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Sharing Economy in Local Energy Markets

Zhaoyuan Wu, Jianxiao Wang, Haiwang Zhong, Feng Gao, Tianjiao Pu, Chin-Woo Tan, Xiupeng Chen, Gengyin Li, Huiru Zhao, Ming Zhou, and Qing Xia

***Abstract*—With an increase in the electrification of end-use sectors, various resources on the demand side provide great flexibility potential for system operation, which also leads to problems such as the strong randomness of power consumption behavior, the low utilization rate of flexible resources, and difficulties in cost recovery. With the core idea of "access over ownership", the concept of the sharing economy has gained substantial popularity in the local energy market in recent years. Thus, we provide an overview of the potential market design for the sharing economy in local energy markets (LEMs) and conduct a detailed review of research related to local energy sharing, enabling technologies, and potential practices. This paper can provide a useful reference and insights for the activation of demand-side flexibility potential. Hopefully, this paper can also provide novel insights into the development and further integration of the sharing economy in LEMs.**

***Index Terms*—Energy sharing, flexibility potential, local energy market, information and communication technology, sharing economy.**

I. Introduction

To cope with a series of social and environmental problems such as environmental pollution and the greenhouse effect caused by the increasing consumption of fossil energy, the world is currently undergoing a major energy transformation, which is also leading to profound changes in the production, structure, and consumption mode of the energy system [1]-[3]. In September 2020, China clearly indicated at the United Nations General Assembly that its carbon emissions would reach a peak by 2030 and that the country would achieve carbon neutrality by 2060, which is also called "dual carbon" target. In March 2021, the future development direction of building a new power system with variable renewable energy as the main body was further proposed. Driven by the "dual carbon" target, the integration of a high proportion of variable renewable energy will become the basic feature and development form of the future power system [4]-[6].

The integration of a high proportion of renewable energy poses new challenges to the flexible operation of power systems. However, in sharp contrast to the current rapid development of variable renewable energy, the flexibility construction of China's power system is still insufficient [7]-[9]. Although in recent years, with the development of distributed energy, multi-type energy storage, and demand-side response technology, the development of flexibility technology in all links of power systems has achieved remarkable results, providing an effective solution to improving flexibility. However, the wide application of certain technology depends on its cost competitiveness, and needs to be supported by a reasonable market mechanism. The urgent problem faced by flexible resources is the insufficient utilization rate, which leads to difficulties in cost recovery [10]-[12].

In recent years, the emerging sharing economy has provided a new paradigm for solving such problems. With the core idea of "access over ownership", energy sharing, which allows users to trade directly and form a reasonable shared market price through competition, is expected to achieve the effect of matching supply and demand nearby [13]. In the energy sector, the concept of "energy sharing" was first proposed by an American energy economist, Jeremy Rifkin, in his book "The Third Industrial Revolution" [14]. He holds the view that Internet technology will be combined with renewable energy and that energy mining, distribution, and utilization will change from the traditional centralized mode to an intelligent distributed mode, turning the global power grid into an energy sharing network. This will be a new industrial revolution brought by the combination of energy and communication technology, and it will cause foundational changes in the human business model and social development mode [15]-[17]. In essence, due to the complementari-

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Z. Wu and H. Zhao are with School of Economics and Management, North China Electric Power University, Beijing 102206, China, and Z. Wu is also with State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing 102206, China (e-mail: wuzy@ncepu.edu.cn; zhaohuiru@ncepu.edu.cn).

J. Wang (corresponding author) is with National Engineering Laboratory for Big Data Analysis and Applications, Peking University, Beijing 100871, China (e-mail: wang-jx@pku.edu.cn).

H. Zhong and Q. Xia are with State Key Lab of Power Systems, Department of Electrical Engineering, Tsinghua University, Beijing 100084, China (e-mail: zhonghw@tsinghua.edu.cn; qingxia@tsinghua.edu.cn).

F. Gao is with Department of Industrial Engineering and Management, College of Engineering, Peking University, Beijing 100871, China (e-mail: gaofeng@pku.edu.cn).

T. Pu is with China Electric Power Research Institute, Beijing 100192, China (e-mail: tjpu@epri.sgcc.com.cn).

C. Tan is with Department of Civil and Environmental Engineering, Stanford University, Palo Alto, CA 94305, USA (e-mail: tancw@stanford.edu).

X. Chen is with Engineering and Technology Institute Groningen, University of Groningen, 9742 AG Groningen, the Netherlands (e-mail: xiupeng.chen@rug.nl).

G. Li and M. Zhou are with State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing 102206, China (e-mail: zhouming@ncepu. edu. cn; ligy@ncepu.edu.cn)

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ty of distributed resources and energy supply and demand among different individuals, the sharing economy has strong application potential in local energy markets (LEMs) [18]-[20]. In recent years, a large number of transactive energy projects based on the sharing economy have been launched. For example, the Pacific Northwest National Laboratory has implemented a transactive-based project for peak shaving by sharing idle resources on the demand side, and several companies in the United States have been investing in non-wire alternative projects, which enable DER owners to share idle capacity to defer generation and transmission expansion [21]-[23].

The concept and business model of the sharing economy will bring new challenges and opportunities for LEMs [24]. Therefore, in this paper, we provide an overview of the potential market design for the sharing economy in LEMs and conduct a systematic review of research and practice related to local energy sharing. We provide a useful reference and insights for demand-side flexibility potential, and hopefully, some novel insights into the development and further integration of the sharing economy in LEMs.

To provide an overview of existing research on the local sharing economy, a bibliometric analysis was conducted on July 1, 2022 using a well-established and acknowledged database, Web of Science (WoS). The query for WoS was as follows: TS= ((sharing economy OR energy sharing) AND (local energy market OR peer to peer (P2P) OR transactive energy)). The number of publications since 2005 retrieved from WoS is shown in Fig. 1, and 1928 publications were found. As shown in the figure, relevant literature on the sharing economy in the field of energy was less published before 2011 and has increased rapidly since 2016. This result is in line with reality. In recent years, the development of the Internet, communication, and other technologies has provided more possibilities for further application of the sharing economy in the energy sector, which has also spawned more journal publications.

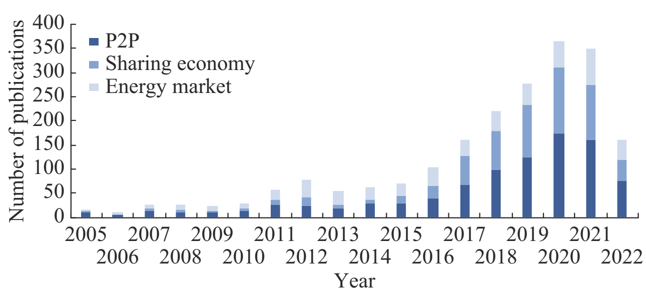

Fig. 1. Number of publications since 2005 retrieved from WoS.

Here, we also conduct a brief review of several review articles related to local energy sharing. In [25], the potential market design related to grid integration of prosumers is discussed and evaluated, which sheds light on the flexibility potential activation on the demand side. In [26], different market structures for P2P trading are compared from the perspective of decentralization degree and topology of market design. In [27], four business models for energy sharing, i.e., possessed resource sharing, underused resources utilization, idle resources exchange, and resource ability exploitation are summarized. In [28], a systematic classification in local energy sharing in terms of market participants, market clearing model as well as potential market design is conducted. In [29], the sharing economy is defined and compared from the perspective of sustainability for academics, policy-makers, entrepreneurs, and consumers interested in the sharing economy for its sustainability potential. Reference [30] analyzes the principles and perspectives of the sharing economy in the electricity market and pays special attention to the assessment of sustainability perspectives based on its economic, social, and environmental pillars.

Digital platforms are the key characteristic of the sharing economy. They provide accurate real-time measurement of surplus capacity and enable the connection between potential users of an asset and owners. Reference [31] points out that a platform intermediary must offer inherent value beyond the simple mediation process for the two sides of the market. The P2P concept has been strongly applied under the principles of the sharing economy. In [32], an overview of the use of game-theoretic approaches for P2P energy trading as a feasible and effective means of energy management is provided. From the perspective of demand response, the state-of-the-art of integrated demand response (IDR) in multiple energy systems is reviewed for the first time, and value analysis of IDR is introduced in [33]. In [34], a business model for energy storage based on the principles of the sharing economy is developed, and some key influencing factors in local energy sharing mechanism design are investigated in [35]. Further, digital platforms for local energy sharing as well as existing transactive energy projects are compared in [36] and [37], respectively. In [38], a security and privacy analysis of the sharing economy in the electricity market has been conducted, highlighting privacy risks, specifying security and privacy requirements, and suggesting potential mechanisms to achieve these requirements.

The aforementioned review papers provide useful insights into the sharing economy in energy sectors from a special aspect, and it has been widely stated that the sharing economy promotes sustainable consumption. We can also observe that different expressions for local energy sharing are adopted such as transactive energy, P2P trading, prosumer market, etc. Actually, the expression of the above differences belongs to the scope of local energy sharing. The reason behind the diversity of expression lies in the different emphasis of different studies. In addition, with the further increase in the electrification of end-use sectors, the application of the sharing economy in LEMs is still an emerging research field. This paper attempts to provide a systematic review of current research and identify the contributions that energy sharing can make to future sustainable development. The topics discussed in this paper and the existing review papers related to local energy sharing are compared in Table I.

The concept of the sharing economy has been integrated into the rapidly ongoing energy market transformation and advocated as a promising solution to facilitating the accommodation of renewable energy.

TABLE I
TOPICS DISCUSSED IN THIS PAPER AND EXISTING REVIEW PAPERS RELATED TO LOCAL ENERGY SHARING

Literature	Individual & resource elements	Mechanism design	Application	Technology	Pilot project
This paper	√	√	√	√	
[25]	√	√	√		
[26]	√	√	√		√
[27]	√	√	√		
[28]	√	√	√		
[29]	√	√	√		√
[30]		√	√	√	
[31]			√		√
[32]			√		√
[33]		√		√	
[34]	√		√		√
[35]	√		√		√
[36]	√				√
[37]				√	√
[38]		√	√		

However, few studies have summarized the applications and enabling technologies of the sharing economy in LEMs. Thus, this paper attempts to provide a systematic review of current research and identify the contributions that local energy sharing can make to future sustainable development. The contributions of this paper are as follows.

1) The correlation between the sharing economy and LEMs is analyzed, and the framework and key elements of the sharing economy in LEMs, i.e., individual elements, resource elements, technological elements, and environmental elements, are proposed.

2) A comprehensive literature review of current research on the mechanism design of local energy sharing is provided, and the enabling technologies for local energy sharing are discussed to identify the challenges of sharing economy application in the future market.

3) From the "energy sharing+" perspective, we elaborate on the further application of the sharing economy in energy fields such as data transactions, decarbonization, and new infrastructure construction in the energy sector.

The remainder of the paper is organized as follows. Section II presents the concept of the sharing economy in LEMs. Section III reviews current research on energy sharing mechanism design. Section IV presents enabling technologies and business models for local energy sharing, and Section V provides a discussion and the open research topics for local energy sharing. Section VI draws the conclusions.

II. CONCEPT OF SHARING ECONOMY IN LEMs

A. Sharing Economy Development

The sharing economy has been developing rapidly in recent years. It reshapes conventional business models that have a clear distinction between companies and customers by directly connecting products with consumers. In the traditional economy, consumers own too many things that they do not need or do not use frequently, leading to an enormous waste of resources. For example, according to the Wall Street Journal, Americans spend over $1.2 trillion annually on nonessential goods. Therefore, there are a growing number of people who are attracted to the sharing economy for personal, economic, and environmental reasons.

The concept of the sharing economy originated from collaborative consumption theory jointly proposed by Marcus Felson and Joe L. Spaeth in 1978. This theory describes a new way of life consumption, i.e., multiple individuals consume economic goods or services together in joint actions [39]. However, limited by factors such as technology and consumption concepts, the development speed of the sharing economy has been very slow. With the gradual maturity of mobile Internet technologies such as cloud computing and online payment, internet platforms can integrate distributed offline resources, eliminate the barriers in time and space between the supply side and the demand side, and inject new vitality into the sharing economy. In 2010, [40] proposed the concept and development model of collaborative consumption in the internet era, introducing a brief definition of the traditional application of the sharing economy. Reference [41] studied the promoting effect of online platforms on user-generated content, sharing, and collaboration. In 2014, [42] reviewed and compared the characteristics of the traditional sharing economy and the internet-based sharing economy. In 2016, [43] argued that the internet-based sharing economy is an activity for the sharing of various goods and services in a peer-to-peer manner through community-based online service coordination.

At present, the definition of the sharing economy is still controversial in academia, but scholars have basically reached a consensus on some aspects. First, the sharing economy is a new development form of the modern economy. Many problems in economic development have been difficult to solve for a long time, mainly due to the influence of profit-seeking and information asymmetry. The emergence of the sharing economy has greatly changed the reality of information asymmetry and is an innovation in the economic field. Second, the sharing economy is the optimal solution to resource allocation. Driven by Internet trading platforms, massive, scattered, and diversified resources and demand information can be integrated, enabling quick matching between supply and demand. Third, the sharing economy is a concept of sustainable consumption and development. The sharing economy advocates the reuse of items, conforming to the concept of "heavy use, light possession". The sharing economy has affected many businesses including hospitality, transportation (cars, bikes, boats, etc.), babysitting, home/garden tool businesses, and the financial sector. These successful cases provide important value for the application of the sharing economy in the energy sector.

B. Key Elements of Local Energy Sharing

For the sake of simplicity and clarity, this paper summarizes the sharing economy as a business model in which a user shares individual idle resources with others and is paid, with others being able to take advantage of the shared resources to improve social welfare. Actually, LEM can be considered as a kind of practical application of sharing economy in the energy sector, which is referred to local energy sharing.

The following four elements, i. e., individual, resource, technological, and environmental elements of the sharing economy itself have been given specific meanings in local energy sharing, which is also the correlation between the sharing economy and LEMs.

1) Individual elements: individual elements mainly include the energy supply side and demand side involved in local energy sharing. The supply side wants to share its idle resources, while the demand side wants to obtain the right to use energy or resources at a lower cost. In practice, the roles of buyers and sellers will change at any time in the process of local energy sharing; in other words, individuals are both the starting point and the ending point.

2) Resource elements: there are distributed energy resources (DERs) in the LEM. Making full use of these idle resources can help overcome the reliability, flexibility, and sustainability challenges of energy systems. On the other hand, the potential complementarity of different resource and energy combinations also lays the foundation for the sharing economy. The application of the sharing economy in LEMs can effectively promote the collaborative consumption of idle resources and improve energy efficiency.

3) Technological elements: the application of the sharing economy in LEMs requires the support of key technologies, and the innovative development of relevant technologies is of great significance for the deep integration of the sharing economy and energy market in the future. The main enabling technologies of the sharing economy in energy markets include energy conversion technology, blockchain technology, and communication-related technology. For example, the development of energy conversion technologies such as power-to-heat (P2H) and power-to-gas (P2G), has brought more joint production and consumption and has expanded the scope and diversity of market participants in local energy sharing.

4) Environmental elements: the environmental elements of local energy sharing mainly refer to policies and social culture, among which policies refer to the support of relevant energy policies, laws, and regulations for local energy sharing, while social culture refers to a common understanding formed by different market members through long-term accumulation and evolution such as the energy consumption outlook and values. The in-depth application of the sharing economy in LEMs requires not only support at the policy level but also improvement in the general acceptance of energy sharing in society.

In practice, from the perspective of specific industrial energy sharing projects, individual and resource elements mainly refer to the main participants and matching methods of the sharing economy, which also indicates the complementary potential of different prosumers in local energy sharing. While the technological elements and environmental elements refer to specific enabling technology, e.g., blockchain and edge computing technology, and support policy for local energy sharing.

It is believed that the sharing economy based decentralized structure for LEMs will replace the traditional hierarchical structure in the future. A well-designed market mechanism should at least satisfy the conditions of individual rationality, incentive compatibility and budget balance and ultimately realize the maximization of social welfare. In LEMs, a well-designed incentive mechanism is needed to effectively stimulate true generator set quotes, promote the active response of distributed energy sources, and comprehensively promote the healthy development of the energy market.

C. Framework of Sharing Economy in LEMs

The core of the application of the sharing economy in LEMs is the sharing of idle resources among different market entities. Based on the above elements of energy sharing and the related roles between them, the key elements of sharing economy in LEMs can be specifically expressed as a tri-level framework, as shown in Fig. 2.

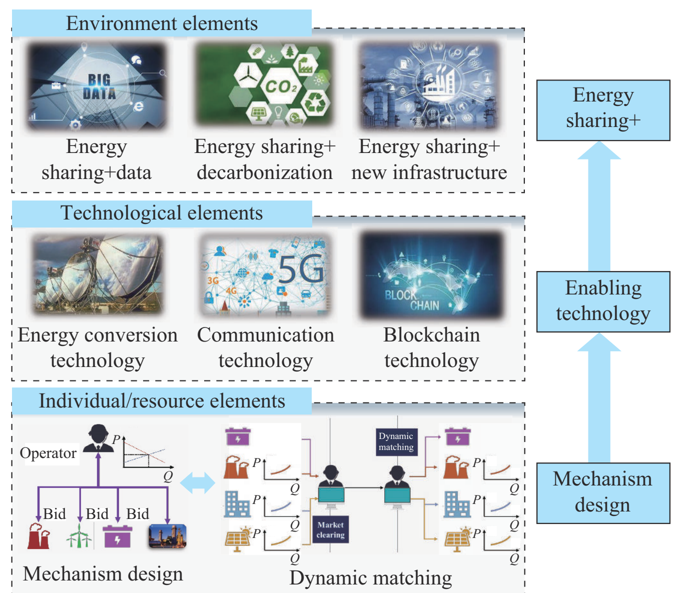

Fig. 2. Key elements of sharing economy in LEMs.

1) The bottom level is related to the above individual/resource elements, mainly dynamic matching of idle resources including the analysis of the complementary characteristics of different entities and collaborative optimization operations. In general, the sharing entities in LEMs mainly include residential users, distributed resources of different energy types, distributed energy storage, and other flexible resources. Actually, the individual and resource elements in local energy sharing provide the foundation of mechanism design.

2) The middle level is related to the technological elements. The application of the sharing economy requires the support of key technologies, and the innovative development of relevant technologies is of great significance for the deep integration of the sharing economy and LEM. In this paper, energy conversion technology, blockchain technology, and communication-related technology are discussed as the main

enabling technologies for local energy sharing.

3) The top level refers to the environmental elements, which is related to the current policy and other external elements such as social culture. In practice, further development in the energy system and the process of decarbonization will create new opportunities and challenges from the perspective of "energy sharing+", e.g., energy sharing+data, energy sharing+decarbonization, and energy sharing+new infrastructure.

In this paper, the research contents corresponding to the above tri-level framework will be further discussed in Sections III, IV, and V, respectively.

III. Local Energy Sharing Mechanism Design

In general, a well-designed local energy sharing mechanism is supposed to stratify the following principles: ① the dynamic spatial matching of energy demand and supply can be achieved; ② the mechanism can achieve fairly distribution of social welfare in local energy sharing; and ③ the mechanism is easily implemented and understood with various participants [17]. Based on the above principles, the application of the sharing economy in LEMs mainly has two forms: ① aggregator-based local energy sharing; and ② platform-based local energy sharing. In this section, we introduce the research on energy sharing mechanism design based on these two aspects.

A. Aggregator-based Local Energy Sharing

In LEMs, multiple market members can form an alliance, and the aggregator is responsible for the energy management of each market member in the alliance and determines a reasonable cooperative surplus profit-sharing mechanism. A local energy sharing model with general aggregator based on Nash bargaining theory can be formulated as follows:

$$\max_{\boldsymbol{X},\pi} f^{NB}=\left(-r^{A,0}+r^{A}-\sum_{i=1}^{N}\pi_i\right)\prod_{i=1}^{N}(c_i^{U,0}-c_i^{U}+\pi_i)^{\alpha_i} \tag{1}$$

$$\boldsymbol{X}\in\varphi\bigcap\varphi^{S} \tag{2}$$

$$-r^{A,0}+r^{A}-\sum_{i=1}^{N}\pi_i\geq 0 \tag{3}$$

$$c_i^{U,0}-c_i^{U}+\pi_i\geq 0\quad \forall i \tag{4}$$

where $\boldsymbol{X}$ and π are decision variables that represent the operation and settlement results of local energy sharing, respectively; φ and φ^S are the feasible regions of market members and the aggregation, respectively; $c_i^{U,0}$ and c_i^U are the operation costs of market members before and after energy sharing, respectively; $r^{A,0}$ and r^A are the expected revenues of the aggregator before and after energy sharing, respectively; and α_i is the market power of market member i ($i=1,2,\ldots,N$) in Nash bargaining.

The core of the above local energy sharing is how to identify the contributions of different market members in the cooperation and to design the corresponding profit-sharing mechanism to ensure the stability of the alliance. In [44], a profit-sharing mechanism is designed based on cooperative game theory to incentivize flexible ramp service provision from multiple microgrid operators. In [45], an energy sharing scheme and profit-sharing mechanism considering the participation of DER aggregation in capacity markets are proposed. The contribution of different market members is identified by the sharing contribution rate. In [46], an efficient cost allocation method is proposed for storage sharing in LEMs based on cooperative game theory.

The above studies are inspiring and provide a solid technical foundation for profit-sharing mechanism design in local energy sharing. However, in aggregator-based local energy sharing, market participants are supposed to disclose their energy information to aggregators for information asymmetry elimination, which may also lead to possible privacy problems [47]-[49]. To address the aforementioned privacy problem, there are many studies focusing on the decentralized solution method in local energy sharing, e.g., optimality condition decomposition (OCD) and Lagrangian relaxation (LR) [50]. In [51], a decentralized framework is proposed for energy trading among different interconnected microgrids to minimize information exchange in local energy sharing. In [52], an architecture and the corresponding supporting algorithms are designed for privacy preservation in local energy sharing, in which market participants do not need to disclose detailed information about their preferences to aggregators. In [53], a distributed optimization program is implemented in an agent-based model in LEMs to protect the information privacy of different market participants. The above distributed solution needs to converge to the market equilibrium and obtain the clearing results through distributed iteration process [54]-[56]. However, the iterative solution is inconsistent with the actual market transaction process, and it is difficult to accurately quantify the underlying economic intuition as well as utility function of participants in local energy sharing.

In general, an energy sharing mechanism based on a cooperative game can maximize the overall welfare of participants, but for complex systems, especially considering information asymmetry and user privacy protection, how to design an effective redistribution scheme urgently needs to be solved.

B. Platform-based Local Energy Sharing

With the gradual expansion of the scope of energy sharing and the increase in market participants, aggregator-based local energy sharing will face many limitations. Therefore, many studies have focused on the platform-based energy sharing model. That is, the LEM members can submit declaration information based on their idle resource characteristics through platform-organized transactions, and idle resources can be shared among different market members. In theory, platform-based local energy sharing can be understood as a tri-level framework, as shown in Fig. 3.

The top level represents the platform trading scheme design, which aims to promote energy sharing on the demand side through reasonable platform transaction mechanism design such as transaction variety design and the pricing mechanism. The middle level represents the energy decision-making process, where market participants submit application information to the platform based on the corresponding platform design and their own resource combination. The bottom level represents the market clearing, and the platform operator determines the transaction result of the energy sharing declaration based on all the declaration information of market members. In practice, such energy sharing can also be understood as an iterative optimization process of platform design. The top-level platform designer will adjust the platform trading and pricing mechanism based on the energy sharing situation to promote sharing in the LEM as much as possible. Actually, the framework shown in Fig. 3 can be considered as non-cooperative game-based local energy sharing. According to the difference of interaction between platform operators and participants in different local energy sharing modes, [27] further divides the non-cooperative game-based local energy sharing into Stackelberg game [57], bilateral Nash game [58], and multi-leader multi-follower game [59], etc.

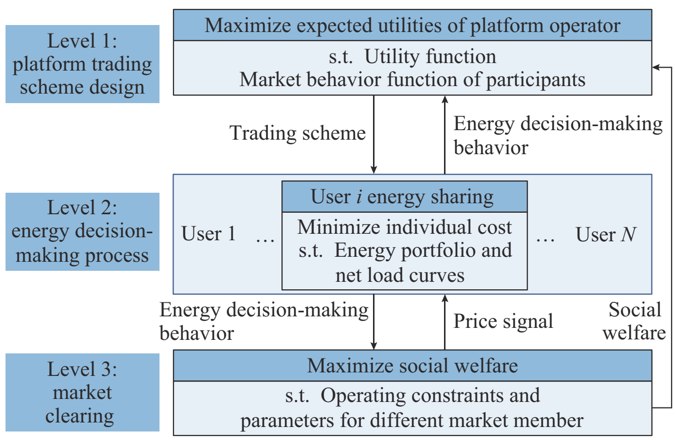

Fig. 3. Tri-level framework of platform-based local energy sharing.

As mentioned above, the core of the platform-based local energy sharing is to make trade-offs between the interests of different energy sharing participants, i.e., how to design effective profit-sharing mechanism for cooperation surplus according to the actual contribution of each participant. It is considered that the network constraints in the local energy system affect the feasibility of energy sharing among market members in different locations without changing the nature of mechanism design. As a result of this, some studies focus more on the design of trading mechanisms and the evaluation of energy sharing benefits, and the network constraints are ignored [60]-[62].

With the further integration of various DERs at the distribution level, some studies have also focused on a network-aware pricing mechanism for local energy sharing to guide market members to share their idle resources. In essence, the network on which the energy system depends also provides a natural platform for the application of the sharing economy. Distribution locational marginal pricing (DLMP) can be an effective solution to reflecting the spatial value difference of DERs in different locations. Since line losses can be substantial in distribution networks with lower voltages, the core of DLMP is to reflect the contribution of different distributed energy resources to line losses, which may shed light on the local energy sharing between participants in different locations [63]. There have been some studies focusing on the DLMP-based pricing mechanism in local energy sharing [64], [65]. In [66], a DLMP-based pricing mechanism is designed to facilitate peer-to-peer energy trading, and the designed pricing scheme was able to enhance the economic benefits compared with the traditional local energy sharing framework. In [67], the implementation of a dynamic operating envelope is explored to depict the operational and technical limits of DERs at the distribution level. In this way, the various sharing values of different DERs in local energy sharing can be identified [68]. As for the third level, which refers to the market clearing process in local energy sharing, [28] compares different market clearing methods in local energy trading as well as the optimization objective in clearing process.

With the deepening integration of the sharing economy and the LEM, there will be competition from multiple platforms, and such competition appeared in other sharing fields such as transportation and housing. In [68], the impacts and the role of the pricing mechanism in platform competition have been investigated. It is further pointed out in [68] that under the sharing economy, service providers may choose whether to provide services or assets based on their own needs and the price of leased assets. Therefore, the supply-demand relationship of energy sharing in the platform is uncertain. That is, how to achieve efficient matching based on the preferences of platform users is the key to platform operations. In [69], the concept of creating shared value is proposed, and this concept can be integrated into the sharing platform to support the matching process. Reference [70] indicates that the price may not exert an influence on the stickiness of sharing platform users, while the intrinsic value of appropriability resources is of significant importance.

IV. Enabling Technologies and Business Models

The application of the sharing economy requires the support of key technologies, and the innovative development of relevant technologies is of great significance for the deep integration of the sharing economy and energy market in the future. The main enabling technologies of the sharing economy in energy markets, including energy conversion technology, blockchain technology, and communication-related technology, are summarized in this section. Actually, different enabling technologies correspond to different local energy sharing processes, which are presented in Fig. 4.

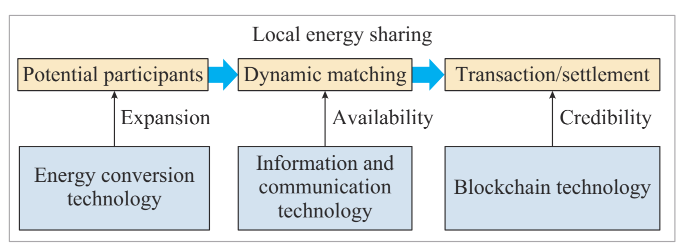

Fig. 4. Relation between different enabling technologies and different local energy sharing processes in local energy sharing.

A. Energy Conversion Technology

An efficient and highly liquid multi-energy market coupling transaction is the mechanism basis for the multi-energy system to realize energy sharing, and energy conversion technology is the necessary condition for the multi-energy system to realize energy sharing. In recent years, the development of energy conversion technology, e.g., P2H and P2G, has expanded the scope of energy sharing as well as the diversity of market participants in the sharing economy [71]-[73].

In terms of energy conversion in the natural gas-electricity coupling system, the emergence of P2G technology has changed the coupling between electricity and natural gas systems from traditional one-way conversion through natural gas generators to two-way conversion. P2G technology is advocated as an appealing way to provide additional flexibility and facilitate energy sharing in the natural gas-electricity coupling system. Recently, P2G has received increasing attention and developed rapidly due to cost reduction, improved P2G efficiency, and increased penetration of renewable energy and hydrogen consumption [74]-[76].

P2G technology mainly includes two categories. The first one is power-to-hydrogen technology, which uses a water electrolysis system to split water into oxygen and hydrogen. Currently, the two main commercially available water electrolysis technologies are proton exchange membrane electrolysis cells (PEMECs) and alkaline electrolysis cells (AECs). The second one is power-to-methane technology, in which water is first decomposed into oxygen and hydrogen through an electrolytic reaction, and then hydrogen and carbon dioxide are combined to form methane [77]. Although the reaction efficiency of electricity-hydrogen technology is relatively high, currently there lacks effective large-scale long-distance transmission means for hydrogen. The injection of hydrogen into an existing natural gas pipeline will cause hydrogen embrittlement and penetration in the pipeline. Relying on the existing natural gas pipeline and storage device, methane can realize large-scale energy storage and long-distance transportation. P2G technology can make use of its large-capacity storage performance to convert surplus renewable energy generation into natural gas, which is stored in the natural gas pipeline and then converted from gas to electricity for power supply when the power system is short of power [78]. With the development of large-scale new energy, power-to-gas technology provides technical support for improving the utilization of new energy and energy sharing in the natural gas-electricity coupling system.

For the integrated heat and power system, although the traditional combined heat and power unit can establish the connection between the electric heating systems, it is limited by its technical characteristics, and the operation flexibility is low. With the gradual maturity of energy conversion technologies such as electric boilers and heat pumps, their application in cogeneration units helps to weaken the thermoelectric coupling characteristics and reduce the mutual restriction of energy supply in heat and power systems, which has shown good characteristics in practice in some countries [79]. In addition, some studies consider the thermal inertia of buildings in district integrated heat and power system, which further extends the scope of energy sharing [80]-[82].

In general, energy conversion technology enables the closed-loop flow of energy between different energy systems, which fundamentally expands the scope of energy sharing and the diversity of users involved in energy sharing. With the help of energy conversion technology, the mutual conversion of different energy sources on the supply side also enables users to choose different forms of energy to achieve the same goal. This kind of multi-energy complementarity on the supply side fundamentally strengthens the integration of the sharing economy in the energy market.

B. Blockchain Technology

A blockchain network is a point-to-point network. The entire network has no centralized hardware or management organization, nor does it have a central server or a central router. Each node in the network has equal status and can act as a client and a server at the same time. In a blockchain system, each node saves all the data in the entire blockchain. Therefore, the data of each node are jointly owned, managed, and supervised by all participants. The blockchain uses a decentralized collaboration mechanism to track and analyze the behavior of participants through credit, evidence, and transaction records to ensure that all transactions and data are credible [83]. The core advantage of blockchain is that due to its transparency and decentralization, it ensures that different entities can trust each other, thereby greatly reducing the cost of reshaping or maintaining trust. As a result, blockchain technology can be further extended to the areas other than currency, the economy, and markets. Reference [84] has designed a reputation recording system based on blockchain technology that can be used in multiple networks in response to the security vulnerabilities in the current reputation system.

Notably, the potential application areas of blockchain include the energy sharing mechanism. It can promote the coordination of multiple forms of energy and the participating entities, promote the further integration of information and physical systems, and realize the diversification and low cost of transactions [85]. Power grid enterprises, financial institutions, new energy generators, green energy service providers, and power users are regarded as a node access blockchain network. Blockchain can provide users with a low-cost, open, and transparent power resource market trading platform to participate in energy sharing [86]. Participants can make two-way choices on this platform. Whenever users decide to participate in energy sharing, smart contracts pre-deployed on blockchain systems can support transactions and settlements between users participating in local energy sharing. At the same time, the rate of contribution of each user's participation in the sharing of energy to the entire energy system is open and transparent, and can be reasonably measured and certified to inspire users and distributed energy sources to participate in the operation of energy sharing. Many scholars have focused on existing transaction scenarios to redesign the network architecture of blockchain technology in power transactions and the multichain integration of a smart electricity transaction payment blockchain. The transaction structure of [87] and [88] is a two-layer model.

The first layer is the peer-to-peer network supported by the multiagent system, which builds an alliance of agents or manufacturers to realize pricing negotiation. The second layer is a transaction settlement mechanism based on blockchain. Reference [89] designed a domain-based model. Business domains include automatic demand response, energy custody, ancillary services, and energy efficiency analysis; operation domains include ledger issuance, targeted maintenance, contract maintenance, and configuration updates; information domains include the peer-to-peer network protocol, equity certification, and the dissemination mechanism; and asset domains include power generation assets, energy storage assets, load assets and financial assets.

Before blockchain technology is widely used in various application scenarios, including the energy sharing industry, there are still a series of problems that urgently need to be solved. ① The scope of application of existing theories and projects is still limited to a small community. How to realize regional-level energy sharing transactions is the primary issue that should be considered in current technology development and application research. ② The online local energy sharing system may be subject to numerous network attacks during the development and application process. How to effectively prevent data from being tampered with from the branch network and from the source and ensure the authenticity of data with the support of blockchain technology is an important task of application research. ③ Although blockchain technology can provide effective support for P2P trading, effective local energy sharing still needs to rely on reliable market supervision. Market participants will lack a sense of security and their enthusiasm for participation will be reduced without reliable market supervision. This is also the key to further deepening the application of blockchain in local energy sharing.

C. *Information and Communication Technology*

The promotion of the energy sharing mechanism needs to realize the information interconnection between devices at the distribution network level. The increasing number of DERs on the user side places a high demand on the capacity of the communication system [90]. Energy sharing should consider different needs and interactions of users. Massive control signal exchanges need to be completed in a relatively short time, which sets the requirements for a low delay of communication. 5G communication can economically and efficiently enable the distribution of power grids to achieve information interconnection. Compared with 4G communication, 5G communication exhibits a large leap in bandwidth and the time delay as well as other advantages, which enables efficient local energy sharing [91]-[93].

With the enhancement of the coupling of the power grid information physical system, the construction of large-scale communication base stations (BSs) has become the development trend of the future. From the perspective of energy consumption, the power consumption of communication BSs accounts for approximately 70%-80% of the power consumption of communication system according to statistics [94]. It is estimated that in 2025, the deployment density of BSs will exceed 13 million, which is 10 times the existing scale, and the corresponding energy consumption will reach 200 billion kWh [95]. With the increasing number of BSs, the energy consumption of BSs, which cannot be ignored, will exert a great influence on the power distribution and voltage fluctuation of the distribution network. Therefore, the supply-demand interaction between the 5G communication network and the active distribution network has been deeply discussed.

BSs are the main intermediary between the communication network and the power network. The communication network is an important transfer point of wireless information transmission. A power network is the main communication device that consumes electricity. There is a coupling of energy and information between the communication system and the power system. On the one hand, the communication network requires an energy supply from the distribution network. The operation strategy of the communication system may change the power flows in distribution lines. On the other hand, communication systems effectively guarantee the precise control of power networks. However, the interference and noise between different BSs may lead to bit errors, resulting in the failure of energy sharing transactions. To illustrate the interaction mechanism, a tri-layer framework is proposed in [96], in which a number of microgrids aggregate demand-side energy and a communication BS, and the impact of communication reliability on energy sharing in active distribution networks is also studied.

V. Discussion and Open Research Topics

Although the application of the sharing economy in the energy sector has attracted extensive attention from both academia and industry, further development in the energy system and the process of decarbonization will create new opportunities and challenges. In this section, we discuss the key challenges in mechanism design in local energy sharing. Besides, several open research issues related to local energy sharing are highlighted, i. e., energy sharing + data, energy sharing + decarbonization, and energy sharing + new infrastructure from the "energy sharing +" perspective.

A. *Energy Sharing + Data*

The application and development of information processing technologies such as big data and artificial intelligence provide a broader space for the construction of new power systems. Data have become an important asset in local energy sharing, which are also regarded as the key driving force for the upgrading of inherent assets and the development of emerging businesses. Most existing studies assume a symmetric information environment in local energy sharing mechanism design. The core of these studies is how to reveal the real needs of different participants through effective mechanism design, promote the sharing of idle resources, and activate the flexibility potential of the system. In the process of local energy sharing, the information among different participants is symmetrical, i. e., only their own information is known by each participant or all information is shared; but in fact, information symmetry is more common in practice, which is actually one of the important ways to reflect the value of data as an asset in local energy sharing.

With the improvement of digital programs in the energy field, the energy big data center will become the hub of data sharing and exchange in the future. In view of the "dual carbon" target and the trend of the clean and low-carbon transformation of energy systems, energy big data center is supposed to play an important role in giving full play to the value of energy big data, supporting the modernization of government governance, promoting the energy transformation, and helping the high-quality development of the energy industry.

Energy big data centers can widely interconnect various energy entities such as oil, water, gas, and electricity on a larger scale and promote the cross-border integration, sharing and application of various energy data. First, they promote the convergence of energy data. Driven by the government, energy big data centers will gradually gather all kinds of energy data, make energy data visible and accessible, promote the transformation from "business data" to "data business", and stimulate the vitality of data decision-making and data innovation. Second, they promote energy data sharing [97]. Relying on government guidance and matchmaking, we will help break through the data barriers between energy enterprises, achieve an efficient flow and the full sharing of data resources, promote cross-border data integration, and highlight the value of energy data. Even with the promotion of policies, the information privacy issues involved in energy and data sharing are still a matter of widespread concern. In existing research, data protection technology represented by federal learning has been regarded as the key to solving data islands and promoting energy data sharing, and the general information privacy framework based on data encryption is shown in Fig. 5 [98]-[100].

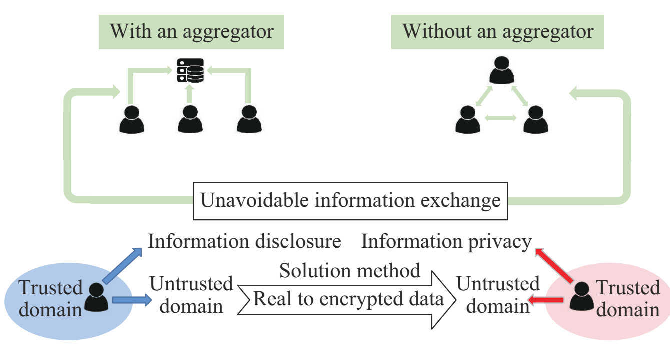

Fig. 5. Information privacy framework based on data encryption.

B. Energy Sharing + Decarbonization

Currently, the existing studies related to local energy sharing mainly focus on the electric power sector. Actually, with the help of energy conversion technology and energy market construction, efficient local energy sharing can accelerate the integration of oil, coal, natural gas, electricity, and other energy resources and promote sustainable energy development and facilitate the decarbonization of the energy system. It is inevitable to investigate local energy sharing in multi-energy sector, which can contribute to realize the efficient dynamic matching, collaborative management, interactive response, and mutual assistance between different energy subsystems, and effectively improve the energy efficiency while meeting diversified energy consumptions.

In practice, local energy sharing is able to build an integrated innovation platform through data technology and energy technology, and directly supports the intelligent energy supply and personalized energy consumption. Besides, local energy sharing can analyze the characteristics of energy consumption, characteristics of carbon emission, and trends of different market members, provide more "dual carbon" data innovative products, and help environmental governance, the docking of carbon emission supply and demand, and the improvement in the energy efficiency of key enterprises.

Overall, local energy sharing is widely connected with multiple entities in the upstream and downstream of the energy industry chain, radiating many industries, promoting the construction of an energy internet ecosystem, and stimulating the value creation vitality of the energy industry. Local energy sharing can meet the personalized and diversified energy needs of users, improve the efficiency of terminal power consumption, and accelerate the decarbonization process of the energy system by implementing user portraits and grasping the needs of different market entities.

C. Energy Sharing + New Infrastructure

The existing work in local energy sharing mostly focuses on how to reduce the operating costs of market participants or the overall system through the matching of supply and demand of idle resources, especially with the support of different interactive energy facilities such as distributed energy, user-side energy storage, and electric vehicles. With the development of energy digitalization, the new infrastructure is expected to provide a new way for the application of sharing economy in the LEM. Specifically, new infrastructure mainly includes seven fields: 5G BS construction, ultra high-voltage (UHV) projects, intercity high-speed railway and urban rail transit, new energy vehicle charging piles, big data centers, artificial intelligence, and the industrial Internet, involving many industrial chains. It is an infrastructure system that provides services such as digital transformation, intelligent upgrading, and integrated innovation.

With the help of new infrastructure, energy enterprises can absorb the scientific and technological power brought by the digital era, fully release the connection, integration, and shared value of the industrial internet, promote the transformation of industries while promoting the transformation of enterprises, and comply with the development pace of the new era. Energy enterprises rely on technology, management, and business model innovation to improve the level of refined operation and lean management, effectively carry out the long-term layout of integration with the digital economy and the real economy, and realize the mutual promotion of scientific and technological innovation and industrial upgrading.

Local energy sharing provides more "blue oceans" for future energy business. Just as 4G has promoted the development of the consumer internet and brought changes in retail, catering, travel, and other aspects, the 5G era will combine energy infrastructure with digital infrastructure, which will inevitably lead to more new businesses in the energy industry. For example, the "photovoltaic + 5G communication BS" mode, which combines distributed photovoltaic with 5G and energy storage, can configure energy storage batteries through the communication BS network to form an enormous distributed energy storage system to realize the flexible allocation of peak and low power consumption stages. The intelligent microgrid-integrated storage and charging system based on the "microgrid + charging piles" can realize energy storage service, charging service, and electric vehicle detection service at the same time. Through a large number of data collection applications and resource integration and sharing, the "intelligence" of the energy system will be effectively improved.

VI. Conclusion

Exploring an efficient local energy sharing paradigm is of great significance for coordinating multiple energies, improving energy efficiency, and accelerating the construction of a clean, low-carbon, safe, and efficient energy system. In this paper, we conduct a comprehensive review of the sharing economy in LEMs, and the key elements in mechanism design as well as enabling technologies for local energy sharing are analyzed. In addition, the further application of the sharing economy in energy fields such as data transactions, decarbonization, and the new infrastructure construction of the energy sector are elaborated from the "energy sharing +" perspective.

The core of the application of the sharing economy in LEMs is the sharing of idle resources among different market entities, thus realizing the complementarity of heterogeneous individual energy supply and demand. The market-oriented development of energy and carbon trading will provide a new way for the efficient development of local energy sharing. The further integration of sharing economy and LEM need to rely on the support of multiple enabling technologies. The design of local energy sharing mechanism in the future should be developed in the direction of multiple energy entities, different information environments, and multi-value stream.

With the trend of re-electrification and the improvement of digitalization in the whole industry, which will provide massive application scenario for local energy sharing and also represent a new social form, we should further explore the optimization and integration role of the sharing economy in the allocation of social resources, deeply integrate the achievements of energy technology innovation into various fields, form a new form of energy industry development, and improve the innovation and productivity of the whole society.

Hopefully, this paper will provide readers with a useful reference and a clear vision for the further integration of the sharing economy in the energy sector.

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Zhaoyuan Wu received the B.S. and Ph.D. degrees in electrical engineering from North China Electric Power University, Beijing, China, in 2016 and 2021, respectively. He is currently a Lecture in the School of Electrical and Electronic Engineering, North China Electric Power University. His research interests include electricity markets and economics of power system.

Jianxiao Wang received the B.S. and Ph.D. degrees in electrical engineering from Tsinghua University, Beijing, China, in 2014 and 2019, respectively. He was a Visiting Student Researcher at Stanford University, Palo Alto, USA. He is currently an Assistant Professor with Peking University, Beijing, China. He received IEEE PES Outstanding Volunteer Award, Young Elite Scientists Sponsorship Program by CAST, and Beijing Young Talent Award. He is an Editor of IET Renewable Power Generation, IET Energy Conversion and Economics, and Protection and Control of Modern Power Systems. His research interests include smart grid operation and planning, hydrogen and storage technology, transportation and energy system integration, electricity markets and data analytics.

Haiwang Zhong received the B.S. and Ph.D. degrees in electrical engineering from Tsinghua University, Beijing, China, in 2008 and 2013, respectively, where he is currently an Associate Professor with the Department of Electrical Engineering, Tsinghua University. He was a Recipient of the ProSPER.Net Young Scientist Award in 2014, the Outstanding Ph.D. Graduate and Outstanding Post-Doctor of Tsinghua University. He serves as the Editor for International Transactions on Electrical Energy Systems and a Subject Editor for CSEE Journal of Power and Energy Systems. He currently serves as the Chair of the Demand Response Working Group under the IEEE PES Power System Operations, Planning and Economics Committee, the Secretary of the IEEE PES SBLC Architecture Subcommittee, and the Secretary of CIGRE D2.53 Working Group on Technology and Applications of Internet of Things in Power Systems. His research interests include smart grids, power system operations, electricity markets, and demand response.

Feng Gao received the B.E. degree in industrial engineering from Shandong University, Jinan, China, the M.S. degree in management science and engineering from China University of Petroleum, Beijing, China, and the Ph.D. degree from University of Chinese Academy of Sciences, Beijing, China, in 2017, 2019, and 2022, respectively. He is currently working as a Postdoc in Peking University, Beijing, China. His research interests include big data analytics in power system, data pricing and data-driven decision analysis.

Tianjiao Pu received the B.S. degree from the Department of Electric Power Systems and Automation, Tianjin University, Tianjin, China, in 1997, and has worked ever since at the China Electric Power Research Institute (CE-

PRI), Beijing, China. He is a Professorate Senior Engineer, the Director of the Artificial Intelligence Application Research Department of CEPRI, a core member of the "Science and Technology Tackling Team of Energy-saving Economic Dispatching" in the State Grid Corporation of China, a Fellow of IET, a Senior Member of IEEE, a Senior Member of the Chinese Society for Electrical Engineering, a CIGRE Member, Secretary General of the AI Committee of CSEE, and a Deputy Editor-in-Chief of IET Smart Grid. His research interests include power dispatching automation, smart grid simulation, active distribution network, artificial intelligence and other fields.

Chin-Woo Tan received the M.A. degree in mathematics and the Ph.D. degree in electrical engineering, both from University of California, Berkeley, USA, respectively. He directs the Smart Grid Lab at Stanford University, Palo Alto, USA. He was a Technical Lead for the Los Angeles Department of Water and Power Smart Grid Regional Demonstration Project. Prior to that, he was a Research Engineer and Project Manager with the PATH Program at University of California, Berkeley for 10 years, working on intelligent transportation systems. He was also an Associate Professor with the Electrical Engineering Department at California Baptist University, Riverside, USA. He has research and management experience in smart grid, intelligent transportation, automated vehicles, and supply chain management. His current research interests include integration of distributed energy resources and grid stability.

Xiupeng Chen received the B.Sc. degree and M.Sc. degree in electrical and electronic engineering from North China Electric Power University, Beijing, China, in 2017 and 2020, respectively. He is currently pursuing the Ph.D. degree in control engineering in University of Groningen, Groningen, the Netherlands. His research interests include mechanism design of energy markets, game theory and algorithm design.

Gengyin Li received the B.S., M.S., and Ph.D. degrees from North China Electric Power University, Beijing, China, in 1984, 1987, and 1996, respectively, all in electrical engineering. Since 1987, he has been with the School of Electrical and Electronic Engineering, North China Electric Power University, where he is currently a Professor. His research interests include high-voltage direct current (HVDC) transmission, power quality analysis and control, and new transmission and distribution technologies.

Huiru Zhao received the B.S., M.S., and Ph.D. degrees from North China Electric Power University, Beijing, China, in 1983, 1985, and 2004, respectively. Since 1985, he has been with the School of Economics and Management, North China Electric Power University, where she is currently a Professor. Her research interests include energy policy and electricity markets.

Ming Zhou received the B.S., M.S., and Ph.D. degrees in electrical engineering from North China Electric Power University, Beijing, China, in 1989, 1992, and 2006, respectively. Since 1992, she has been with the School of Electrical and Electronic Engineering, North China Electric Power University, where she is currently a Professor. Her research interests include power system economics, high-voltage direct current (HVDC) transmission, electricity markets and power quality analysis.

Qing Xia received the Ph.D. degree from the Department of Electrical Engineering, Tsinghua University, Beijing, China, in 1989. He is currently a Professor with Tsinghua University. His research interests include electricity markets, generation scheduling optimization, and power system planning.