REVIEW FOR SURVEY TECHNOLOGIES PEER TO PEER ENERGY TRADING PARTICIPANTS WILLINGNESS IN COMMUNITIES

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Keywords: PEER-TO-PEER ENERGY TRADING, WILLINGNESS FACTORS, COMMUNITY ENGAGEMENT, RE-NEWABLE ENERGY, REGULATORY POLICIES

Abstract

The rapid advancement of renewable energy technologies and energy storage technologies is profoundly reshaping the framework of the traditional energy system and offering technical support for the advocacy of green, decarbonized, and decentralized energy markets. Concurrently, the transformation of the en-ergy architecture is exerting a profound impact on energy distribution and en-ergy trading aspects, spawning novel models. P2P energy trading, as a transac-tion form that is congruent with this, has been investigated and implemented on a global scale. This transaction form enables participants to circumvent the grid power market and conduct direct electricity transactions, featuring an ex-tremely high degree of flexibility and autonomy. Researches on it encompass various aspects such as operation models, technical approaches, and incentive mechanisms, providing theoretical guidance for pilot practices. The practical outcomes will also supplement the deficiencies in the theoretical research sys-tem, presenting new foci and revealing universal principles. This paper com-mences from the perspective of users' participation willingness, studies and analyzes global cases and related academic reports, and explores the factors in-fluencing the willingness of community members to engage in P2P energy trading, with the aim of providing assistance for the subsequent development of this model and the refinement of management policies.

1 Introduction

With the promotion and deepening of relevant policies on the concept of sustainable development, low-carbon energy saving and green economy, the drawbacks of traditional energy systems are increasingly revealed, such as high energy consumption, high maintenance costs and low system resilience, which seriously limits its further development under the current economic structure[1]. To address these challenges, the construction of a modern energy system has emphasized the need for decentralization. Fortunately, the rapid advancement and widespread adoption of renewable energy generation, distributed power generation, and energy storage technologies have provided critical technical support and assurance[2][3]. These developments are fundamentally reshaping the energy architecture, enhancing system sustainability, and introducing innovative models for energy distribution and trading[4]. Among these emerging models, the P2P energy trading model enables participants to directly trade energy, thereby decentralizing the power market. This approach holds significant potential for optimizing energy distribution and improving energy efficiency within the system. The fundamental mode of P2P energy trading is depicted in Fig. 1 [5].

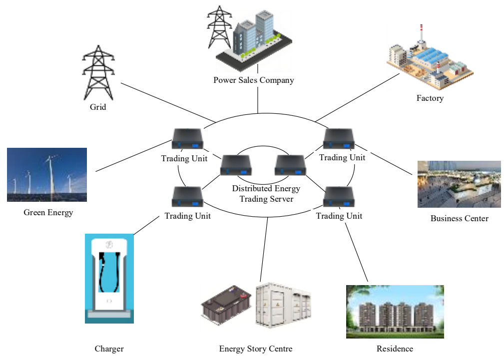

Fig. 1 Peer-to-peer energy trading

For the power system, P2P energy trading facilitates the localization of energy transactions, effectively reducing transmission losses. For instance, the Berlin microgrid project demonstrates a reduction in line loss rates from 6.2% to 1.8% through localized energy management. Furthermore, users' dynamic and spontaneous energy trading behavior can alleviate peak load pressures, contributing to improved voltage control in the power grid. For participants, P2P energy trading empowers users with greater energy autonomy and enhances power supply reliability. Additionally, it reduces electricity costs for participants and even allows some to generate profits. The benefits of P2P energy trading extend beyond these aspects, as existing economic conditions and policies often favor its implementation, aiming to establish a mature P2P trading framework[6].

Despite technological advancements, community participation in most P2P energy transactions remains limited. According to survey data from the German Energy Agency (DENA) in 2023, in communities equipped with smart meters, blockchain trading platforms, and distributed energy management systems, the actual participation rate is only 12%, significantly lower than the theoretical threshold of 35% predicted by the Institute for Energy Economics (EWI).

While P2P energy trading undoubtedly offers substantial benefits to society, a structural gap exists between technology deployment and behavioral response, leading to disparities in responsiveness. This gap prevents the full realization of its potential and complicates subsequent deployment and operation. Therefore, this paper analyzes and summarizes the factors influencing participants' willingness to engage in P2P energy trading based on global case studies and academic surveys[7].

2. Key Determinants of Willingness

This paper reduces the key factors affecting users' participation in P2P energy trading to the following seven points, as depicted in Fig. 2.

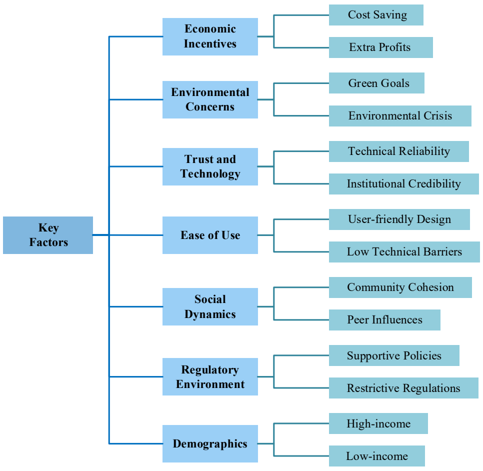

Fig. 2 Seven key factors influencing users' wiliness of engaging P2P energy trading

2.1 Economic incentives

Users' sensitivity to economic rewards significantly affects their willingness to participate, either in search of cost savings or in the hope of profiting from excess energy incentives[8]. A 2023 follow-up study of a community in Berlin, Germany, shows that when users' expected annual income exceeds the €300 threshold (equivalent to 23% of the local household's annual electricity bill), the participation rate presents a non-linear jump. The same rules of economic incentives apply in developing countries. But unlike these monetary incentives, developing countries have alternatives. A pilot project in the slums of Nairobi, Kenya, found that when the proceeds from peer-to-peer transactions could be converted into mobile traffic packets, youth participation reached 68%, 2.1 times that of cash-only incentives.

Moreover, the dynamic pricing mechanism can further enhance the appeal of P2P energy transactions to users[9]. A comparative study of the German Energy Transition revealed that in Munich, where the fixed FIT scheme is still used, only 12% of residential PV participated in P2P transactions, while in Berlin, where real-time pricing was implemented, the participation rate reached 31%.

2.2 Environmental concerns

Environmental concerns are also an important factor in the willingness to participate in P2P energy trading. Surveys show that environmentally conscious people actively participate to reduce their carbon footprint, even if the economic benefits are small[10]. In the Fujisawa Sustainable Smart Town project in Japan, residents trade green electricity through a blockchain platform, and the premium portion is automatically donated to the research fund for sea level rise. Despite the electricity sales revenue being 7% lower than the grid buyback, the participation rate still reached 94%.

There are also cases where the environmental crisis directly drives user participation. The traditional power supply on Maui, Hawaii, suffered a devastating blow in August 2023, when 94% of the island's population experienced a 72-hour blackout. After the grid was rebuilt after the disaster, the participation rate of residents in P2P energy transactions soared from 15% to 89%, but fell back to 22% six months after the disaster. Environmental crisis can affect participants' behavior in a short period of time, and security needs increase their willingness to participate, but it is difficult to solidify into long-term behavior habits.

2.3 Trust and technology

Technical reliability and institutional credibility are two important dimensions of technological trust. The former includes the stability of platform infrastructure and the ability to resist risks, which is of great significance to ensure the security of transactions. The latter includes the design rationality of governance rules such as pricing transparency and privacy protection policies, which is crucial to improving user trust. The P2P energy trading platform primarily depends on blockchain technology. The implementation approach is depicted in Fig. 3 [11].

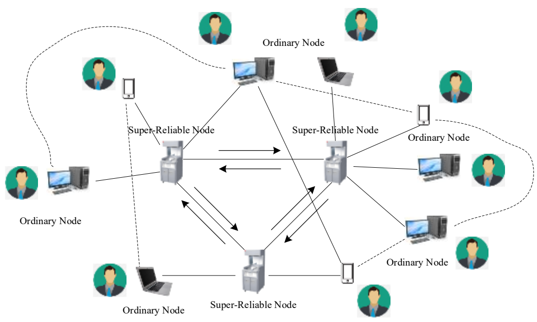

Fig. 3 Blockchain technology

The German Sonnen community is a P2P trading platform that adopts Byzantine fault-tolerant consensus mechanism, node failure tolerance reaches 33%, and dynamic pricing formula.

Concerns over data privacy and fraud could impede participation, highlighting the necessity of sound governance. The Dutch PowerPeers trading platform ensures the privacy and security of users' energy consumption data through zk-SNARKs encryption technology, effectively resisting 99.7% of hacker attacks. Moreover, each transaction can generate a "privacy passport" through which users can anonymously verify the compliance of transactions[12].

2.4 Ease of use

User-friendly interface design, low technical barriers to entry, and education campaigns have played a key role in increasing users' willingness to participate in P2P energy trading, especially among non-technical groups[13].

User-friendly interfaces can significantly reduce operational complexity and thus increase user acceptability. A study by the Tokyo Institute of Technology found that abandonment rates jumped 83% when the interface took more than five steps. The Jouliette platform in the Netherlands used AI to streamline the process and increased the engagement rate of users over 60 years old to 39%, higher than the industry average of 21%.

Low technology barriers can improve user engagement by removing barriers to user participation. Brooklyn Microgrid Project achieves "senseless operation" at the user end through the combination of smart meters and blockchain technology. Users only need to install a smart meter, and the system can automatically collect data on power generation and consumption, and complete transaction settlement through the blockchain.

2.5 Social dynamics

Community cohesion and peer influence show significant synergies in driving participation in P2P energy transactions. In the case of Brooklyn's LO3 Energy project, for example, the key to its success was the design of the energy trading system as a social relationship strengthening tool[14]. By trading energy, users establish a direct connection with their neighbors, forming a collective identity as an "energy self-sufficient community." This identity encourages participants to align their personal interests with community goals, such as reducing carbon emissions, thereby boosting their willingness to participate in the long term.

Peer influence establishes behavioral norms through the leading role of demonstrators, and enhances value identification and trust among members. When individuals realize that their own behavior is deeply tied to the collective goals of the community (e.g., carbon neutrality, energy democratization), their participation in decision making will shift from purely economic rationality to social value co-creation[15].

2.6 Regulatory environment

Supportive policies increase willingness[16]. The Berlin government in Germany has offered community PV investors income tax relief for the first three years. This measure significantly reduced the initial investment burden, resulting in a 217% increase in the installation rate of rooftop PV. This tax incentive directly reduces the financial pressure and enhances the motivation of individuals and enterprises to participate.

In contrast, restrictive regulations are a major obstacle. The US state of Texas charges a transmission system fee of $3.50 per kilowatt per month for P2P transactions. The fee has caused the yields of many community projects to fall below the 5% warning line, severely undermining their economic viability. Brazil has set a minimum registered capital requirement of R $5 million, excluding a large number of small and medium-sized community projects. This high threshold is clearly not conducive to the development of small and medium-sized players[17].

2.7 Demographics

There are differences between the participation of different demographic groups in the energy transition process. Most of the high participation groups are homeowners, people with high economic incomes, and people who have access to renewable energy equipment. For the low-participation group, such as tenants and low-income people, they face multiple barriers such as physical space restrictions, financial access barriers, and information asymmetry. In Paris, France, 78% of apartment tenants are unable to install renewable energy equipment because their lease contracts prohibit exterior wall renovation, involving about 3.8 million potential users.

This disparity not only reveals the impact of socioeconomic status on energy participation, but also the inadequacy of the current energy system in terms of inclusion[18].

3. Case Studies and Regional Insights

This part undertakes a research on three global P2P energy trading platforms, namely the LO3Energy project in the United States, the PowerLedger project in Australia, and the Piclo project in European countries[19][20][21]. Through the analysis of their operation modes, technical approaches, and economic environments, the core driving forces that differentiate them from other platforms are acquired, as illustrated in Fig. 4.

Fig. 4 Three successful international cases of P2P energy trading

3.1 LO3Energy

LO3Energy is a blockchain startup based in Brooklyn, New York, that works to use blockchain technology to drive peer-to-peer energy transfer. In April 2016, the LO3 team established the Brooklyn Microgrid pilot project and the world's first energy blockchain transaction[14].

Community cohesion and peer influence are key determinants of willingness to participate, and the Brooklyn project is a good example of this. It uses community participation mechanisms that allow governance to sink in. Under this mechanism, a community energy council composed of elected representatives is set up, which is given the right to propose amendments to trading rules and make decisions on annual revenue distribution. It also stipulates that any rule amendment must be approved by more than 75% of the votes to ensure the fairness and transparency of the rules. In addition, the project follows the technology trust route. It uses blockchain technology to achieve a high degree of transparency. For example, every energy transaction is recorded to see its own trading history and the trading data of other users. All transactions are done through smart contracts, without the need for third-party intermediaries. The design, which balances transparency and privacy, has won high recognition from residents.

3.2 PowerLedger

PowerLedger is an Australian-originated blockchain energy trading platform founded in 2016 and headquartered in Perth[22]. It innovatively proposes a dual token system. POWR tokens are used for platform access and governance, giving holders the right to participate in platform decisions, and Sparkz tokens anchor the energy unit of fiat currency, making cross-border energy transactions more convenient and reliable.

The successful operation of the Power Ledger project in Australia has benefited from regulatory support and clear economic benefits[23][24][25]. The Australian Tax Office (ATO) identified energy token trading as a GST exemption, reducing transaction costs by 10 per cent. Under the ASEAN Energy Mutual Recognition Agreement, carbon credits from the pilot project in Thailand can be exchanged for Climate Active certificates in Australia, enabling cross-border circulation of environmental rights and interests. In terms of economic benefits, the project has a three-tier revenue superposition model. Participants can gain basic benefits through P2P energy trading price differences, and gain value-added benefits in response to government needs, such as subsidies for participating in peak regulation. Finally, participants can earn additional income through carbon credit trading. At the same time, the platform is also equipped with AI dynamic pricing algorithms, combined with weather forecasting and load analysis, to help participants increase energy storage arbitrage income.

3.3 Piclo

Piclo is a representative energy trading platform within the European Union, originated in the UK and expanded to multiple European countries. The project is based on the EU's Clean Energy Package and focuses on building a transparent, flexible, and environmentally beneficial energy market system that can be quantified. Besides helping participants make profits, it is also an efficient tool for achieving climate goals. This technology-institutional collaborative innovation model leverages the climate concerns of participants and the policy goals of regulators to transform the Clean Energy Package into programmable market rules, creating a positive cycle between environmental goals and market mechanisms. Essentially, it builds a "digital twin" system for climate action: blockchain ensures the trustworthy transfer of environmental value, regulatory technology enables the procedural execution of policy rules, and P2P networks activate the participation energy of participants. The positive feedback loop formed by the coupling of the three provides a verifiable, scalable, and sustainable systemic solution for the global carbon neutrality process.

4. Barriers to Participation

4.1 High upfront costs

The high upfront costs of distributed energy systems, energy storage systems and transaction licenses required for P2P energy trading have deterred many residents, limiting the growth of participation[26][27]. According to data from the German Federal Solar Energy Association (BSW-Solar), the average installation cost of a household photovoltaic system in 2023 was approximately 1.3-1.5 euros per watt. Taking a 6kW photovoltaic system as an example, its market price was about €7,920 (including installation). However, when combined with a 10kWh lithium-ion energy storage system, the total expenditure increased to €20,220.

In addition to these hardware costs, users also need to consider the additional costs brought about by technical compatibility[28]. Many old buildings cannot directly support the installation of photovoltaic systems due to their structure, thus requiring additional renovations.

The economic threshold issue of P2P energy trading essentially reflects the implicit barriers erected by the traditional energy system through institutional design and technical standards[29]. These barriers not only constrain the popularization of technology but also intensify social inequality. low-income households are precluded from the clean energy transition because they cannot bear the exorbitant initial investment, thereby further widening the gap in energy access between the wealthy and the poor.

4.2 Awareness Gaps

In the development process of P2P energy trading, the cognitive gap has become one of the key factors hindering its popularity[30]. This knowledge gap not only exists in the level of technical understanding, but also involves many dimensions such as institutional cognition and cultural acceptance.

Many communities lack a clear understanding of the technical principles of P2P energy trading[31]. In addition, the concept of smart contracts is still relatively abstract to the average user, leading to confusion or fear among some potential participants due to their unfamiliarity with the terminology[32]. This lack of technical knowledge directly limits users' willingness to participate.

Different cultural backgrounds also shape people's attitudes toward P2P energy trading[33]. Among Poland's traditional mining communities, coal has long been seen as the backbone of the national economy and a symbol of social status, so when new renewable energy solutions emerge, there is often strong resistance.

4.3 Technical challenges

Renewable energy sources, such as solar and wind energy, present challenges to the stability of power supply due to their pronounced intermittency and unpredictability, thereby influencing the perception of reliability in P2P energy trading[34]. Such instability can trigger sharp fluctuations in market prices[35][36]. Take the "duck curve" phenomenon in California as an example; during midday, due to excessive power generation from photovoltaic systems, electricity prices approach zero or even turn negative; while during the evening peak consumption period, prices soar to several times the average[37]. These extreme price variations increase the complexity of trading strategies. Moreover, when the power supply is unstable, sellers are more inclined to retain electricity for their own use rather than participate in market transactions; buyers may also opt to exit the market due to concerns about obtaining a continuous power supply, further reducing transaction volume and frequency.

The design of traditional power grids is primarily based on centralized power generation models (such as coal-fired power plants or nuclear power plants), characterized by stable output and ease of control. However, the integration of distributed energy systems introduces new technical challenges to the grid. P2P transactions require flexible power transmission between different nodes, yet existing grids typically only support unidirectional flow.

5. Conflicting Findings and Gaps

5.1 Cultural variations

Cultural variations can take many forms in different regions, and there are also cultural variations in motivations for P2P energy trading[38]. Taking Europe as an example, due to its high economic level and relatively complete social security system, the public pays more attention to environmental protection and sustainable development, and most participants take the realization of environmental goals as the primary motivation for P2P energy trading[39]. In many European countries, reducing carbon emissions, promoting renewable energy and protecting natural ecosystems are core goals of policy formulation. The formation of this environmental awareness not only comes from a deep understanding of climate change issues, but also is closely related to long-standing cultural traditions and social values[40].

In contrast, in many developing countries, economic factors tend to play a more important role. These countries are usually under pressure to grow their economies and need to address issues such as poverty, employment and infrastructure development. For individual participants, conducting P2P energy transactions means a reduction in the cost of electricity. For managers, peer-to-peer models can reduce construction costs.

5.2 Long-Term engagement

A great deal of research has focused on why users choose to join these platforms, such as policy incentives (such as tax breaks), environmental awareness, or financial benefits. Data shows that more than 70% of users sign up for the motivation of "green energy subsidies" or "reducing their carbon footprint". However, there is very limited research on whether users are active for a long time after joining, and what factors influence their continued usage behavior. Data from a community energy sharing platform in Berlin, for example, showed that despite an initial sign-up rate of 90 per cent, after two years only 35 per cent of users were still trading at least once a month. This striking gap has not been explored in depth.

The reasons for the above phenomena are multi-dimensional, including but not limited to the limited research period, the difficulty of data collection, the limitation of research methods, and the different orientation of policies and practices. Continuous participation in research requires a large amount of longitudinal data, including users' behavior habits, payment history, feedback on satisfaction, etc.

5.3 Geographic bias

Research on P2P energy trading does have a clear geographic bias, with most studies focused on developed countries and relatively little relevant research in the global South. Developed countries often have advanced power grid systems and digital platforms, which provide a solid foundation for P2P energy trading. Large numbers of people in the global South do not have access to stable power grids, especially in rural areas. In sub-Saharan Africa, for example, some 600 million people still rely on traditional fuels for their basic energy needs. In this context, off-grid peer-to-peer energy trading, such as micro-grid-based solutions, could become an important alternative[41].In addition, the popularity of digital payment systems has also affected the ease of transactions. A typical case is Kenya's M-Pesa, which provides users with easy access to financial services while also creating the possibility for peer-to-peer energy trading. However, existing studies are mostly based on credit cards or other payment methods commonly used in developed countries, ignoring the application scenarios of mobile payments in developing countries.

This information asymmetry makes the academic community more inclined to study cases in developed countries, while ignoring the actual needs of countries in the global South.

6. Recommendations

6.1 Policy

The subsidy measures can effectively reduce the initial investment cost of users, thus attracting more participants to join the P2P energy trading market. Different countries and regions can choose appropriate subsidy models according to their own economic conditions and development stages. For example, in developed countries, Germany encourages residents to install solar panels through tax breaks and allows them to sell excess power to the grid or trade it directly with other users. While in the developing world, India has used microcredit to help low-income households get access to renewable energy equipment. This flexible subsidy mechanism not only facilitates energy trading, but also promotes equity in energy use.

The complicated approval process is often one of the main obstacles hindering the development of P2P energy trading. Therefore, simplifying regulations has become an important task. It is especially important to establish a clear legal framework to safeguard the rights and interests of both sides of the transaction. Smart contracts, as an emerging technology, can play an important role in this process. In addition, governments can draw on international best practices and develop uniform standards and norms to promote the P2P energy trading model globally.

6.2 Technology

The core goal of the user center design is to improve the user experience, thus lowering the threshold of participation, so that more users can easily integrate into the P2P energy trading system. First, in terms of interface design, developers need to ensure that the operating interface of the platform is intuitive and easy to understand. Secondly, simplifying the operation process is one of the key steps to improve the user experience. Finally, the provision of personalized services can further enhance user satisfaction and loyalty. Through the analysis of users' behavior data, the platform can recommend energy products or trading modes that best suit their needs.

Enhancing the resilience of the power grid is one of the important measures to ensure the stable operation of the P2P energy trading system. First of all, natural disasters are one of the major threats to the stability of power grids worldwide. To counter this, the independence and resilience of local grids can be enhanced by deploying microgrid technology and distributed energy storage systems. Second, technical failures are also common causes of grid outages. This can include a variety of factors such as aging hardware, software bugs or human error. To mitigate these risks, there needs to be greater investment in intelligent monitoring platforms that use advanced sensors and data analytics to monitor the state of the grid in real time and spot potential problems in a timely manner.

6.3 Community engagement

Foster local leadership and education initiatives are the key means to build trust. By identifying and supporting those local leaders with potential, it can not only enhance the cohesion among community members, but also effectively promote the dissemination of information, resource sharing and practice implementation. This bottom-up approach makes the project more practical and easier to win the support and active participation of community members. In addition, since these leaders are members of the community themselves, they are more likely to gain the trust of other residents, thus reducing the resistance in the implementation process. The cultivation of local leadership also helps to break through the constraints of traditional energy supply models and explore innovative solutions tailored to local conditions.

Education is an important way to change perceptions and spread knowledge. Through systematic educational activities, people can not only understand complex concepts, but also stimulate their interest and acceptance of new things. In many developing countries, the roll-out of renewable energy technologies often faces cultural or economic resistance, as parts of the population may be accustomed to relying on traditional fossil fuels.

7. Conclusion

The willingness of participants in peer-to-peer energy trading is a complex and multi-dimensional issue, influenced by multiple economic, social, technological and regulatory factors. To drive sustainable development in this emerging field, future research needs to delve deeper into the dynamics of long-term user engagement and develop more inclusive and scalable solutions that take into account the characteristics of different geographical contexts. At the same time, close collaboration between policy makers and platform designers is essential, and only by working together to lower the barriers to participation can we maximize the economic benefits and social value that community drive can bring.

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