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A Review on the Rural Household Energy in China From 1990s —Transition, Regional Heterogeneity, Emissions, Energy-Saving, and Policy

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Rural energy is related to the domestic energy supply, consumption, and improvement of living standards of more than one-third of the population in China. In the "14th Five-Year Plan," it has been clearly pointed out that it is necessary to strengthen the clean utilization of coal and implement the construction of rural clean energy projects. At present, the energy consumption structure of rural areas in China is transiting from traditional solid energy to commercial energy and clean energy. Based on this background, this paper reviews the transition trend, influencing factors, and regional differences of China's rural household energy consumption structure from the 1990s. Taking into account China's goal of carbon peaking by 2030 and carbon neutrality by 2060, carbon dioxide and pollutant emissions generated in the process of energy consumption and the energy-saving potential of rural households are analyzed and discussed. Moreover, the evolution of rural energy policies in China is presented and related proposals are also made. This review aims to provide reference for relevant researchers and policy makers.

Keywords: rural China, energy transition, regional heterogeneity, carbon dioxide emissions reduction, energy policy

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1 INTRODUCTION

Rural energy is not only an important material basis for the survival of rural residents, but also an essential part of the modern energy system. It covers the energy supply and consumption of the entire rural area, including energy production, consumption, and the utilization of local resources. It involves many aspects of industrial and agricultural production and people's lives in rural areas. Rural energy access and consumption is a key issue worldwide, especially for developing countries (Cao et al., 2021). As the largest developing country in the world, China's rural energy mainly includes commercial energy, such as coal, electricity, oil, and liquefied petroleum gas (LPG), traditional non-commercial energy, such as firewood and straw, and clean energy, such as solar energy, biomass energy, and geothermal energy. Rural energy consumption accounts for a large

Abbreviations: CGSS, Chinese General Social Survey; GHG, green house gas; Kgce, kg of coal equivalent; LPG, liquefied petroleum gas; MOA, Ministry of Agriculture; Mtce, metric tons of coal equivalent; NAC, National Agricultural Census; NBS, National Bureau of Statistics; NDRC, National Development and Reform Commission; NEA, National Energy Administration; NPC, National People's Congress; TSP, total suspended particles.

proportion of China's energy consumption, and its per capita energy consumption has exceeded that of cities and towns (Long et al., 2022).

With the rapid development of economy, the problem of environmental pollution has attracted more and more attention. The production and consumption of energy have a serious impact on the environment. At the fourth session of the 13th National People's Congress, "Carbon Peak and Carbon Neutrality" were written in the government work report for the first time. The "Outline of the 14th Five-Year Plan (2021–2035) for National Economic and Social Development of the People's Republic of China and the Long-Range Objectives Through the year 2035" issued in March 2021 elaborated the key points of China's development and reform in the next 5 years. The main indicators of economic and social development in the "14th Five-Year Plan" period fully demonstrate the "green" connotation of economic development. Among them, the target of "reducing energy consumption per unit of GDP by 13.5% between 2021 and 2025" is clearly put forward. According to the latest data from National Bureau of Statistics, by 2021, China's rural population reached 498.35 million, accounting for 35.28% of the country's total population. Rural energy is related to the domestic energy supply, consumption, and improvement of living standards of more than one-third of the population in China. Carbon emissions from rural energy consumption have become a potential contributor to China's carbon emissions peak (Zhang and Li, 2022).

Energy transition and intensity growth have always been the two main characteristics of China's rural energy development, affecting the formulation and implementation of rural energy policies (Wu and Han, 2022). In recent years, through promulgating and amending of laws and regulations, and implementing financial subsidies, China has obtained a remarkable achievement in encouraging the development of rural renewable energy projects and the improvement of energy-saving technologies. However, due to the complex topography and remoteness of rural areas, information is relatively blocked compared with cities. In addition, the development of renewable energy industry lags behind, and rural residents are generally less educated, and do not have a high awareness of energy conservation. There is an imbalance between the distribution characteristics of natural resources and local economic development in China's rural areas. The level of regional economic development directly affects the level of clean energy consumption (Han et al., 2022). For example, although the ecologically fragile areas in West China are rich in clean energy, the promotion and use of clean energy still faces great challenges (Li et al., 2022). Therefore, the rural energy utilization efficiency remains at a low level, which hinders the transition of rural energy consumption structure. Optimizing rural energy consumption structure, improving rural energy efficiency and promoting rural energy reform will ultimately benefit ecological restoration, environmental improvement and improvement of people's livelihood. The non-negligible problems of rural waste and pollutant emissions in China all originate from the energy consumption side. Therefore, it is of great significance to make a comprehensive analysis of China's rural energy consumption. This paper reviews the transition trend, influencing factors, and regional differences of China's rural household energy consumption structure since the 1990s. Carbon dioxide and pollutant emissions generated in the process of energy consumption and the energy-saving potential of rural households are analyzed and discussed. Moreover, the evolution of rural energy policies in China is presented and related proposals are also made. This review will provide policymakers with suggestions on optimizing rural energy supply structure and promoting rural energy reform.

In ScienceDirect and Google Scholar, the relevant literature on rural energy in China in was searched. The literature related to energy consumption was artificially selected. MindMaster was used to analyze the literature and organize and style this review. The rest of this paper is structured as follows. In order to promote the rapid transition of energy consumption structure of rural household, **Section 2** describes the influencing factors of energy consumption structure of rural household in China. Although the variation trend of energy consumption in rural areas in China is generally similar, there is an obvious regional heterogeneity of energy consumption. Therefore, **Section 3** focuses on this regional heterogeneity. Considering environmental problems caused by energy consumption cannot be ignored, **Section 4** analyzes the carbon dioxide and pollutants emissions in the process of energy consumption. Although there has been significant development in the field of renewable energy utilization in rural areas of China, the consumption of clean energy still accounts for a small proportion of the total energy consumption in rural areas. Therefore, **Section 5** analyzes the influencing factors of rural households' choice of clean energy and energy-saving behavior. **Section 6** presents the evolution of rural energy policies in China for supporting the transition of energy consumption and makes some related proposals. **Section 7** gives conclusion.

2 TRANSITION OF ENERGY CONSUMPTION STRUCTURE

2.1 Trends of Energy Consumption of Rural Household

Since the 1990s, China's economy has experienced unprecedented development, people's living standards have been improving, and energy consumption has also presented a rising trend. According to the data in "China Statistical Yearbook 2020," from 1990 to 2018, the total energy consumption of Chinese residents rose from 157.88 million Mtce (metric tons of coal equivalent) to 604.36 Mtce, with an average annual growth rate of 10.10%. The per capita energy consumption increased from 139 kg of coal equivalent (Kgce) to 434 Kgce, with an average annual growth rate of 7.58%. Rural energy consumption is an indispensable part of China's energy consumption. With the promotion of New Socialist Countryside Construction, rural energy consumption also increases rapidly.

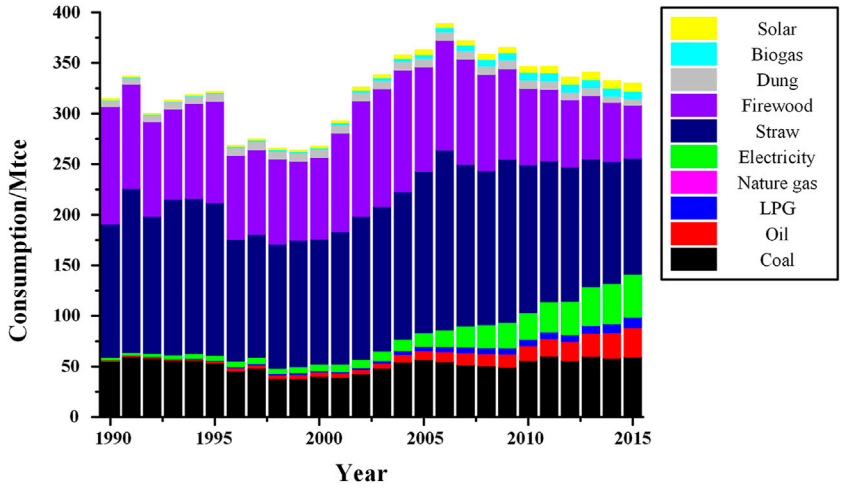

FIGURE 1 | Energy consumption structure of rural households in China from 1990 to 2015 [Data source: (Niu et al., 2019)].

2.1.1 Energy Consumption by Energy Type

In terms of type, the energy consumed by Chinese rural residents mainly includes commercial energy (such as coal, electricity, petroleum products, and LPG), non-commercial energy (such as straw and firewood), and clean energy (such as solar energy and biogas). **Figure 1** depicts the energy consumption structure of rural households in China from 1990 to 2015.

In 1991, coal was the main energy consumed by rural households in China, and its consumption accounted for 93.7% of the total household energy consumption. In 2012, this figure dropped to 57.42%. During this period, coal was the main energy supply for rural households. The share of electricity and petroleum products in household consumption was increasing year by year. The proportion of electricity consumption has increased from 4.28% in 1991 to 27.21% in 2010 (Zhang and Guo, 2013). After nearly 40 years of energy reform, by 2017, China's rural electricity consumption rate had reached 100% (He et al., 2018). Meanwhile, the share of petroleum products in rural households rose from 1.96% in 1991 to 15.26% in 2010 (Zhang and Guo, 2013). The consumption of LPG also showed a significant growth trend, with an annual growth rate of 12.32% from 1991 to 2014 (Han et al., 2018). It can be seen that the consumption of commercial energy (such as electricity, LPG, etc.) other than coal shows a steady growth trend. In general, the proportion of commercial energy consumption in the total energy consumption of rural households is steadily increasing. In 1990, the share of commercial energy consumption was 23%, and by 2015, the proportion rapidly increased to 68% (Niu et al., 2019). It indicates that commercial energy has occupied a dominant position in the energy structure of rural households, which may be due to the improvement of the availability and affordability of commercial energy in rural areas (Li et al., 2019).

Traditional non-commercial energy, such as straw and firewood, is also familiar to rural residents. As time goes by, the proportion of non-commercial energy consumption in the total energy consumption of rural households gradually decreases. In 1991, the consumption of straw and firewood accounted for 49.4% and 31.01% of the total energy consumption of rural households, respectively. At that time, traditional solid fuels dominated the energy structure of rural households (Han et al., 2018). However, the consumption of firewood decreased slowly at an average annual rate of 2% between 2001 and 2008 (Yao et al., 2012). In 2013, about 10% of households in Beijing and Baoding used crop straw as fuel (Zhi et al., 2017). By 2016, the share of firewood and straw in the energy consumption of rural households in China had fallen to 19.5% and 11.7%, respectively (Li et al., 2019). Taking Tiantangzhai village in Anhui Province as an example, it has relatively high altitude and long heating time in winter. Considering the advantages of easy access and zero cost, firewood is still widely used. However, 87% of households prefer to use firewood in combination with commercial energy

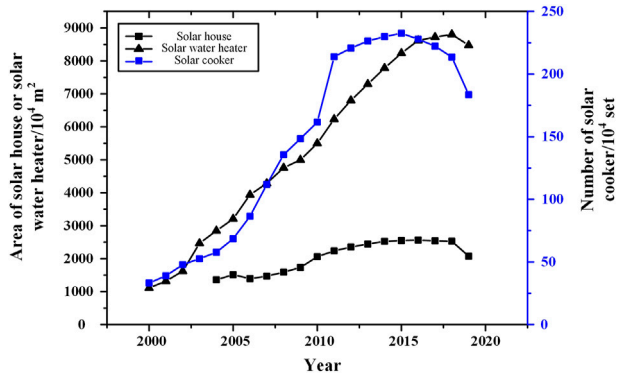

FIGURE 2 | The variation trend of the number of solar cookers, the areas of solar water heaters and solar houses [Data source: (National Bureau of Statistics of China, 2018); National Bureau of Statistics of China, 2020b].

(electricity or LPG) instead of relying entirely on firewood as fuel (Song et al., 2018).

Since the 1990s, rural residents' acceptance of clean energy such as solar energy and biogas has gradually increased. Solar water heater, solar house, and solar cooker are the main utilization forms of solar energy in rural areas. The variation trend of the number of solar cookers, the areas of solar water heaters and solar houses since the 21st century is shown in **Figure 2**. In 2010, the total area of solar water heating systems installed in rural areas has exceeded 55 million square meters (He et al., 2014). In 2015, this figure reached 82.33 million square meters (Huang F et al., 2020), and by 2019, it had reached 84.767 million square meters. According to the data on the China Economic and Social Big Data Research Platform, the number of rural solar cookers was 332,000 in 2000, and reached a peak of 2.326 million in 2015 followed by a slight decline. By the end of 2019, the number of rural solar cookers had reached 1.836 million. Its average annual growth rate is approximately 23.84% compared with year 2000. Rural areas have unique geographical advantages and abundant biogas resources, which can be used for cooking and lighting in residents' daily life. In 1991, the proportion of biogas consumption in the total energy consumption of rural households was only 0.25%. By 2014, the proportion had increased to 3.44% (Han et al., 2018). By the end of 2019, 33, 802, 653 household biogas digesters had been built in rural areas of China, and the number of biogas projects had reached 102,650. It proves that rural areas have achieved remarkable results in the field of clean energy utilization.

2.1.2 Energy Consumption by Energy Using Purpose

According to the energy using purpose, the energy consumption of rural household can be divided into cooking energy consumption, heating energy consumption, cooling energy consumption, and lighting energy consumption. Among them, heating energy consumption and cooking energy consumption dominate the total energy consumption of rural households in China.

Affected by different cooking habits in the north and south, the northern rural residents prefer to choose coal and straw as the main cooking fuel, while the southern rural residents mainly rely on coal and firewood. Similarly, there are differences in the use of heating fuels between the north and the south. Coal is the main heating fuel in the north, while firewood is in the south. Therefore, the coal consumption of northern households is approximately 12 times that of southern households (Shan et al., 2015). In the western rural areas, adobe kang or man-made central heating equipment is mainly used for heating (Meng et al., 2015). In the areas to the south of the Yangtze River, single-unit air conditioners are mainly used for heating and cooling (Feng et al., 2020). As rural energy structure gradually shifts from traditional solid fuels to commercial energy, taking northern rural areas as an example, the energy consumed for cooking includes coal, firewood, and straw, as well as LPG and electricity. Heating energy consumption accounts for 53.6% of the total energy consumption of rural households. Natural ventilation by opening windows supplemented by electric fans in summer is the main method for cooling in northern rural area. Therefore, the cooling energy consumption is low. Lighting energy consumption relies almost completely on electricity (Xu et al., 2018). On the whole, as of 2017, the energy consumption structure of cooking and heating was still at a low-quality level in rural areas in China. Solid fuels still dominated, but the consumption of solid fuels varies greatly in different regions. General speaking, northern rural residents consume the coal for cooking and heating, while eastern rural residents mainly use electricity and natural gas (He et al., 2018).

2.2 Influencing Factors for Energy Choice of Rural Household

The transition trend of energy consumption pattern of rural households in China is quietly significant. The proportion of consumption of commercial energy (except coal) and clean energy is increasing steadily, while the proportion of traditional solid fuel is decreasing gradually. Therefore, it is necessary to explore the influencing factors for energy choice of rural household so as to promote the rapid transition of energy consumption structure of rural household. The main influencing factors for energy choice of rural household include household characteristics (income level, household size, education level, etc.), energy availability, energy prices, etc.

2.2.1 Household Characteristic

Income level is the most critical factor affecting rural energy choices (Li et al., 2019). From 1991 to 2010, the increase of rural household income led to the continuous growth of energy consumption (Zhang and Guo, 2013). With the growth of income, the consumption of electricity and novel clean energy (such as solar energy and biogas) increases, while the consumption of traditional biomass energy (straw and firewood) decreases (Qiu et al., 2018). Since 2001, the proportion of coal utilization has declined year by year, while the proportion of high-quality commercial energy (such as electricity, petroleum products, and LPG) has increased year by year (Yao et al., 2012). Therefore, the proportion of rural households relying on solid fuels has shown a downward trend. In 2000, 92.8% of the total rural households in China were solid fuel based and by 2012, the proportion had dropped to 75.8% (Tang and Liao, 2014). It can be seen that the growth of income can enable rural residents to choose more convenient and efficient energy (Jiang et al., 2020a), thus promoting the transition of energy consumption structure of rural household.

Household size is another important factor affecting rural household energy consumption. Household energy consumption increases with the expansion of household size, that is, household size and energy consumption are positively correlated (Yang et al., 2018). Compared with other commonly used energy, the expansion of household size has a significant impact on the increase in the consumption of LPG and electricity (Zou and Luo, 2019). Moreover, due to the increase of rural population and the expansion of household size, the income of rural households will also increase, which in turn promotes the increase of energy consumption of rural households (Nie et al., 2018). The analysis based on binary logit regression model shows that the expansion

of household size will increase the consumption of firewood and solar energy and decrease the consumption of coal (Huang J et al., 2020), but its impact on the consumption of natural gas is not significant (Jiang et al., 2020a).

The education level of family members also has an important effect on household energy consumption. With the improvement of the education level of family members, the consumption of solid fuels (such as firewood) will decrease, but the consumption of natural gas and LPG will increase (Huang J et al., 2020). Especially in economically developed provinces, highly educated families will consume more electricity and petroleum products (Zhou and Shi, 2019). It can be seen that the higher the education level of family members, the more modern energy they are inclined to use, thus promoting the transition of household energy consumption structure from traditional solid fuel to modern fuel (Song et al., 2018).

2.2.2 Energy Availability

Energy availability is another factor influencing the energy choices of rural households. The terrain, altitude, transportation, and other external conditions of village will affect the regional development, and then affect the energy supply in the rural area (Wu et al., 2018). In plain areas, the terrain is flat, transportation is developed, household income is relatively high, and energy supply is convenient. Rural households usually prefer to use coal and LPG rather than natural gas and biomass energy. In mountainous areas, due to the complex terrain and inconvenient transportation, the production of agricultural and sideline products is underdeveloped and the consumption level is low. Biomass energy resources (such as firewood and crop residues) are abundant and easy to obtain, so they become the most popular choice of most families, while the consumption of electricity, natural gas, and LPG is small (Zou and Luo, 2019). This leads to a single energy consumption structure in mountainous areas. For instance, 71% of rural households in Beijing used firewood in 2013. This was because many suburban counties in Beijing (such as Huairou District) are located in mountainous areas, and firewood was relatively easy to obtain (Zhi et al., 2017). In addition, the shorter distance to market means a higher chance of accessing to modern energy (Qiu et al., 2018).

2.2.3 Energy Prices

Fluctuations in energy prices have a certain impact on the energy demand of rural households. The decline in the price of energy other than electricity promoted the increase in energy consumption of rural households from 2001 to 2002. From 2002 to 2003, although most rural energy prices rose, coal prices fell sharply. It led to an increase in coal consumption by rural households, which accounted for 77% of total rural energy consumption during that period. From 2006 to 2007, the decline of coal and electricity prices also led to a significant increase in rural residential energy consumption (Nie et al., 2018). A survey on households in ten suburban districts of Beijing in 2009 found that the rise of coal and LPG prices would lead to a sharp decline in per capita coal consumption and per capita LPG consumption, but the impact on alternative energy was very small (Zhang and Kotani, 2012).

2.2.4 Other Influencing Factors

Climate influences the heating and cooling conditions of rural households, thus influencing household energy consumption. From 2001 to 2012, climate change promoted the increase in rural residential energy consumption. Especially after 2007, due to the increase of abnormal temperature days, rural residential energy consumption increased significantly (Nie et al., 2018). The average heating area of a region also has an impact on energy consumption. Taking Beijing as an example, the difference in average coal consumption in different regions is mainly due to the difference in average heating area. For instance, the coal consumption of rural residents in Changping, Chaoyang, Fengtai, Haidian, and Tongzhou is higher, because the average heating areas of these regions had reached 110 square meters in 2015 (Yu Y. et al., 2017). The annual average temperature and annual average sunshine hours have no significant impact on the energy consumption of rural households (Han et al., 2018). The living habits of residents will also affect energy consumption. In rural areas, the per capita energy demand of residents with smoking and drinking habits are 2.54 GJ and 3.925 GJ higher than those of non-smokers and non-drinking residents, respectively. Moreover, a good mental state of rural resident has a positive impact on reducing household energy consumption (Chen C et al., 2019).

3 REGIONAL HETEROGENEITY OF ENERGY CONSUMPTION

Although the variation trend of energy consumption in rural areas in China is generally similar, there is an obvious regional heterogeneity of energy consumption in rural areas due to the differences in terrain, geographical location, economic development level, energy availability, climate, and residents' lifestyle etc.

According to different geographical locations, China (excluding Hong Kong, Macao, and Taiwan) can be divided into seven geographical regions, namely Northeast China (including Liaoning, Jilin, and Heilongjiang), North China (including Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia), East China (including Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, and Shandong), South China (including Guangdong, Guangxi, and Hainan), Central China (Henan, Hubei, and Hunan), Northwest China (including Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang), and Southwest China (including Chongqing, Sichuan, Guizhou, Yunnan, and Tibet). **Figure 3** shows the regional differences in energy consumption in rural areas in China. By 2015, North China had the largest demand for coal compared with other regions (Zou and Luo, 2019). This was because Shanxi Province is rich in coal resource. Moreover, due to the cold and dry winter in North China, rural residents mainly used coal as heating fuel (Wang and Jiang, 2017). As far as Inner Mongolia Autonomous Region was concerned, its coal consumption accounted for the largest

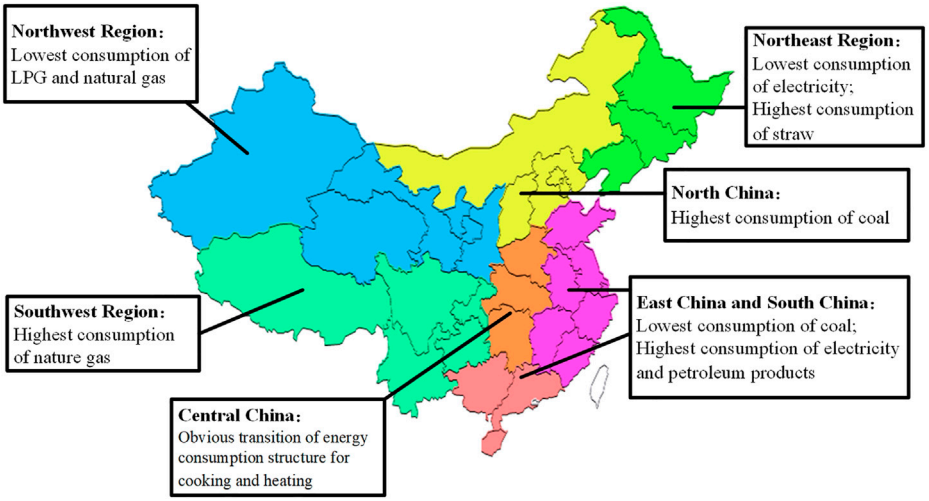

FIGURE 3 | Regional differences in energy consumption in rural areas in China.

proportion of carbon footprint in 2004, which was as high as 70%. Coal is a very important energy source for local rural residents (Jiang et al., 2020b). Besides North China, Northwest China also has a large demand for coal. A survey conducted in Linwei District, Weinan City, Shaanxi Province found that rural households in the plains mainly rely on commercial energy, such as coal, honeycomb briquettes, and electricity. Among them, coal consumption is the highest. This may be due to the flat terrain, developed transportation, high household income, and convenient energy supply in the plain area (Wu et al., 2018). However, the consumption of clean energy, such as LPG and natural gas, in Northwest China is very low. Taking Qin'an County in Gansu Province as an example, only 3.16% of rural households use LPG, and the consumption of biogas and natural gas is almost zero (Zhao et al., 2019). Rural households in South China and East China are less reliant on coal. The main energy they use is electricity, followed by petroleum products (Zhou and Shi, 2019). Taking Jiangsu Province as an example, in 1995, coal and electricity accounted for 60.4% and 36.7% of energy consumption in rural areas, respectively. By 2011, due to the use of electrical appliances and transport tools, electricity and petroleum products had become the first two main types of energy consumption in the rural area, which accounted for 68.57% and 28.34% respectively. While coal only accounted for 3.08% (Zhang et al., 2016). In addition, in 2016, the energy consumption structure of rural households in Shandong Province had also been dominated by electricity, and it was transiting to "electricity + coal + solar" energy structure (Yu et al., 2017b). In Southwest China, although the power grid penetration rate and electricity consumption are at a relatively low level, the transition rate of energy consumption structure of rural household from solid fuels to electricity is relatively fast, especially in terms of cooking energy consumption (Zhu et al., 2018). According to national population census data in 2010, only 17.7% of rural households in Guizhou and 15.4% in Yunnan Province used electricity. However, since 2000, the proportion of rural households consuming electricity has shown a sustained increase (Tang and Liao, 2014). Compared with other regions, Southwest China consumes the highest amount of natural gas, but it still accounts for a relatively low proportion of the total household energy consumption, while natural gas is almost not used in northeast China (Zou and Luo, 2019). Taking Xuanwei County in Yunnan Province as an example, local rural residents are more willing to choose the "electricity + gas + coal" mix energy mode (Yuan et al., 2020). The region with the least electricity consumption is Northeast China. A survey conducted in Yushu City and Dehui City of Jilin Province in 2018 found that in the total energy consumption of rural households for heating, cooking, lighting, and household appliances, the share of electricity was only 11.7%, while the share of dried stalk/straw was 36.1% (Li and Dong, 2020). In addition, taking Shulan County of Jilin Province as an example, straw and biogas are dominant energy consumptions in local rural households. Shulan County is one of the rice production regions in Jilin Province and it possesses tremendous straw resources which are mainly used for heating by local peasant households. Moreover, as a pilot county for biogas construction determined by the Ministry of Agriculture and Rural Affairs, Shulan County has a biogas utilization rate as high as 97% (Wang et al., 2017). It can be seen that rural residents in Northeast China mainly rely on biomass energy, which may be related to the energy availability and affordability. A survey on rural residential heating energy consumption in three Northeastern provinces in 2015 found that rural residents in Jilin mainly use straw for heating, while Heilongjiang Province has the highest proportion of commercial energy consumption for heating (Wang et al., 2016). There is an obvious transition of energy consumption structure for cooking and heating in Central China. Before 2010, a considerable number of rural households in Henan Province relied on solid fuels for cooking (Tang and Liao, 2014). By 2015, in addition to firewood and coal, liquefied petroleum gas has become the energy for cooking favored by rural households in

TABLE 1 | Number of rural households by main types of domestic energy.

	The whole of China	Eastern region	Central region	Western region	Northeastern region
Straw	10177	2090	2770	4225	1092
Coal	5506	2239	1124	1789	354
Coal gas, Natural gas, LPG	11347	5297	4017	1770	263
Biogas	156	20	47	87	1
Electricity	13503	4354	4096	4295	758
Solar energy	56	17	18	20	1
Others	126	16	14	94	2

*Data source: (National Bureau of Statistics of China, 2016).
Unit: Ten thousand households

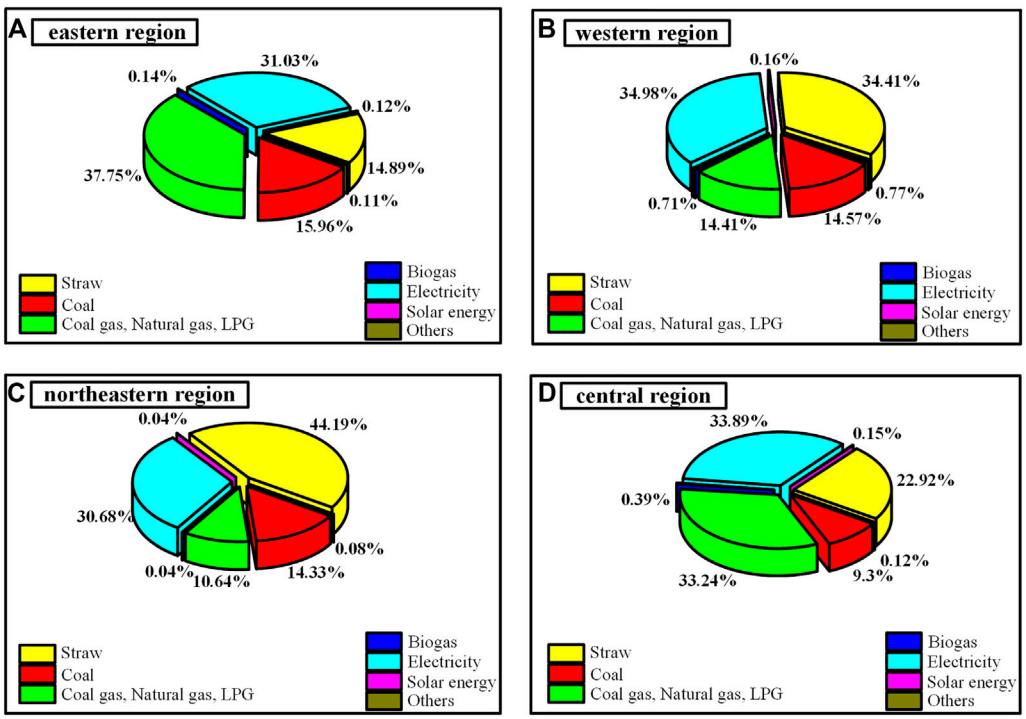

FIGURE 4 | Energy consumption structure of rural households in China: **(A)** The eastern region, **(B)** The western region, **(C)** The northeastern region, and **(D)** The central region.

Henan Province, and electricity has also become the second largest energy source for heating in rural households in Henan Province (Xu et al., 2018). Moreover, after 2010, the energy consumption structure for cooking and heating in Hubei Province has been dominated by natural gas and electricity respectively (Wang and Jiang, 2017).

In the Third National Agricultural Census, China (excluding Hong Kong, Macao, and Taiwan) was divided into four regions, namely the eastern region (including Beijing, Tianjin, Hebei, Shandong, Shanghai, Zhejiang, Jiangsu, Guangdong, Hainan, and Fujian), the central region (including Henan, Shanxi, Anhui, Hubei, Hunan, and Jiangxi), the western region (including Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Tibet, Inner Mongolia, Chongqing, Sichuan, Yunnan, Guizhou, and Guangxi), and the northeastern region (including Heilongjiang, Jilin, and Liaoning). According to the extracted census results shown in **Table 1**, it can be seen that, in 2018, electricity, LPG, and other commercial energy, had become an indispensable part of the energy consumption of rural households in China. However, in the northeastern region, rural households still consumed traditional solid fuels. The energy consumption structures of rural households in the eastern, western, northeastern, and central regions are depicted in **Figure 4**.

Generally speaking, rural households in western, central, and northern China mainly rely on coal, straw and other traditional solid fuels. Due to the developed economy and high per capita income of residents, the energy consumption structure of rural households in the eastern and southern China is the most

reasonable and clean, that is, local households mainly use electricity, petroleum products, and other commercial energy, while the consumption of coal and straw is small. Worldwide, as a developing country, the energy consumption structure of rural households in China is still dominated by traditional solid fuels. However, the energy consumption structure of rural households in developed countries has been dominated by electricity, natural gas, and petroleum products (Wu et al., 2019).

4 THE ANALYSIS OF CARBON DIOXIDE EMISSIONS AND POLLUTANT EMISSIONS

4.1 Carbon Dioxide Emissions

The impact of rural residents' lifestyles on carbon dioxide emissions can be divided into the following two categories.

1) Direct carbon dioxide emissions: Carbon dioxide emitted from direct energy consumption by rural residents, such as lighting, heating, and cooking. 2) Indirect carbon dioxide emissions: Carbon dioxide will not be emitted through the consumption of household commodities other than energy products. However, during the production and processing process of these household commodities, carbon dioxide emits. For example, entertainment and transportation (Chen G et al., 2019).

Since this paper studies the energy directly consumed by rural residents, only direct carbon dioxide emissions are analyzed.

Direct carbon dioxide emissions in rural areas of China are mainly from coal, electricity, petroleum products, and LPG. In 2001, carbon dioxide produced by coal, electricity, petroleum products, and LPG accounted for 61.23%, 32.33%, 3.46%, and 1.80% of the total emissions, respectively. In 2008, the proportion of carbon dioxide produced by these four types of energy became 44.49%, 46.97%, 4.51%, and 3.81%, respectively (Zhang and Guo, 2013). It can be seen that coal dominated carbon dioxide emissions in 2001, and electricity in 2008. The annual growth rate of carbon dioxide emissions from LPG was as high as 21.67%. Taking Shandong Province as an example, carbon dioxide emissions mainly come from commercial energy. In 1995, the carbon dioxide produced by rural households consuming coal, LPG, and electricity accounted for 32.1%, 0.65%, and 67.2% of the total emissions, respectively. By 2010, the above three proportional values had become 13.0%, 4.11%, and 82.5%, respectively. The carbon dioxide produced in the process of consuming electricity and LPG has increased significantly, and carbon dioxide emissions increased with the increase of commercial energy consumption (Jiang et al., 2017). Taking Inner Mongolia Autonomous Region as an example, coal occupied the dominant position in the carbon footprint of energy consumption from 2000 to 2012. While the consumption of electricity, petroleum products, and natural gas maintained a low level. It indicates that coal was the most important energy resource in Inner Mongolia during that period. However, the share of coal in the carbon footprint of energy consumption dropped sharply from 2012 to 2016. The reduction in coal demand led to an increase of other alternative energy consumption, that is, the proportion of carbon dioxide produced by electricity, petroleum products, and natural gas increased.

The development and utilization of renewable energy can not only increase energy supply, but also reduce carbon dioxide emissions from rural energy consumption. Therefore, the Chinese government has vigorously promoted the development and utilization of renewable energy, such as solar energy, geothermal energy, small hydropower, and biogas, which can be regarded as low-carbon energy in rural areas (Liu et al., 2013). As the most commonly used renewable energy for rural households, solar energy has almost reached zero carbon dioxide emissions. Geothermal power generation in rural areas of China can save energy by 2.89 Mtce per year and reduced carbon dioxide emissions of 7.20 Mt. Ground source heat pumps can save energy of 70.86 Mtce per year and reduce carbon dioxide emissions of 177 Mt (Li et al., 2014). By 2005, the installed capacity of small hydropower under exploitation in rural areas of China would reach 71.87 GW. The annual power generation output would reach 660.47 TWh, which was equivalent to energy saving of 266.83 Mtce. Reduction of carbon dioxide emissions was about 665.07 Mt (Li et al., 2014). By 2009, the numbers of household biogas digesters and large and medium-sized biogas projects had reached 35.07 million and 22,570, respectively. The biogas production was about 13.08 billion cubic meters, which was equivalent to Green House Gas (GHG) emissions reduction of 51 Tg CO_2e (Liang et al., 2013). In the rural areas of Gansu Province, 310,000 rural households had built household biogas digesters by 2012, which could reduce 470,000 tons of carbon dioxide emissions (Niu et al., 2014). It can be seen that the development of renewable energy, such as solar energy, geothermal energy, small hydropower, and biogas, plays a positive role in carbon dioxide emissions reduction.

4.2 Pollutant Emissions

In the process of rural energy consumption, in addition to the emission of a large amount of carbon dioxide, the emission of pollutants, such as sulfur dioxide, nitrogen oxides, total suspended particles (TSP), etc., should also not be underestimated.

Pollutants mainly come from coal, crop straw, firewood, and other traditional solid fuels. Shandong Province, as one of the most populous provinces in China, 72.6% of its TSP emission caused by rural household energy consumption came from the burning of crop straw in 1995. In 2010, the proportion changed to 44.5%, which remained high. Coal and electricity are two main sources of sulfur dioxide emissions caused by rural households' energy consumption in Shandong Province. In 1995, sulfur dioxide emissions from coal and electricity consumption accounted for 57.4% and 36.8%, respectively. In 2010, the proportion of sulfur dioxide emissions caused by coal dropped to 32.1%, while that caused by electricity consumption increased to 62.3%. The emissions of nitrogen oxides mainly come from straw and electricity consumption. In 1995, the nitrogen oxide emissions from straw burning and electricity accounted for 64.7% and 20.8%, respectively. By 2010, the proportion of nitrogen oxide emissions caused by straw had dropped to 35.91%, while that generated by electricity had increased to 52.4% (Jiang et al., 2017). This is due to the implementation of China's rural energy development and construction policies. The energy consumption

structure of rural households is gradually transiting. The proportion of traditional solid fuels used by rural households in Shandong Province has decreased, while the consumption of commercial energy has increased year by year. However, as far as the whole China was concerned, although non-solid fuels had widely been used in rural areas of China by 2015, traditional solid fuels still accounted for 42.7% of the total energy consumption of rural households. The impact of the uncleanness of solid fuels on the rural environment (such as serious haze problems) still cannot be ignored (Niu et al., 2019). Moreover, the use of non-clean solid fuels also poses a threat to the health of rural residents. Clear evidence shows that the combustion of solid fuel is associated with highly pathogenic pneumonia diseases (such as respiratory infection and respiratory tract cancer) and other chronic diseases (Shan et al., 2015). Therefore, reducing the utilization rate of non-clean solid fuels in rural areas and increasing the share of renewable energy in the rural energy structure is an important task. A survey conducted in July 2011 on the energy consumption of rural households in Zhangziying Town in Beijing found that compared with rural households using non-renewable energy, rural households using renewable energy can save 32838.12 kgce, and reduce 22329.92 kg of TSP emissions annually (Li et al., 2015). The Beijing municipal government has taken a lot of measures to improve the rural energy consumption structure to reduce pollutant emissions. By the end of 2017, the Beijing municipal government had built 700 "no-coal villages" in Chaoyang, Haidian, and Mentougou Districts. Banning the use of coal in rural households has played a significant role in improving air quality in Beijing. It is estimated that if natural gas is used to replace coal and biomass used by all households in Beijing, the emission reduction rates of NOx, NMVOCs, SO2, and PM2.5 will be as high as 98.5%, 99.5%, 99.5%, and 99.6%, respectively (Cai et al., 2018). Therefore, increasing the utilization rate of renewable energy plays a vital role in environmental protection in rural development.

5 ENERGY-SAVING POTENTIAL OF RURAL HOUSEHOLDS

5.1 Willingness to Adopt Clean Energy of Rural Residents

Although there has been significant development in the field of renewable energy utilization in rural areas of China, the consumption of clean energy still accounts for a small proportion of the total energy consumption in rural areas. Therefore, it is of great significance to analyze the factors that influence the rural households' choice in clean energy.

From an objective point of view, the main factors influencing rural households' choice in clean energy are household characteristics (including education level, household income, and the age of head of household) and energy transition costs. Among them, education level and household income are the key factors influencing rural households' choice in clean energy. The education level of household members has a positive impact on environmental awareness. Highly educated households are more inclined to use clean energy due to their strong environmental awareness. With the development of national economy, rural household income shows a rising trend. **Table 2** shows the relationship between the per capita disposable income of rural residents and their energy selections. The higher the household income level, the stronger the ability to pursue a higher quality of life. Therefore, high-income households are usually more willing to choose clean energy with high price but convenience. The age of the head of household has a negative impact on the willingness to use clean energy. The old generation of rural residents generally are less educated and are more willing to use non-clean energy due to the influence of their traditional living habits (Yan et al., 2020). The rise of energy prices directly affects the total expenditure of rural household energy consumption. Rural residents have a high acceptance of traditional solid energy (such as firewood and straw) due to its low cost and easy access (Li et al., 2015). However, the cost of using clean energy is relatively high, and most rural residents refuse to pay the cost of energy transition. Therefore, the cost of energy transition has a negative impact on the clean energy selection of rural households (Li and Dong, 2020). Among the traditional energy sources used by rural residents, the cost of firewood and straw is zero, and the price of coal is also very low. Compared with these traditional energy sources, clean energy, such as electricity and natural gas, has no price advantage. For the consumer end where rural residents are located, the price of renewable energy is only reflected in the electricity price. In addition, a field survey on 3685 rural households in Chengdu and its neighboring counties in Sichuan Province found that the proportion of centralized households choosing clean cooking energy was higher than that of non-centralized households. It indicates that the centralized residence will increase the possibility of rural residents choosing clean cooking energy (Liu et al., 2020). Moreover, the impact of urbanization policies also makes rural residents more inclined to choose clean energy (Wang and Gao, 2018).

From a subjective point of view, the main factors influencing rural households' choice in clean energy are environmental awareness, environmental perception, and user evaluation. Environmental awareness urges rural households to choose clean energy. The stronger the residents' perception of the changes in the surrounding environment, the greater the probability that they are willing to choose clean and efficient energy. A survey conducted in Mishan town, Gaoping County, Jincheng City, Shanxi Province found that rural residents were more willing to choose clean energy when they believed that coal mining and excavation had a negative impact on their health. The evaluation on clean energy by relatives and neighbors will affect the choice of rural residents to a certain extent. A survey conducted in rural areas in northeast, eastern, and central China found that the herding behavior of relatives, neighbors, and village cadres had a significant positive impact on residents' willingness to adopt biogas (Zeng et al., 2019). It means that good user evaluation can improve the adoption rate of clean energy in rural households.

5.2 Energy-Saving Behavior of Rural Residents

Since China advocated energy conservation and emission reduction, rural residents' awareness of energy conservation

TABLE 2 | The relationship between the per capita disposable income of rural residents and their energy selections.

Item	2013	2014	2015	2016	2017	2018	2019
Per capita disposable income	9429.6	10488.9	11421.7	12363.4	13432.4	14617.0	16020.7
Energy selection	Traditional biomass energy			→	Commercial energy + Clean energy		

*Data source: (National Bureau of Statistics of China, 2020a).
Unit: RMB (yuan).

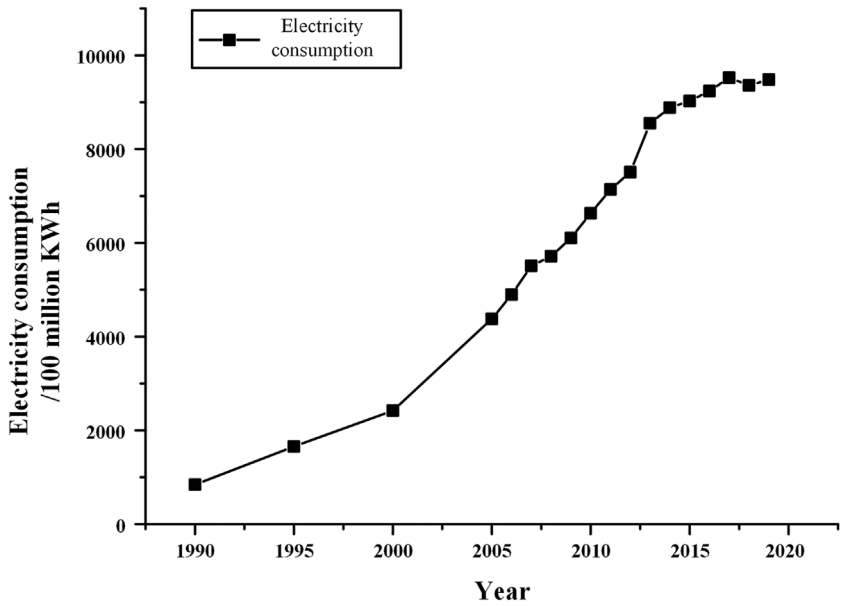

FIGURE 5 | Electricity consumption in rural China [Data source: (National Bureau of Statistics of China, 2020a)].

has been significantly improved. A survey conducted in the rural areas in Qin'an County, Gansu Province in 2016 found that 88.74% of farmers believed that energy conservation was necessary, only 7.11% of farmers believed that energy conservation has nothing to do with themselves, and the remaining 4.15% of farmers held a neutral attitude. Although rural residents have a high awareness of energy conservation, their energy-saving measures are relatively simple. Generally, energy-saving measures taken by rural residents include green travel, installation of clean energy equipment (such as solar water heaters), and the use of energy-saving appliances (such as energy-saving lamps and energy-saving refrigerators) (Zhao et al., 2019). An investigation found that the comprehensive utilization of clean energy equipment (biogas, solar stoves, and energy-saving stoves) achieved the best energy-saving effect (Ding et al., 2014). At present, the most widely used clean energy by rural residents is electricity. **Figure 5** shows the trend of significant increase in rural electricity consumption since 1990. The larger the household size is, the more household appliances are, and the higher the household electricity consumption is. Electricity fees have become an indispensable expenditure for rural households. The main electrical equipment used by rural households are lamps, refrigerators, washing machines, televisions, air conditioners, etc. Chinese General Social Survey in 2015 found that only 27% of rural households did not use energy-saving lamps, which indicated that energy-saving lamps had been widely used in rural China. About 72% of refrigerators used by rural residents were energy-efficient. This is because compared with other electrical appliances, refrigerator has a longer operation time and consumes more electricity. Therefore, rural residents were inclined to buy energy-saving refrigerators. 63% of rural households used energy-efficient washing machines, and about 33% of rural households chose first-level energy-efficient washing machines, and followed by 19% choosing second-level energy-efficient washing machines. Televisions and air conditioners are common electrical appliances in rural areas, but the televisions and air conditioners used by most rural households did not meet the energy-saving standards. About 17% of rural households had two and more televisions, but 82% of them did not choose energy-saving televisions. Similarly, more than 95% of rural households used a room air conditioner. However, about 41% of rural households did not choose the energy-efficient air conditioners (Zou and Mishra, 2020).

There are many factors influencing rural residents' energy-saving behavior, such as the education level of the head of household, energy prices, information feedback (frequency of paying electricity bills), etc. The education level of the head of household has a positive impact on the energy saving of rural

household. The higher the education level, the stronger the awareness of energy conservation, and the higher the possibility of purchasing energy-saving appliances (Yu et al., 2017a). In 2014, the survey on electricity consumption of Chinese residents found that the increase in electricity prices had little impact on the electricity consumption efficiency of rural households. It may be because compared with electricity, low-cost biomass energy still dominated the energy consumption structure of most rural households. As an alternative energy to electricity, biomass energy is easy to obtain. This results in low electricity dependence of rural households, and it also weakens the response of rural residents' electricity demand to price changes. Information feedback mainly refers to the frequency of paying of electricity bills. The higher the frequency that households pay for electricity, the stronger their awareness of saving electricity. Information feedback plays an important role in influencing residents' electricity saving behavior (Li et al., 2020). In addition, improving women's family status can also increase the possibility of household energy-saving behaviors to a certain extent (Huang F et al., 2020). Upgrading equipment and promoting energy-saving appliances in rural areas can improve energy efficiency. The standby time of electrical appliances can be reduced by changing residents' behavior of using electrical appliances, thereby achieving the energy-saving effect. However, compared with the energy saved by equipment upgrading, the energy-saving effect of the second method mentioned above is limited (Yu et al., 2017b). Therefore, the government can provide subsidies to eliminate high-energy consumption household equipment and promote low-cost energy-saving appliances in rural areas (Li Y et al., 2020).

6 RURAL ENERGY POLICY IN CHINA

6.1 The Evolution of Rural Energy Policies

Rural energy policies in China mainly involves fossil fuels, biomass energy, and clean energy. Affected by the economic system, social culture, and ecological environment, rural energy policies have different focuses in different periods.

In the early days of the founding of the People's Republic of China in 1949, due to financial, technical, and other issues, the supply of rural commercial energy was limited. The Great Leap Forward Movement from 1958 to 1960 caused serious damage to energy industry, especially the coal industry. By the end of 1978, due to the rapid increase in the rural population and the aggravation of energy shortages, the construction of biogas triggered the government's concern. During that period, rural energy policies intended to relieve energy shortage by using alternative energy. Some energy policies focused on social issues (such as national energy security) rather than rural energy issues, and the implementation of policies lacked financial support. Therefore, the implementation effect of energy policies was poor. The Reform and Opening-up in 1978 greatly improved China's rural economy, but the problem of energy shortage still existed (Wu, 2020). In the early 1980s, the National Improved Stove Program (NISP), the world's largest public financing project for the function improvement of stoves, was organized by the Chinese government to deal with the widespread shortage of biomass fuels in rural areas (Sinton et al., 2004). During that period, there were no obvious differences in rural energy policies involving fossil fuels, biomass energy, and clean energy. However, the policies involving fossil fuels were slightly more than those involving the other two types of energy. Therefore, it can be concluded that rural energy policies focused slightly on fossil fuels (Wu, 2020).

During the "6th Five-Year Plan" period, the guiding principle of rural energy construction in China was "adjusting measures to local conditions, multi-energy complementation, comprehensive utilization, and focusing on cost-effectiveness". Moreover, it was emphasized that "Energy development and conservation should be carried out at the same time, and energy conservation is currently the top priority". As a result, the number of policies involving biomass energy increased rapidly. By the 1990s, the main issue of rural energy had changed from energy shortage to unbalanced energy structure. Biomass energy accounted for more than 60% of rural residential energy consumption. In 1997, the Fourth Session of the Eighth National People's Congress (NPC) adopted the 9th Five-Year Plan for New Energy and Rural Energy and the Long-Range Objectives to the Year 2010 to promote the construction of the rural energy industry. In order to rationally develop and utilize coal resources, adjust and optimization the structure of the coal industry, regulate the order of coal production and operation, realize a basic balance of coal production and demand, improve safe in production, and promote the healthy development of the coal industry, the State Council issued the "Notice on Issues Concerning the Closure of Illegal and Irrational Coal Mines" on 5 December 1998. After 2005, coal was no longer the key point of rural energy policies, and energy policies attached equal importance to commercial energy, biomass energy, and clean energy (Wu, 2020). In the early 2000s, lot of emphasis was given on decentralized renewable energy, especially wind energy (Ackermann and Söder, 2000; Lew, 2000) and biomass energy (Li et al., 2001; Liu et al., 2001), to improve energy access in rural China. At that time, China's renewable energy development was mainly supported by international aid programs (Ackermann and Söder, 2000) and United Nations Development Program (Li et al., 2001; Liu et al., 2001).

After the outbreak of global financial crisis in 2008, China stimulated domestic demand through the construction of rural renewable energy projects. In addition, the ecological impact of rural energy has been emphasized in the Construction of New Socialist Countryside and the Construction of Beautiful Countryside. In 2012, a 1-year subsidy program for rural energy-efficient household appliances was launched (Yu and Guo, 2016). In 2014, The Energy Development Strategy Action Plan (2014–2020) issued by the General Office of the State Council clearly proposed to develop the energy utilization of crop straw especially biogas production according to local conditions (Zeng et al., 2019). Taking Gansu Province as an example, the construction cost of biogas digester for each rural household is reduced due to the subsidy of 1000 RMB from local government (Niu et al., 2014). In 2017, the general office of

National Development and Reform Commission, the general office of Ministry of Agriculture, and the comprehensive department of National Energy Administration jointly issued Guiding Opinions on the Construction of Clean Energy Utilization Project of Crop Straw Gasification. It emphasized the application of pyrolysis technology and anaerobic fermentation technology for biogas (heat and electricity) production from agricultural wastes with crop straw as the main raw material (Zeng et al., 2019). It can be seen that during that period, the rural energy policy system had been improved to a certain extent through the promulgation and amendment of laws, regulations, and other policies. By 2018, biogas and electricity had become the core issues of rural energy policies, and the number of policies involving solar and wind energy had also increased. It indicated that the focus of rural energy policies had been shifting to environment-friendly energy (Wu, 2020).

6.2 Policy Implications

At present, the energy structure of rural households in China is transiting from traditional solid fuels to commercial energy and clean energy. However, commercial energy and clean energy do not have price advantages over traditional solid energy. The trend of energy structure transition increases the financial burden of rural households to a certain extent, especially for those who are not wealthy. Therefore, in order to accelerate the rapid transition of rural energy structure and the promotion and application of renewable energy equipment, the construction of rural infrastructure should be accelerated, including accelerating the construction of rural gas distribution pipelines to improve the level of clean energy consumption in rural areas, and implementing the transformation and upgrading of rural power grids, etc. Moreover, the government can formulate subsidies and tax policies to stimulate the consumption demand for commercial energy and renewable energy. Specifically, short-term subsidies can be converted into long-term support policies to reduce the economic burden of rural residents, and financial subsidies, tax reductions and exemptions can be adopted to support the development of renewable energy enterprises.

It is not enough to promote the transition of the energy structure of rural households by relying solely on policy support. What is more important is to fundamentally improve the awareness of energy conservation of rural residents, and form a good atmosphere for the whole society to actively participate in the construction of rural energy projects. Therefore, it is necessary to strengthen the popularization of green energy knowledge in rural areas, make full use of TV, radio, social networks and other platforms to widely publicize the health and environmental benefits of renewable energy, and mobilize the enthusiasm of rural residents to participate in the construction of rural energy projects.

The construction and development of rural energy projects is inseparable from science and technology. It is necessary to promote the application of distributed energy technology according to local conditions in rural areas, such as the geographical conditions, resource advantages, climate, and economic conditions. China's "No. 1 Central Document" for 2016 pointed out that "vigorously promote the "Internet +" modern agriculture, and promote the upgrading of the entire industrial chain of agriculture" (The Central Committee of the Communist Party of China and the State Council, 2016). Therefore, the innovative mode of "Internet +" smart energy should be explored to achieve efficient utilization of energy in rural China. Moreover, it is also necessary to strengthen the training of talents in the field of rural energy, improve the scientific quality of rural energy construction personnel, and lay a solid foundation for talent reserve for promoting the transition of rural energy structure and the construction of Beautiful Villages project.

7 CONCLUSION

Since the 1990s, China's economy has been developing steadily, and energy consumption of rural household has also shown a rising trend. There is an obvious transition of rural energy structure from traditional solid energy to commercial energy and clean energy. However, due to the complex topography, the development of renewable energy industry lags behind, thus hindering the transition of the rural energy consumption structure to a certain extent. Clean energy accounts for only a small proportion of total energy consumption in rural areas. According to the end use of energy, heating energy consumption and cooking energy consumption dominate the total energy consumption of rural households in China. However, the energy consumption structure of cooking and heating is at a low-quality level, and solid fuels still dominates in heating and cooking energy consumption.

The main influencing factors for energy choice of rural household include household characteristics (income level, household size, education level, etc.), energy availability, energy prices, etc. In addition, it is also influenced by the local climate and residents' living habits. There is an obvious regional heterogeneity of rural energy consumption. Rural households in the western, central, and northern China mainly rely on traditional solid fuels, such as coal and straw. However, rural households in the eastern and southern China mainly rely on electricity and LPG, while the consumption of coal and straw is small.

Carbon dioxide emissions caused by rural energy consumption mainly come from coal, electricity, petroleum products, and LPG. In the carbon footprint, the share of coal decreases significantly, while the shares of electric power, petroleum products, and LPG increase. The utilization of clean energy, such as solar energy, biogas, and geothermal energy, is conducive to reducing carbon dioxide emissions. In addition to carbon dioxide emissions, other pollutant emissions mainly come from the consumption of traditional solid fuels, such as coal, crop straw, and firewood.

Clean energy accounts for only a small proportion of total energy consumption in rural areas. From an objective point of view, the main factors influencing rural households' choice in clean energy are household characteristics (including education

level, household income, and the age of head of household) and energy transition costs. From a subjective point of view, the main factors influencing rural households' choice in clean energy are environmental awareness, environmental perception, and user evaluation. Although rural residents have a high awareness of energy conservation, their energy-saving measures are relatively simple. The energy-saving behavior of rural residents is mainly related to the education level of the head of household, energy prices, and information feedback (frequency of paying electricity bills).

Through promulgation and amendment of laws and regulations and implementation of financial subsidies, China has obtained a remarkable achievement in improving the rural energy policy system. Rural energy policies in China mainly involves fossil fuels, biomass energy, and clean energy. Affected by the economic system, social culture, and ecological environment, rural energy policies have different focuses in different periods. Before 1978, rural energy policies focused slightly on fossil fuels. After 2005, coal was no longer the key point of rural energy policies, and energy policies attached equal importance to commercial energy, biomass energy, and clean energy. The focus of rural energy policy has been shifting to environment-friendly energy.

The government can formulate subsidies and tax policies to stimulate the consumption demand for commercial energy and clean energy. It is necessary to fundamentally improve the awareness of energy conservation of rural residents and strengthen the popularization of green energy knowledge in rural areas. It is necessary to promote the application of distributed energy technology and explore the innovative mode of "Internet +" smart energy. It is also necessary to lay a solid foundation for talent reserve for promoting the transition of rural energy structure and the construction of Beautiful Villages project.

The limitation of this review is that it only focuses on rural energy consumption in China. As an important base of agricultural production, in rural areas, the energy and environmental problems in the process of agricultural production cannot be ignored. Therefore, the future research on China's rural energy can focus on the process of agricultural production.

AUTHOR CONTRIBUTIONS

XZ: conceptualization, formal analysis, funding acquisition, methodology, project administration, writing–original draft, and writing–review and editing. KX: conceptualization, formal analysis, and writing–original draft. MH: conceptualization, writing–original draft, and writing–review and editing. JW: project administration and writing–review and editing.

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