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# ADAPTATION TO CLIMATE CHANGE IN RURAL CHINA TO ENHANCE THE WELFARE EFFECTS OF CLEAN ENERGY TRANSITION CONSIDERING TOPOGRAPHY AND E-COMMERCE

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**Abstract**
The purpose of this paper is to explore the welfare effects of clean energy adoption, especially its impact on the environment, economy and farmers' production and life. Additionally, it explores the adaptation to climate change in rural China. In this study, a differentially differential model is used to effectively separate the welfare effects of clean energy by comparing the changes before and after the promotion of clean energy. The results are as follows. (1) the adoption of clean energy can increase the income of rural production and living energy by 43.90% and reduce rural carbon emissions by 33.00%. (2) At present, the impact of rural clean energy adoption on farmers' health and rural energy use efficiency has not been shown. (3) The proportion of clean energy in mountain areas (57.69%) is much lower than that in plain areas (84.21%), and the use of traditional energy in plain areas is reduced to 15.79%. Mountain residents, migrant workers can make them understand the different rural energy use situation from the local area. The popularity of e-commerce in both plain and mountainous areas has a significant impact, and the impact on plain areas is greater than that in mountainous areas. This study not only provides a scientific evaluation method for the welfare effects of clean energy, but also provides theoretical support and practical guidance for the future energy policy formulation and the promotion and application of clean energy.

***Keywords:*** *rural clean energy, welfare effect, carbon emission, production and living cost, farmer health, energy efficiency.*

***JEL Codes:*** *O13, Q48.*

## Introduction

Clean energy plays a vital role in today's society. First of all, with the depletion of traditional energy and the increasingly serious environmental problems, clean energy has become an important pillar of sustainable development. Improving the development and utilization of clean energy through scientific and technological innovation is not only conducive to the transition from traditional energy sources, but also conducive to improving today's environment and achieving green development [1]. Secondly, the use of clean energy can significantly reduce greenhouse gas emissions, which is of great significance for combating climate change. By promoting clean energy sources like solar and wind, we can slow the rate of global warming and protect our planet.

In addition, the development of the clean energy industry has also spawned a range of new technologies and new business forms, creating tremendous opportunities for economic growth and employment. With the continuous innovation and popularization of technology, clean energy will play a more important role in the future and make great contributions to the sustainable development of human society. Embracing a long-term perspective, we aim to catalyze the transition towards clean energy, instilling a heightened sense of responsibility, mission, and urgency. This endeavor accelerates the advancement of the clean energy sector, fostering industrial transformation and elevation, thereby fostering significant contributions to the new trajectory of socialist modernization [2].

In recent years, China's rural areas have made remarkable progress in the adoption of clean energy. With the proposal of the national "double carbon" goal in 2020, low-carbon development has received the attention of all sectors of society, and new energy logistics equipment, as an important application of new energy in the field of commerce and trade, is of great significance to achieve carbon reduction in transportation [3]. The government has introduced a series of policies to support the development of clean energy in rural areas, including financial subsidies, tax breaks, financial loans, etc., to encourage farmers to adopt clean energy technologies. Solar photovoltaic power generation and biomass energy utilization technology have been widely used in rural areas. Many rural families began to install solar photovoltaic power generation systems, using solar power for their own use. At the same time, biomass resources such as straw, livestock and poultry manure are also widely used in rural cooking, heating and biomass power generation. Solar heating technology is also evolving. Hebei Province is a province with abundant solar energy resources and has a good background for solar heating [4]. With the continuous development of the clean energy market, more and more enterprises have begun to enter the field of rural clean energy, launching clean energy products and solutions suitable for the rural market. The intensification of market competition has gradually reduced the price of clean energy products, further promoting the popularization and application of rural clean energy.

However, there are still some challenges and problems in China's rural clean energy adoption. On the one hand, the economic development of rural areas is relatively backward, and the infrastructure construction is imperfect, which affects the promotion and application of clean energy [5]. On the other hand, some farmers lack understanding and low awareness of clean energy technologies and products, and need to strengthen publicity, education and training. In addition, the government's support policy for rural clean energy needs to be further improved and implemented to promote the wide application and sustainable development of clean energy in rural areas [6].

In contrast, before the implementation of the clean energy policy, there were widespread problems such as energy shortage and environmental pollution in rural areas. The implementation of clean energy policy has provided policy support and guidance for the development of clean energy in rural areas, and promoted the energy transformation and environmental improvement in rural areas. By 2025, in the no-policy scenario, the total emissions of greenhouse gases and air pollutants will be reduced by about 15% compared with 2015, and in the northern heating region, where the role of clean transition policies is most obvious, compared with the no-policy scenario, The emissions of PM2.5, VOCS, $SO_2$, NOx, CO and $CO_2$ were reduced by 76.0%, 76.7%, 75.6%, 55.4%, 76.6% and 43.2%, respectively, which has an ideal pollution reduction effect [7]. However,

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the current problems still restrict the development of rural clean energy.

In recent years, the research on the adoption of clean energy has become a hot topic for scholars. Scholars have conducted research from different subjects and different perspectives. In terms of policy, scholars have conducted in-depth research on China's clean energy policy, including policy formulation, implementation and effect evaluation. They analyzed our government's policy tools, incentives, and laws and regulations in promoting clean energy development, and explored the impact of policies on clean energy adoption [8]. In the economic aspect, scholars have studied the role of clean energy in the economic development of our country from the perspective of economics. They analyzed the impact of the clean energy industry on economic growth, employment, investment and other aspects, and discussed the development prospects and potential of the clean energy industry [9]. On the social side, the authors also looked at public awareness and acceptance of clean energy from a sociological perspective. Through surveys and interviews, they learned about the public's attitude, willingness and behavior toward clean energy, and discussed how to increase public awareness of environmental protection and participation in clean energy [10].

In terms of the main body of research, there are some deficiencies in the research of scholars. First, there may be limitations in research perspectives and methods, resulting in insufficient comprehensive understanding and in-depth analysis of clean energy adoption issues. Secondly, due to the rapid upgrading of clean energy technologies, research subjects need to constantly update research materials and data to ensure the timeliness and accuracy of research. In addition, the development of clean energy varies by region and industry, and scholars' research may not be able to fully cover the various situations and challenges. In short, scholars have studied the adoption of clean energy in our country from many angles, but there are still some shortcomings that need to be further improved and perfected. The purpose of this study is to explore the welfare effects of rural clean energy adoption before and after the implementation of policies by using differential model, and provide a new idea for the adoption of clean energy.

In theory, the research of this paper enriches the theoretical basis of the welfare effect of clean energy and provides a basis for policy makers to make decisions. In practice, the findings of this paper have important guiding significance for guiding the sustainable development of clean energy, optimizing the energy structure, improving the efficiency of energy utilization, and realizing the coordinated development of economy, environment and social welfare.

The remaining contents of this paper are as follows: The Section 2 of the rural clean energy policy and rural clean energy to reduce carbon efficiency of literature review; The Section 3 puts forward three hypotheses and research framework according to the four aspects that affect farmers or rural areas before and after the development of clean energy. The Section 4 describes the main methodology used in this paper. The Section 5 draws the results, the Section 6 discusses, and the Section 7 draws the relevant conclusions and future prospects.The research framework of this paper is shown in Figure 1.

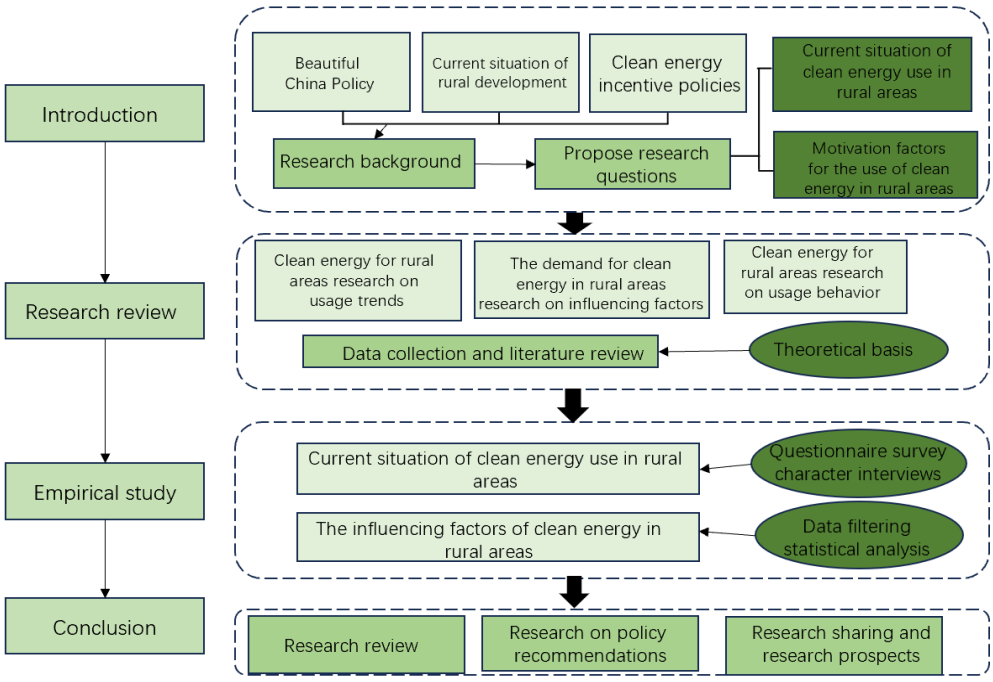


**Figure 1. Annual sales penetration rate of domestic new energy vehicles**

## Literature review

### *Rural clean energy policy*

Domestic scholars' research on rural clean energy policy mainly involves the policy content, implementation effect and optimization suggestions. The Chinese government attaches great importance to the development of rural clean energy and has introduced a series of policy measures. In the "13th Five-Year Plan" and the "Strategic Plan for Rural Revitalization (2018-2022)", the state clearly proposed to accelerate the construction of rural clean energy and optimize the energy structure. Local governments have also formulated corresponding implementation rules and supporting policies in light of the actual situation.

In terms of policy content, Kong et al (2013) pointed out that the development of rural clean energy needs financial support. Financial support for the development of rural clean energy can not only improve the rural living environment, make full use of rural bioenergy, but also save energy consumption for the country [11]. Xi (2018) to improve the village traffic conditions, improve the rural residents policy cognition, intensify pool policy and solar water heater policy, significantly reduce rural residents for clean energy support policy overall evaluation for the possibility of "dissatisfaction", increase the rural residents to clean energy support policy overall evaluation for the possibility of "satisfaction" [12]. Yao et al (2023) suggested to develop and utilize renewable energy in the form of "multi-energy complementarity" such as biomass energy, photovoltaic and solar hot water, play the driving role of pilot, summarize and accumulate successful experience that can be promoted, and cultivate a new green and low-carbon modern model of rural energy [13]. Fields (2023) believed that policy adjustments, increased wind power production, energy efficiency penetration, financial and investment security, development of storage

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technology, and improvements in power transmission and distribution should be prioritized [14]. Yin et al (2014) found that the main challenges in implementing the coal-to-clean energy policy in rural Beijing included difficulties in rural-urban areas, loose coal management, oversight of non-registered populations, unsustainable subsidies, and weak interaction between policy implementers and recipients [15]. Omri (2024) believed that clean energy policies and climate change legislation are relatively less effective in reducing carbon emissions [16].

In terms of the implementation effect, Shi (2017) found that the development and utilization of new clean energy not only facilitates the production and life of farmers, but also protects the ecological environment; it not only reduces the energy expenditure of farmers, but also increases the income of farmers [17]. Liu (2018) studied that the adoption of rural clean energy solved the non-point source pollution in the rural areas, promoted the construction of new countryside, improved the civilized quality of farmers, and developed the agricultural circular economy [18]. Xu (2021) used the grey correlation method based on the 2012-2018 Statistics. The results showed that the rural resident security policy in the rural clean energy policy has a great impact on the rural clean energy consumption [19]. Wang et al (2022) The clean energy policy promotes rural economic growth by improving relevant infrastructure construction, optimizing the rural energy consumption structure, and boosting the formation of new forms of business and new industries [20]. Li (2024) believed that further investment in the energy sector is necessary [21]. Lin (2024) believed that the increment of clean energy business significantly alleviates the capital constraints, while the stock of clean energy business does not produce this effect [22].

In terms of optimization suggestions, Xu et al (2011) pointed out that the centralized construction of clean energy must be included in the planning; strengthening publicity, education and clean energy training in rural areas [23]. In order to promote social development and effectively solve the problem of environmental pollution, Liu (2017) pointed out that we should carry out the clean energy training and education in rural areas, establish the rural clean energy system, strengthen the rural clean energy infrastructure, and increase the rural clean energy policy subsidies [24]. Wang (2019) proposed optimization suggestions: focusing on the development of biogas digester and solar new energy; building clean energy foundation according to the degree of development in different regions to promote the healthy development of local clean energy; and strengthening the concept of scientific and rational use of new clean energy in rural areas [25]. Zhang (2021) believed that the balance of energy structure and economic development, to achieve the sustainable development of China's economic environment [26]. Wang (2022) believed that strengthening close cooperation between existing multilateral initiative platforms for clean energy innovation to promote technological innovation will support the global goal of net zero emissions [27]. Li (2022) believed that strengthening environmental policies to encourage clean energy consumption as a practical solution to reduce carbon dioxide emissions to achieve China's carbon neutral goals [28]. Zhang (2023) believed that in order to achieve sustainable development, the concept of green cleaning should be implemented in the whole process of energy development [29]. Yin et al. (2024) recommended promoting clean energy in rural households by strengthening air

pollution control policies, supporting energy transitions through government assistance, and improving farmers' income and financial capacity to adopt clean energy solutions [30]. Liu (2024) believed that increasing the space for clean energy consumption, while taking various measures to make flexible transactions and increase the intensity of clean energy consumption [31]. Li et al. (2024) proposed the improvement of clean energy utilization in the process of the new rural construction [32].

To sum up, domestic and foreign scholars have carried out a lot of research on the rural clean energy policy, and achieved fruitful results. However, there are still some problems worth further discussion: first, how to better integrate rural clean energy policy with national strategies such as poverty alleviation and rural revitalization, how to improve the sustainability and long-term effectiveness of the policy; third, how to motivate farmers to participate in rural clean energy construction, and relatively few studies of the policy implementation, and study the welfare effect of rural clean energy adoption before and after the policy.

***Clean energy adoption effect in rural areas***

Reducing carbon emissions and increasing efficiency through clean energy in rural areas is an important means to achieve low-carbon development in rural areas, as well as an important measure to promote rural revitalization. By promoting the application of clean energy in rural areas, we can reduce reliance on traditional fossil fuels, reduce carbon emissions, improve energy utilization efficiency, and promote green and sustainable development of the rural economy.

In terms of the development status and trends of clean energy in rural areas, Fan et al (2018) pointed out that the growth rate of carbon emissions from per capita living energy consumption of rural residents is higher than that of urban areas and higher than the national average level [33]. In this context, China actively participates in the construction of global ecological civilization and promises to strive to achieve carbon peak before 2030 and carbon neutrality before 2060 [34]. Sun (2020) pointed out that in poverty-stricken areas in the central and western regions, residents still mainly rely on traditional energy consumption methods and cannot enjoy modern energy services [35]. Zhang et al (2022) pointed out that the proportion of carbon emissions in the agricultural sector to the total global carbon emissions has reached 13%. As a major agricultural country, China's agriculture is inevitably one of the important carbon sources focused on in the "dual carbon" goal [36]. Zhang (2023) pointed out that the transformation of clean energy consumption is an important link in promoting sustainable rural socio-economic development and achieving the "dual carbon" goals [37]. Later, after years of national policy tilt, rural areas in China fundamentally changed the long-standing pattern of cooking and heating energy dominated by firewood, and entered a situation where traditional energy and modern clean energy coexist. Luo (2023) pointed out that under the guidance of carbon peak and carbon neutrality goals, emerging industries such as clean energy in China have achieved rapid and comprehensive development [38]. Yin (2023) believed that the development of new energy production equipment in rural areas lags behind, leading to insufficient cleanliness in energy consumption. There is still a significant gap compared to the target requirements of agricultural and rural modernization [39]. Li (2024) believed that the application of clean energy can significantly improve the health status of rural women, and the positive health effects are significant for middle-aged and elderly women, illiterate women, and women living in the Northeast region [40]. Theresa (2024) believed that the use of clean

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fuels in rural households has strong feasibility and acceptability [41]. In terms of the carbon reduction effect of clean energy in rural areas, Fu (2020) believed that vigorously developing clean energy and the development of the Clean Energy Expo are of great significance for responding to the country's creation of spiritual civilization cities and strengthening environmental protection and governance [42]. Wang (2021) pointed out that the transformation of energy production structure contributes to the achievement of carbon peak goals [43]. Zhang et al (2021) proposed an evaluation index system that includes four dimensions: energy structure, energy efficiency, energy security, and energy prices. They compared and analyzed it with other major countries and found that China has achieved certain results in energy transformation, but there is still a significant gap in certain key indicators [44]. Lin et al (2023) believe that we should actively implement clean energy substitution and accelerate the research and development of green and low-carbon key technologies and equipment in the energy field [45]. Wang (2023) believed that energy conservation and environmental protection expenditures have a positive impact on the synergistic efficiency of pollution reduction and carbon reduction, especially in developing economies [46]. Huang et al. (2024) argue that the popularization of low-carbon energy plays a crucial role in the development of developing countries [47]. Xian (2024) believed that achieving the synergistic effect of reducing carbon emissions and air pollution is the key to promoting green development of China's economy and society [48].

Numerous literature studies have shown that the promotion and application of clean energy in rural areas can significantly reduce carbon emissions in rural areas. Traditional methods such as burning coal and firewood generate a large amount of greenhouse gases such as carbon dioxide. The utilization of clean energy in rural areas can reduce the emissions of these greenhouse gases, lower carbon emissions in rural areas, and contribute to mitigating global climate change.

In terms of enhancing the efficiency of clean energy in rural areas, Sun (2018) believed that the development of clean energy in rural areas is conducive to adjusting the energy structure and improving environmental quality [49]. Li et al (2024) believe that the rural energy revolution is conducive to accelerating the clean and low-carbon transformation of energy in rural areas and achieving high-quality development of rural energy [50]. Based on comprehensive literature, the utilization of clean energy in rural areas not only has environmental significance, but also has economic benefits. Wei (2024) believed that optimizing industrial clean energy scheduling under the "dual carbon" goal has become a key element in industrial development [51]. Adao et al. (2024) argues that clean energy has a dual marginal effect on $CO_2$ emissions and economic growth [52]. Yang (2024) believed that the low emission characteristics of green hydrogen can reduce financial costs [53]. Wang (2024) believed that clean energy is an important growth pole of global energy production and consumption, and relevant discourse has subsequently become an important carrier of national cultural soft power and international discourse power [54].

In summary, the literature review on carbon reduction and efficiency enhancement of clean energy in rural areas indicates that the development of clean energy in rural areas is of great significance for mitigating climate change and promoting sustainable rural economic development. The government and enterprises should

increase investment in the research and development, promotion, and application of clean energy technologies in rural areas, while strengthening policy guidance and publicity education, improving farmers' environmental awareness and participation, and jointly promoting the sustainable development of clean energy in rural areas.

## Research framework and hypothesis

### *Research framework*

The development of clean energy in rural areas can be approached from the perspectives of farmer health status, rural carbon emissions, rural energy utilization efficiency, farmer production and living costs, and their interrelationships [19]. Multiple solutions can also be provided from the perspective of sustainable development capabilities. Due to its flexibility and plasticity, it provides ideas for the transition of rural clean energy development from a short-term static model to a long-term dynamic trend. This article examines the improvement of rural and farmer living conditions under the background of clean energy in rural areas within a dynamic sustainable development framework, and constructs a corresponding analytical framework (as shown in Figure2).

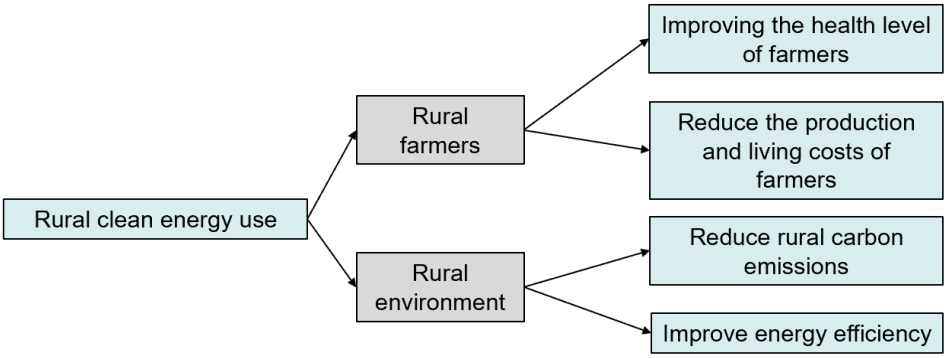


**Figure 2. Study pathways**

This article combines existing research results and defines the development of clean energy in rural areas as the health status of farmers, rural carbon emissions, rural energy use efficiency, and the combination of clean energy use. It comprehensively examines the positive impact of rural clean energy development on the improvement of farmers' living standards. Firstly, the promotion and use of clean energy in rural areas can improve the energy consumption structure of farmers, reduce dependence on traditional energy, improve energy utilization efficiency, reduce energy expenditure, and thereby increase the economic benefits of farmers. Secondly, the development of clean energy in rural areas can also improve the quality of life of farmers. With the popularization of clean energy in rural areas, the living environment of farmers has been improved, reducing the emissions of pollutants generated by traditional energy combustion and improving the health level of farmers. At the same time, the use of clean energy in rural areas has also brought many conveniences, such as solar water heaters, biogas stoves, etc., providing farmers with safer and more convenient energy services. In addition, the development of clean energy in rural areas can also promote the development of rural economy. The development of rural clean energy industry can drive the development of related industrial chains, create more employment opportunities, and promote the growth of rural economy [23]. Farmers can participate in

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the clean energy industry and obtain more economic benefits, thereby improving their living standards.

The development strategy of clean energy in rural areas requires the joint efforts of the government, enterprises, and various sectors of society, starting from multiple aspects such as policy, technology, market, infrastructure, and industrial synergy, to promote the rapid development of clean energy in rural areas. Specific development strategies can be approached from the following aspects: Firstly, policy support: The government should increase its support for the development of clean energy in rural areas, formulate relevant policies, such as financial subsidies, tax reductions, etc., and encourage farmers and enterprises to participate in the development and utilization of clean energy. Secondly, technological innovation: Strengthen the research and innovation of clean energy technologies in rural areas, improve technological level and application effectiveness, reduce the development cost of clean energy, and promote the popularization and application of clean energy [25]. Thirdly, market promotion: By means of publicity, demonstration, and promotion, we aim to increase the market awareness and acceptance of clean energy in rural areas, guide farmers and enterprises to actively adopt clean energy, and create a good market atmosphere. Fourthly, infrastructure construction: Strengthen the construction of clean energy infrastructure in rural areas, such as power grids, gas networks, biogas digesters, etc., improve the transmission, distribution, and storage capacity of energy, and ensure the stable supply of clean energy. Fifth, industrial synergy: promote the coordinated development of the rural clean energy industry with other industries, form a complete industrial chain and cluster, and enhance the competitiveness and sustainable development ability of the industry.

### *Research hypothesis*

*The impact of rural clean energy development on the health status of farmers*

The impact of clean energy development in rural areas on the health status of farmers is mainly reflected in the following aspects: Firstly, reducing indoor air pollution: Traditional rural energy use methods, such as burning coal, wood, etc., will produce a large amount of indoor air pollution, including harmful substances such as smoke and carbon monoxide. Long term exposure to such an environment can easily lead to health problems such as respiratory diseases and eye diseases for farmers [26]. Clean energy sources, such as biomass and solar energy, do not produce or produce fewer pollutants during use, which helps improve indoor air quality and protect the respiratory health of farmers. Secondly, reducing environmental pollution and health risks: The development of clean energy helps to reduce the use of fossil fuels, thereby reducing greenhouse gas emissions and environmental pollution. This is crucial for improving the overall environmental quality and ecosystem health in rural areas. A clean environment is not only beneficial to the physical health of farmers, but also helps to improve the quality and yield of agricultural production. Thirdly, promoting public health improvement: The promotion and application of clean energy can also drive the improvement of infrastructure in rural areas, such as power grid upgrading and road construction.

The improvement of these infrastructure helps to enhance the public health level in rural areas, such as improving water supply, drainage, garbage disposal, etc., and reducing the risk of disease transmission [31]. Fourthly, improving the quality of life and health awareness of farmers: The use of clean energy can provide farmers with more convenient, efficient, and

environmentally friendly living services, such as solar water heaters, biomass energy cookstoves, etc. This not only improves the quality of life for farmers, but also helps to raise their health awareness, making them more concerned about their own health and environmental protection.

In summary, the development of clean energy in rural areas has a positive impact on the health status of farmers. By reducing indoor air pollution, reducing environmental pollution and health risks, promoting public health improvement, and enhancing the quality of life and health awareness of farmers, clean energy can help improve the health status of farmers and enhance their quality of life. Based on this, we propose the hypothesis:

**H1:** The development of clean energy in rural areas has a positive promoting effect on the health status of farmers.

*The impact of rural clean energy development on rural carbon emissions*

The development of clean energy in rural areas has a significant impact on rural carbon emissions. With the promotion and application of clean energy in rural areas, carbon emissions in rural areas are expected to gradually decrease. Firstly, the development of clean energy in rural areas helps to reduce dependence on fossil fuels, thereby reducing carbon emissions. For example, using renewable energy sources such as solar, wind, and biomass for power generation, heating, and cooking can significantly reduce the consumption of fossil fuels. Secondly, the development of clean energy in rural areas can also promote the resource utilization of waste. For example, the fermentation of biogas can purify some organic waste and reduce greenhouse gas emissions such as methane; Waste such as straw and animal manure can also be converted into renewable energy through technologies such as biomass energy, reducing dependence on fossil fuels and reducing carbon emissions [55]. In addition, the development of clean energy in rural areas can also promote the optimization and transformation of rural economic structure. Traditional agricultural production and rural lifestyle rely heavily on fossil fuels, while the development of clean energy can promote the green transformation of rural economy and promote its development towards a more environmentally friendly and low-carbon direction. The development of clean energy in rural areas is of great significance for promoting green and low-carbon development, achieving carbon peak and carbon neutrality goals. Through policy guidance, technological innovation, and market mechanisms, the pace of rural clean energy development can be further accelerated, injecting new impetus into the sustainable development of rural areas [56]. Based on the above theoretical analysis, we propose a hypothesis:

**H2:** Rural clean energy development reduces rural carbon emissions.

*The impact of rural clean energy development on rural energy use efficiency*

With the promotion and application of clean energy in rural areas, the development of clean energy in rural areas has a significant impact on the efficiency of rural energy use. Firstly, improving energy utilization efficiency: Clean energy sources such as solar energy, wind energy, biomass energy, etc. typically have higher energy conversion efficiency. For example, solar photovoltaic cells can directly convert sunlight into electricity, while wind turbines can use wind energy to drive turbines to generate electricity. These clean energy technologies have higher energy utilization efficiency compared to traditional fossil fuel combustion methods, thereby helping to reduce energy waste [32]. Secondly, optimizing energy structure: The promotion and application of clean energy can promote the development of energy structure in rural areas towards greater diversification and cleanliness. The proportion of traditional

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fossil fuels such as coal and diesel in the energy structure is gradually decreasing, while the proportion of clean energy is gradually increasing, which helps to optimize the energy structure and improve energy efficiency. Thirdly, promoting technological progress and industrial upgrading: The development of clean energy relies on advanced technology and equipment, which can promote technological progress and industrial upgrading in rural areas. With the continuous development and improvement of clean energy technology, energy facilities and equipment in rural areas will also be constantly updated and upgraded, thereby improving energy efficiency. Finally, improving the quality of life for residents: The use of clean energy can not only reduce environmental pollution, but also improve the quality of life for rural residents [45]. For example, clean energy equipment such as solar water heaters and biomass cooking stoves can provide more convenient, efficient, and environmentally friendly living services for rural residents, improving their living conditions. The development of clean energy in rural areas promotes the optimization and transformation of rural economic structure. Traditional agricultural production and rural lifestyle rely heavily on fossil fuels, while the development of clean energy can promote the green transformation of rural economy and promote its development towards a more environmentally friendly and efficient direction. Based on the above theoretical analysis, we propose a hypothesis:

**H3:** The development of clean energy in rural areas can improve the efficiency of rural energy use.

*The cost-reduction effect of clean energy development in rural areas*

The development of clean energy in rural areas has a multifaceted impact on the production and living costs of farmers. Firstly, reducing living costs: The promotion and use of clean energy such as solar energy and biomass energy in rural areas can provide farmers with clean and efficient energy supply methods, reducing their dependence on traditional fossil fuels. In this way, farmers can reduce the cost of purchasing fuels such as coal and diesel, thereby lowering their living costs. Secondly, reducing agricultural production costs: the application of clean energy can also reduce agricultural production costs. For example, using biomass energy for greenhouse heating, irrigation and other agricultural production activities can reduce dependence on traditional electricity and lower electricity bills [57]. Meanwhile, the comprehensive application of by-products such as biogas, biogas slurry, and biogas residue can improve crop yield and quality, further reducing agricultural production costs. Thirdly, improving energy utilization efficiency: Clean energy typically has higher energy conversion and utilization efficiency, which means farmers can access more energy services without consuming more energy resources. This can not only reduce energy costs, but also help improve the quality of life and production efficiency of farmers. Fourthly, promoting rural economic development: The development of clean energy in rural areas can also drive the development of related industries, such as the manufacturing, installation, and maintenance of clean energy equipment. This will provide more employment opportunities and sources of income for farmers, promoting the development of rural economy.

In summary, the development of clean energy in rural areas can reduce the livelihoods of farmers. Production and living costs, farmers can better utilize clean energy, reduce production and living costs, and improve quality of life. Based on the above theoretical analysis, we propose a hypothesis:

**H4:** The development of clean energy in rural areas has a reducing effect on the living costs of rural residents.

## Methodology

### *Study area and data overview*

*Research area*

In order to analyze the impact of clean energy use in rural areas and the regional differences, this paper selects the areas with different geomorphic features and whether clean energy is popularized as the research area. Starting from the plain and hill, the hilly area in this study is located in a province in southern China, with an altitude between 500 meters and 1000 meters, and the mountains are east-west. The region belongs to the subtropical monsoon climate, with four distinct seasons and the same rainy season. It is hot and rainy in summer, and mild and less rainy in winter. This climate feature has a certain impact on the utilization of solar energy and wind energy. Rural residents in hilly areas mainly rely on traditional biomass energy sources, such as wood, straw, etc. With the improvement of living standards, the demand for clean energy is growing. The plain area in this study is located in the eastern coast of China, with flat terrain, low altitude and convenient transportation. The region has a temperate monsoon climate with four distinct seasons, hot and rainy summer and cold and dry winter. The wind speed and light conditions in the plain areas are relatively good, which is conducive to the utilization of clean energy.

There are significant differences in rural energy use and the implementation of clean energy policies between hills and plain areas. In hilly areas, the implementation of clean energy policies lags behind. Policy publicity and promotion are not enough, and farmers' awareness of clean energy is low. In plain areas, the implementation of clean energy policies is relatively effective. The government has increased the publicity and promotion of clean energy, and improved the farmers' awareness of clean energy. Farmers in mountainous areas and plain areas before and after the use of clean energy were selected as the survey objects to investigate the impact of the use of clean energy on rural "farmers' health", "rural carbon emissions", "rural energy use efficiency" and "farmers' cost of production and living".

*Data profile*

The research data from the clean energy questionnaire using questionnaire survey, in order to ensure the comparability of the countryside, the change of the use of the questionnaire survey, according to the needs of the research, the survey sample is divided into clean energy use area and unused area samples, then will use the sample area is divided into plain samples and hill samples. A total of 2408 sample questionnaires were issued. The average answer of the respondents of this questionnaire was 6 minutes. If the answer of a questionnaire was less than 2 minutes and more than 10 minutes, we think that the questionnaire was not answered under the rational situation of the respondents. We set the questionnaire with less than 2 minutes and more than 10 minutes as invalid questionnaires, so 1992 valid sample questionnaires were recovered with an efficiency of 82.7%. Among them, 1368 valid sample questionnaires in the area and 624 without clean energy. Among the 1368 valid sample questionnaires in the area, 1512 were plain samples and 216 mountain samples. Before data processing, the reliability and validity of the survey data were tested by SPSS software, and the results showed that Cronbach's α value was 0.942, indicating that the reliability of sample data is acceptable; KMO value is 0.929, and Bartlett spherical test significance level value is 0.000, which passed the validity test, indicating that the sample data

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has high correlation between them and has good structural validity.

Among the 1512 questionnaires in the plain, natural gas accounted for 59.26% for heating, 10.58% for air conditioning for heating, clean coal for 3.70%, ordinary coal for 4.74%, and electric heat pumps for 2.65%. Among the 216 questionnaires in mountainous areas, 15% used natural gas for heating, 10% used air conditioning for heating, 16.67% clean coal for heating, 31.67% ordinary coal, and 1.67% electric heat pumps. Among the 1,368 questionnaires that use clean energy, 36.51%, the use of clean energy can improve 36.51%, the use of clean energy by 17.46%, the use of clean energy by 20.11%, the use of clean energy can reduce carbon emissions by 32.27%, and the use of clean energy can improve the health of rural areas by 24.87%.

***Analytical method and variable setting***

*Analytic technique*

In order to investigate the impact of rural clean energy use on farmers' health, rural carbon emissions, rural energy use efficiency, and farmers' production and living costs, the DID model is used to test the relationship between rural clean energy use and farmers on the basis of controlling local characteristics. The use of DID models suffers from sample selection problems, namely, policies may be endogenous, leading to non-consistent estimation results. In econometrics, the following three methods are mainly used to solve the problem: one is to ignore the problem, to admit biased and inconsistent estimation results; the other is to find unobserved variables and use the appropriate proxy variables are not easy to find; the third is to assume that the missing variable is non-temporal variable, the fixed effect method or first-order difference method can be adopted. This paper uses the third method.

The measurement formula of the double difference method is as follows:

$$Y_{it} = \alpha + \beta \cdot Z_{it} + \gamma X_{it} + \mu_t + v_t + \varepsilon_{it} \quad (1)$$

Formula (1): $Y_{it}$ is the explained variable of farmer i in year t; $Z_{it}$ shows whether farmer i is involved in clean energy system reform in year t, If involved, Then $Z_{it}$ = 1, otherwise, $Z_{it}$ =0, $X_{it}$ It means that other covariates affecting farmers' health, rural carbon emissions, rural energy use efficiency, personal characteristics, family characteristics and location characteristics, Including regional fixed utility value, respondent age, school age, occupation, family population, e-commerce popularization in the area, local garbage classification, etc.; $\mu_t$ and $v_t$ indicate fixed effect of farmers and time fixed effect respectively; $\varepsilon_{it}$ is a random disturbance item; α, β, γ Is the parameter to be estimated, Where β is the most predominant parameter, It can reflect the impact of clean energy reform on farmers' health, rural carbon emissions, rural energy use efficiency, and farmers' production and living costs.

When using the double difference method, the experimental group dummy variable treated is generally set according to whether the policy is affected, and a group affected by the policy is taken as the experimental group, with a value of 1 and a value of 0 to the control group. At the same time, the experimental stage virtual variable period is set successively according to the time of the policy implementation, and the period in the year and after the policy implementation is 1, and the period before the policy implementation is 0. Accordingly, the samples can be divided into four groups: the control group before the policy implementation (treated=0, period=0), the

control group after the policy implementation (treated=0, period=1), the experimental group before the policy implementation (treated=1, period=0), and the experimental group after the policy implementation (treated=1, period=1). Among them, the interaction term treated period of the two virtual variables of experimental grouping and experimental stage is the net effect of the policy implementation.

*Variable settings*

This paper is interpreted variables are "farmers' health", "rural carbon emissions", "rural energy efficiency", "farmers living cost", and for virtual variable, "completely disagree" value is 1, "not agree" value is 2, "general" value is 3, "comparison agree" value is 4, "fully agree" value is 5. To test the effect of the use of clean energy on the explained variables, we also set four covariates: personal characteristic variables, family characteristic variables, regional environmental variables, and reform time variables. The related variables are explained in Table 1.

**Table 1.Variables interpretation**

| Type of variable | Variable quantity | Variable interpretation |
|---|---|---|
| A:Dependent variable | A1:Rural health status | 1. Complete disagree; 2. Disagree; 3. General; 4. Comparative agree; 5. Complete agree |
| | A2:Rural emissions | 1. Complete disagree; 2. Disagree; 3. General; 4. Comparative agree; 5. Complete agree |
| | A3:Rural energy use efficiency | 1. Complete disagree; 2. Disagree; 3. General; 4. Comparative agree; 5. Complete agree |
| | A4: Farmers' production and living costs | 1. Complete disagree; 2. Disagree; 3. General; 4. Comparative agree; 5. Complete agree |
| B:Personal characteristic variables | B1: Gender | 1. Male; 2. Female |
| | B2: Age | One full year of life |
| | B3:Educational level | 1. Primary school or below; 2. Junior high school; 3. Senior high school; 4. Junior college or above |
| | B4: Career | 1. Agriculture; 2. Work; 3. Individual operation income; 4. Teachers and cadres; 5. Civil servants |
| C:Family characteristic variables | C1:Number of family migrant workers | 1. None; 2.1; 3.2; 4.3 or more |
| | C2:Family housing area | 1.60 m 2 and below; 2.61-90 m 2; 3.91-120 m 2; 4.121 m 2 and above |
| D:Regional environment variable | D1: Region | 1. Plain; 2. Mountain area |
| | D2:Popularization of regional e-commerce | 1. Not universal; 2. Partially universal; 3. Fully universal |
| | D3: Open burning of straw in the place | 1. Common; 2. Existing but not common; 3. Little; 4. Not understanding |
| E:Reform the time variable | E1:The convenience of the clean energy policy situation | 1. Complete disagree; 2. Disagree; 3. General; 4. Comparative agree; 5. Complete agree |
| | E2:Whether to use clean energy sources | 1. Yes; 2. No |

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## Results

### *Descriptive statistical analysis*

The descriptive statistics of the clean energy adoption of the selected overall sample are shown in Table 2 below.

Can be seen from table 2 for rural clean energy adopted can improve health, reduce carbon emissions, improve energy efficiency in rural areas, reduce the average cost of rural production and living, respectively 3.83,4.01,3.70,3.42, prefer to compare agree, that rural clean energy adopted to improve health, rural carbon emissions, improve energy efficiency in rural areas, reduce the cost of rural production and living impact.

**Table 2. Descriptive statistics for the main variables**

| Variable quantity | Average value | Standard error | Maximum | Minimum |
|---|---|---|---|---|
| A1 | 3.83 | 0.020 | 5 | 1 |
| A2 | 4.01 | 0.020 | 5 | 1 |
| A3 | 3.70 | 0.021 | 5 | 1 |
| A4 | 3.42 | 0.025 | 5 | 1 |
| B1 | 1.79 | 0.009 | 2 | 1 |
| B2 | 1.75 | 0.015 | 4 | 1 |
| B3 | 3.56 | 0.018 | 4 | 1 |
| B4 | 2.30 | 0.029 | 6 | 1 |
| C1 | 1.98 | 0.022 | 4 | 1 |
| C2 | 2.92 | 0.019 | 4 | 1 |
| D1 | 0.76 | 0.010 | 1 | 0 |
| D2 | 1.98 | 0.013 | 3 | 1 |
| D3 | 2.82 | 0.015 | 4 | 1 |
| E1 | 3.76 | 0.019 | 5 | 1 |
| E2 | 0.69 | 0.010 | 1 | 0 |

### ***Analysis of the double difference results***

According to the above theoretical assumptions, this study used the double difference estimation of farmers' health status, rural carbon emissions, the effect of rural energy use efficiency, and farmers' production and living cost as explained variables before and after farmers using clean energy.

*The impact of rural clean energy development on rural farmers*

(1) The impact of clean energy development in rural areas on the health status of farmers.

**Table 3. Results of double differential estimates of farmers' health status by clean energy adoption**

| Clean energy adoption | Item | Effect value<br>Health status of farmers | P |
|---|---|---|---|
| Before using | Control group | 1.969 | |
| | Experimental group | 2.047 | 0.268 |
| | Diff | 0.078 | |
| After using | Control group | 1.760 | |
| | Experimental group | 1.954 | 0.003** |
| | Diff | 0.194 | |
| Diff-in-Diff | | 0.115 | 0.189 |

*Note:* indicates significant at a significance level of 0.05 ,* * significant at a significance level of 0.01 and * * * significant at a significance level of 0.001.*

It can be concluded from Table 3 that, the effect value of the double difference did not present a significance, The empirical analysis showed that, Clean energy adoption has no significant impact on farmers' health status, Before the use of clean energy in rural areas, Differential effect size of the experimental and control group was 0.078, And did not show a significance, There was no statistically significant difference between the experimental group and the control group, The difference effect size between the experimental and control group before clean energy adoption was 0.194, After the adoption of clean energy, the difference between the experimental group and the control group expanded by 2.49 times, However, the double difference results between the experimental group and the control group were not significant, This shows that the adoption of clean energy has no significant impact on the health of farmers, Rural clean energy can improve farmers' health by 11.5 percent, The effects were not particularly significant, Negative version of the null hypothesis, H1 is not valid. In theory, the adoption of clean energy in rural areas should have a positive impact on the health status of farmers, because the use of clean energy can reduce pollutant emissions, reduce air pollution and indoor air pollution, thus improving the living environment and health status of farmers. However, in this paper, the impact of rural clean energy adoption on rural health may not be significant, but there may be the following reasons: the proportion of clean energy used is not high. Although the clean energy resources are rich in rural areas, the proportion of clean energy use in rural areas may not be high due to technical, economic and other reasons. Farmers may still rely on traditional energy sources such as coal and wood, which will produce certain pollutants and threaten their health; some farmers may lack health awareness of the importance of clean energy. They may be more concerned with the economics of energy than environmental protection, thus ignoring the health impact of the use of clean energy, which can reduce the emission of some pollutants, but cannot completely solve all health problems.

(2) The impact of clean energy development in rural areas on the production and living costs of farmers.

**Table 4. Results of double differential estimates of production and living costs for farmers**

| Clean energy adoption | Item | Effect value Rural energy use efficiency | Standard error | t | p |
|---|---|---|---|---|---|
| Before using | Control group | 2.758 | | | |
| | Experimental group | 3.263 | 0.081 | 6.226 | 0.000** |
| | Diff | 0.505 | | | |
| After using | Control group | 3.143 | | | |
| | Experimental group | 3.209 | 0.074 | 0.895 | 0.371 |
| | Diff | 0.066 | | | |
| Diff-in-Diff | | -0.439 | 0.100 | -4.369 | 0.000** |

*Note:* indicates significant at a significance level of 0.05, * * significant at a significance level of 0.01 and * * * significant at a significance level of 0.001.*

From Table 4, The effect value of the double difference showed significance, The empirical analysis showed that, The adoption of clean energy in rural areas has a significant impact on reducing the working and living costs of farmers, The two-fold difference effect value was-0.439, We will

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increase farmers' income by 43.9 percent of the energy used for production and living purposes, It also shows that the impact of clean energy adoption has a negative impact on rural carbon emissions, Before the adoption of clean energy, The differential effect size between the experimental and control group was 0.505, After the adoption of clean energy, The differential effect value between the experimental group and the control group was 0.066, The P-value is less than 0.05, Explain that the hypothesis H4 holds, Clean energy in rural areas can reduce farmers' working and living costs of energy, Rural areas usually rely on traditional biomass energy sources (such as wood, straw, etc.) or fossil energy sources (such as coal, diesel oil, etc.) for production and living, These energy sources are not only more expensive to obtain, And in the process of use may produce environmental pollution.

The adoption of clean energy can reduce the dependence on these traditional energy sources, thus reducing the cost of energy access and environmental governance; in order to encourage the development of clean energy, many countries and regions have introduced relevant policy support and subsidy measures, which can reduce the purchase cost of clean energy equipment and thus further reduce the cost of production and living expenses in rural areas. The adoption of clean energy in rural areas reduces the cost of production and living in rural areas by improving energy efficiency, reducing dependence on traditional energy sources, reducing maintenance costs, and obtaining policy support and subsidies. This will not only help to improve the economic situation in rural areas, but also to promote the promotion and sustainable development of clean energy. Therefore, theoretically and in this paper, the use of clean energy in rural areas has a significant impact on reducing the production and living costs of farmers.

*The impact of rural clean energy development on the rural environment*

(1) The impact of rural clean energy development on rural energy use efficiency.

**Table 5. Results of dual differential estimates of clean energy adoption for rural energy use efficiency**

| Clean energy adoption | Item | Effect value<br>Rural energy use efficiency | Standard error | t | p |
|---|---|---|---|---|---|
| Before using | Control group | 2.520 | | | |
| | Experimental group | 2.857 | 0.100 | 3.380 | 0.001** |
| | Diff | 0.337 | | | |
| After using | Control group | 2.699 | | | |
| | Experimental group | 2.903 | 0.091 | 2.235 | 0.026* |
| | Diff | 0.203 | | | |
| Diff-in-Diff | | -0.133 | 0.123 | -1.082 | 0.280 |

*Note:* indicates significant at a significance level of 0.05, * * significant at a significance level of 0.01 and * * * significant at a significance level of 0.001.*

From Table 5, The dual difference model has an adjoint probability P-value of 0.280, Greater than 0.05, So the effect value did not show a significance, The empirical analysis showed that, The impact of clean energy adoption on improving rural energy

efficiency is not significant, Before the use of clean energy in rural areas, A Diff effect value of 0.337> 0 and showed a 1% level of significance, It means that the effect value of the experimental group is significantly higher than that of the control group; After using clean energy in rural areas, A Diff effect value of 0.203> 0 and showed a 5% level of significance, Memeans that the effect value of the experimental group is significantly higher than the control group, However, the double difference effect value (Diff-in-Diff) is-0.133, Did not show significance (p> 0.05), It shows that clean energy adoption does not have a significant impact on improving the efficiency of rural energy use, Negative version of the null hypothesis, The H3 is not valid. In theory, the adoption of clean energy is beneficial to improve the efficiency of rural energy use, but the results of the empirical analysis, the possible reasons: although rural clean energy gradually popular in rural areas, but not every household installed clean energy, which result from the overall analysis of the sample, not all used clean energy, cognitive and analysis deviation; in addition, although the traditional energy is not friendly to the environment, but want to achieve the same effect, clean energy needs more than the traditional energy, which may also be one of the reasons for the analysis is not significant. (2) The impact of rural clean energy development on rural carbon emissions.

**Table 6. Results of dual differential estimates of rural carbon emissions from clean energy adoption**

| Clean energy adoption | Item | Effect value<br>Rural carbon emissions | P |
|---|---|---|---|
| Before using | Control group | 3.235 | |
| | Experimental group | 3.845 | 0.000** |
| | Diff | 0.610 | |
| After using | Control group | 3.517 | |
| | Experimental group | 3.796 | 0.000** |
| | Diff | 0.280 | |
| Diff-in-Diff | | -0.330 | 0.000* |

*Note:* indicates significant at a significance level of 0.05, * * significant at a significance level of 0.01 and * * * significant at a significance level of 0.001.*

From table 6, the double difference effect value is significant, empirical analysis shows that the rural clean energy adoption for rural carbon emissions, double difference effect value of 0.330, also shows the clean energy adoption for rural carbon emissions is negative influence, clean energy adoption, the difference effect size of 0.610, clean energy adoption, the experimental group difference effect value of 0.280, and present significant influence, that the original hypothesis, H2, rural clean energy development to reduce rural carbon emissions. The development of rural clean energy to reduce rural carbon emissions is mainly through the replacement of traditional fossil fuels. Traditional rural energy mainly relies on fossil fuels such as coal and firewood, which will produce large amounts of carbon dioxide and other greenhouse gases, while clean energy such as solar energy and wind energy do not produce carbon emissions, so it can effectively replace fossil fuels and reduce rural carbon emissions. In addition, when rural clean energy projects are successful, they can also produce demonstration effect, driving the development of clean energy and reducing carbon emissions in surrounding areas and even wider areas.

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## Discussion

### *Impact of regional differences on clean energy adoption*

The above content from the farmers' health, rural carbon emissions, rural energy efficiency, farmers' production and living cost of four Angle analyzes the influence of the rural clean energy after use, however, for the experiment group on the basis of regional variables, we try to do further discussion, study the use of clean energy in different areas is different.

**Table 7. Cross-analysis results of clean energy use in different regions**

| Title | Apellation | Clean energy use status of (%) | | Total | $X^2$ | P |
|---|---|---|---|---|---|---|
| | | Unused | Used | | | |
| Area | Mountain area | 264(42.31) | 216(15.79) | 480(24.10) | | |
| | Plain | 360(57.69) | 1152(84.21) | 1512(75.90) | 164.761 | 0.000** |
| Total | | 624 | 1368 | 1992 | | |

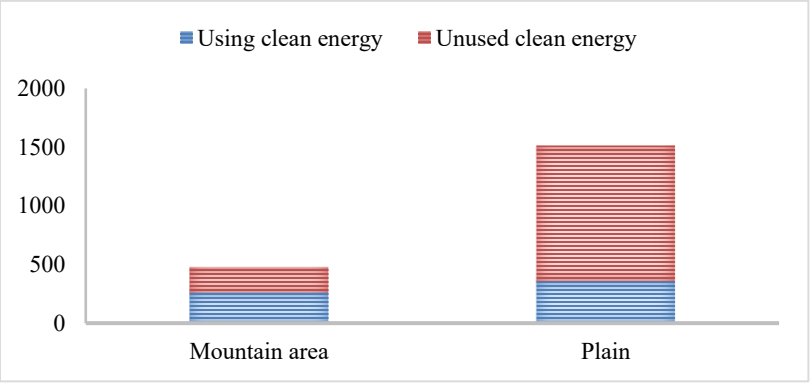


**Figure 3. Clean energy use status in different regions**

From Table 7 and Figure 3, we can clearly see that the use of clean energy is significant at 0.01 (chi=164.761, p=0.000 <0.01). According to the percentage difference, the proportion of clean energy in mountainous areas (57.69%) is much lower than that in plain areas (84.21%). In the plain area, the utilization rate of traditional energy is reduced to 15.79%. Therefore, the samples of clean energy usage show significant differences in all the regions. Therefore, when the state issues clean energy policies in the future, it can appropriately tilt to mountainous areas and increase publicity, so that people in mountainous areas can have more understanding of clean energy and improve the enthusiasm of people in plain areas for the use of clean energy.

### *Impact of occupational differences on clean energy adoption*

According to the above analysis, different regions may lead to differences in the willingness to adopt clean energy. However, in this survey, we also classified the occupations of the investigators. This section discusses whether the different occupations of the respondents will affect their willingness to adopt clean energy.

**Table 8. Impact of occupational differences on clean energy adoption in mountain areas**

| Title | Apellation | The main source of family income | | | | Total | $X^2$ | P |
|---|---|---|---|---|---|---|---|---|
| | | Throw in labour force | Agriculture | Individual operation | Public officer | | | |
| Clean energy adoption | Not adopted | 72 | 144 | 16 | 8 | 240 | 26.423 | 0.000*** |
| | Adopted | 96 | 88 | 8 | 24 | 216 | | |
| Total | | 168 | 232 | 24 | 32 | 456 | | |

**Table 9. Impact of occupational differences on clean energy adoption in the plains**

| Title | Apellation | The main source of family income | | | | Total | $X^2$ | P |
|---|---|---|---|---|---|---|---|---|
| | | Throw in labour force | Agriculture | Individual operation | Public officer | | | |
| Clean energy adoption | Not adopted | 120 | 136 | 48 | 56 | 360 | 24.256 | 0.000*** |
| | Adopted | 288 | 424 | 264 | 120 | 1096 | | |
| Total | | 408 | 560 | 312 | 176 | 1456 | | |

As can be seen from Table 8 and Table 9, the number of mountain residents who not adopt clean energy is more than those adopted, but in the working families, more than those adopted. This is likely due to the willingness to adopt clean energy in the plain area is not affected by occupational differences, which indicates that residents in plain area widely accept and recognize clean energy. In general, the difference of occupation has no significant impact on the plain residents, but for the mountainous area residents, the migrant work can make them know the energy use situation different from that in the region, and thus promote the development of clean energy.

***Impact of e-commerce popularization on clean energy adoption in different regions***

In addition to different areas in different regions do classification analysis, also considering the rural e-commerce popularity may have certain influence on clean energy adoption, therefore, the popularity of electronic commerce is divided into no popularization, partial popularity and fully universal three levels, discusses the popularity of electronic commerce and clean energy adoption will cross influence.

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**Table 10. The impact of the popularity of e-commerce in mountainous areas on the willingness to adopt clean energy**

| Title | Apellation | Popularization of e-commerce in mountainous areas | | | Total | $X^2$ | P |
|---|---|---|---|---|---|---|---|
| | | Full popularity | Part of the popularization | No popularization | | | |
| Clean energy adoption | Not adopted | 72 | 160 | 32 | 264 | 7.25 | 0.000*** |
| | Adopted | 40 | 136 | 40 | 216 | | |
| Total | | 112 | 296 | 72 | 480 | | |

**Table 11. Impact of e-commerce popularization on the willingness to adopt clean energy**

| Title | Apellation | Plain e-commerce popularization situation | | | Total | $X^2$ | P |
|---|---|---|---|---|---|---|---|
| | | Full popularity | Part of the popularization | No popularization | | | |
| Clean energy adoption | Not adopted | 96 | 208 | 56 | 360 | 42.308 | 0.000*** |
| | Adopt | 144 | 824 | 184 | 1152 | | |
| Total | | 240 | 1032 | 240 | 1512 | | |

From the cross-analysis of Table 10 and Table 11, the popularity of e-commerce in plain areas has a positive effect on clean adoption, the result of the adoption of clean energy, the conclusion that the popularization of e-commerce in the rural areas is beneficial to farmers to realize the benefits of clean energy and promote the adoption of clean energy. In general, in the process of promoting the use of clean energy, e-commerce should be actively promoted, which has a guiding role for both mountainous and plain residents.

## Conclusion and future prospects

### *Conclusion*

In recent years, significant progress has been made in clean energy adoption in rural China. With the proposal of the national "dual carbon" goal in 2020, low-carbon development has attracted attention from all sectors of society.

As an important application of new energy in the commercial field of trade, new energy logistics equipment is of great significance to the realization of carbon reduction in transportation. However, there are still some challenges and problems in the adoption of clean energy in rural China. On the one hand, the relatively backward economic development in rural areas and the imperfect infrastructure construction, which affect the promotion and application of clean energy; on the other hand, some farmers lack awareness of clean energy technologies and products, and need to strengthen publicity, education and training. Therefore, in view of the current situation and problems of clean energy development in China, this paper discusses and analyzes the adoption of clean energy in rural areas. By using a two-fold

differential model, It can be known that (1) the effect value of rural clean energy adoption on reducing the production and living costs of farmers is-0.439, This suggests that by using clean energy, It can increase the income of farmers' production and living energy consumption by 43.9%, and the effect value of rural clean energy adoption on rural carbon emissions is-0.330, It shows that the impact of clean energy adoption on rural carbon emissions has a negative impact. (2) At present, the impact of rural clean energy adoption on farmers' health status and the efficiency of rural energy use is not shown. In a further discussion, Using a cross-over analysis, We can also get the following conclusions: (3) the proportion of clean energy selected in mountainous areas (57.69%) is much lower than that in plain areas (84.21%), In the plain region, The utilization rate of traditional energy was reduced to 15.79%. (4) The difference in occupation has no significant effect on the plain residents, For the mountain residents, Migrant workers can help them about the different energy use in the region, To promote the development of clean energy; (5) The popularization of e-commerce in both plain areas and mountainous areas has a significant impact, More impact on plain areas than on mountainous areas, This tells us that in the process of clean energy, Should pay attention to the policy to the mountainous areas, Stimulate the enthusiasm of people in mountainous areas to use clean energy.

## *Implication*

*Theoretical implications*

In the process of analysis, this paper selects the double difference model as the empirical analysis model, and concludes that the development of rural clean energy has a positive impact on the health of farmers and the rural environment. Compared with the research of scholars such as Zhang Gongwang, In this paper, following progress in a double difference, Further classification analysis of different occupations and the popularity of rural e-commerce, Thus exploring that plain residents and mountain residents have a more positive attitude towards clean energy, The conclusion that mountain residents are conducive to promoting the use of clean energy and the development of e-commerce is conducive to the popularization of clean energy, Making this paper more extensive and comprehensive than that of previous scholars, Thus broadening the research perspective, Make the research scope more extensive, Research questions are much more practical, It provides ideas for the government to adopt different encouraging policies for the residents in different areas.

*Practical implications*

According to the study, the welfare effect brought by clean energy has a significant impact on the reduction of production and living costs for farmers, and has a significant impact on the reduction of carbon emissions in rural areas. Therefore, the degree of its influence should be amplified.

Suitable energy types and development models should be selected according to local conditions, and the role of combining government guidance and market mechanism should be played. The government can encourage farmers to use clean energy by providing economic incentives and policy support. For example, farmers using clean energy are given certain subsidies or tax incentives to reduce the cost of using clean energy. The development of rural clean energy to reduce costs, energy saving efficiency, reduce carbon emissions and improve farmers' happiness is of great significance, the government and society should increase support for the development of rural clean energy, to promote the popularization and application of clean energy, for rural clean energy adopted for

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farmers' health, rural energy efficiency is not significant, although clean energy technology in rural areas have a certain promotion, but due to the lack of technology popularization, farmers lack of knowledge and skills, lead to the use of clean energy efficiency and effect is limited; Farmers may have insufficient understanding and understanding of clean energy, and lack of relevant education and publicity. If farmers do not understand the advantages and importance of clean energy, they may not have been motivated enough to adopt and use these technologies. For the plain area, clean energy demonstration projects can be built to demonstrate the advantages and benefits of clean energy. Through the case promotion, farmers and residents can see the practical application effect of clean energy, enhance their confidence and willingness to adopt clean energy, increase the investment in the construction of clean energy infrastructure, and ensure that the plain areas have the conditions for clean energy supply. For mountainous areas, in view of the topographic characteristics of mountainous areas, clean energy technologies suitable for local conditions should be selected. For example, small wind power, micro-hydropower and biomass energy may be more suitable for mountainous areas. Also, consider the use of solar photovoltaic panels, especially in sunny areas; establish partnerships with the private sector to promote clean energy projects in mountainous areas. In the plains and mountainous areas, we should take targeted measures and adapt measures to local conditions to make farmers a better use of clean energy.

### *Limitations and future prospects*

In terms of data selection, the representativeness of the sample data in this paper needs to be further improved. For example, we should pay attention to the balance of male and female research and the proportion of all ages. Secondly, in terms of analysis, this paper does not classify and analysis according to different family income and different family backgrounds, or further discuss whether it is related to clean energy adoption intention in two aspects. Therefore, in future studies, more attention should be paid to the selection and classification of data to make the research more rigorous.

The future prospect of rural clean energy development can be said to be full of hope and challenges. First of all, rural areas are rich in clean energy resources, including wind, solar, biomass, etc., which are renewable and pollution-free resources with huge development potential. Secondly, with the increasingly serious global climate change and environmental problems, the development of clean energy has become a global consensus, which also provides a good external environment for the development of clean energy in rural areas.

However, in the process of the study, we also explored some challenges to the development of clean energy in rural areas. First of all, the infrastructure construction in rural areas is relatively backward, and the conditions of electricity and transportation are limited, which restricts the development of clean energy to some extent. Secondly, the research and development and application cost of clean energy technologies is high, which requires the support and investment of the government and all sectors of society. In addition, farmers' awareness and acceptance of clean energy also need to be further improved.

In view of the current situation and current problems of clean energy development in rural areas, this paper puts forward the following suggestions for the development of rural clean energy in the future:

First, technological innovation: with the continuous progress of science and technology, the cost of research and development and application of clean energy technologies will gradually reduce, and the efficiency will continue to improve. In the future, we can look forward to the more efficient and environmentally friendly application of clean energy technologies in rural areas.

Second, infrastructure construction: the government and all sectors of society should increase the investment in infrastructure construction in rural areas, improve the power, transportation and other conditions, and provide a good hardware environment for the development of clean energy.

Third, policy support: the government can introduce a series of policies to support the development of clean energy in rural areas, such as fiscal subsidies, tax incentives, etc., to encourage enterprises and individuals to actively participate in the construction and application of clean energy.

Fourth, publicity and education: strengthen the publicity and education of clean energy for farmers through various channels, improve their awareness and acceptance of clean energy, so as to promote the popularization and application of clean energy in rural areas.

To sum up, the future development of clean energy in rural areas is full of hope, but it also faces some challenges. Only with the joint efforts of the government, enterprises and all sectors of society to strengthen technology research and development, infrastructure construction, policy support and publicity and education, can we promote the rapid development of clean energy in rural areas and make positive contributions to the sustainable development of rural areas.

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## References

[1] Zhao, J., Dong, K., & Dong, X. (2024). How does energy poverty eradication affect global carbon neutrality?. Renewable and Sustainable Energy Reviews, 191, 114104.

[2] Hassan, Q., Viktor, P., Al-Musawi, T. J., Ali, B. M., Algburi, S., Alzoubi, H. M., ... & Jaszczur, M. (2024). The renewable energy role in the global energy Transformations. Renewable Energy Focus, 48, 100545.

[3] Hu, R.,Wang, L., Zhao, H.T., & Gao, S.Y. (2024). Policy Research on Promoting the development of new energy logistics Equipment in Jiangsu Province. Trade Fair Economics, 1, 132-138.

[4] Wang, H. M., Li, J. W., Jia, W. G., Wang, T. H., Wang, X., & Bao, L. L. (2024). Analysis of the operation characteristics of solar-assisted shallow geothermal energy systems in rural residential areas in southern Hebei Province. Applied Geophysics, 5, 1-18.

[5] Min, Y., & Mayfield, E. (2023). Rooftop solar, electric vehicle, and heat pump adoption in rural areas in the United States. Energy Research & Social Science, 105, 103292.

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[6] Clausen, L. T., & Rudolph, D. (2020). Renewable energy for sustainable rural development: Synergies and mismatches. Energy Policy, 138, 111289.

[7] Wang, C., Bao, A.,Liu, J., Zhou, X., Zhao, X.Y., Peng, L., Wang, Y., An, H.W., Tang, X.L., & Yi, H.H. (2024). Study on emission reduction effect of rural residential source inventory and clean energy policy based on household survey, China Environmental Science, 25, 1-28.

[8] Tian, Y., Wang, R., Yin, M., & Zhang, H. (2023). Study on the measurement and influencing factors of rural energy carbon emission efficiency in China: evidence using the provincial panel data. Agriculture, 13(2), 441.

[9] Ren, Y. S., Kuang, X., & Klein, T. (2024). Does the urban–rural income gap matter for rural energy poverty?. Energy Policy, 186, 113977.

[10] Yao, T.Q., Ni,H.Y.,Wang ,M.T., Liu, J.S., & Guo, Y.R. (2023). Analysis of rural residents willingness to use clean energy and its influencing factors based on Logit model: A case study of Shijiazhuang City, Village Committee Director, 7, 139-142.

[11] Kong, Z.L.,Wang ,Y.H. (2013). Research on fiscal policy for promoting rural clean energy construction in Yunnan Province. Modern Property, 6, 56-58.

[12] Xi, J.Y., & Teng,Y.H. (2018). bear wing new, Study on rural residents' satisfaction with clean energy support policies, Western Economic Management Forum, 4, 46-54.

[13] Yao, J.N., & Yang, M.Y. (2023). China. It is suggested to introduce subsidy policies for clean energy use in rural areas. China Energy News, 13, 004.

[ 14 ] Fields, N., Ryves, D., & Yeganyan R. (2023). Evidence-Based Policymaking: Insights and Recommendations for the Implementation of Clean Energy Transition Pathways for Kenya's Power Sector. Energies, 354, 120275-120275.

[15] Yin, S., Wang, Y., Liu, Y., & Wang, S. (2024). Exploring drivers of behavioral willingness to use clean energy to reduce environmental emissions in rural China: An extension of the UTAUT2 model. Journal of Renewable and Sustainable Energy, 16, 045903.

[16]Omri, A., & Boubaker, S. (2024). When do climate change legislation and clean energy policies matter for net-zero emissions, Journal of environmental management, 16(23). 1256.

[17] Shi, L., & Yang,C. (2017). Mr. Analysis on the promotion of rural new clean energy in Baishui County. Modern Agriculture, 11, 50-51.

[18] Liu, N.N., & Lu,P. (2018). Promotion measures and implementation effect of clean energy in Zhidan County. Friends of the Rich Farmers, 14, 233.

[19] Xu, X. (2021). Mr. Analysis on the impact of rural clean energy policies implementation. Rural Economy and Science and Technology, 3, 14-16.

[20] Wang, Y.R.,Yang, C.Y., & Liu, X.Y. (2022). Study on the impact of clean energy policy on promoting rural economic development, Price Theory and Practice, 10, 192-195.

[21] Li, Z., & Chen, S. (2024). Chang Achieving clean energy via economic stability to qualify sustainable development goals in China.Economic Analysis andPolicy, 81, 1382-1394.

[22] Lin, B., & Li, M. (2024). MicroMechanisms Driving China's Clean Energy Flourish.International Review of Financial Analysis, 92, 103107.

[23] Xu, L.D., & Tong, Y.H. (2011). Analysis and suggestions on clean energy development in rural China. China's Population, Resources and Environment, 7, 20-27.

[24] Liu,Y.L. (2017). Capital, China. Analysis on the development and suggestions of clean energy in rural China. Agriculture and Technology, 3, 168-169.

[25] Wang, Y.D. (2019). Beijing, China. Analysis of the development status and practical application of clean energy in rural areas in China. Contemporary Chemical Industry Research, 7, 2-4.

[26] Zhang, J.F., Xu, W.J., & Wang, Y.Q. (2021). On the investigation and analysis of China's carbon emissions for carbon neutrality. Huadian Technology, 43(10), 1-10.

[27] Wang, L. (2022). Status and Prospect of Energy Science and Technology Cooperation between China and the International Energy Agency. Coal Quality Technology, 37(1), 1-7.

[28] Li, B.B., & Nils, H. (2022). The role of clean energy, fossil fuel consumption and trade openness for carbon neutrality in China.Energy Reports. 8, 1090-1098.

[29] Zhang, H.W.,Zhu, H.B., & Wu, X.R. (2023). Current status and development trend of green and clean energy technology under the double-carbon goal, Petroleum Science Bulletin, 8(5), 555-576.

[30] Yin, S., Wang, M., Shi, Y., Zhao, Y. (2024). Assessing rural energy poverty and early warning based on long-run evolution for clean energy transition in China. Journal of Renewable and Sustainable Energy, 16, 043125.

[31] Liu, J.W.,Ting, L., & Quan, T. (2024). Analysis and research on development status of Sichuan power grid and clean. China Environmental Science, 21, 3659-3668.

[32] Li, R., Zhang, M., Yin, S., Zhang, N., & Mahmood, T. (2024). Developing a conceptual partner selection framework for matching public‐private partnerships of rural energy internet project using an integrated fuzzy AHP approach for rural revitalization in China. Heliyon, 10(10), e31096.

[33] Fan, J.S., & Zhou, L.(2018). Comparative study on changes in carbon emissions from daily consumption of urban and rural residents in China. China Environmental Science, 15, 4369-4383.

[34] Xu, J., Tong, B., Wang, M., & Yin, S. (2024). Does environmental pollution governance contribute to carbon emission reduction under heterogeneous green technological innovation? Empirical evidence from China's provincial panel data. Environment, Development and Sustainability, 3, 1-30..

[35] Sun, R.N., Yang, M., & Su, J. (2020). Current Situation and Development and Utilization Models of Rural Energy in China. Journal of China Agricultural University, 25(8), 163-173.

[36] Zhang, J.B. (2022). What can we do Research on low-carbon development of agriculture under the "dual carbon" goal Agricultural Economic Issues, 9, 35-46.

[37] Zhang, Z.Y., Pan ,J.T., & Xiong, R. (2023). Research on the Issues and Paths of Clean Energy Consumption Transformation in Rural Areas of Hubei . Rural Economy and Technology, 34(20), 227-230.

[38] Luo, J.C., Deng, Y., & Hou, G.G. (2023). Current Status, International Experience, and Inspiration of Environmental Management of Emerging Solid Waste in the Clean Energy Industry Monthly Environmental Protection, 25, 41-45.

[39] Yin, S., & Zhao, Z. (2023). Energy development in rural China toward a clean energy system: utilization status,co-benefit mechanism, and countermeasures. Frontiers in Energy Research, 2023, 11.

[40] Li, N., Zhang, G., Zhang, L., Zhou, Y., & Zhang, N. (2022). Improving rural women's health in China: Cooking with clean energy. Environmental Science and Pollution Research, 29(14), 20906-20920.

[41] Tawiah, T., Iddrisu, S., Gyaase, S., Twumasi, M., Asante, K. P., & Jack, D. (2022). The feasibility and acceptability of clean fuel use among rural households. A pilot study in Central Ghana. Journal of Public Health in Africa, 13(3), 2205.

[42] Fu, R., & Liu, Z.Y. (2020). Development and Significance of Environmental Protection Expo under the Background of Clean Energy Development, Market Weekly, 6, 28-29.

[43] Miao, R., Wang, L.F., & Wu,, D. (2012). Construction and Preliminary Evaluation of China's Energy Sustainable Development Evaluation Index System. China Energy,12, 82-86.

[44] Zhang, N., Xue. M.M., & Wu, X.Y. (2021). Comparison and Inspiration of Energy Transformation at Home and Abroad. China Electric Power, 34(3), 22-27.

[45] Lin, W.B. & Shao, C.H. (2023). How to strengthen the synergy and efficiency of pollution reduction and carbon reduction source prevention and control,World Environment, 54(2), 113-119.

[46] Wang, F. (2023). Research on the Impact of Government Energy Conservation and Environmental Protection Expenditures on Synergistic Efficiency of Pollution Reduction and Carbon Reduction. China Academy of Financial Sciences, 11, 14-16.

[47] Huang, R., Wang, P., & Zhang, S. (2024). Experiences and lessons for China's energy transition: From the firewood era to the low carbon era. Energy for Sustainable Development, 78, 101368.

[48] Xian, B. & Wang, Y.,Xu, Y. (2024). Assessment of the co-benefits of China's carbon trading policy on carbon emissions reduction and air pollution control in multiple sectors. Economic Analysis and Policy, 35(2), 402-426.

[49] Sun, Z.F. (2018). Analysis of Rural Solar Photovoltaic Clean Energy Heating Technology Model in Hebei Province, Hebei Agricultural Machinery, 81, 1322-1335.

[50] Li, L., & Zhang, S.J. (2024). The rural energy revolution presses the fast forward button China Energy News, 2024.000137.

[51] Wei, X.L. (2022). Optimization of Industrial Clean Energy Scheduling and Emission Management under the Dual Carbon Goal Green Technology, 2024. 000001.

[52] Adao, B., Narajabad, B., & Temzelides, T. (2024). Renewable technology adoption costs and economic growth. Energy Economics, 129, 107255.

[53] Yang, J.,Lai, X., & Wen, F. (2024). Green hydrogen credit subsidized renewable energy-hydrogen business models for achieving the carbon neutral future. International Journal of Hydrogen Energy, 26, 1323-1344.

[54] Wang, L. (2024). Construction of clean energy discourse system under the two-carbon target. Journal of China University of Petroleum (Social Science Edition), 60, 189-193.

[55] Yin, S., Gao, Z., & Mahmood, T. (2023). Artificial intelligence-driven bioenergy system: digital green innovation partner selection of bioenergy enterprises based on interval fuzzy field model. Kybernetes. Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/K-08-2023-1495

eISSN 2345-0355. 2024. Vol. 46. No. 3: 285-311
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[56] Haq, I., Khan, M., Chakma, S., Hossain, M. I., Sarkar, S., Rejvi, M. R. A., ... & Sarker, M. M. R. (2024). Determinants of household adoption of clean energy with its rural‐urban disparities in Bangladesh. Scientific Reports, 14(1), 2356.

[57] Zhao, Y., Zhang, Y., Song, Y., Yin, S., & Hu, C. (2023). Enhancing building energy efficiency: Formation of a cooperative digital green innovation atmosphere of photovoltaic building materials based on reciprocal incentives. AIMS Energy, 11(4), 694-722.