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Urban Energy Use and Its Friendly Interaction with Power Grid

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The development and utilization of energy drive the progress of modern civilization. However, the consumption of fossil fuels has exacerbated global climate and environmental crises. Energy transition and sustainable development have become a global consensus. China is accelerating reforms in energy consumption, energy supply, energy technologies, and energy system, while comprehensively cooperating with other countries to realize energy security in an open environment. The user side is the primary cause of energy consumption and carbon emissions, therefore, reforming energy consumption is a critical aspect. Urban cities, as concentrated areas of human activity and production, are the major contributor to energy consumption and serve as the primary battlefield for achieving energy transition.

In recent years, the proportion of "green energy" in urban energy use has been significantly increased through measures in energy conservation and emissions reduction, cleaner utilizations of fossil fuels, and the expansion of renewable power generation. However, the development of a new urban energy ecosystem is still facing many challenges. The rapid growth in demand for energy, including electricity, heat, cooling, and gas, has intensified pressures on carbon emissions and posed significant challenges to the ecological environment. Additionally, periodic shortages in electricity and gas supply have also exposed the vulnerability of urban energy systems in coping with extreme weather and complex scenarios. Renewable energy generation is intermittent and stochastic. With the large-scale integration of renewables and new-type power loads, a serious temporal-spatial mismatch between energy production and consumption has emerged, intensifying the contradiction between two sides. Moreover, energy efficiency and carbon efficiency in high energy-consuming sectors such as industry, construction, transportation and data centers remain relatively low, imposing heavy burdens on the transition of end-use energy consumption towards cleaner and low-carbon alternatives. Furthermore, the prices of energy and adjustable resources fail to reflect their utilization value, scarcity degree, and environmental costs. The energy market system, which involves multiple stakehold-

ers in renewable energy production, storage, and use, needs further improvement.

Users' energy-use (EU) behavior can directly impact the energy efficiency, carbon emissions and the renewable energy hosting capacity of urban EU systems. By exploring and aggregating adjustable resources such as distributed renewable energy, energy storage, and new-type loads, significant flexibility potential can be unlocked on the user side. Fully leveraging these urban resources can enhance the utilization capacity for green renewable energy at both local and metropolitan levels. Therefore, accelerating a green and low-carbon energy transition from the user side deserves significant attention. Through the energy consumption reform, the methods and concepts of energy use can be transformed fundamentally, which enables full coordination across energy production, transmission, conversion, and use. This reform represents a profound reshaping of human production and lifestyles.

To achieve the goal of energy consumption reform, some key factors include the unified benchmark quantitative evaluation of heterogeneous energy sources, value quantification of distributed renewable energy and user-side flexibility resources, definition of EU rights and responsibilities for EU resources, as well as the channels for numerous decentralized user-side resources to participate in market decision-making and interaction. Thus, the author proposed the EU-Net theory in 2016, introducing innovative concepts of the energy element and EU rights (EUR). The study established an EUR trading model based on energy element, using value flow to guide shifts in user awareness and adjustments in EU behavior, thereby fully unleashing the flexibility of vast energy resources. This laid a theoretical foundation for the green and low-carbon transformation of urban energy use and for fostering friendly interaction between users and the power grid.

In 2016, based on the Energy-use Net theory, the author conceive the National Key Research and Development Program of China "Supply-Demand Friendly Interaction System Between Urban Users and Power Grid", taking responsibility for the overall design, formulation of the technical roadmap, as well as theoretical research and demonstration applications. This project established a theory of supply-demand interaction between urban users and the power grid under market conditions. It also revealed the mechanisms of friendly interaction, proposed an electricity supply-demand interactive model featuring coordinated autonomy between multiple users and the grid, and pioneered a market mechanism that utilizes a "point-integral-based" system for price-based and incentive-driven proactive demand-side response as a regularized practice. Additionally, a simulation and service platform for user-grid friendly interaction was developed. Jiangsu Province has implemented the world's largest friendly interaction demonstration involving 164,000 users. This project has successfully reduced energy consumption and minimized peak-valley load differences while maintaining the interests of participating users. Subsequently, a configuration and control methodology for multi-energy zero-carbon building microgrids was proposed, along with an energy-carbon coordination approach covering the entire process of electricity/heat/cooling supply and consumption. Additionally, China's first zero-carbon building integrating smart energy use and building energy efficiency was constructed. The study also explored coordination mechanisms between the EU rights market and markets for energy commodities, financial derivatives, and warrants. A decision-support system for electricity spot trading on the user side was developed to leverage value-driven economics in mobilizing flexible resources for the green and low-carbon energy use.

With the advancement of electricity spot markets, along with technologies like big data, artificial intelligence, trusted privacy computing, and Web 3.0, the theory of the EU-net can be more effectively applied in practice. Through innovative pricing and incentive mechanisms, the flexible regulation potential of distributed resources, such as PV systems, energy storages, air conditionings, heat pumps, and electric vehicles can be fully mobilized. These mechanisms guide the efficient allocation of urban EU resources and motivate end-users to adjust their EU behaviors. By focusing on the efficient conversion of electricity, heat, cooling, and gas, a highly efficient urban EU system that coordinately integrates the entire chain of "generation-grid-load-storage" can be built. Breakthroughs in key technologies, such as assessment and control of EU resources, price calculation and bidding strategies, design of EU right trading mechanisms and rules, trusted operation and transaction platforms, user-side information integration and interaction, big data mining and resource regulation, as well as resource aggregation and virtual power generator equivalence, will enable interactive sharing of EU resources. This will create a new EU Net-based consumption model with extensive user participation, and build a novel industrial ecosystem for the urban energy use and its friendly interaction with power grids. Consequently, it will facilitate the gradual realization of green and low-carbon energy use.

"Energy Use" is an international and multidisciplinary research journal in the field of energy utilization, covering various sectors such as electricity, industry, construction, transportation, information technology, and agriculture. It includes topics like energy system modeling, design and planning, friendly interaction between energy systems and power grids, energy assessment and management, the application of artificial intelligence and new materials in energy systems, as well as energy use in carbon markets and policies. The journal is dedicated to promoting the synergistic development of scientific research, technological innovation, and engineering applications in the field of energy utilization. The journal includes topics ranging from modeling, design, and planning of EU systems; friendly interaction between EU systems and the power grid; EU assessment and management; applications of artificial intelligence and new materials in EU systems; to energy-related carbon markets and policy. It aims to foster the synergistic development of scientific research, technological innovation, and engineering applications in the EU sector. We look forward to more scholars joining this research field to generate further outcomes and reshape the green and smart EU ecosystem through theoretical and technological innovations. We sincerely welcome researchers from around the world to contribute cutting-edge scientific findings, novel perspectives, and innovative technologies related to energy use. We are devoted to further strengthening the awareness of multi-disciplinary integration and actively exploring the effective ways of energy research, which will provide an infinite source for energy innovation and development. Our editorial team is committed to providing a fair and rigorous peer-review process that upholds the highest standards of scientific integrity to welcome contributions from researchers worldwide.

Let us work together to promote the energy consumption reform and move collectively toward a green and low-carbon future!

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DECLARATION OF INTERESTS

Xingying Chen is the Editor-in-Chief of Energy Use and was blinded from reviewing or making final decisions on the manuscript. Peer review was handled independently of this member and their research group