DOI 10.15302/J-SSCAE-2019.05.011

Typical Paradigms and Implementation Paths for Ecological Civilization Construction Based on Rural Energy Revolution

Liu Xiaolong[1,2], Ge Qin[2], Jiang Lingling[2], Huhetaoli[3], Cui Leilei[4], Li Bin[1], Du Xiangwan[4]

1. School of Social Sciences, Tsinghua University, Beijing 100084, China
2. Center for Strategic Studies, Chinese Academy of Engineering, Beijing 100088, China
3. Changzhou University, Changzhou 213164, Jiangsu, China
4. Chinese Academy of Engineering Physics, Beijing 100083, China

Abstract: The weak link of ecological civilization construction in China lies in rural areas. Rural energy revolution plays an important role in promoting ecological civilization construction in rural areas and implementing the strategy of rural revitalization. In this paper, the current situation of energy consumption and production in rural areas in China and the main problems facing it are summarized, and the vast rural areas in China are categorized into developed suburban rural areas, underdeveloped traditional rural areas, and remote rural areas, according to economic development levels, resource endowment, and energy consumption. Furthermore, typical paradigms and implementation paths for ecological construction based on rural energy revolution are proposed. Developed suburban rural areas is recommended to conduct overall planning, improve their facilities, and interact with urban areas to realize energy interconnecting. The underdeveloped traditional rural areas is recommended to take measures according to local conditions, employ multiple energies, and prioritize energy conservation while focusing on efficiency. The remote rural areas is recommended to exploit energy resources in a concentrated manner and focus on external delivery, thus to satisfy energy consumption and demand. This study is hoped to provide references for energy revolution and ecological civilization construction in the rural areas in China

Keywords: rural energy revolution; ecological civilization construction; measures based on local conditions; urban–rural integration

1 Introduction

The Ecological Civilization Construction (ECC) concept was proposed during the 18th National Congress of the Communist Party of China (CPC), and it was to be incorporated in all aspects and processes pertaining to China's economy, policies, culture, and society. The aim of the ECC is to resolve the root causes of issues regarding resources, environment, and ecology in China, as well as to propel the revolution of energy production and consumption. This will help to bring about fundamental improvements to China's mode of development, quality of growth, and

Received date: August 10, 2019; **Revised date:** September 25, 2019
Corresponding author: Du Xiangwan, senior science advisor of Chinese Academy of Engineering Physics; Academician of the Chinese Academy of Engineering. Major research fields include applied physics and energy strategy. E-mail: duxw@cae.cn
Funding program: CAE Advisory Project "Research on Several Strategic Issues on Ecological Civilization Construction (Phase III)" (2017-ZD-09)
Chinese version: Strategic Study of CAE 2019, 21 (5): 106–112
Cited item: Liu Xiaolong et al. Typical paradigms and implementation paths for ecological civilization construction based on rural energy revolution. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2019.05.011

ecological environment. The energy revolution lies at the heart of the ECC [1]. In May 2015, the *Opinions of the CPC Central Committee and the State Council on Accelerating the Ecological Civilization Construction* were promulgated, which clarifies the requirements for the energy revolution in terms of energy production, consumption, and security. During the 14th meeting of the Central Financial and Economic Affairs Commission in December 2016, General Secretary Xi Jinping noted that clean winter warming in Northern China is an important part of the energy production and consumption revolution. Moreover, this tended to affect the lives of rural residents, as clean winter heating is essential to ensure the comfort and warmth of these residents in Northern China, while reducing the number of smog-laden days. In addition, it was noted that livestock excreta processing and recycling projects must be rapidly propagated, as they affect the living environments and productivity of over 600 million rural residents and are an important part of the rural energy revolution. It is noteworthy that this was the first time that the rural energy revolution was proposed in China. In the report on the 19th National Congress of the CPC that was held in October 2017, it was noted that the rural revitalization and coordinated regional development strategies will be implemented as essential components of China's development agenda. The CPC Central Committee and State Council issued *The Strategic Plan for Rural Revitalization (2018–2022)* in September 2018, which states that the developmental imbalances in China are most prominent in rural areas. This is because infrastructure and livelihoods in these areas have fallen far behind those in the rest of China, and the environmental and ecological problems faced by rural areas have become very severe. Therefore, there is an urgent need to improve the overall level of development in rural China, and the construction of modern rural energy systems is essential for improving the rural infrastructure facilities.

Although the rural ECC is an important part of China's ECC strategy, it has always represented a weakness in the strategy, and therefore, there is an urgent need to accelerate this process. Moreover, the realization of the rural energy revolution is a core requirement for the rural ECC, as well as an important part of the rural revitalization strategy. In this work, we shall review and analyze the current state of energy production and consumption in China's rural areas, and provide a scientific categorization of China's rural areas based on their level of economic development, resource endowments, and energy consumption characteristics. On this basis, we shall further explore the paradigms and implementation pathways for the rural ECC based on the rural energy revolution.

2 Current status and problems of rural energy development

2.1 Current status of rural energy development

The total rural energy consumption of China was 6.5×10^8 tce in 2016. This accounts for 15% of China's total energy consumption, and has decreased by 14% compared to that in 2014. The rural household energy consumption was 3.5×10^8 tce in 2016, and the consumption of coal, electricity, firewood, and straw, respectively, accounted for 36.9%, 11.7%, 19.5%, and 11.7% of this figure. The rural production energy consumption was 3.5×10^8 tce, and the consumption of coal, refined oil, electricity, and firewood respectively accounted for 46.6%, 24.1%, 15.8% and 6.2% of this figure [2].

Rural energy includes biomass energy derived from direct combustion of biomass, biogas, biomass molding, biomass-based ethanol, and biomass diesel; electricity generated via small-scale power plants including off-grid photovoltaic power plants, off-grid wind power plants, and micro-hydropower plants; and solar thermal energy (used for water heating, heating, refrigeration and air conditioning, and for operating heat pumps, sunrooms, and solar cookers). The rural energy sector, as represented by biogas, solar energy, biomass power generation, and biomass molding fuel, has become reasonably developed over recent years. The variety and quality of rural energy products have increased over time, and they have yielded significant benefits all-around (Table 1).

2.2 Problems faced by rural energy development

The development of rural energy in China is currently facing several severe problems. (1) The current structure of rural energy consumption has not been sensibly planned, as there are a few regions wherein the supply of energy is inadequate [3]. (2) Rural energy facilities tend to be small and decentralized, and China lacks a specialized and commercialized energy service system for these facilities [4]. (3) The consumption of non-commercial energy sources accounts for a large proportion of energy consumption in rural households; these sources (e.g., firewood and

DOI 10.15302/J-SSCAE-2019.05.011

straw) tend to be consumed using primitive and inefficient methods. (4) Coal accounts for a large proportion of the rural energy source consumed, and scattered coal use is a major problem in rural areas. In 2016, 7.5×10^8 t of scattered coal was used in China, with rural heating accounting for 27% of all scattered coal consumption [5]. (5) Infrastructure development is inadequate in rural areas. This has resulted in electricity, natural gas, and renewable energy representing a very small portion of rural energy consumption; moreover, the consumption of low-quality energy is prevalent in rural areas. In addition, the burning of raw biomass and scattered coal in rural areas has led to varying degrees of air pollution, and these areas also face issues such as a lack of facilities to properly process livestock waste and random littering of agroforestry waste. These issues are direct obstacles faced by the ECC and the Beautiful Countryside strategy of China [6].

The rural energy revolution is a prerequisite for the ECC, an important component of China's energy revolution, and also an important tool for solving the Three Rural Issues. Furthermore, the rural energy revolution is important for the Beautiful Countryside, Rural Revitalization, and Moderately Prosperous Society strategies. Hence, studies concerning development strategies for the rural energy revolution are of significant practical and academic interest. Luo et al. [7] noted that it would be prudent to construct a rural energy supply system that is based on electricity and is clean, safe, low-carbon, and efficient. Gong et al. [8] proposed that clean winter heating should be used as an opportunity to accelerate the rural energy revolution. Li et al. [9] conducted a case study on energy consumption in rural Henan, and they discussed an implementation pathway for the rural energy revolution that is based on electricity, focused on rural residents, and supported by a robust energy development system. Yan et al. [3] conducted a study of the institutional problems faced by the rural energy sector in Beijing, Tianjin, and Hebei.

However, it should be noted that the current research literature focuses only on analyses of rural energy production and consumption, as well as the implementation of rural energy in certain regions. A study on the rural energy revolution in different rural areas from a nationwide perspective is yet to be conducted, and studies concerning the paradigms and implementation pathways for the ECC from the standpoint of the rural energy revolution have not been carried out thus far. In this work, an analytical exposition of the aforementioned issues is conducted to address these issues.

Table 1. The state of rural renewable energy production in 2016.

Type of renewable energy	Production levels
Biomass energy	The total installed biomass power generation capacity of China is approximately 1.03×10^7 kW. Household biogas digesters have been installed in 4.38×10^7 households, which produce 1.18×10^{10} m^3 of biogas per annum. There are 1.1×10^5 large-scale biogas plants in China, which produce 2.7×10^9 m^3 of biogas per annum. The annual consumption of biomass molding fuel is 8×10^6 t. In terms of biomass liquid fuels, the annual production of fuel ethanol and biodiesel are 2.1×10^6 t and 8×10^5 t, respectively.
Solar energy	There are 4.77×10^7 solar water heaters operating in China, which have a combined collector area of 8.62×10^7 m^2. There are 2.28×10^6 solar cookers in China and 2.93×10^5 sunrooms, which have a total collector area of 2.56×10^7 m^2. China has 3.68×10^4 small photovoltaic power plants, which have an installed capacity of 9.5×10^4 kW.
Small wind-power	There are 1.07×10^5 small wind-power turbines (> 1 kW and < 50 kW) in China, which have a total installed capacity of 3.57×10^4 kW.
Micro-hydropower	There are 2.57×10^4 micro-hydropower plants (< 500 kW) in China, which have a total installed capacity of 8.68×10^4 kW.

Note: This data were derived from statistical data published by the Ministry of Agriculture.

3 Classification of rural villages from an energy-based standpoint

China has a vast territory and a very diverse set of topographies and climates. Consequently, lifestyles in China can vary significantly from one region to another. The demographic changes in China have been characterized by constant migration from rural to urban areas, and the aim of the new generation of migrant workers (Mingong) is to settle in cities and integrate themselves into urban life. This has caused the rural population to decrease over time. In the long term, the overall energy requirements of China's rural areas will decrease gradually. In economic terms, rural household incomes tend to be higher in Eastern and Southern China, and lower in Western and Northern China. Rural energy consumption intensity varies significantly from one region to another, as energy consumption per capita is higher in Northern and Eastern China, and lower in Southern and Western China [2].

The energy consumption of each region depends on factors including climate and resource endowment. In

particular, resource availability is the main factor that determines the type of energy consumption in each region. For example, regions like Shanxi, Inner Mongolia, Hebei, and Guizhou are rich in coal resources, which is why coal accounts for large proportions of their energy usage. Biomass energy accounts for a larger proportion of energy consumption in Northeastern and Southwestern China than in other regions, which is consistent with the distribution of biomass resources across China.

The rural villages of China may be divided into three classes, based on the supply- and consumption-side characteristics of rural energy, natural geographic and economic divisions, as well as populations, economies, geographic locations, resource endowments, and energy consumptions of these villages.

3.1 Economically-developed suburban villages

Suburban villages are located around or near cities and have well-developed transportation networks. Their production structure is dominated by secondary industries, and agriculture only accounts for a very small share of their production. These villages have strong economic foundations and their residents have high educational levels. These villages have relatively well-developed energy infrastructure and public services, and they also possess excellent energy service systems and high energy consumption capacities. The transportation of external energy resources to these villages is straightforward, and their development is significantly influenced by that of their surrounding cities, which is conducive for the implementation of the Urban Areas Supporting Rural Areas strategy. The villages in Eastern and Southern China generally fall under this category, especially the villages within the administration areas of major cities like Shanghai, Suzhou, Hangzhou, and Shenzhen. These villages are largely modernized, and the realization of integrated urban and rural development can be achieved in these villages by relying on the influence of nearby cities.

3.2 Traditional villages with moderate levels of economic development

The traditional villages are usually located far away from cities and important transportation routes. The residents in these villages are mainly employed by the agricultural sector and have an average level of economic prosperity. The energy infrastructure is established to a certain extent in these areas and the energy is mainly supplied by conventional means. In addition, renewable energy resources are abundant in these villages. These are the most common type of villages in China, and they are found in Northern, Central, and Northeastern China. The villages of Northern China use large amounts of scattered coal; thus, they suffer from severe air pollution. However, they are rich in geothermal resources, wind power, and solar power. Some areas of Northern China also possess unconventional natural gas resources such as coal seam gas. The villages of Central China are rich in biomass resources as they have highly-developed aquaculture and animal husbandry industries. However, the scale of agricultural production is highly variable in these villages. The villages of Northeastern China have a tremendous need for winter heating, and they are rich in agroforestry biomass resources. Agriculture is highly aggregated and mechanized in this region. As a whole, these villages are lagging behind the villages of Eastern and Southern China in terms of economic development, as the development of these villages has not been assisted by the influence of urban areas. The villages in this category are currently the primary focus of the rural energy revolution.

3.3 Economically-underdeveloped remote villages

Remote villages refer to small and scattered villages that are located in remote areas. The populations of these villages are mainly engaged in the agricultural sector, but they are not very productive and their economic conditions are generally poor. The energy infrastructure facilities and public service systems in these villages are inadequate, and large amounts of primitive and inefficient energy resources (such as firewood) are consumed. Although remote villages are rich in renewable resources such as wind-, solar-, and hydro-power, their energy consumption capacity is very low. Villages in this category are typified by the villages in Northwestern and Southwestern China.

4 Paradigms and implementation pathways for ecological civilization construction based on the rural energy revolution

The key to the rural energy revolution lies in the construction of clean, efficient, and secure energy security systems to establish a distributed energy landscape with a balanced and harmonious mixture of energy resources that

DOI 10.15302/J-SSCAE-2019.05.011

suits the characteristics of Chinese villages. This shall improve the quality and security of the supply and consumption of energy in rural areas. To achieve this, following measures need to be implemented: (1) guide and encourage the development of a low-carbon distributed energy network, and optimally deploy combinatorial renewable energy development models that include solar, wind, biomass, and geothermal energy. (2) Initiate the development of rural natural gas networks, cultivate rural demand for natural gas, and increase the proportion of natural gas in rural energy usage. (3) Improve the electrification of rural areas and simultaneously develop distributed and centralized power grids.

In the following sections, we propose a development policy for the rural energy revolution that is strategically led, ecologically conscious, clean, low-carbon, safe, and efficient, while being adaptive to local conditions, innovative, and inclusive. It also incorporates a balanced mixture of complementary energy sources. By implementing the aforementioned energy-based classification of rural areas with the trends of the rural energy revolution and the energy requirements of rural households, we describe the paradigms and implementation pathways for ECC based on the energy revolution for each type of village.

4.1 Economically-developed suburban villages

The infrastructure facilities and service systems of economically-developed suburban villages (such as the villages in Eastern and Southern China) are not independent of each other. Therefore, an integrated urban–rural energy network should be constructed via urban planning to drive the rural energy revolution and ECC.

4.1.1 Drive the construction and improvement of rural energy infrastructure in suburban villages by formulating coordinated development plans and using urban areas to support the development of rural areas

Based on the national rural revitalization strategy and coordinated regional development strategy, the area of influence of urban areas should be fully utilized to drive the development of suburban villages, and urban planning should be used to create linkages between these villages and urban areas. The industrial layout, energy supply, public services, and infrastructure facilities of each city and their surrounding villages should be planned in an integrated manner, and the rural energy problem should be included within the scope of regional energy plans. Coordinated plans should be formulated to modify the villages' power grid infrastructure. The construction and modification of rural power grids should be performed with adequate consideration of the load and access requirements of new energy sources, distributed energy sources, and electric car charging facilities, to improve the power supplying capacity and reliability of rural power grids. A coordinated plan should be formulated to accelerate the extension of natural gas pipelines from urban areas towards suburban villages, thus driving the substitution of scattered coal with natural gas and increasing the adoption of natural gas by rural households in these villages. Because suburban villages have relatively high population densities, living standards, and high domestic waste production rates, urban and rural wastes should be combined for their comprehensive utilization.

4.1.2 Achieve the integration of urban and rural energy supplies through coordinated development, urban–rural interactions, and energy supply linkages

To achieve the harmonization of urban and rural development, the strengths of rural and urban areas must be fully utilized through the sharing of resources, so as to achieve the integration of urban and rural energy supplies. Industrial residual heat from urban areas should be used as a source of heat for suburban villages, and the renewable resources of rural areas should be developed and utilized. The "Internet+" smart grid should be used to construct a regional "energy internet" and to establish a smart grid-based energy internet demonstration project that is able to coordinate distributed low-carbon energy networks, natural gas networks, heat distribution networks, and traffic networks, as well as to interconvert different types of energy (i.e., electricity, heating, and cooling). The rural power grid should then be connected to and integrated with major power grids, thus realizing the integration of urban and rural energy supplies, leading to the coordinated development of these supplies.

The pathway for implementing the rural energy revolution in villages within the area of administration of large cities should be based on the pathway being used to implement the energy revolution in that city, and the aim is to first realize the coordinated development of urban and rural areas.

4.2 Traditional villages with moderate levels of economic development

In traditional villages with moderate levels of economic development (such as the villages in Northern, Central, and Northeastern China), the rapidly growing energy needs of rural life have become irreconcilable with the currently underdeveloped energy infrastructure and service systems. The rural energy revolution is urgently needed for ECC in these villages.

4.2.1 Establish distributed low-carbon energy networks with clean and balanced energy mixes that are adapted to local conditions

Multi-energy systems that are clean, efficient, and secure should be constructed based on local resource endowments, such that the energy resource advantages of these villages can be converted into advantages in economic development.

To curb the use of scattered coal, awareness of the effects of utilizing this resource should be increased, resource monitoring efforts should be strengthened, and the consumption of clean energies should be encouraged. In regions where scattered coal use is especially intense, the supply of scattered coal to the market should be restricted to reduce its consumption and the resulting pollutant emissions. Clean and affordable sources of energy should then be introduced to comprehensively replace scattered coal and thus reduce the habitual reliance of rural residents on this resource. “Coal-less village” demonstration projects should be initiated in villages that promote renewable resources and amenable economic conditions. The use of clean energies such as natural gas should be promoted, and the level of support for clean winter heating must be maintained in these villages. In this way, the use of clean energies in rural areas will be gradually increased. The supply of clean energies must also be securely maintained to comprehensively improve the service quality of clean energy supplies in rural areas.

As renewable energy technologies are constantly improving and there is an abundance of policy support for the adoption of renewable energies, it has become increasingly advantageous to utilize the renewable resource endowments of rural areas. Because traditional villages are often rich in multiple types of renewable energy resources, wind power, photovoltaic power, biomass energy, and geothermal energy should be developed on large scales around these villages. Waste-to-resources and waste-to-energy projects should also be implemented to make use of rural domestic waste and livestock excreta via biomass energy. Renewable energy bases should be constructed near these villages to establish a clean energy supply system with multiple complementary sources of energy. This will also assist in gradually making renewable energies the primary source of energy in these villages, thus enhancing their self-sufficiency in terms of energy supply. Moreover, it is also important to simultaneously strengthen the construction of energy distribution networks and storage facilities in these areas. Multi-energy systems based on complementary electricity, gas, and renewable energy sources should be piloted in certain villages. Moreover, innovations should be encouraged in energy supply, business, and participation models to fulfill the diverse energy needs of these villages and increase the income of their residents. This shall lay the foundation for the construction of low-carbon energy networks, thus driving the rural energy revolution and ECC.

In the rural areas of Northern China (such as the villages of Hebei), the consumption of scattered coal is highly prevalent, and has resulted in severe air pollution. As wind, solar, and geothermal energies are naturally abundant in some of these regions, distributed low-carbon multi-energy systems, which include geothermal–solar–biomass, wind–solar, and solar–biomass systems, should be constructed in Northern China.

The rural areas of Central China (such as the villages of Henan) are agricultural production zones that are rich in biomass resources like straw. However, straw burning and littering are common in these areas. By adopting ideas from systems engineering, the rural energy supply system could be expanded into an integrated energy generation and waste processing system to simultaneously resolve the energy and environmental problems of these villages. To this end, distributed low-carbon energy networks should be constructed that are mainly based on biomass energy from agricultural waste and supplemented by renewables like wind, solar, or geothermal energy.

The heating demands of Northeastern China are especially large due to the harsh winter climate in this region. Consequently, the inefficient use of raw biomass has caused severe environmental problems in this region. The abundances of agroforestry biomass resources and solar energy in this region should be utilized via the construction of distributed low-carbon energy networks that are mainly based on large-scale biomass power generation from agroforestry waste and supplemented by solar energy.

DOI 10.15302/J-SSCAE-2019.05.011

4.2.2 Promote energy-saving practices and energy efficiency in villages

Energy-saving practices and environmental conservation should be promoted extensively in traditional villages, and the importance of energy saving practices in everyday life, production, and building construction should be strongly emphasized. In addition, rural energy production and consumption should be transformed from extensive and inefficient models into efficient, energy-saving, and environmentally friendly models. The concepts of energy-saving practices and energy efficiency must be infused into all aspects of socioeconomic development in these villages.

Awareness concerning the importance of energy-saving practices should be strengthened. Moreover, the villages should be guided to stop using extensive modes of energy consumption and cease their use of inefficient and low-quality energy sources such as scattered coal and firewood.

Energy-saving buildings should be promoted by supporting the construction of green buildings and energy-saving modifications through plans, policies, technologies, standards, and design. The implementation of insulating measures for rural residential buildings should be promoted and demonstrated to encourage the use of energy-saving doors and windows. New rural buildings should be encouraged to adopt renewable energy technologies such as rooftop photovoltaic panels and building-integrated photovoltaic thermal collectors; moreover, efforts should be made to promote the augmentation of existing rural buildings with these technologies.

Energy-saving and emission-reduction measures in agricultural production should be strengthened, and the long-term mechanisms that have been put in place for the development of an agricultural circular economy should be improved. In addition, new energy-saving and environmentally friendly agricultural industries should be set up, and the collection and recycling of agricultural waste should be implemented.

4.3 Economically-underdeveloped remote villages

Economically-underdeveloped remote villages (such as the villages in Northwestern and Southwestern China) are typically located in harsh regions that include mountainous zones, subsidence zones, and deserts. These villages have significant room for improvement in terms of their production and living standards. These villages urgently require measures led by the rural energy revolution to drive the ECC.

4.3.1. Utilize the abundance of space and renewable resources in remote villages by developing renewable energy generation systems that mainly supply energy to other regions, based on a “consumption first” mindset

The villages of Northwestern China are characterized by low population densities and high turnover rates. As it is very expensive to develop long-distance power supply systems, most of these villages have not benefited from the expansion of major power grids in China. Due to the long and cold winters in this region, winter heating accounts for a large proportion of energy consumption in these villages. As Northwestern China is rich in wind and solar power resources, decentralized wind-solar energy systems with strong foundations should be constructed in this region. Decentralized wind and solar power generation projects that are connected to low-voltage distribution networks and meant for local consumption should be constructed progressively. Moreover, the integration of household solar heating systems with rural buildings should be implemented in these villages to optimally utilize the decentralized wind and solar power resources of this region. In addition, the rate of wind and solar power utilization in Northwestern China should be increased according to the needs of each locality to effectively solve the electricity and heating problems of the residents of this region. Because the total energy needs of remote villages are relatively small, power transmission facilities should be constructed to channel excess energy to other localities, thus expanding the area powered by new energies. Emerging industries including modern high-energy, agricultural processing, and modern equipment manufacturing industries should be introduced in these regions with strategic planning to establish circular industrial parks and high-quality means of energy consumption, thus promoting the local consumption of renewable energies.

Southwestern China is mountainous, densely populated, and economically underdeveloped. However, it is rich in hydropower resources and forestry biomass resources. Therefore, it would be appropriate to construct distributed energy networks that are mainly based on micro-hydropower and supplemented by biomass and solar energy. Micro-hydropower stations should be developed to supply electricity to local residents, and they should be included in the emergency backup system of the power grid. The advantages of utilizing micro-hydropower stations for backup

power in distributed energy networks should be highlighted in planning, construction, and operation of power grids for villages in Southwestern China. This will allow for the use of their ability to guarantee the security of the power grid and mitigate disaster risks. As micro-hydropower systems tend to be slightly unstable, these systems can be supplemented by biomass power generation from agroforestry waste and rooftop photovoltaic systems.

4.3.2 Fulfill the basic energy needs of remote villages through poverty-reduction based approaches

As the economies and public services of these villages are currently underdeveloped, considerable work is required to ensure a moderately prosperous society and the development of a power grid. Therefore, the essential daily-life and production needs of the residents in these villages must be prioritized in all development plans. The overall level of the electricity service must be improved and problems associated with the construction of a rural power grid must be addressed. In addition, efforts to construct public lighting facilities and upgrade power supply facilities for agricultural production should be bolstered so as to fulfill the essential electricity needs of rural residents. Awareness-boosting campaigns should be organized to gradually transform the energy-use modes of these villages and change traditional energy consumption habits, leading to the reduction in the use of low-quality energy sources like firewood. Electricity-based energy consumption models should be developed as rapidly as possible to shift the villagers' mode of energy consumption towards high-quality modes.

Targeted "energy for poverty-reduction" programs and poverty alleviation policies should be implemented, and the level of support provided by the urban counterparts should be either maintained or increased. In addition, micro power grids and local renewable energy power grids should be constructed to connect the rural power grids to distributed new-energy networks to fulfill the daily-life and production needs of impoverished rural areas. Energy plans for these areas should be formulated and optimized. In addition, the "biomass for poverty-reduction" and "photovoltaics for poverty-reduction" programs should be implemented and conformed with reliable long-term project operation mechanisms and income distribution policies for poverty reduction. This will enhance the ability of impoverished regions to sustain and develop themselves.

5 Policy recommendations

China attaches great importance to the development of rural energy and the improvement of rural lifestyles. To this end, several essential requirements have been proposed to accelerate the rural energy revolution. Based on the aforementioned paradigms and implementation pathways for the rural energy revolution and ECC for the various types of villages in China, we propose the following policy recommendations.

(1) The strategic importance of the rural energy revolution should be increased such that rural energy development is included in China's ECC, energy revolution, and rural revitalization frameworks. A national agency should be established to lead and coordinate the construction of rural energy systems, as well as to formulate middle- to long-term development strategies and five-year-plans pertaining to the rural energy systems across China as early as possible. Rural energy management mechanisms should be re-evaluated and optimized. Metrics such as the electrification rate, comprehensive straw utilization rate, electric power substitution for scattered coal (EPSSC), domestic waste utilization, and livestock excreta utilization rate should be used (in accordance with local conditions) to evaluate rural energy systems in each type of village. These metrics should also be used as strategic measures in socioeconomic development assessments and government performance management systems. Rural energy development should be included in the agenda of all government ministries and all levels of government, so that the government can work in its entirety to improve the rural energy development landscape and make up for the shortcomings of current efforts to realize a moderately prosperous society.

(2) The concept of integrated urban–rural development should be incorporated in all development plans, and the commonalities between urban and rural energy systems should be taken into account in these plans. The aim of these plans should be intended towards developing an integrated urban–rural energy system that will distribute energy resources in an equitable manner and facilitate holistic, harmonious, and sustainable socioeconomic development, thus driving the energy revolution in urban and rural areas.

(3) Education on the importance of saving energy and energy efficiency should be strengthened in rural areas to increase the environmental awareness of rural residents. Successful experiences in the adoption of new energies should be promoted and propagated to encourage the participation of rural residents in the construction and use of

DOI 10.15302/J-SSCAE-2019.05.011

new energies. In addition, talent cultivation should be strengthened in rural areas.

The rural energy revolution is important, although substantial work is required before the goals of this revolution can be achieved. The cooperation of all relevant parties is necessary to achieve these goals, and it is important to actively search for replicable and scalable paradigms and pathways for the implementation of the rural energy revolution-based ECC; this will ensure the success of the energy revolution and ECC in China.

References

[1] Du X W. Construction on ecological civilization and revolution on energy production and consumption [M]. Beijing: China Science Publishing & Media Ltd., 2017. Chinese.

[2] Du X W, Liu X L, Huang Q X, et al. Research on rural energy revolution and distributed low-carbon energy development strategy in China [M]. Beijing: China Science Publishing & Media Ltd., 2019. Chinese.

[3] Yan X H, Li Z, Xie K C. Preliminary study on institutional problems of rural energy in Beijing–Tianjin–Hebei region [J]. Energy of China, 2016, 38(1): 32–36. Chinese.

[4] National Development and Reform Commission of the PRC. Medium and long-term development plan for renewable energy [R]. Beijing: National Development and Reform Commission of the PRC, 2007. Chinese.

[5] He K B, Li X Y. Research report on China's bulk coal treatment 2017 [R/OL]. (2017-11-30)[2019-05-06]. http://coalcap.nrdc.cn/pdfviewer/web/?15180772751437518672.pdf. Chinese.

[6] Chai F H, Xue Z G, Zhi G R, et al. Complex control measures of rural coal combustion pollution [J]. Environmental Protection, 2016, 44(6): 15–19. Chinese.

[7] Luo G L, Zhou R Z. Promote a rural energy revolution centered on electricity [J]. China Electric Power, 2018 (9): 78–79. Chinese.

[8] Gong H, Luo Z X, He Z, et al. Promote clean winter heating and speed up rural energy revolution [J]. Energy Conservation and Emission Reduction in Petroleum and Petrochemical Industry, 2017, 2(4): 6–10. Chinese.

[9] Li P, Wang L L, Liu M H, et al. Research on rural energy transformation and development in the new era [J]. Rural Science and Technology, 2019 (5): 113–115. Chinese.