Blockchain in the Peer-to-Peer Energy Trades

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Advancements in rooftop solar panel technology have sparked a revolution in the electricity markets. This has given rise to a new concept of energy exchange—the ability for consumers and producers to trade localized energy. This concept has been made possible by the emergence of blockchain technology, which has gained significant traction in the energy markets. Its unique ability to facilitate peer-to-peer (P2P) energy transactions has made it a promising solution for the trilemma of scalability, security, and decentralization.

energy management blockchain microgrids P2P artificial intelligence machine learning renewable energy sources

1. Introduction

Over the past decade, Distributed Energy Resources (DER) have experienced a substantial global proliferation [1][2][3][4]. These resources have revolutionized the dynamics of energy generation and distribution within the energy sector by enabling consumers and prosumers (individuals who both generate and consume electricity) to engage in direct energy sharing without the necessity of intermediaries. This paradigm shift is exemplified by peer-to-peer (P2P) energy systems, which facilitate surplus energy exchange among prosumers and other network participants, including consumers and prosumers.

Trading electricity in a P2P manner caters to the requirements of both consumers and prosumers while simultaneously reducing transmission losses. Nonetheless, the inherent fluctuations in the supply and demand of energy might introduce instability, potentially impacting its reliability. The “energy trilemma” encapsulates the central challenges that confront the energy industry, characterized by the conflicting imperatives of energy security, equity, and environmental sustainability.

DERs present localized energy solutions, which are different compared to standard unidirectional energy systems. In the traditional model, power is generated at centralized power stations, distributed through expansive distribution networks, and subsequently transmitted to consumers. Conversely, DERs facilitate energy exchange within a P2P network, classifying end-users into consumers and prosumers, both of whom can engage in reciprocal energy sharing, referred to as energy trading.

2. Blockchain Energy Trading in Peer-to-Peer

P2P energy trading has gained attention in academia and industry. Researchers like [5] categorize P2P systems into building, storage, and renewable domains, exploring network features and market dynamics. They classify P2P energy trading systematically, addressing virtual and physical layer challenges. Similarly, Ref. [6] highlights blockchain's integration benefits in smart energy systems, emphasizing the required technologies. Researchers explore blockchain's use cases in energy trading, analyzing its relevance and potential advantages in this sector. Ref. [7] offers criteria to decide when blockchain surpasses traditional databases. When it comes to peer-to-peer (P2P) power trading, blockchain eliminates intermediaries in favor of decentralized miners that verify transactions and maintain the trade ledger. Blockchain technology helps P2P energy trading tremendously by enabling a successful renewable electricity market on a digital P2P platform. This approach enhances energy security, promotes sustainability, and supports low-carbon solutions. The on-chain issue in blockchain has been a topic of discussion in literature for several years. Ref. [8] highlights the challenges that arise when trying to scale blockchain technology. They argue that the current block size limit in most blockchain networks is a major barrier to scalability, as it limits the number of transactions that can be processed in a given time. This ultimately leads to slower transaction processing times and higher transaction fees. Similarly, Ref. [9] also identifies the on-chain issue as a major obstacle to the widespread adoption of blockchain technology. They note that the current transaction processing speed of most blockchain networks is significantly lower than traditional payment systems, such as Visa and Mastercard. This makes it difficult for blockchain to compete in industries where fast transaction processing times are crucial, such as finance and supply chain management. Various solutions have been proposed in the literature to address the on-chain issue. One approach is to increase the block size limit, as proposed by [8]. This would allow for more transactions to be processed in each block, thereby increasing the overall transaction processing speed. However, this solution has its limitations, as it could lead to centralization of the network and compromise its security. Another proposed solution is the implementation of off-chain scaling solutions, such as the Lightning Network. In [10], the authors describe how the Lightning Network can be used to enable fast and cheap transactions off-chain while still leveraging the security of the underlying blockchain. This solution has gained significant traction in recent years, with many blockchain networks, including Bitcoin and Ethereum, implementing or planning to implement off-chain scaling solutions. Additionally, researchers have explored the use of sharding as a solution to the on-chain issue. Sharding involves dividing the blockchain network into smaller subsets, or shards, and processing transactions in parallel. This would increase the overall throughput of the network and allow for more transactions to be processed simultaneously. However, this approach is still in its early stages and requires further research and development before it can be implemented effectively.

Peer-to-peer (P2P), business-to-business (B2B), energy markets, commodities trading, and nonprofit endeavors are just a few of the applications being investigated by established organizations and pilot projects throughout the world for blockchain integration in the energy sector [11]. A notable blockchain use case that promotes the expansion of renewable energy and the shared economy is peer-to-peer energy trading. Though relatively new, companies in this field signify blockchain's early development. The lack of concrete proof of its performance in the P2P energy trade has sparked ongoing arguments about its prospects and problems, particularly in the context of the blockchain trilemma. However, as described in [10], energy trading (P2P) and the application of blockchain in it presents several technological difficulties. Strong protocols and algorithms are required for network administration to oversee blockchain activities. On-chain and off-chain data [12] handling is both a part of data management. The resolution of consensus management's throughput and latency problems is essential for transaction validation. Power loss management addresses fluctuations in distribution and consumption. Dynamic pricing models offer avenues for further exploration tailored to P2P energy trading dynamics. Innovative prosumer business models and the promotion of renewable energy communities for energy transition are facilitated through a P2P strategy proposed by [13], which integrates demand and production forecasting. However, researcher's approach stands out as it does incorporate the blockchain-based scalability layer. This involves creating a second layer on top of the main blockchain network, which can handle a higher volume of transactions at a lower cost. The scalability layer is built on top of the main blockchain network and acts as a sidechain. It can handle a higher volume of transactions by processing them off-chain, meaning they are not recorded on the main blockchain but are still secured by it. This improves the speed and efficiency of transactions while reducing the cost. One of the key advantages of this approach is its ability to enable micro-transactions. With the scalability layer, smaller transactions can be processed without clogging up the main blockchain network. This is particularly beneficial for industries such as gaming and content creation, where micro-transactions are common. Moreover, the scalability layer also allows for faster confirmation times. As transactions are processed off-chain, they can be confirmed and settled almost instantly. This is a significant improvement from the main blockchain network, where confirmation times can take several minutes or even hours. Another benefit of this approach is its cost-effectiveness. With the scalability layer, fees for transactions are significantly lower compared to the main blockchain network. This makes it more feasible for businesses and individuals to use blockchain technology for everyday transactions. Furthermore, the scalability layer also promotes interoperability between different blockchain networks. As it is built on top of the main blockchain network, it can connect with other scalability layers, allowing for cross-chain transactions. This is a crucial step toward achieving a truly decentralized and interconnected blockchain ecosystem. The novelty of this research lies in its ability to provide a scalable solution for blockchain technology. By incorporating a second layer, it addresses one of the major challenges of blockchain and makes it more practical for real-world use. It also maintains the core principles of blockchain, such as security and decentralization, which are crucial for its widespread adoption. Some notable companies that have adopted Blockchain for peer-to-peer energy trading are reported in **Table 1**.

Table 1. Energy trading P2P companies applying blockchain technology (data from ICObench11, updated from [12] [14]).

Startup	Description	Distributed Ledger Technology (DLT) Platform	Country
Electrify	An energy market that operates in a decentralized manner, leveraging blockchain technology, is being actively developed by Electrify. Peer-to-peer (P2P) trade platform support is also available through this marketplace.	Ethereum	USA, Singapore

Startup	Description	Distributed Ledger Technology (DLT) Platform	Country
Pylon Network	P2P energy trading platforms are Pylon Network's area of expertise.	Private blockchain	USA, China, South Korea
Alliander, https://www.alliander.com/en	In addition to launching a peer-to-peer (P2P) energy trading platform and introducing a blockchain-based currency for sharing renewable energy, Alliander has also performed a trial.	Ethereum	Spain
WePower	It is driven on the basis of a peer-to-peer energy trading network. The energy market's supply and demand are also estimated using artificial intelligence.	Ethereum	UK
Conjoule	The blockchain-powered platform of Conjoule enables P2P energy trades between owners of rooftop photovoltaic (PV) systems and potential consumers from the public or business sectors.	N/A	Spain
Power Ledger	P2P energy trading solutions on the blockchain are being actively developed by Power Ledger.	Ethereum	Germany
LO3 Energy	Following blockchain technology application, Exergy takes a creative approach to developing localized energy markets.	Private blockchain	Australia
Electron, https://www.electron.org.uk	With the aim of promoting and supporting peer-to-peer (P2P) energy trades, Electron uses blockchain technology to develop the energy industry.	Ethereum	USA
Volt Markets	To increase the effectiveness of energy distribution, tracking, and trading procedures, Volt Markets supports energy trading inside a peer-to-peer (P2P) market.	Ethereum	USA
Verv	To provide access to inexpensive, low-carbon energy, VLUX integrates advanced artificial intelligence powered by deep learning with the capabilities of blockchain technology. Peer-to-peer (P2P) energy	Ethereum	USA, China

The original Bitcoin blockchain introduced a 1-megabyte block size limit to defend against potential malicious attacks, particularly denial-of-service attempts. This constraint prevented an attacker from flooding the network with

Startup	Description	Distributed Ledger Technology (DLT) Platform	Country
	trading is made possible, which helps people do this.		
Toomuch	A peer-to-peer energy trading platform designed exclusively for business clients is being actively developed by Toomuch Energy.	N/A	Belgium and Austria

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...ansaction validation time and throughput. Scalability, a key issue in blockchain technology, involves trade-offs, such as security or decentralization. This balance is critical in energy trading. Blockchain-based P2P energy trading decentralizes transactions, reducing reliance on intermediaries. Varying consumption patterns lead to differing transaction volumes between prosumers and lower-energy households. Achieving this balance is essential for blockchain-based energy trading. The energy trading blockchain trilemma relates to trade-offs between scalability, security, and decentralization. Scalability challenges affect transaction processing speed and security. P2P energy trading relies on direct matching of energy supply and demand, emphasizing the need for a delicate balance within the trilemma.

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