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A Roadmap Toward Environmental Sustainability

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Recent Trends, Challenges, and Future Aspects of P2P Energy Trading Platforms in Electrical-Based Networks Considering Blockchain Technology: A Roadmap Toward Environmental Sustainability

Haseeb Javed[1], Muhammad Irfan[2,3,4]*, Moazzam Shehzad[5], Hafiz Abdul Muqeet[6], Jumshed Akhter[5], Vishal Dagar[7] and Josep M. Guerrero[8]

[1]Department of Electrical Engineering, Muhammad Nawaz Sharif University of Engineering and Technology, Multan, Pakistan, [2]School of Management and Economics, Beijing Institute of Technology, Beijing, China, [3]Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing, China, [4]Department of Business Administration, Ilma University, Karachi, Pakistan, [5]Department of Electrical Engineering, University of Engineering and Technology (RCET), Lahore, Pakistan, [6]Department of Electrical Engineering Technology, Punjab Tianjin University of Technology, Lahore, Pakistan, [7]Great Lakes Institute of Management, Gurgaon, India, [8]The Villum Center for Research on Microgrids (CROM), AAU Energy, Aalborg University, Aalborg, Denmark

Peer-to-peer (P2P) energy trading platform is an upcoming energy generation and effective energy managing strategy that rewards proactive customers (acting as prosumers) in which individuals trade energy for products and services. On the other hand, P2P trading is expected to give multiple benefits to the grid in minimizing the peak load demand, energy consumption costs, and eliminating network losses. However, installing P2P energy trading on a broader level in electrical-based networks presents a number of modeling problems in physical and virtual network layers. As a result, this article presents a thorough examination of P2P studies of energy trade literature. An overview is given with the essential characteristics of P2P energy trading and comparatively analyzed with multiple advantages for the utility grid and individual prosumers. The study then addresses the physical and virtual levels that systematically categorize the available research. Furthermore, the technological techniques have been gone through multiple problems that need to overcome for P2P energy trading in electrical networks. Finally, the article concludes with suggestions for further research.

Keywords: P2P energy trading, physical and virtual layers, game theory, energy management, auction theory, storage, energy market, network loss

INTRODUCTION

Distributed energy resources on a small scale, including behind-the-meter net generations, inverters, control loads, battery energy storages, and electrical cars, have seen significant expansion and growth in recent years (Elavarasan et al., 2021; Nuvvula et al., 2022). The rise in the utilization of distributed renewable energy resources at the residential level, in particular, has been extraordinary (Ali et al., 2021). For example, every 6 years, the worldwide market for solar PV that is anticipated to rise up to 11%, with household energy storage increasing from 97 to 3,800 MW during 2016–2025. These small-scale energy resources may be used to more effectively and efficiently manage energy demand and integrate a considerable amount of green energy for the utility grid (Irfan et al., 2019c). However, it is highly critical for the proprietor of these energy resources to behave as active customers or prosumers and dynamically engage in the energy market (Tanveer et al., 2021).

Feed-in-tariffs (FiTs) have been widely utilized in this context to allow prosumers to engage in energy trading (Irfan et al., 2019a, Irfan et al., 2020). Energy prosumers having rooftop PV panels can trade surplus energy toward the network and purchase power back from the utility in case of power outage scenario under the FiT (Zhang and Zhu, 2021). Unfortunately, prosumers have reaped only a slight advantage from current FiT systems (Lyu C. et al., 2021). As a result, FiT programs have been phased out in several world regions (Irfan et al., 2019b).

Accordingly, P2P energy trade has developed as a future generation efficient energy managing approach for an intelligent grid, allowing prosumers that dynamically engage in an energy sector either in trading extra energy or with decreasing energy demand through megawatts, for example, negative watts or demand reduction (Perger et al., 2021). However, prosumers control the terms of energy transactions and delivery of product and service, and it is predicted that the benefits of P2P trade will be considerable (Esmat et al., 2021). Simultaneously, the grid, which includes retailers, generators, and distributed network system providers (DNSPs), can save money by cutting peak demand (Nasir et al., 2021) and operational costs, lowering investment cost (Delarestaghi et al., 2021), reducing the system reserves need (Mohiti et al., 2020), and increasing the PV system dependability (An et al., 2020).

Therefore, trading in a P2P network is tough. It is for the reason that, in P2P trading, prosumers are believed to trade their system's energy with each other with less influence on a centralized controller, formulating P2P platforms as a trust-free system. As a result, encouraging prosumers to collaborate in such a trusted environment is a difficult challenge (Hebal et al., 2021). Furthermore, a more challenging thing is to simulate the decision mechanism aimed at numerous trading characteristics in a power system with a lot of users since their logical decisions may clash with the interests of other producers and consumers in the network (Thukral, 2021). Furthermore, the trading of energy is distinct from any other type of exchange of products. This is because prosumers are connected to an electrical grid, which has its own set of technological limitations on energy trade among grids (Dagar et al., 2021; Elavarasan et al., 2022). Finally,

decentralized peer-to-peer energy trading may make it difficult to keep the network's technical limit within a normal limit (Azim et al., 2021a). In this vein, the question is how to sell this energy in a P2P electrical network not including or affecting the network securities that must be addressed. Ultimately, a many utility grid partners might seek peer-to-peer service from prosumers by a variety of goals in mind. As a result, new pricing schemes are required to up-rank the customer's request that provide a less overloaded operation in an entire electrical network whereas the main aim is to minimize the electrical network losses (Jamil et al., 2021).

To that end, a lot of new novel studies have lately been published in the literature with the goal of addressing these issues. Because of the problem's complexity and the wide range of approaches that have been attempted to address it, understanding the complete model of contemporary peer-to-peer energy trading research is important. Also, having knowledge of current peer-to-peer energy research is necessary with the aim of 1) establishing a novel research path, 2) addressing novel issues in the energy industry, 3) building cost-effective and more efficient energy trading methods for deployment in actual network, and 4) providing new facilities through P2P energy trading. Therefore, having a thorough understanding and up-to-date P2P energy research can help in future energy and electricity system researchers. This is especially true for researchers who wish to help build a sustainable future by utilizing dispersed energy resources.

In light of this, this article seeks to offer an overview of advance and innovative studies in the existing P2P trading literatures that make necessary contribution in the upcoming energy sector revolutionizations with necessary contribution:

> This literature offers an extensive background on the explanation for peer-to-peer electrical network, characteristics of energy trading platforms, a peer-to-peer electrical market, and a review for P2P trading challenges and problems.
> It aims to identify the key technical approaches used by current researches to develop distinct P2P trading solutions and offer a comprehensive explanation of each methodology.
> A number of possible study areas are proposed that might be worthwhile to pursue as expansions of present research practices.

Furthermore, latest review papers address several elements of peer-to-peer trading that are also studied here. Doan et al. (2021) offer an overview of numerous P2P initiatives now being implemented in various regions of the world (Sabillon et al., 2021; Samuel and Javaid, 2021), providing a comprehensive overview of several kinds of community markets and P2P energy trading systems. However, Haggi and Sun (2021) and Cao et al. (2021) describe how several blockchain with multiple distributed-based ledger technology may be used for diverse applications in the power industry, while Al-Obaidi et al. (2021) discuss the problems and potential of these applications.

Indeed, previous studies have made significant contributions to the field of energy trading knowledge, allowing academics to
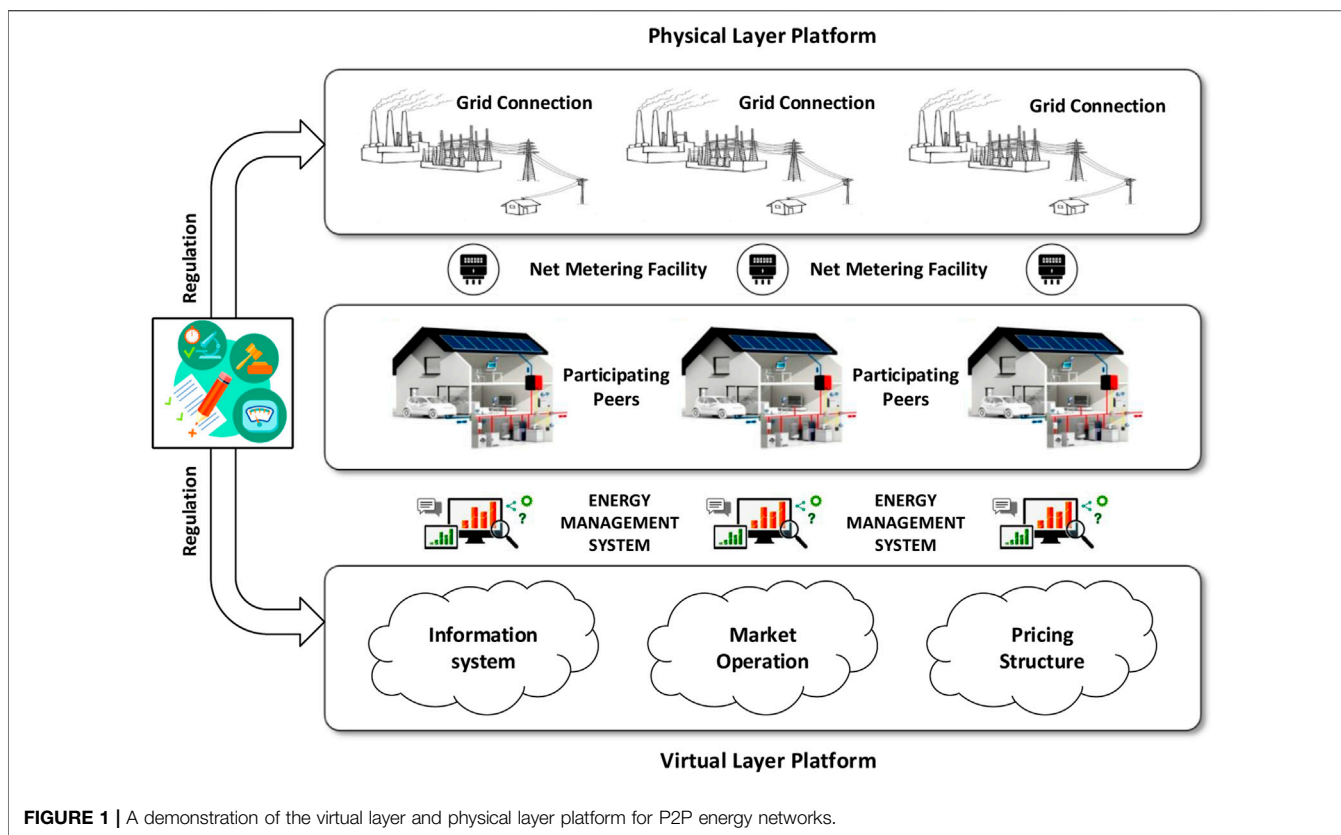
FIGURE 1 | A demonstration of the virtual layer and physical layer platform for P2P energy networks.

get a thorough grip of different technical elements of P2P trading. These evaluations, on the one hand, are best suited to people who have a basic knowledge for energy trade, peer-to-peer networks, and DR (Demand Response)–based management approaches. On the other hand, our article takes a step back and offers a fundamental understanding among most areas of P2P trading, such as the definitions, various layers, network elements, and pricing policies of P2P networks, to a public with little previous understanding of P2P trading. The article then helps the readers identify research paths in a certain layer by explaining the difficulties and solution methods for that layer. This article then gives readers a deep overview of the challenges and technological techniques that are relevant to that layer. Furthermore, this article differs from previous research in terms of structure and discussion focus, which focuses mostly on trading techniques for tackling relevant layer issues. This study may also be beneficial for experienced researchers who want to update their knowledge of this subject area.

The framework of the paper is laid out as follows. We begin with an overview of P2P network elements in Section-II and follow through a glance at P2P energy markets configured in Section-III. Following a methodical classification, Section-IV gives a thorough overview of current up-to-date research concerning P2P trading. Section-V identifies and discusses the important technical methods in P2P energy trading. Section-VII concludes with some closing observations and a list of possible future study paths.

P2P ENERGY TRADING: NETWORK ELEMENTS OVERVIEW

A P2P network is an organized distributed network design where members contribute a portion of their individual energy resources among each other. Some shared resources can provide network service and gain control directly by other peers without the use of intermediate organizations (Paudel et al., 2020). Furthermore, in an electrical network, some entity may be changed or combined when needed without causing any network service interruption. An et al. (2020) provide a formal description of P2P networks.

P2P networks may be split into two levels, as indicated in **Figure 1**:

Virtual layers.
Physical layers.

The virtual-based layers simply offer players with a secure link *via* which they may set their trade parameter. It guarantees each and every participant have equivalent approach toward the virtual layer where all types of information can be exchanged, selling and buying orders can be created, a market mechanism can be used to closely match the transactions, and financial transactions can be completed after the orders have been successfully matched.

The physical layer is simply a physical network that allows the transmission of energy from producer to consumer once
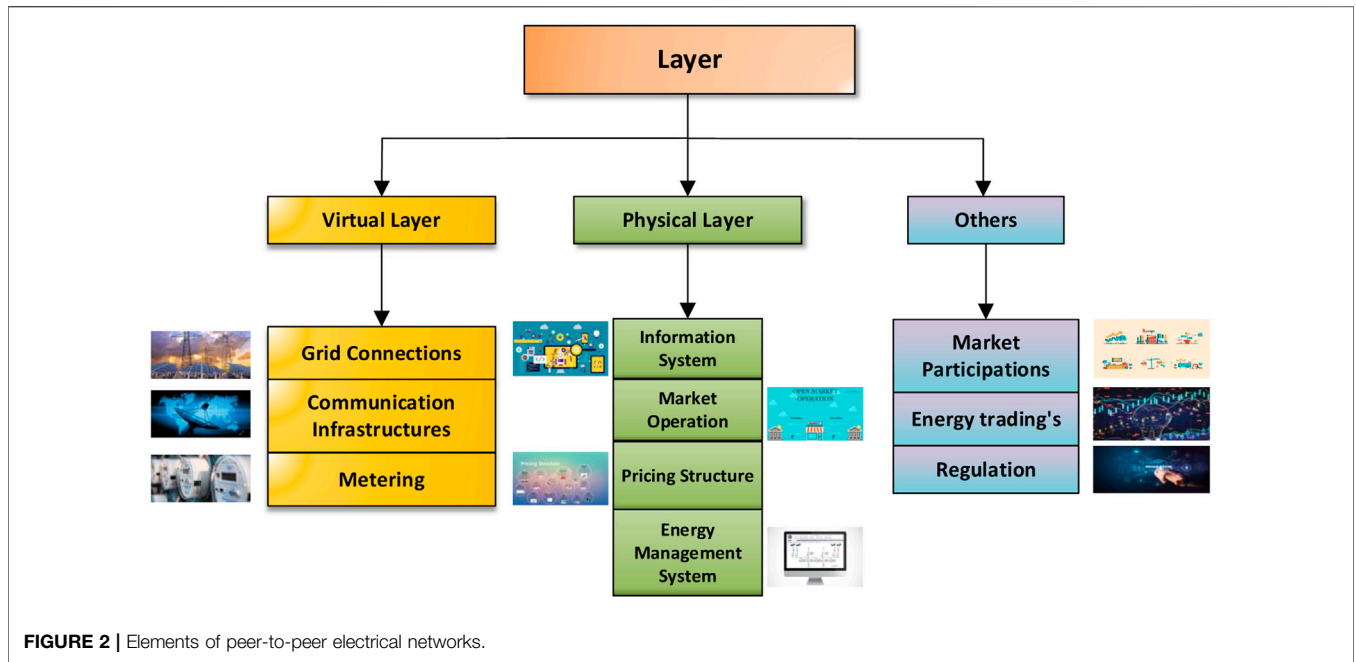
FIGURE 2 | Elements of peer-to-peer electrical networks.

the virtual layer platform has completed the financial clearances among mutual parties. The physical networks might provide the typical distributed network and managed with the autonomous systems operator, otherwise distinct physical distributed microgrids that work in tandem with the regular grid (Gomes et al., 2020). It has the essential infrastructure in favor of allowing communication between energy producers and consumers. It is significant to mention that finance clearances among every energy prosumer on the virtual layer platform give no guarantee in the basic transmission of energy.

Instantly, a number of important factors are required to properly support energy trade among every prosumer inside P2P networks. The following are the brief description of these components as indicated in **Figure 2**.

Virtual Layer Elements
Information System
A high-performing and secure information system lies at the core of the peer-to-peer energy network. This information system must be able to 1) accept all market suppliers to interact with each other to contribute in P2P energy trading, 2) incorporate with the suppliers inside an appropriate market platform, 3) provide an equivalent access to the common markets, 4) supervise market operations, and finally, 5) put limits on members' decision to guarantee electrical network reliability while focusing on their security. Blockchain-based agreements especially smart agreements (Hosseini et al., 2020), general consortium blockchain (Wilkins et al., 2020), and then Elecbay by Zhang et al. (2016) are also some important examples of secure information systems.

Market Operation
A P2P network's information system enables market functioning that includes market allocation, a well-defined bidding structure, and payment regulations. The primary objective of market operations is to offer participants with an effective trading platform by balancing selling and purchasing order in an actual time-based accuracy. In these operations, every electricity producer has an influence on the extreme and lowermost energy allocation thresholds. Various market perspectives may be present in the operations, each of which must be capable of producing adequate energy allocation at each step.

Pricing Procedures
Price procedures are planned to balance energy supply and demand efficiently. The pricing methods employed in P2P trading are fundamentally different from those utilized in regular power markets. In traditional power markets, for example, power surcharges and taxes account for a considerable percentage of the price. However, renewable energies usually have minor costs (Baron et al., 2020), in which prosumers may earn extra benefits by properly selecting the tariff pricing of their energies. However, pricing methods must reflect the status of energy inside the P2P network, i.e., an increasing electricity excess for the users inside the system must decrease the electricity cost.

Energy Management System (EMS)
A prosumer's EMS guarantees its energy supply while engaging in P2P trading through a specific bidding mechanism. For such purpose, an EMS uses the transactive meter to get real-time and proper admittance for the prosumer's supply/demand data, on

which it builds the prosumer's energy generation and load consumption profile, and then decides on a bid pricing approach to contribute in energy trade taking place with the prosumer's side. For example, when the cost per unit energy reduces below its prime cost barrier, an efficient prosumer's EMS continuously buy electricity in an energy market (Muqeet and Ahmad, 2020b).

Elements in the Physical Layer
Grid Connection
Both islanded and grid-connected electrical networks can engage in P2P energy trade. The primary utility connection points must be defined to balance energy demand and production in a grid-connected system. The situation is feasible in analyzing the success of electrical network; it focuses in terms of cost savings and energy, by attaching smart meters to these points of contact (Sosa et al., 2020). Participants in islanded microgrids must have sufficient power production capacity that provides a sufficient security level and dependability in delivering the electricity toward customers (Muqeet et al., 2021).

Metering
To engage in P2P trade, every prosumer should have suitable metering infrastructure while focusing with the standard energy meters, each prosumer must supply with a transactive meter (Shahzad et al., 2021). A transactive energy can determine whether or not to participate in the P2P market based on demand and generation data, as well as market information with (total demand, price, network conditions, and total available generation).

Communication Infrastructure
The identification of prosumers and exchange of information inside the network are two of the most important communication requirements in P2P trade. Structured systems, unstructured systems, and hybrid P2P communication systems have all been described in the literature (Kalbantner et al., 2021). The communication platform that are used here must fulfill the IEEE standards (1547.3-2007) performance criterion for the incorporation of DERs, which include throughput, latency, security, and dependability (Haggi and Sun, 2021).

Additional Element
Market participant: P2P trading necessitates a larger portion of essential participants inside an electrical network, with a fraction of the members having the potential to generate energy. Because the objective of P2P energy trading has an influence on price mechanisms and market processes, it should be stated openly. Furthermore, the type of energy (heat or electricity) was exchanged.

Regulation: Regulatory energy policy will most likely determine the viability of P2P trading in the upcoming power markets. So, a country's legislative laws determine what sort of market design is permitted, and how charges and taxes are allocated. Governments can utilize legal measures to help P2P energy markets, speeding the effective use of renewable energy resources while also minimizing environmental damage. They can, however, stymie the development of such marketplaces if it has a detrimental impact on current energy systems.

P2P ENERGY TRADING: MARKET STRUCTURES OVERVIEW

P2P energy trading, contrary to the existing energy market's top-down strategy, would need restructuring electricity markets around decentralized management with cooperative principles, allowing a method that empowers prosumers (Gomes et al., 2020). In **Figure 3**, the energy market structure described in the literature may be classified into three kinds to decide whether P2P energy trade can be able to perform in a peer-to-peer electrical network or not: There are three types of markets: 1) decentralized-based market, 2) community-based market, and 3) composite-based market.

Decentralized-Based Markets
Completely decentralized markets are those markets in which energy prosumers can easily exchange energy trading with each other without the influence of centralized control. As stated by Perger et al. (2021), such decentralized control of a P2P market is based on mutual agreements between specific prosumers (Neagu et al., 2020). It incorporates both the forward market uncertainty and energy balance into the model via the specified contract. The authors suggest another completely decentralized market for multi-bilateral optimal allocation by Kumar Nunna et al. (2019), in which prosumers with energy demand may pick their preferred energy source for trading, such as required renewable technology. Zia et al. (2020) find completely decentralized market in which authors examine different features of market decentralization while using the Brooklyn microgrid as a testbed case. Scarabaggio et al. (2021) offer a distributed methodology focused on the agreements and methodologies to synchronize limited energy generating facilities, storage devices, and flexible load inside the microgrid to develop an economic dispatch distributed load algorithm.

Community-Based Markets
Community microgrids (Das and Zaman, 2019; Hossain et al., 2019) and groups of surrounding prosumers (Delarestaghi et al., 2021) are instances of community-based P2P markets where users have similar interests and goals despite not being in the same location. Members have the option of cooperating (Hayes et al., 2020) or competing (Nguyen, 2020). Through a community manager, each member of a community market swaps their energy inside the community. Certainly, every peer might decide either trade their energy among each other or either outsource the community, where the community-based managers are responsible for the energy transferred with the energy markets. A community manager, for example, controls trade activity inside the community by adopting the position of an auctioneer (Doan et al., 2021), as well as acting as a link between the community and with the rest of the network. The privacy of each community member has significant preferences
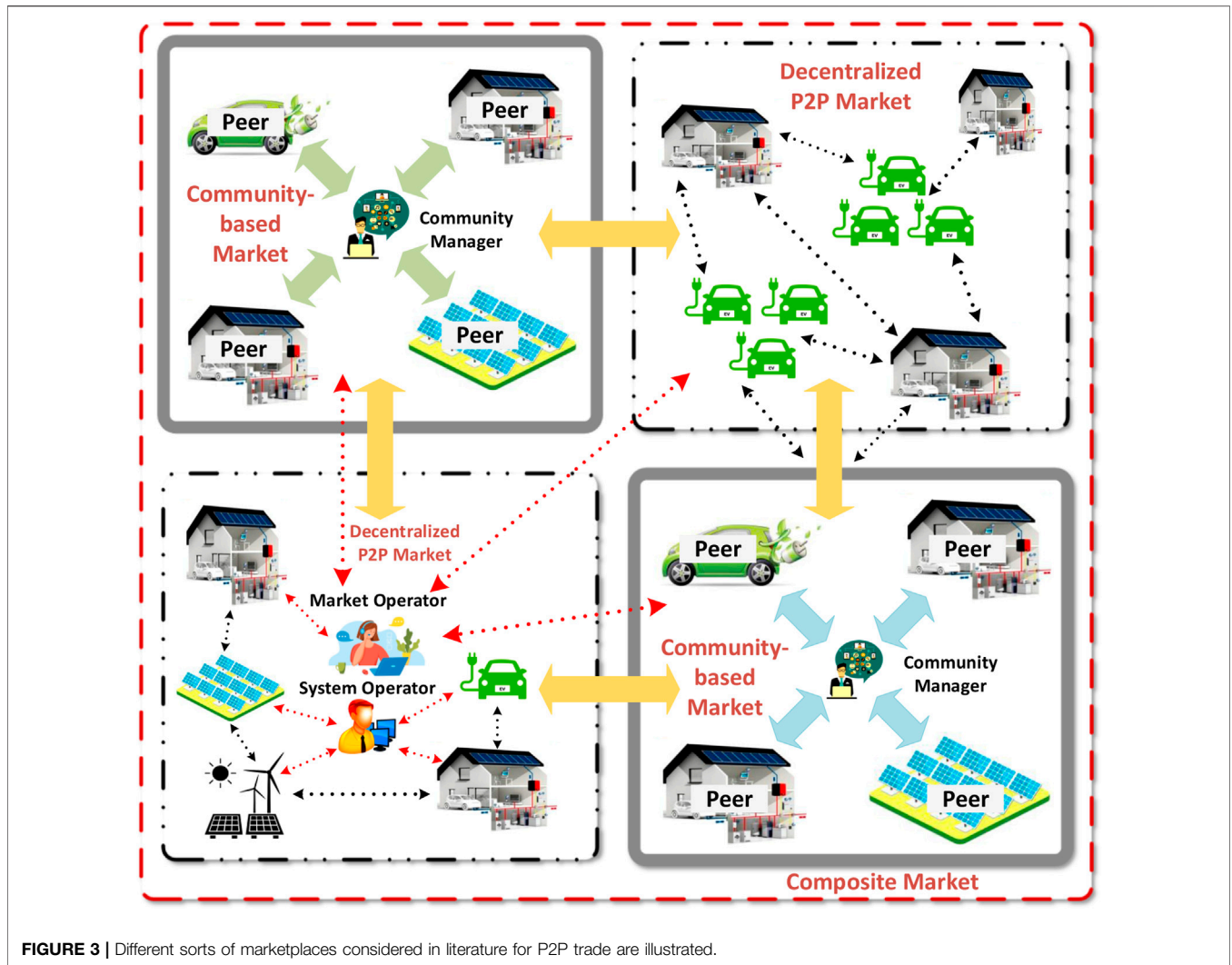
FIGURE 3 | Different sorts of marketplaces considered in literature for P2P trade are illustrated.

and strategic plans, which are protected through community-based energy trade (Monroe et al., 2020). Furthermore, various types of prosumers' choices are represented in the energy parameters they choose to trade within the community (Muqeet et al., 2021). In **Figure 3**, you can see an example of a community-based energy market.

Composite-Based Markets

Composite-based markets are those between totally decentralization-based and community markets, allowing each organization and individual prosumer to participate while maintaining their own market features. As a result, every prosumer may participate in P2P trading while also participating in other markets, such as totally distributed marketplaces. A community manager, on the other hand, can supervise trade inside a network. Prosumers may be layered into one another in such a market, forming a community for trading inside the local community. AbuElrub et al. (2020) and Park et al. (2018) both provide examples of such marketplaces.

A prosumer may now have to manage with both regulatory and deregulatory P2P markets in a grid system. As a result, figuring out how to combine the two into a particular framework remains a difficulty. Existing research, however, offers some insight on the various methods for such marketplaces to coexist. For example, Son et al. (2020) suggest a third-party P2P trading approach in which a community-based manager engages in P2P energy trading with energy prosumers that fulfill the community's load demand for electricity to maintain various community facilities. When a community-based manager is not able to get entirely essential power from suppliers inside a network, then an involvement in a regulated energy market becomes necessary. The community-based manager then purchases electrical energy in a controlled market.

Iqbal et al. (2019) proposes another interesting integration scenario in which prosumers mostly acquire energy in controlled (regulation) electrical markets like conventional consumers. When there is a high energy demand for the utility grid, the utility directs a pricing signal to a designated prosumer, instructing them stop buying energy from the utility grid for
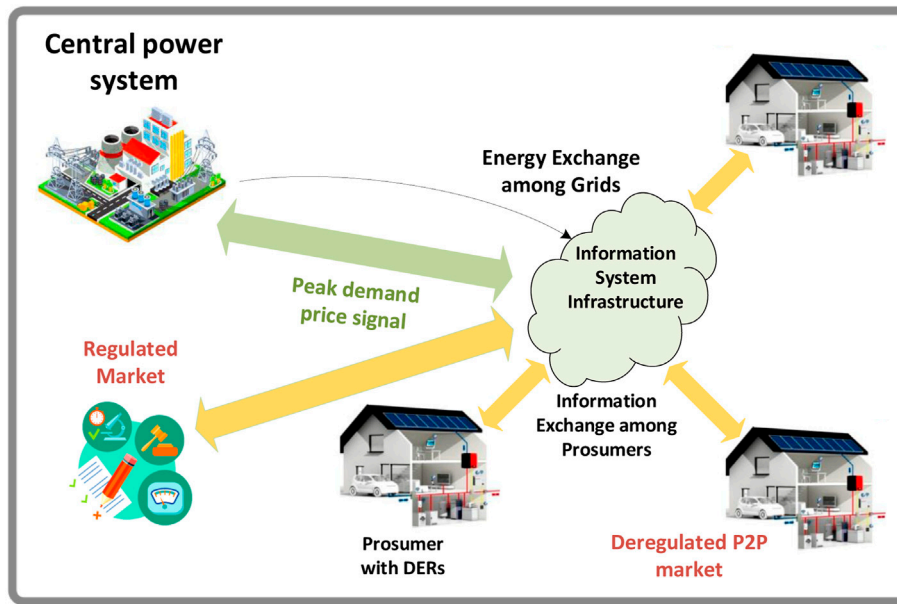
FIGURE 4 | Provides an example to cooperate among controlled and unregulated P2P markets by prosumers using distributed resources that may be addressed here. By a pricing signal from the utility, consumer energy trade transitions are from controlled towards unregulated P2P market.

an exact amount of time period. As a result, prosumers establish a complete decentralization in a P2P market for every individual, while fulfilling the energy need from the national grid. **Figure 4** depicts a graphical representation of the market processes.

P2P ENERGY TRADING: CURRENT CHALLENGES

Certainly, in engaging with various energy market frameworks, P2P trading participants want to tackle a variety of issues connected with the energy trade, such as lowering energy costs, expanding and sustaining sustainable renewable energy consumption, and enhancing prosumer social involvement. Prosumers' decision-making processes to solve these problems, on the other hand, are constrained by the hard limitations set by electricity network operators to ensure the dependable functioning of the electrical network without breaching the voltage level on prosumer endpoints while maintaining complete system losses within acceptable limits. Consequently, further it describes the summary of present researches that has created P2P energy trading systems as a feasible solution and it is reliable for the energy management approaches in addressing a variety of major future smart-grid issues.

Virtual Layer: P2P Energy Trading Challenges

The majority of analyses presented in this current study focuses on developing P2P trading systems that consist of appropriate pricing scheme allowing a huge proportion of prosumers to participate. Financial transactions must be handled safely

without the involvement of a third entity community manager, while also contributing to the attainment of desirable goals such as evaluating demand and supply, lowering prosumer energy prices, and reducing peak loads. As a result, current literature on the virtual layer may be classified into five main general groups, as shown in the next section, focusing on the study's topic.

Minimizing Energy Cost

The initial set of research looks at P2P trading that can lower energy costs for consumers. Basically, P2P energy trading allows small-scale energy prosumers containing distributed resources that trade any extra electricity with the prosumers in case of power shortages, which is demonstrated to dramatically reduce energy costs (Vera et al., 2019). Interactions among contributing prosumers are crucial to facilitating such a trading mechanism (Paudel et al., 2020). P2P's cost-saving performance may be increased even more if the system's batteries engage in the market (Hebal et al., 2021). It is worth noting that P2P trading can help prosumers save money in a variety of ways, such as remote systems and open-urban markets (Alturki et al., 2020), completely decentralized systems (Ahmad et al., 2020), and community microgrids (Moura et al., 2020).

Balancing Energy Demand and Supply

When compared with the conventional market, P2P trading allows prosumers with deficiencies to fulfill their demand by purchasing electricity from prosumers with surplus at a lower cost (Alturki et al., 2020). However, in a local environment, such trade needs a balance of energy requirements within the community, as that is the topic of the second group of research. Now, a ledger is required to balance demand and

TABLE 1 | A summary of several types of research aimed at achieving different types of objectives for virtual–physical layer platforms

Various layers	Objectives	Overview	References
Virtual layer	Reducing energy cost	To assist prosumers in lowering their energy costs by allowing limited prosumers with distributed generation selling their surplus power to those energy prosumers who are in need	Chedid et al. (2020), Obeng et al. (2020), Reihani et al. (2020), Shah and Mehta, (2020), Vahedipour-Dahraie et al. (2021), Hinokuma et al. (2021)
	Balancing grid generations demand	To allow energy prosumer for maintaining power consumption with plan buying and selling orders while balancing the community's demand and supply	Paliwal et al. (2019), Muqeet et al. (2019a), Muzi et al. (2019), Oh and Son, (2020), Bidgoli et al. (2021)
	Engaging prosumers and incentivizing	To motivate and encourage prosumers to sell energy in the P2P network, a strategy must be devised that will offer prosumer-centric outcomes	Cui et al. (2019), Chung and Hur, (2020), Lovati et al. (2020), Azim et al., 2021, Delarestaghi et al. (2021), Park et al. (2021)
	Integrating price-based mechanism	To model price-based mechanisms to appropriately use for the P2P network to assure rapid and frequent trade	Silva et al. (2020), Vahedipour-Dahraie et al. (2020b), (2020a), Doan et al. (2021), Lin et al. (2021), Bidgoli et al. (2021)
	Detecting asynchronicity and uncertainty	To discover issues with communication and computation complexity to provide a stable system	González-Romera et al. (2020)
Physical layer	Capacity and voltage constraint	To avoid overvoltage and reversal power flow issues caused by P2P trading	Sabillon et al. (2021), Zhang et al. (2021)
	Power losses for electrical networks	To determine effects for the P2P energy trade with system losses and consequent cost allocations among energy trading participants	Azim et al. (2021a), Kalbantner et al. (2021), Moreno et al. (2021), Thukral, (2021), Vahedipour-Dahraie et al. (2021), Zheng et al. (2021)
	Strengths of a system	To determine influence toward the growing usage of renewable energy resources in the electrical network	Al-Ghussain et al. (2020), Muqeet and Ahmad (2020a), Mansour-Saatloo et al. (2020), Mohiti et al. (2020), Vahedipour-Dahraie et al. (2020a), Zia et al. (2020)
	Securing prosumers transactions	To make it easy for prosumers to engage in P2P trading network by allowing them to execute secure money transfers among peers	Samuel et al. (2020), Tesfamicael et al. (2020), Al-Obaidi et al. (2021), Mohamed et al. (2021), Samuel and Javaid, (2021)
	Ensuring network stability	To determine influence on the stability and reliability of an electrical system	Ahmad et al. (2020)

supply since it must track all activities and the available supply and demand of every contributing prosumer. As demonstrated by Delarestaghi et al. (2021), this is now done in P2P trade by utilizing blockchain-based platforms. Prosumers use the blockchain-based platform to learn about different sellers' and purchasers' energy usage patterns, to regulate their individual energy consumption using domestic demand response schemes (Lyu J. et al., 2021), and then trade with each other among the local community (Palma-Behnke et al., 2019) that is able to maintain the supply and demand in a balanced way. Indeed, if there is still a supply–demand gap, it may be filled at a greater cost by the utility grid, diesel generator, or community storage. **Table 1** provides the summary with different objectives.

Incentivizing and Engaging Prosumers

Clearly, prosumers must be actively participating in the trading system to gain the benefits described in the preceding two sections (Delarestaghi et al., 2021). This is only feasible if prosumers view the P2P trade outcomes to be helpful to them. As a result, the mechanisms must be centered on the customer (Zhang et al., 2020) (also, denoted as prosumer centric). The third type of the present work focuses on determining ways to motivate prosumers to engage in significant P2P trade. Under the same category, a wide variety of methods have been anticipated to guarantee prosumer as well as centric with successful results such as motivational psychology, multi-class approach (Niyomubyeyi et al., 2020), bilateral-contractual theory (Hu et al., 2021), game theory (Hasankhani and Hakimi, 2021), reinforcement-based learning (Mohamed et al., 2021), consensus-based approach

(Yang et al., 2021), forecasting integrated double auction (Hayes et al., 2020), and battery-controlling technique (Abdolrasol et al., 2018).

Upgrading Pricing Mechanisms

The participation of prosumers in P2P trading and advantages of results are solely dependent on financing the transactions between the market participants in the trade. As a result, it focuses on the novel pricing scheme suites for P2P energy trade, which is the major focus of the current literature's fourth category of research. In addition, a credit-based pricing structure and regular energy trading is suggested in [24], while [34] investigates a distributed cost-directed optimization technique based on several types of prosumer categories, whereas [58] describes a discriminatory pricing mechanism that may be used in a P2P network, and [59] and [60] provide further examples of alternative pricing methods.

Classifying Uncertainties and Asynchronicity

P2P marketplaces provide significant benefits in terms of product differentiation, consumer engagement, and cheap energy transaction cost. When prosumers participate in P2P energy transactions, processing and communicational complexities' concern must be addressed so that the system focuses on operating properly. As a result, Kaya et al. (2021) provides a comprehensive computational study of current decentralization of the systems with some distributed algorithm. The average duration per iteration is shown to be influenced by both communication and computation difficulty. The average

duration per iteration is shown to be influenced by both computation and communication difficulties. As in case of idle hardware and the solution of complex optimization sub-problems, computation delays arise. Bandwidth restrictions or high internet traffic might create communication delays. Yahaya et al. (2020) and Zia et al. (2020) provide additional examples of similar research.

Physical Layer: P2P Energy Trading Challenges

The virtual platform research has established main groundwork of the P2P energy trading for electricity networks while incorporating prosumers' policymaking processes in focusing on safe and efficient trading platforms, and also designing pricing schemes to assure their widespread involvement. The real transmission of an approved quantity of energy is then shifted toward the physical layer after the choice on the energy trade parameter is made in virtual layer. The electricity system now imposes strict restrictions on energy interchange across its network (Dorrell and Lee, 2020). As a result, if the virtual layer platform's decision-making process ignores the possible impacts of P2P energy in physical platform, the energy transmission opens a wide range of technological limitations. For example, Zia et al. (2020) analyze the viability of peer-to-peer trading in an electrical network, where it is revealed that if peer-to-peer trading is synchronized while not considering the network's constraints, many bus voltages could surpass the network's applied voltage limit, compromising the network's reliability and security.

Violation of Capacity and Voltage Constraints

Prosumers are linked to the distribution network of low voltages, and their dynamic involvement in the P2P energy trading may result in an overvoltage problem and voltage fluctuations (Yanchao et al., 2019). However, a unique sensitivity analysis–based approach is investigated by Jiang et al. (2021) for assessing the influence of P2P exchange for the system and the associated cost considers the energy transmission to combat such situations. Now, the inverters that are installed in prosumers' homes are largely in control for advancing electricity to an electrical network, and substantial power transactions over the P2P electrical network would certainly expand the inverters' load. Utility voltages that assist in certain methods for efficient and smart inverters, which comprised planning and P2P communications, can help to minimize this (Muqeet et al., 2019b). Another negative effect of a large number of prosumers transmitting power through the network might be operational burden, which can raise the cost of energy transmission owing to the need to maintain a lengthy chain with numerous blocks (Jamil et al., 2021). It also describes the blockchain-based P2P trading mechanism that takes use of localized energy storage, which is demonstrated to be successful in avoiding such circumstances. Finally Vera et al. (2019) discusses how big prosumers, such as community-based microgrids that run at different voltage levels, can engage in the energy exchange process.

In this regard, there has lately been a rising interest in addressing issues that may obstruct energy transfer *via* P2P networks' physical layer platform. In the current research, three types of network problems have been explored in particular: 1) capacity and voltage limitations are violated; 2) there is an increment in the system's power losses; 3) systems lose their strength. **Figure 5** depicts a summary of these difficulties.

Rise in Electrical Network Power Losses

Energy transmission among prosumers and consumers through P2P trading has the potential to increase the nodal voltage and overloading networks capacity; it also has the potential to cause losses. As a result, any market entrance will have to generate and recoup additional energy quantities and costs just above local cumulative demand (Zaabar et al., 2021). It also proposes and tests a graph allocation-based losses method in reconciling the physical characteristics for low-voltage distribution utility grid. Another cost distribution approach is described by Ahmad et al. (2020), in which the grid operators use expensive incentives to transfer the market prices of P2P to associated players. The system's operator is allowed a degree of discretion in this allocation phase to achieve cost recovery. Besides cost allocation, adopting an efficient power routing technique (Hebal et al., 2021) might be another intriguing approach for reducing loss during peer-to-peer trading. The feasibility is to improve the power dispatch by lowering the power losses among the electricity parties involved inside the P2P network, as illustrated by Bracco et al. (2017). Ultimately, according to Muqeet and Ahmad (2020a), energy categories are introduced in the system to be considered as a diverse commodity and to manage P2P trading while reducing the network losses cost.

Losses of System Strength

Synchronous generators, by contributing system inertia and strength, help to properly stabilize the power systems again in following voltage/frequency disruptions (González-Romera et al., 2020). However, as emerging fields like P2P energy trading gain momentum, the usage of renewable (RERs) energy sources in the electrical system has increased. In recent years, this has caused the removal of substantial synchronous machines. As a result, sustaining system robustness in renewable-dominated power grids is becoming increasingly difficult (Leskarac et al., 2018). The historic blackout in South Australia is a great illustration of overall grid failure owing to a deficiency of a system's inertia.

As a result, it is critical to investigate the influence of renewable energy on system robustness. Lovati et al. (2020), Muqeet and Ahmad (2020b), and Zhang et al. (2021) are three examples of similar research. A real-time approach for solar plants is described by Kristiawan et al., (2018), which integrates inverters and energy storages to maintain voltage control.

Securing Transactions

Financial transactions between prosumers must be safe for them to effortlessly engage in P2P trade. Furthermore, in addition for prosumers to be rewarded and engage in trading, buying and selling orders and price information must be provided through a
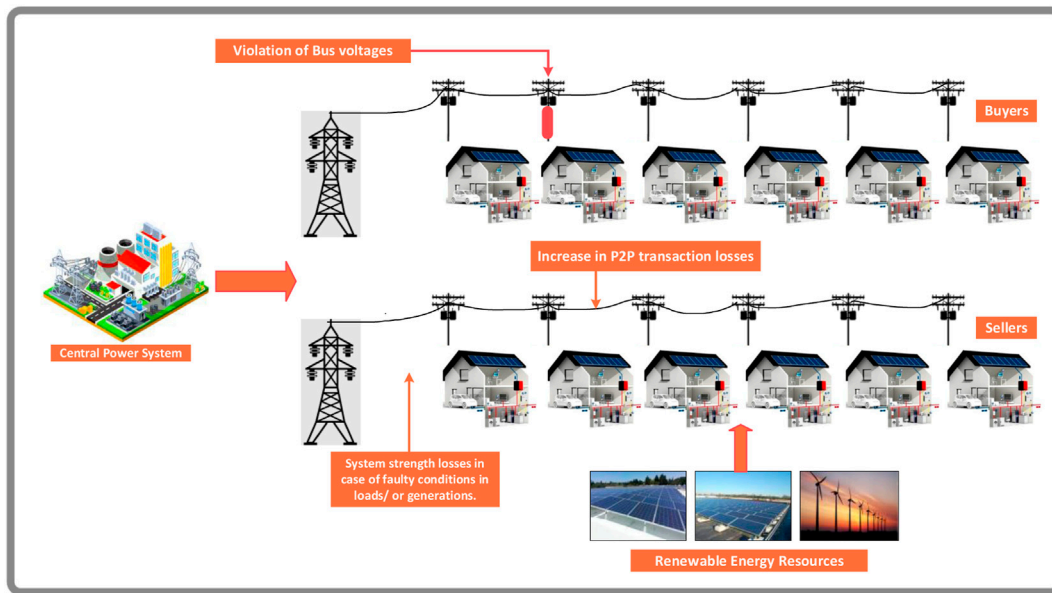
FIGURE 5 | Physical layer challenges in a peer-to-peer network.

secure network (Sanchez-Squella et al., 2020). The blockchain platform is also used to simulate many sorts of secure transactions among banks also. For example, consortium blockchains are used to perform P2P trade for electrical cars, etc. Hyperledger (Jamil et al., 2021), multi-signature blockchain (Tushar et al., 2020), smart contracts (Al-Obaidi et al., 2021), Elecbay (Hu et al., 2021), and Ethereum (Son et al., 2020) are some prominent examples of trusted transaction platforms to efficiently trade the energy in a resident community.

P2P energy trading is used to accomplish secure transactions among smart grids to ensure safety and reliability (Rana et al., 2021) and to establish a smart power plant (Savić et al., 2019) and supply ancillary service among the utility grids.

Ensuring Network Stability
The transmission network and distribution network have such a high penetration level of renewable energy to preserve the stability of the electricity network or to optimize the profitability of trading users. Users in the network can sign transactional contracts with one another for P2P energy transactions as energy prosumers. However, because power must be delivered over the power grid, network limits have an impact on P2P transactions (Zaabar et al., 2021). To assess system robustness and voltage fluctuation of renewable electricity systems, Rancilio et al. (2019) suggest a location-based short circuits ratio. Finally, to confront uncertainty of solar output, Husein and Chung (2019) evaluate the diesel engine features such as spinning-reserve techniques, time delay management, and gradient rate to build an appropriate PV-storage controlling scheme and to manage the capacity.

Obviously, implementation of P2P energy trading in electrical networks is somehow difficult. So, a variety of technological techniques have been used to offer trading frameworks that solve various difficulties in both virtual and physical layers at the same time. To that aim, the next part provides a summary for technical techniques that depicts the simulation of P2P energy trading on both layer platforms.

P2P ENERGY TRADING: TECHNICAL APPROACHES OVERVIEW

Four major approaches may be recognized as the most important contributions in the advancement of current P2P energy trading platforms composed of methods used in recent literatures. Auction-based theory, game theory, constrained optimizations, and especially blockchain are the four approaches normally used in many literatures. The goal of auction-based theory is to keep track of a group of P2P market distributors and purchasers' collaboration to enable them to exchange power in a sequential manner. On the other hand, game theory is the best mathematical way for assessing the decisions of a group of particular individuals in a plausible and competitive setting where one person's action is impacted by and effects the actions of others. At the same time, constrained-based optimization implements the mathematically programmed technique to optimize P2P trade parameters under a variety of market constraints. Lastly, blockchain establishes a needed data format for users in peer-to-peer networks to replicate and disseminate data to facilitate secure, transparent, and decentralized energy trade. **Table 2** provides a summary of the various technical techniques used by current investigations.

Game Theory–Based Approach
Introduction
Game theory–based approach is the best mathematical approach for analyzing the decisions for a group of specific players in a

TABLE 2 | Summary of various technological approaches used for enabling the P2P trading

Technological approach	General approaches	Famous methods	Virtual layers recent literatures	Physical layers recent literatures
Game-based theory	To take rivalry and collaboration among diverse participant in the P2P trading market to offer a stable, frequently optimum, and mutually advantageous solution to maximum parties concerned	Stackelberg games, coalition creation games, generalized Nash games, non-cooperative Nash games, canonical coalition games	Huang et al. (2019), Wu and Lu, (2019), Azim et al. (2021a), Romanuke, (2021), Zou et al. (2021)	Huang et al. (2021b)
Auction-based theory	To record the cooperation among a group of P2P market distributors and purchasers to allow them to exchange their electricity in a sequential way	Double auctions	Tushar et al. (2020)	Doan et al. (2021)
Constrained-based optimization	To apply a mathematically programmed approach to optimize the parameters of P2P trading under various market restrictions	LP, ADMM, NLP, MILP	Das and Kumar, (2017), Hosseini et al. (2020), Opathella et al. (2020), Zhang and Troitzsch, (2021)	Kamble et al. (2018), Lamedica et al. (2018), Oh and Son, (2020), Muqeet et al. (2021)
Blockchain	To create a required data format to reproduce and distribute between users in peer-to-peer networks to enable safe, transparent, and decentralized energy trading	Smart contract, Elecbay, Hyperledger, consortium blockchain, Ethereum	Silva et al. (2015), Park et al. (2018), Hosseini et al. (2020), Hua et al. (2020), Son et al. (2020), Al-Obaidi et al. (2021), Jamil et al. (2021), Samuel and Javaid, (2021)	None

reasonable and competitive environment where one person's action is influenced by and influences the actions of others (Paudel et al., 2019). It consists of two types, such as

1) Non–Cooperative-Based Games

The strategical decisions taken for a group of autonomous players with partly or with totally conflicted interests are examined in non–cooperative-based games to discover the consequences that are impacted by their actions. Players make decisions without speaking with each other in such games. Any collaboration in a non–cooperative-based game must not be the consequence of communicating with each other or strategy harmonization among participants (Vahedipour-Dahraie et al., 2020b).

Static-based games and dynamic-based games are the two forms of non–cooperative-based games that are used to create a trading program in general. In a static-based game, participants act just only once, either at the same moment or at different periods. In a dynamic-based game, time is a major factor in each player's decision-making and players choose several actions and have impact on other players' decisions.

A Nash-based equilibrium is a steady equilibrium condition in non-cooperative based games where any other participant may be well compensated through independently deviating its strategy, as long as all other players follow their Nash equilibrium tactics. Let us say a static game is described as $T = \{N, s_n, U_n\}$, where N is the series of entire players on field, s_n is the player n's strategical vector in N, while U_n is the function of the utility for n players that better replicates the advantage of players n may receive through selecting a normal strategy s_n. This Nash equilibrium is written as follows:

$$\{s^*: s^* = [s_n^*, s_{-n}^*], U_n(s^*) \geq U_n(s_n, s_{-n}^*)\},$$

where s_{-n}^* is a strategical player vector in $N/\{n\}$.

The Stackelberg game (Zhang and Zhu, 2021) is an example of non–cooperative-based games, which is widely utilized in recent literatures to develop P2P trade. A Stackelberg game focuses on strategical games where only one person is selected as a head, which takes the initial choice and commits to a plan before the other players. Other players participate as the game's followers, optimizing their plans in reaction to the Leader actions. This Stackelberg-based equilibrium is the solution idea of a Stackelberg game, in which followers play as a Nash-based game between each other and achieve a steady state in reaction with the superior choice. In Stackelberg equilibria, both leader and followers have no choice to divert from the plan (Zhang and Zhu, 2021).

2) Cooperative-Based Games

Cooperative-based game, defined by coalitional game, focuses on the incentives in encouraging an individual decision selector to behave by a single entity to better their role in their games. The frequent type for coalitional-based games is generally characteristics form (Garcia, 2021), in which strengths for the coalition are decided with its game's member regardless of the structure. Coalition games may now be divided into three categories.

1) *Canonical-based coalition games:* In canonical games, formulating a big alliance altogether with each other that is not injurious. As a result, some major goals of this game are to see that either a great coalition is established or not, it is to see if this big alliance is firm and steady, and either it comes up with a reasonable income distributions plan to distribute the coalition benefit between participants. The core (Sheikh et al., 2021) is the most often regarded solution notion in a canonical-based coalition game. Meanwhile, the nucleolus, Kernel, Shapley value, and especially epsilon core are the most common income distribution techniques.

2) *Coalition creation games:* The goal of the coalition creation games is to investigate the coalitional networks topology. These dynamical coalitional games are affected by external factors, such as variation in the number of participants and a change in network architecture. As a result, the primary goal of this dynamic game is to investigate the creation of a structure of coalitional games by player interaction, as well as the structure's characteristics and resilience to environment changes (Mohamed et al., 2021).

3) *Coalitional-based graph games:* Coalition-based graph game is concerned as communication interconnection among game players that provides less complex distributed methods for the participants to create a network graph while investigating the graph characteristics (Singh et al., 2021).

Game Theory–Based Virtual Layer for P2P Trading

Game theory has been widely employed in the virtual layer platform to achieve multiple objectives mentioned in *Double Auction Market*. For instance, the Stackelberg game is used to lower energy costs (Perković et al., 2017), as well as to create an appropriate pricing structure for safe transactions in P2P trade (Azim et al., 2021b). Non–cooperative-based Nash games have been used in P2P trading for a variety of purposes, including lowering energy costs (Obeng et al., 2020), regulating demand and local generation (Li et al., 2018; Zacharia et al., 2018), increasing prosumer involvement in trade (Choi and Min, 2018; Damisa et al., 2018), enhancing transaction security (Vahedipour-Dahraie et al., 2020b), and peak shaving (Soman et al., 2020). Lastly, Azim et al. (2021b; 2021a) show the structure of a canonical-based coalition game that is utilized in reducing the energy costs by matching supply and demand.

Game Theory–Based Physical Layer for P2P Trading

Therefore, the use of this theory in the physical layer framework has been limited. Liu et al. (2020) describe one application of various leader–follower-based Stackelberg game with the goal of determining the impact of transmission losses on retail and customer trade behavior. The authors suggest an optimum pricing and energy schedule model based on credit ratings, with retail as leaders or bosses and customers as follower. The energy exchange losses in P2P trading cannot be disregarded since they might result in a substantial discrepancy between the real power supplied by customers and their requests if they are not avoided.

Double Auction Market
Introduction

A market comprising many buyers and sellers wishing to connect to exchange their commodities (Mauser, 2017) is referred to as a double auction. In a double-auction market, interested customers offer bids toward bidder offerors and possible sellers ask for pricing from the auctioneer simultaneously. This is generally accomplished in the following manner:

The reservation prices are submitted in ascending order by the sellers.

Buyers are ordered in order of decreasing reserved bids.

After the buyers and sellers have placed their orders, the combined supply–demand curves are created, which converge at the intersection point.

Normally, point of intersection determines the auction prices as well as sellers' and buyers' quantity that participate in trading markets.

For the market to operate well, sellers and buyers must disclose their reservation prices and bids accurately in the double-auction process. As a result, auction methods must fulfill individual reasoning and incentive compatibility criteria (Sanchez-Squella et al., 2020). Nowadays, a double-auction system has an attribute for specific reasoning if a definite utility is received by prosumers in engaging for auction process that may not be enhanced in any other way, assuming that almost all prosumers are adopting the preferred approaches. However, this double-auction process is said to be an incentive compatible in which each participant may obtain an optimal outcome for themselves by relying on their real preferences given in steps 1 and 2 of the process.

A Double Auction Approach for Virtual Layer

In Wang et al. (2020) and Haggi and Sun (2021), the authors have utilized the double-auction approach on the virtual layer platform to meet the goals to meet local production and demand, controlling demand at peak hours, and boosting prosumer involvement in trade. To keep the balance between local power generation and distribution, Muzi et al. (2019) suggest a coalition blockchain-supported double-auction method in choosing the power prices and it exchanged energy quantity for prosumers. In Khaloie et al. (2021), the authors propose an optimum bidding method for residential properties using a twofold auction for a similar goal. The authors use a Nash equilibrium model that are able to build double-auction structures in Zou et al. (2021), respectively, in lowering the peak load demand and increasing prosumer participation in P2P trade.

A Double-Auction Approach for Physical Layer

The use of a double auction to solve difficulties with the physical layer platforms are discussed by Haggi and Sun (2021). The authors also propose a decentralized peer-to-peer framework that allows locally energy trade among grids. The authors clearly consider the basic network limitations among distribution levels when formulating the method. The market structure is built by utilizing a continuously double-auction approach, which is a basic market arrangement that connects people engaged in the trading than owning a trading commodity. Therefore, double-auction method is ideal for only P2P transactions. Karimi and Jadid (2019) also show that energy trades are typically Pareto-improving in ongoing double-auction including profitable bidders with sensible motives (i.e., members make profit only from trading).

Constrained Optimization
Introduction

P2P energy trading schemes have designed using a variety of restricted optimization approaches. Linear programming (LP),

alternating direction method multipliers (ADMM), mixed integer linear programming (MILP), and nonlinear mixed integer linear programming (NLMILP) are some examples of methods.

1) *LP*: Linear programming (LP) is a mathematical optimization approach for achieving the best possible result in a model where all criteria are expressed in linear forms. In its canonical form, any LP may be represented as

$$Maximize\ b^T x \qquad (1)$$

subject to $Ax \le c$ and $(x \ge 0)$ are equal. (x) is an unknown variable vector, where c and b are the normal coefficient vectors, and A is a coefficient matrix. The goal function in (**1**) is known as a constraint function, and inequalities $Ax \le c$ and $x \ge 0$ are defined as general constraints in which conditions must be met.

2) *MILP*: Mixed-integer linear programming (MILP) is mostly used for the system analysis and the optimization problem as it presents a flexible and a powerful method for solving complex problems such as the case with process integration and industrial symbiosis. A MILP can be represented mathematically as a mixed-integer linear programming problem.

$$Maximize\ b^T x \qquad (2)$$

such as $Ax + s = c$, $(x \ge 0)$, $where (s \ge 0)$, and $x \in Z^n$, in which given entries are not normally integers.

3) *ADMM*: The ADMM is a method for resolving convex optimization issues by dividing it into smaller portions that are easier to manage (Esmaeili et al., 2019). ADMM is basically an augmented Lagrangian method with partial modifications for dual variables. For an optimal solution, this may be represented mathematically as

$$Maximize_{x,z}\ f(x) + g(z) \qquad (3)$$

subjected to $Ax + Bz = c$, in which z is a second-variable vector. As a result, it has two main purposes, each its own set of variables.

4) *NLP*: Neuro-linguistic programming (NLP) is a psychological and mathematical approach that involves analyzing strategies for solving with a complex nonlinear function and/or nonlinear constraints defining the feasible zone. The problems can be expressed in maximizing form as (1) with a nonlinear objective function.

Constrained-Based Optimization for Virtual Layer in the P2P Energy Trading

On the literature, several constrained optimizations are extensively utilized to create P2P energy trading approaches in virtual platforms. In Zhang et al. (2020), the authors use an LP method that builds an innovative energy management approach composed of multi-energy demand complementarity to investigate optimum energy scheduling challenges for prosumers. In Khaloie et al. (2021), the authors optimize the

utilization of energy obtained from solar PV with batteries using a MILP method. Zhang and Troitzsch (2021) use the ADMM optimization approach to create a multi-class power control technique for P2P trading. The use of NLP in Das and Kumar (2017) is to create a community-wide energy sharing system based on integrated battery control. Oh and Son (2020) provide more examples of limited optimization in peer-to-peer energy trading.

Constrained-Based Optimization for Physical Layer in the P2P Energy Trading

ADMM has been the common restricted optimization approach in the physical layer, as seen by its use by Shang et al. (2021). Liu et al. (2021) present a consensus-based decentralized ADMM for developing a cost sharing method that allows prosumers to automatically split costs of utilizing shared services with P2P infrastructures for trading. However, in Liu et al. (2021), ADMM is used to optimize the active–reactive power adjustment and reduction for all inverters engaging in the P2P energy trading platforms for voltage regulation. In addition to ADMM, the use of restricted optimization has been used to solve network losses concerns of physical layer in Karkhaneh et al. (2020).

Blockchain
Introduction

Blockchain, referred to as a Distributed Ledger Technology (DLT), makes the history of any digital asset unchangeable and transparent with the use of decentralization and cryptographical hashing (Al-Obaidi et al., 2021). A blockchain gathers information organized in groups, also denoted as blocks, that hold sets of information. As a result of the features of P2P trade, blockchain has a lot of potential in the future electricity network. Therefore, many blockchain systems for P2P trading have recently been established.

1) *Smart contract*: Smart contracts are basically programs collected on a blockchain that run when predetermined circumstances are met (Thukral, 2021). They normally are used to automate the implementation of an agreement in which all participants can instantly focus on the outcome, without any time loss or intermediary's involvement. They can also systematize a workflow, triggering the subsequent action when require conditions are met (Yang et al., 2021). It is activated when a number of transactions are addressed to it. As per the data provided in the transaction, it then runs independently and autonomously on each and every node in the electrical network in a specified manner.

2) *Elecbay*: This Elecbay is a microgrid-based software platform that focused on the development of P2P energy trading. Each order comprises information such as the energy exchange time period, the quantity of electricity that is traded, the energy that is traded among each other, and the buyer/seller personal details. Following the placement of orders by peers, Elecbay either accepts or rejects them based on network restrictions. After those orders are accepted or rejected, individual peer creates and utilizes the energy quantity indicated in the agreed orders, which is then

supplied through the distribution network. It has also been described by Gao et al. (2021) as an additional information on this platform.

3) *Consortium-based blockchain:* Federated blockchain or consortium blockchain is a technology of blockchain where instead of only a solo organization, multiple organizations rule the platform. It is set up on approved nodes to allow for public auditing and sharing of transaction data without the need for a trusted third party. Generally, energy transaction records between peers are encrypted and uploaded on approved nodes during P2P energy trade. The approved nodes validate the transaction and register it in the common ledger using an algorithm. Participants and approved nodes linked to the consortium blockchain have open access to this ledger.

4) *Hyperledger:* The Linux Foundation hosts the Hyperledger project, which is an open-sourced cooperative effort to promote this blockchain technology (Kalbantner et al., 2021). It offers a clear and non-tampered distributed ledger via a consensus method. According to Jamil et al. (2021), the Hyperledger IBM's core module operates on an open-source platform known as Docker. As soon as a system's peer wishes for trading, it uses a blockchain systems terminal to log into the system and submit the necessary transaction. The transaction data are forwarded to an energy trading unit, which analyzes and initiates the deal when it is filed. For user queries, the data are stored in the database as a key/value pair. When the mapping is finished, the energy trading unit completes the energy trading by dispatching.

5) *Ethereum:* Ethereum is a programmable blockchain platform with a unique cryptocurrency called Ether (Vivar et al., 2021), which was released in 2015. While Ethereum's structure is very similar to Bitcoin's, one significant distinction is that it lets anyone to install immutable and permanent decentralized applications, with which multiple users can cooperate (Huang et al., 2021a). The network must maintain track of all current information for each Ethereum application, containing individual peer balance, every smart contractual code, and the addresses where it keeps all the record.

Other updated kinds of blockchain methods are commonly used for ensuring safe energy trade in smart grids, in addition to the classifications described. Esmat et al. (2021) and Li et al. (2021) are two examples of such modified systems.

Blockchain for Virtual Layer of P2P Trading

Existing research have used a wide range of blockchain technologies in providing safe energy trade at virtual layer. The authors suggest a blockchain system that focuses on paralleled double-chain paired by high-frequency authentication method, which enables the trustworthy and safe settlement for power trading transaction in Park et al. (2018). Samuel and Javaid (2021) build trading programs based on consortium-based blockchain to attain the required trading efficiency among plugin hybrids and EVs in an electrical market. Tesfamicael et al. (2020) propose a multi-signature blockchain to enable security transaction in smart grid with

decentralized energy trading without relying on third parties. Secured peer-to-peer trading among storage technologies and various edge users in the domestic, industrial, and commercial sectors are accomplished via smart contracts in Thukral (2021) and Vivar et al. (2021). Jamil et al. (2021) use the IBM Hyperledger model to build an operating design for crowdsourcing power system in the distribution systems that takes into account different forms of energy trades and crowdsources. Elecbay is suggested by Thomas et al. (2021) for efficient energy trade in microgrids while Ahmad et al. (2020) discuss the use of blockchain networks with decentralized power requirements and market management through P2P trade.

Blockchain for Physical Layer of P2P Trading

The physical layer is primarily dependable on facilitating energy transmission among producer and consumer after secure transaction; it is unnecessary to focus on the system's security for these transactions that can affect the physical-layer functionality. Although game theory, constrained optimization, double auction, and blockchain have all been widely utilized in this literature to build P2P trading platforms, various novel techniques growing rapidly such as graph theory (Wu et al., 2021), artificial intelligence (Mehmood et al., 2021), multi-agent heuristic simulation (Niyomubyeyi et al., 2020), and activity-based models (Wu et al., 2021) are among trending approaches.

MULTIPLE DISCUSSIONS ON FUTURE RESEARCH

It is worth noting that, although receiving a lot of attention in recent years, energy technology for P2P networks is still very new. As a result, significant effort needs to be done before P2P energy trading is fully integrated into the present energy system. To that aim, the following is a list of issues that should be investigated further. **Figure 6** depicts a high-level summary of these issues.

1) *Network charge recognition:* Prosumers do not normally utilize an entire energy network for P2P energy trading, unlike typical power systems. As a result, they must investigate and change the perception according to what they are charged for power bills, so they can be charged them under a P2P trading concept.

2) *Large-scale network trade and simulation:* As energy cannot be controlled, it is improbable that the designated receiver would get the real power supplied to the network by the transmitter in a very wide network. As a result, the power loss caused by P2P energy trading might be different, necessitating more research. Furthermore, P2P algorithm must be developed with an actual power system design to see how computational complexity affects the way trade is conducted in such a big system.

3) *Grid benefit:* In recent literature, the end user of P2P trade has been clearly demonstrated. The value of P2P energy trading to the distribution system must be proved. In addition, if necessary, the grid should be able to engage in P2P trading as a service provider or a generator.
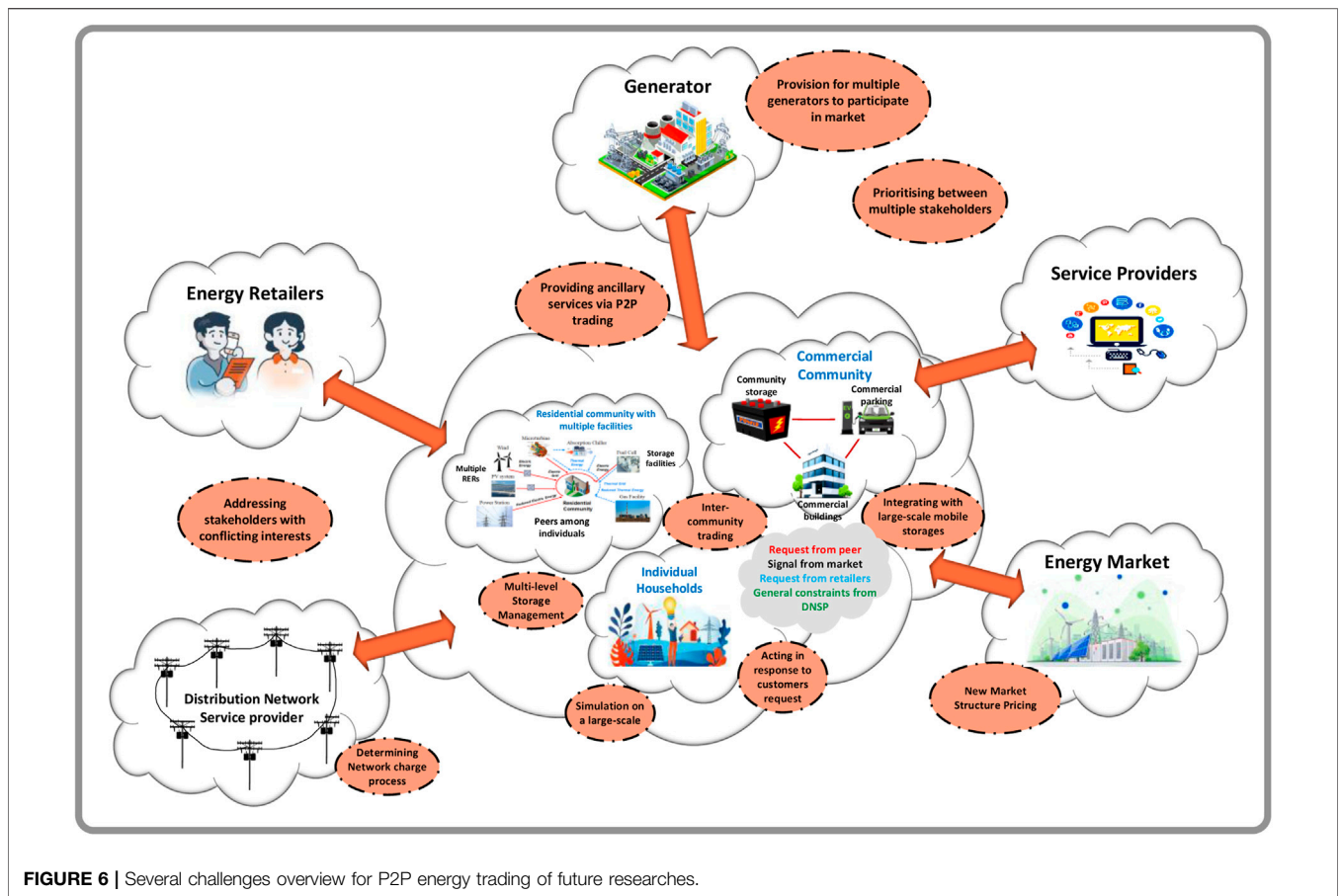
FIGURE 6 | Several challenges overview for P2P energy trading of future researches.

4) *Grid ancillary services:* P2P energy trading has shown the ability to build coalitions between network prosumers to obtain a stable and economical energy supply. Nowadays, it is fascinating to see great alliances that may aid in the provision of auxiliary grid services, such as virtual power plant.

5) *Multi-level storage facility:* With P2P energy trade, a community is likely to have a variety of storage services, such as batteries on prosumers' locations, medium-level community storages, and large-scale storages. Synchronization among various energy storage devices in a cost-effective manner, and the development of appropriate price mechanisms to perform inter-storage energy exchange, would be a difficult challenge to solve. As a result, new scheduling and optimization methods must be created.

6) *Prioritization of stakeholder:* Several stakeholders are obviously concerned in using prosumers' storage facilities to provide various benefits to the consumers while maintaining network security. Generators, for example, also focus on reducing the production instability, DNSPs may want to use them to restrict demand, and consumers might wish battery discharges to fight energy imbalances. These acts, however, may be in contradiction with each other. As a result, P2P energy trading schemes must be

constructed in such a way that energy members' autonomy and benefits are not harmed.

7) *Market mechanism and limitation:* At the moment, each prosumer's optimum quantity of power that their inverter may transmit energy to utility is limited. There are restrictions for prosumer ability to build greater capacity solar PV systems and generate additional benefit to the grid. Prosumers may actively bargain with one another about the quantity of electricity they can sell and the cost using P2P trading. As a result, the input limit must be flexible to get the most benefit of such policymaking process. This demands the creation for innovative market systems that could adjust an input limit composed of energy requirements inside the system network without significantly affecting the system's network.

8) *Integrated model:* At the moment, many researches are focused on either physical or virtual layers. However, it is critical to meet the requirements among both layers for the effective implementation of P2P trading inside the electrical network. As a result, a unified model is required to represent this. This is made feasible by blockchain-based data systems, which enables real-time data accessible both for prosumers and network operators. However, a general amount for grid operators that may

affect prosumer behavior must be clearly defined. Otherwise, P2P trading's decentrity may be jeopardized.

9) *Facilitating data availability with privacy*: The availability of statistically relevant and reliable energy transaction and consumption data among communities, enabling improved prosumer decision-making, is critical to the success of P2P trading, in which both interpersonal and intercommunity groups are considered. Therefore, every prosumer's privacy must be protected by this publicly available data.

10) *Intra- and intercommunity trading*: A prosumer must have enough choice in P2P trading to choose whether they wish to deal with peers inside their group (intracommunity group) or outside the group (intercommunity group). However, general market structures for P2P trade must be equipped with regulations and technology that allow for such flexibility.

11) *Ecommerce applications*: E-commerce applications have also progressed from web-based Internet sales to peer-to-peer (P2P) sales. When compared with traditional client-server systems, P2P will improve e-commerce applications and result in lower-cost solutions.

12) *Cryptocurrency involvement*: P2P will open many secure gateways in trading many digital cryptocurrencies, like Bitcoin and Ethereum. This necessitated the use of encryption and the development of blockchain technology to allow two parties to perform a transaction securely without the involvement of a trusted third party.

CONCLUSION

Existing studies focus on an overview of multiple literatures of P2P (peer-to-peer) energy trading that is presented here. As a result, the history of P2P energy trading in various electrical networks is examined, mainly focusing on P2P network characteristics, market framework for P2P energy trading, and opportunities with a possible challenge. Second, it considers important problems in individual physical and virtual layers that are comprehensively analyzed with some state-of-the-art scientific studies, and a systematic categorization of P2P energy has been presented. Third, the proposed study summarized key technical methods that have been widely employed in the literature. In particular, we provide an overview of how these discussed techniques may be used for P2P trading in physical and virtual layers. In conclusion, the study also discusses other challenges in future research areas to help innovative researchers to get up-to-date literature in this field.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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