockchain-based solutions, enhance the efficiency, transparency, and integration of renewable energy in P2P trading. Renewable Energy Sources (RES) offer environmentally friendly alternatives in the energy transition efforts Among the many policy, economic, technical, and socio-cultural barriers to deploying RES, reducing energyFootnote1 losses in transmission and distribution are a key challenge for renewable energy optimization.

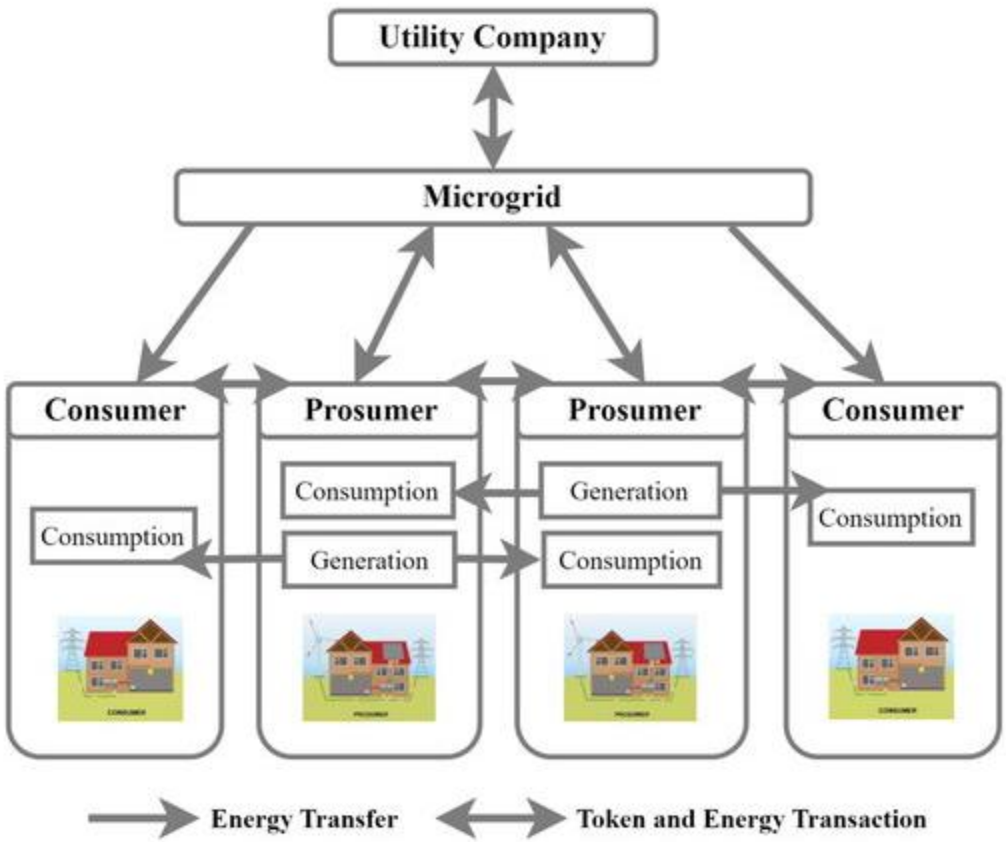

Figure 1; Peer-to-peer Renewable energy trading

Diverse studies, including have reported that P2P energy trading is one way to utilize RES and minimize long-distance transmission and distribution losses. According to the International Renewable Energy Agency (IRENA) P2P electricity trading is a business model based on an interconnected platform that serves as an online marketplace where consumers and producers "meet" to trade electricity directly without the need for an intermediary. In P2P trading, energy is mainly generated from RES and locally traded among members to avoid significant transmission losses The Brooklyn microgrid serves as an example of a small-scale P2P network for energy trading. In P2P trading, stakeholders include: "Utility company," who provide the infrastructure; "Microgrid," who manages the distributed energy transaction; "Prosumers," who both produce and consume energy; and "Consumers," who solely consume energy. Prosumers with surplus energy sell to consumers.

Although P2P energy trading can satisfy growing energy requirements, many implementation issues exist. Stakeholders in P2P will be hesitant to participate in a market lacking trust and transparency. A trusted third party is required for auditing and verifying transactions;Footnote2 commonly suffers from a single point of failure and privacy risks (leakage of confidential user data) (Ma et al., Citation2013). This third party may influence the price, which is against free-market principles. To help address these issues, technology-enabled systems, such as blockchain, need to be put in place to overcome these barriers. Blockchain technology helps mitigate transmission and distribution losses in P2P trading systems by enhancing accountability and auditability. Blockchain is an immutable ledger that ensures accurate, tamper-proof recording of transactions, facilitating real-time validation and efficient energy distribution. As a distributed ledger, instead of a single user, a group of members verifies the transaction (this reduces the risk of a single user influencing the trading), and validated transaction records are stored in a distributed manner across the network. Blockchain also secures transaction records using cryptography.

P2P ENERGY SYSTEM

The different types of losses in the P2P energy system include:

ENERGY PRODUCTION LOSS:

Energy production loss occurs during electricity production at power plants or renewable energy sources such as solar panels, wind turbines, or hydroelectric dams. These losses are primarily due to inefficiencies in converting primary energy sources (e.g., coal, natural gas, sunlight, wind, water) into electrical energy. Typically, these losses range from 40% to 65% in traditional power plants, while renewable energy sources experience lower losses, generally around 10% to 30% (Paudel et al., Citation2020).

TRANSMISSION AND DISTRIBUTION LOSS:

Transmission and distribution loss occur during the transmission of electricity from renewable energy sources to end consumers through the grid infrastructure. In P2P energy trading, where energy trading involves bidirectional flows of electricity, transmission and distribution loss can occur during the import and export of energy. These losses usually fall between 5% to 15%, but can exceed 15% in P2P energy trading systems with decentralized grids (Zhu et al., Citation2022).

CONVERSION LOSS:

Conversion loss occurs when electricity is converted from one form to another, such as alternating current (AC) to direct current (DC) or vice versa, or from high voltage to low voltage for distribution to end consumers. These losses occur due to the inherent inefficiencies of power conversion devices such as inverters, rectifiers, transformers, and voltage regulators. Conversion losses are generally around 2% to 10% per conversion step, depending on the efficiency of devices like inverters and transformers (Suthar et al., Citation2024).

THEFT AND NON-TECHNICAL LOSS:

These losses refer to the unauthorized use or diversion of electricity without proper metering and billing. These losses are due to meter tampering, illegal connections, billing errors, or fraudulent activities by consumers or third parties. These losses can range from 1% to 3% in well-regulated areas but can be as

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high as 10% to 20% in regions with significant issues related to energy theft and metering challenges (Kim et al., Citation2019). In this paper, we specifically address the issue of transmission and distribution losses within P2P energy trading systems. These losses occur during electricity transport from renewable energy sources to end consumers via the grid infrastructure and are exacerbated by the bidirectional flow of electricity inherent to P2P transactions. Our research focuses on minimizing these losses, improving system efficiency, and enhancing the overall feasibility of decentralized energy models. Our proposed system enhances sustainability by minimizing energy waste and reducing greenhouse gas emissions, promoting energy accessibility and equity through transparent and secure transactions, and optimizing energy distribution to reduce costs associated with energy loss. These would help support the transition to a more resilient and sustainable energy system. P2P energy trading faces significant scalability challenges (Ma et al., Citation2013) as the number of participants increases, leading to inefficiencies and potential delays in transaction processing. Additionally, the decentralized nature of these systems often raises concerns regarding trust and transparency, as there is no central authority to oversee and verify transactions. Market volatility further complicates participation, as fluctuating energy prices can create uncertainty for buyers and sellers. Integrating renewable energy sources into P2P trading systems presents additional challenges due to their intermittent and variable nature. The inconsistency in energy generation from sources like solar and wind makes it difficult to ensure a stable energy supply, potentially destabilizing the grid. Furthermore, the current limitations in energy storage technologies exacerbate this issue, as surplus energy produced during peak generation periods is often wasted (Li et al., Citation2020).

By employing blockchain technology and smart contracts, our proposed model directly addresses these shortcomings, as integrating advanced algorithms for real-time energy management helps mitigate the issues of grid instability and energy wastage, promoting a more sustainable and reliable energy system. Additionally, the blockchain system helps to provide a scalable, transparent, and trustworthy platform for P2P energy trading.

The conventional blockchain is unsuitable for P2P energy trading applications where members have limited energy. Consortium blockchain has been used to lower the operational cost in energy trading for electric vehicles (Kang et al., Citation2017) and industrial internet of things.Footnote3 Consortium blockchains use a limited set of users with sizeable available power for energy-intensive tasks, thereby saving the limited energy of most users. The existing models by Aitzhan and Svetinovic (Citation2018) use a proof of work mechanism for updating transactions on the blockchain. This mechanism involves solving a complex mathematical puzzle to elect the leader who will commit the transactions in the blockchain network. Solving this complex puzzle requires a lot of energy and time (Dimitriou & Karame, Citation2013). A different transaction update mechanism is needed to reduce energy consumption and time. Further, Yang et al. (Citation2017) proposed a blockchain model which uses cryptocurrency for trading. Many times, users may not have sufficient cryptocurrency to trade energy. Deng et al. (Citation2015) proposed a model that provides interest-based loans to enable fast and frequent trading. However, many users may be reluctant to use this model due to the interest overhead. Finally, the blockchain-enabled energy trading models provide a free market where sellers and buyers can agree on energy prices. However, these models do not employ any pricing strategies.

The paper introduces a novel approach by proposing and developing a blockchain-based P2P energy trading model. This model directly tackles the limitations of prior systems, such as reliance on energy-intensive mechanisms and centralized intermediaries, by enhancing trust, transparency, and efficiency. The main contributions include the following end-to-end system features: Blockchain-based P2P energy trading model: A blockchain model that enhances trust, transparency, and efficiency in distributed energy systems, significantly reducing energy losses and promoting sustainability. Algorithm Development: Algorithms for real-time energy transaction tracking, enhancing energy flow management and system efficiency. System Design and Implementation: Blockchain-based prototype for energy trading, focusing on traceability and energy loss reduction. Cost and Security Analysis: Evaluates the cost-effectiveness and security improvements of the blockchain solution. Comparison Analysis: Comparative analysis that demonstrates the advantages of the proposed blockchain model over traditional and other blockchain-based systems.

CONCLUSION

Blockchain-enabled peer-to-peer (P2P) renewable energy trading represents a transformative advancement in the way energy is generated, distributed, and consumed. With the increasing adoption of renewable energy sources such as solar and wind power, traditional centralized energy systems are facing challenges in efficiently managing decentralized energy generation. Blockchain technology offers a secure, transparent, and decentralized platform that enables direct energy transactions between energy producers and consumers without the need for intermediaries. This approach enhances efficiency, reduces operational costs, and promotes the effective utilization of locally generated renewable energy. The integration of blockchain with smart grid technologies, Internet of Things (IoT) devices, and smart meters further strengthens the reliability and automation of energy trading systems. Smart contracts play a significant role by automatically executing transactions based on predefined conditions, ensuring trust and transparency among participants. Through this mechanism, prosumers can sell their surplus energy to nearby users, thereby creating localized energy markets and encouraging wider adoption of renewable energy systems. However, several challenges must be addressed to fully realize the potential of blockchain-based P2P energy trading. Issues related to scalability, regulatory policies, data privacy, interoperability, and the energy consumption of blockchain networks remain significant concerns. Future research should focus on developing energy-efficient blockchain protocols, scalable architectures, and supportive regulatory frameworks to enable large-scale deployment of such systems. In conclusion, blockchain-enabled P2P renewable energy trading has the potential to revolutionize modern energy systems by empowering consumers, improving grid resilience, and accelerating the global transition toward sustainable and decentralized renewable energy ecosystems.

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