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Original Research Article

Collaborative research on rural distributed photovoltaic development and new energy vehicles moving to the countryside under the background of dual carbon

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Abstract: In the context of dual carbon, there is a synergistic effect between the development of rural distributed photovoltaics and the introduction of new energy vehicles to the countryside. The synergistic development of the two is of great significance for promoting sustainable development and energy transformation. This paper aims to study how the coordinated development of rural distributed photovoltaic and new energy vehicles in the countryside can produce efficiency, what kind of efficiency it can produce under the background of dual carbon, and explore its collaborative development strategy. Based on the background environment of green development, this paper discusses the current situation, significance, policy effect, and difficulties of the collaborative development of rural distributed photovoltaic development and new energy vehicles in the countryside. On this basis, it analyzes the efficiency and mechanism of its collaborative development. The conclusion indicates that, under the dual carbon background, the development of distributed photovoltaics in rural areas and the deployment of new energy vehicles to rural areas are full of opportunities and challenges. The synergistic development of the two has the synergistic effects of sharing clean energy, complementary energy conservation and emission reduction, optimizing energy consumption structures, promoting economic development, increasing employment opportunities, and improving rural living quality. It is of great significance for achieving the dual-carbon goal. This article provides a reference for the development of distributed photovoltaics in rural areas and the coordinated development of new energy vehicles in rural areas under a dual-carbon background and has certain practical and theoretical significance.

Keywords: rural energy; distributed photovoltaic; new energy vehicles; peak carbon dioxide emissions and carbon neutrality synergistic effect

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1. Analysis on the development of distributed photovoltaics in rural areas under the background of dual carbon

1.1. Significance

Distributed photovoltaic power generation refers to the photovoltaic power generation facilities built near the user site, which are characterized by spontaneous self-use on the user side, surplus electricity on the grid, and balanced regulation in the distribution system. As shown in **Figure 1**, the development of distributed photovoltaics in rural areas under a dual-carbon background is of great significance. The first is to accelerate

the transformation of energy. Rural distributed photovoltaic development is an important part of energy transformation. By promoting distributed photovoltaic power generation systems, solar energy resources in rural areas can be better utilized, thereby improving the efficiency of energy utilization. At the same time, it can decrease dependence on traditional coal and thermal power generation, so as to reduce carbon emissions and environmental pollution[1]. The second is to ensure the reliability and stability of rural power supplies. In rural areas, power supply often faces problems of instability and lack of reliability. Distributed photovoltaic systems can provide reliable power supply to rural residents, reduce the risk of power interruption, and improve the stability of rural power supply. The third is to boost rural economic development. Photovoltaic power generation systems can provide a clean and affordable electricity supply to rural areas, reduce energy costs for residents and agricultural production, and improve the competitiveness of rural areas[2]. The fourth is to increase rural employment opportunities, and the development of distributed photovoltaics can also create employment opportunities and promote rural employment. In the planning, construction, operation, and maintenance of photovoltaic power generation systems, a large amount of labor is required, which will provide employment opportunities for rural areas and improve the employment situation of residents. The fifth is to improve the level of energy technology in rural areas, and the development of distributed photovoltaics in rural areas also helps to enhance the level of energy technology in rural areas. In the construction, operation, and maintenance processes of distributed photovoltaic power generation systems, knowledge and skills in photovoltaic technology, power system technology, and other aspects are required. By participating in photovoltaic power generation projects, rural residents can understand and learn relevant technological knowledge and enhance their own abilities and competitiveness. Overall, the development of distributed photovoltaics in rural areas can provide reliable electricity supply, reduce energy costs, promote rural economic development, and create employment opportunities for residents, contributing to the sustainable development and green rise of rural areas[3].

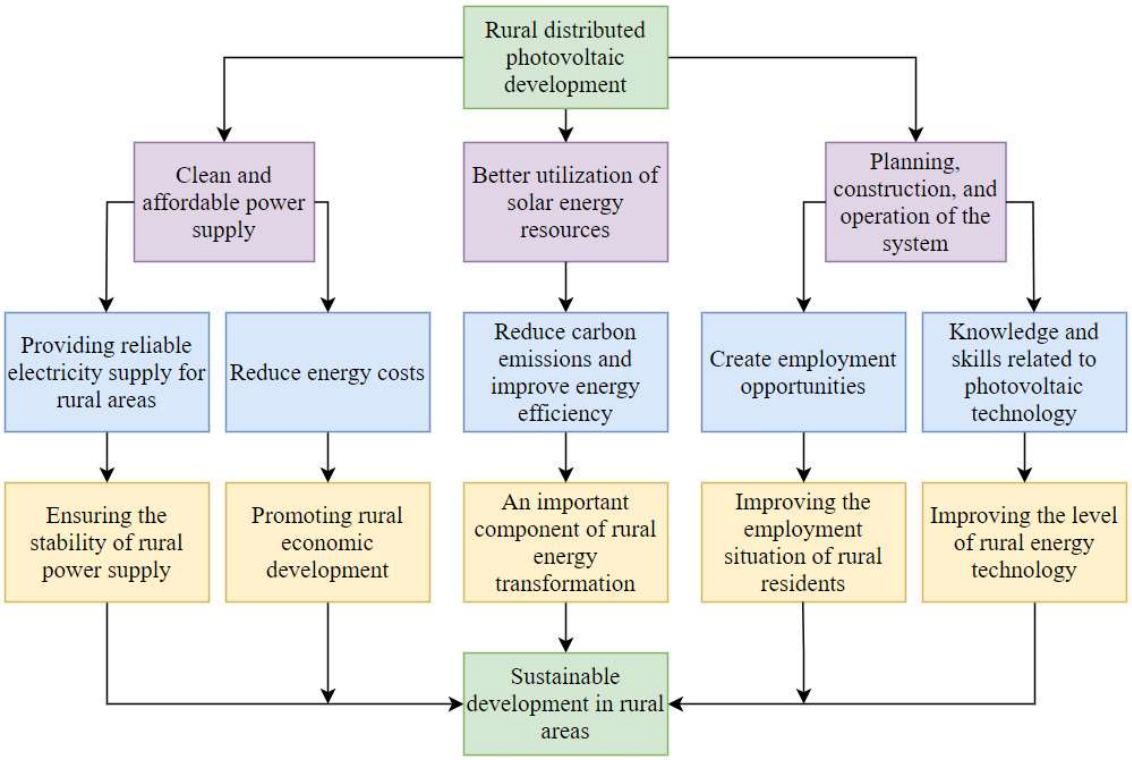

Figure 1. Distributed photovoltaic development promotes rural sustainable development.

1.2. Government support for promoting development

The development of distributed photovoltaics in rural areas has always been a focus of the Chinese government. In order to solve the problem of energy supply in rural areas, improve rural energy utilization efficiency, and promote sustainable development of the rural economy, the government has adopted a series of policies and measures to support the development of distributed photovoltaics in rural areas[4]. Firstly, in terms of policy support, the Chinese government has introduced a series of policies to support the development of distributed photovoltaics in rural areas. This includes developing standards and technical guidance for distributed photovoltaic power generation, establishing a mechanism for approving and facilitating access to the power grid for distributed photovoltaic power generation projects, providing policy support such as financial subsidies and rewards, and encouraging rural residents and enterprises to invest in and build distributed photovoltaic power generation projects[5]. Secondly, in terms of financial support, government financial funds and loans from financial institutions provide financial support for rural distributed photovoltaic projects. For example, setting up financial subsidies and credit policies for rural distributed photovoltaic power generation projects can reduce project construction costs and alleviate the economic burden on farmers. Thirdly, in terms of training and technical support, the government strengthens the training and promotion of rural distributed photovoltaic power generation technology, providing technical consultation and support. By establishing training courses and technical consulting institutions, we aim to cultivate photovoltaic technology talents in rural resident enterprises, promote photovoltaic technology knowledge, and improve the construction capacity, operation, and maintenance levels of distributed photovoltaic projects in rural areas. Fourthly, in terms of market access and grid access, the government has simplified the approval procedures for distributed photovoltaic projects and accelerated their market access. At the same time, strengthen the planning and construction of the power grid, improve the grid connection capacity of rural distributed photovoltaics, and ensure the smooth connection of the project to the power grid[6]. Fifth, in terms of publicity and demonstration projects, the government enhances rural residents' awareness and acceptance of distributed photovoltaic development by organizing promotional activities and showcasing demonstration projects. At the same time, through the construction and promotion of demonstration projects, the economic and environmental benefits of distributed photovoltaics will be demonstrated, and more rural areas will be encouraged to invest in the construction of distributed photovoltaics. **Table 1** shows the relevant policies of China's national ministries and commissions in the household photovoltaic industry from April 2020 to May 2023, roughly divided into five categories: financial support, policy support, technical support, market construction, and demonstration construction. The above policies and measures contribute to promoting the development of distributed photovoltaics in rural areas, achieving the utilization of clean energy, and improving energy supply in rural areas. At the same time, the development of distributed photovoltaics in rural areas has also brought economic development opportunities and employment opportunities to rural areas, promoting sustainable development of the rural economy and the improvement of residents' living standards[7].

Table 1. Policy analysis of China's national ministries and commissions' household photovoltaic industry from April 2020 to May 2023.

Date	Policy name	Relevant content	Support type
April 2020	Notice on Issues Related to the 2020 Photovoltaic Power Generation Grid Price Policy	The subsidy standard for the total electricity generation of household distributed photovoltaics included in the 2020 fiscal subsidy scale has been adjusted to 0.08 yuan per kilowatt hour.	Financial support
May 2020	Guiding Opinions on Promoting the Western Development in the New Era and Forming a New Pattern	Accelerate the on-site consumption of wind and photovoltaic power generation. Continue to increase the construction of key transmission channels across provinces and regions, such as the West to East power transmission, and improve the transmission of clean electricity.	Policy support
January 2021	Catalogue of Encouraged Industries in the Western Region (2020)	Enterprises engaged in the construction and operation of solar power plants in Shaanxi Province, Gansu Province, and other provinces will be subject to corporate income tax at a reduced rate of 15%.	Financial support
March 2021	Standard Conditions for Photovoltaic Manufacturing Industry (2021)	For renewable energy enterprises, we will increase financial support through nine major measures to promote the healthy and orderly development of industries such as wind power and photovoltaic power generation.	Financial support
March 2021	Notice on Guiding and Increasing Financial Support to Promote the Healthy and Orderly Development of Wind Power and Photovoltaic Power Generation Industries	Financial institutions shall negotiate with renewable energy enterprises in accordance with the principle of commercialization for outlook or renewal of loans, and provide reasonable support for rights confirmation loans: appropriately compensate for the interest costs shared by enterprises through the issuance of green power certificates; Prioritize the issuance of subsidies and further increase credit support.	Financial support
March 2021	Outline of the 14th Five Year Plan for National Economic and Social Development of the People's Republic of China and the 2035 Long Range Goals	Accelerate the development of non-fossil fuels, adhere to both centralized and distributed approaches, and vigorously enhance the scale of wind and photovoltaic power generation.	Policy support
July 2021	Notice on Issuing the "Three Year Action Plan for the Development of New Data Centers (2021–2023)"	Encourage enterprises to explore the construction of supporting systems such as distributed photovoltaic power generation and gas distributed energy supply, guide the construction of new data centers towards the new energy generation side, and consume new energy locally.	Technical support
October 2021	Action Plan for Carbon Peak before 2030	Accelerate the construction of wind and photovoltaic power generation bases, accelerate the innovation and upgrading of the intelligent photovoltaic industry and its unique applications, innovate the "photovoltaic+" model, and promote the diversified layout of photovoltaic power generation.	Demonstration construction
December 2021	The 14th Five Year Plan for Green Industrial Development	Encourage factories and parks to carry out the construction of industrial green and low-carbon microgrids, develop rooftop photovoltaics, decentralized wind power, diversified energy storage, efficient heat pumps, and promote the efficient and complementary utilization of multiple energy sources.	Policy support
January 2022	Notice on Issuing the "Action Plan for Innovative Development of the Intelligent Photovoltaic Industry (2021–2025)"	Develop intelligent and digital household intelligent photovoltaic products and systems to achieve plug and play, safety, reliability, and convenience, and promote the development of the household photovoltaic market.	Technical support
January 2022	Opinions on Doing a Good Job in the Key Work of Comprehensively Promoting Rural Revitalization in 2022	Deeply implement the rural power grid consolidation and improvement project. Promote the construction of clean energy sources such as rural photovoltaic and biomass energy.	Demonstration construction

Table 1. (*Continued*).

Date	Policy name	Relevant content	Support type
February 2022	Several Policies on Promoting Stable Growth of Industrial Economy	Organize and implement the special action for innovative development of the photovoltaic industry, implement the construction of large-scale wind power and photovoltaic bases in the desert and Gobi desert areas, and encourage the development of distributed photovoltaics in the central and eastern regions.	Demonstration construction
May 2022	Implementation Plan for Promoting High Quality Development of New Energy in the New Era	Fully mobilize the enthusiasm of rural farmers to develop new energy, increase efforts to support farmers to use their own building roofs to build household photovoltaic systems, and actively promote the development of decentralized wind power in rural areas.	Policy support
July 2022	Industrial Energy Efficiency Improvement Action Plan	Accelerate the development and operation of integrated systems such as photovoltaic, wind power, high-efficiency heat pumps, waste heat and pressure utilization, and smart energy control.	Technical support
August 2022	Notice on Promoting the Collaborative Development of the Photovoltaic Industry Chain	To optimize the establishment of a national photovoltaic industry market, promote high-quality development of the photovoltaic industry, and actively promote the construction of a new energy supply and consumption system.	Market construction
November 2022	Notice on Consolidating the Revitalization and Promoting the Industrial Economy	Accelerate the development of the energy electronics industry, promote the innovative development and industry application of intelligent photovoltaics, and improve the comprehensive standardized technology system for photovoltaics, lithium-ion batteries, etc.	technical support
December 2022	Outline of the Strategic Plan for Expanding Domestic Demand (2022–2035)	Significantly improve the level of clean energy utilization, build clean energy bases that complement multiple energy sources, and accelerate the construction of large-scale wind power and photovoltaic bases with a focus on deserts, Gobi, and desert areas.	Demonstration construction
January 2023	Guiding Opinions on Promoting the Development of the Energy Electronics Industry	Guide the balanced development of solar photovoltaic, energy storage technology, and various aspects of products, avoid overcapacity and vicious competition, accelerate the innovation and breakthrough of intelligent photovoltaic, and develop high-purity silicon materials and large-sized silicon wafer technology.	Technical support
March 2023	Notice on Supporting the Development of Photovoltaic Industry and Standardizing Land Use Management	Make a good connection between the development planning of the photovoltaic power generation industry and the national spatial planning. Encourage the use of unused land and existing construction land to develop the photovoltaic power generation industry.	Policy support
May 2023	Implementation Opinions on Accelerating the Construction of Charging Infrastructure and Better Supporting the Rural Revitalization of New Energy Vehicles	Explore the construction of integrated charging infrastructure that provides photovoltaic power generation, energy storage, and charging in rural areas with low utilization rates of charging stations.	Demonstration construction

1.3. Issues and challenges

Although there have been certain achievements in the development of distributed photovoltaic technology in rural areas, there are still some problems that need to be solved. Firstly, there are technical difficulties. In rural areas, due to the dispersion of natural resources and the imperfect power supply network, there are difficulties in equipment installation, operation, and maintenance[8]. In addition, there are differences in environmental conditions and electricity usage habits between rural areas and urban areas, and targeted

research and application of photovoltaic technology and equipment suitable for rural areas are needed to solve technical difficulties[9]. The second issue is funding, as the lack of sufficient funding in rural areas is one of the main constraints on the development of distributed photovoltaics. Although the government provides certain financial subsidies and support, rural residents and enterprises have limited financial strength, which poses certain difficulties in investing in photovoltaic projects. Therefore, it is necessary to further improve the funding support mechanism and attract more social capital investment. The third issue is the construction of legal, regulatory, and policy systems. The development of rural distributed photovoltaics requires a sound legal, regulatory, and policy system as a guarantee. At present, there is a lack of clear policies and regulations for the development of distributed photovoltaics, leading to uncertainty in project approval, grid connection, and other aspects[10]. In addition, there are certain weak links in the law enforcement and supervision of relevant departments in rural areas, and supervision efforts need to be strengthened. The fourth issue is publicity and training, as rural areas have limited awareness and technical level of distributed photovoltaic development. In the process of widely distributed photovoltaic projects, it is necessary to strengthen publicity and improve the understanding and recognition of distributed photovoltaic among rural residents. At the same time, it is also necessary to strengthen the training of technical personnel in rural areas to improve their professional literacy and technical capabilities. The fifth issue is environmental friendliness, as there is a significant use of traditional energy in rural areas and pollution emissions to the environment. The development of distributed light in rural areas should pay more attention to environmental friendliness, reduce environmental pollution, and promote green ecology and sustainable development in rural areas[11]. In response to the above issues, the government, enterprises, and all sectors of society should work together to increase the support of policies, technologies, and funds, provide a guarantee for the healthy development of rural distributed photovoltaic, help realize the transformation and upgrading of energy structures in rural areas, and promote the sustainable development of energy[12].

2. Analysis of new energy vehicles going to the countryside under the background of dual carbon

2.1. Significance

New energy vehicles to the countryside means that the government uses certain economic means to promote the popularization of new energy vehicles in the countryside, so as to meet the travel needs of farmers and give play to the dual benefits of society and economy. The important significance of new energy vehicles going to the countryside under the dual carbon background is mainly reflected in the following aspects: firstly, reducing carbon emissions. New energy vehicles use electric power instead of traditional fuel, and the emissions of exhaust pollutants are almost zero. Introducing new energy vehicles into rural areas can significantly reduce vehicle exhaust emissions, reduce air quality pollution, and benefit the protection of the ecological environment in rural areas[13]. The second is to reduce energy consumption, as new energy vehicles are more efficient in energy consumption compared to traditional fuel vehicles. By popularizing new energy vehicles, rural areas can reduce their demand for fossil fuels and dependence on energy resources while reducing operating costs in the long term. The third is to promote rural economic development. On the one hand, the consumption demand of new energy vehicles in rural areas can be conducive to the development of the new energy vehicle industry chain and drive the growth of related industries. On the other hand, the purchase and use of new energy vehicles by rural residents can reduce energy expenditure, improve the quality of life, increase residents' income, and drive the prosperity and development of the rural economy[14]. The fourth is to promote the improvement of rural transportation, as the transportation infrastructure in rural areas is relatively lacking and transportation is relatively inconvenient. The introduction of new energy vehicles can

improve the transportation level in rural areas, provide more convenient and environmentally friendly modes of transportation, and improve the quality of life and transportation efficiency of rural residents. The fifth is to advocate for the advancement of renewable energy, and the charging demand of new energy vehicles can promote the development of renewable energy in rural areas. By building charging stations and utilizing new energy resources in rural areas, such as solar photovoltaic power generation and wind power generation, large-scale energy applications can be achieved, reducing traditional energy consumption, and promoting the popularization and application of renewable energy in rural areas. In general, new energy vehicles to the countryside is of great significance in the context of dual carbon, which can reduce carbon emissions and energy consumption, promote rural economic development, improve traffic conditions, popularize renewable energy, and achieve sustainable development in rural areas. The government, enterprises, and residents should work together to promote the implementation and implementation of the policy of new energy vehicles going to rural areas[15].

2.2. Policy expected results

The expected results of the new energy vehicle rural policy under the dual carbon background mainly include the following five points: firstly, reducing carbon emissions. New energy vehicles use clean energy to drive, which reduces the quantity and content of exhaust emissions compared to traditional fuel vehicles and can effectively reduce vehicle carbon emissions. The use of new energy vehicles in rural areas can reduce environmental pollution caused by carbon emissions from motor vehicles and improve air quality. The second is to save energy resources. New energy vehicles use electricity to drive, saving a large amount of limited energy resources such as oil compared to gasoline vehicles. Promoting new energy vehicles in rural areas can effectively reduce dependence on energy resources and improve energy utilization efficiency. The third is to reduce energy costs. By using new energy vehicles in rural areas, electricity can replace the demand for fuel. Compared to traditional fuel vehicles, new energy vehicles have lower energy costs and effectively reduce residents' energy consumption expenses. The fourth is to promote the development of rural economy, and the implementation of the policy of bringing new energy vehicles to the countryside has promoted the development of the new energy vehicle industry in rural areas. The construction and development of the new energy vehicle industry chain can drive industrial upgrading and economic growth in rural areas, and create employment opportunities[16]. The fifth is to improve the transportation conditions of rural residents. New energy vehicles have lower noise and vibration, and the impact on the transportation and living environment in rural areas is relatively small. At the same time, the promotion of new energy vehicles can also improve the transportation convenience and comfort of rural areas and improve the travel of rural residents[17].

It should be noted that in order to achieve the above results, the government, enterprises, and all parties in society should work together to increase policy support and investment for new energy vehicles going to the countryside. At the same time, it is necessary to further improve the charging infrastructure, improve technical level, strengthen publicity and education, and guide consumers to choose more new energy vehicles in order to truly achieve the effectiveness of new energy vehicles in rural areas[18].

2.3. Development status

Under the dual carbon background, the policy of new energy vehicles going to rural areas has achieved certain results, but still faces some challenges. The following are some current situations of new energy vehicles going to rural areas under the dual carbon background. Firstly, policy support is gradually increasing, and governments at all levels have introduced a series of supportive policies and measures after recognizing the importance of new energy vehicles. These policies include financial subsidies, purchase tax exemptions,

and support for charging facility construction, providing economic support for the popularization of new energy vehicles in rural areas[19]. The government's policy on new energy vehicles going to the countryside is gradually increasing, but further improvement is still needed in the policy design and implementation process[20]. Secondly, there are still bottlenecks in the construction of charging facilities, and there are still certain difficulties in building charging facilities in rural areas. Due to the relatively low coverage of the power grid in rural areas and the high construction and operation costs of charging facilities, this has constrained the development of new energy vehicles in rural areas. The government needs to further increase investment in the construction of charging facilities in rural areas, promote the popularization and convenience improvement of charging facilities[21]. Thirdly, the after-sales service and maintenance network need to be improved, and the after-sales service and maintenance network for new energy vehicles in rural areas is relatively weak. The supply chain for car repair and accessories in rural areas is not yet sound, leading farmers to face repair and maintenance difficulties after purchasing new energy vehicles. The government and relevant enterprises need to increase the construction of after-sales service and maintenance networks in rural areas, and provide convenient service guarantees. Fourthly, there is still room for improvement in publicity and education, and the awareness and acceptance of new energy vehicles in rural areas are relatively low. The government and relevant departments need to increase publicity and education efforts in rural areas, improve farmers' understanding of new energy vehicles, and enhance their willingness to accept and use new energy vehicles. Although the policy of bringing new energy vehicles to rural areas has achieved initial results in the context of dual carbon, it still requires the joint efforts of the government, enterprises, and society to promote the popularization and development of new energy vehicles in rural areas, in order to achieve the goal of low-carbon and green travel in rural areas[22].

3. Collaborative analysis of rural distributed photovoltaic development and new energy vehicles moving to the countryside under the background of dual carbon

3.1. Research innovation and significance

From the above analysis, we can easily draw the conclusion that the development of distributed photovoltaics in rural areas and the introduction of new energy vehicles to rural areas can reduce carbon emissions and environmental pollution, both of which play a very important role in achieving the dual carbon goals. Through **Table 2**, we can compare and see that in previous studies, research has often only focused on a single object in the development of rural distributed photovoltaics and the integration of new energy vehicles into rural areas, without paying attention to the huge potential hidden in the collaborative development of rural distributed photovoltaics and the integration of new energy vehicles into rural areas. This article is based on the dual carbon background and revolves around the closed-loop effect generated by the development of rural distributed photovoltaics and the coordinated development of new energy vehicles in rural areas. It explores how to generate efficiency, what kind of efficiency can be generated, and how to better implement it. It broadens the depth and breadth of research, opens up new research perspectives, is innovative and forward-looking, and has certain theoretical and practical significance.

Table 2. Research comparison.

Previous research				**This research**
Title	**Author**	**Research object**	**Research perspective**	
Methods and ideas for promoting new energy vehicles in rural areas under the background of "carbon neutrality"[23]	Yang (2021)	Township new energy vehicles	Promotion significance and suggestions	Research object: Rural distributed photovoltaic development and collaborative development of new energy vehicles in rural areas; Research perspective: How to generate efficiency, what kind of efficiency can be generated, and how to better effectively implement the virtuous loop of rural distributed photovoltaic development and coordinated development of new energy vehicles in rural areas under the dual carbon background
The Impact of Household Distributed Photovoltaics on Farmers' Income: Taking Y County in the Central Region as an Example[24]	La et al. (2022)	Distributed photovoltaics for township new energy vehicle household use	The impact of household distributed photovoltaics on farmers' income and development suggestions	
The New Situation, Opportunities, and Challenges of New Energy Vehicles Going to the Countryside[25]	Li (2022)	New energy vehicles going to the countryside	Current situation, opportunities, and challenges	
On the Technology and Development of Roof Distributed Photovoltaic Power Generation in Rural Areas of Guangxi under the Goal of "Dual Carbon"[26]	Zhan (2022)	Rural rooftop distributed photovoltaic power generation	Development status, technical challenges, and solutions	
Opportunities and challenges brought by the activity of new energy vehicles going to the countryside[27]	Zhu and Dai (2022)	New energy vehicles going to the countryside	Opportunity and challenge	
Research on the Promotion Strategy of Rural New Energy Vehicles from the Perspective of "Dual Carbon Goals+Rural Revitalization"[28]	Guo (2023)	Rural new energy vehicles	Promoting strategy	
Practice and exploration of rooftop distributed photovoltaic power generation projects in the entire county[29]	Tan and Fu (2023)	Distributed rooftop photovoltaic power generation throughout the county	Development status, benefits, risks, problems, and suggestions	
The Application of Distributed Photovoltaics in Rural Areas: Taking Yuanlong Village, Ningxia as an Example[30]	Xu and Ma (2023)	Distributed photovoltaics	Development status, existing problems, and development suggestions	
Socio economic Benefit Evaluation of Rural Photovoltaic Systems Based on LCOE Model: Taking the Roof Distributed Photovoltaic Project in Beijing Suburbs as an Example[31]	Xu et al. (2023)	Rural rooftop distributed photovoltaic	Evaluation of social and economic benefits	
Testing the effectiveness of deploying distributed photovoltaic power systems in residential buildings: Evidence from rural China[32]	Tong et al. (2023)	Distributed photovoltaic power systems in residential buildings	Policy recommendations, environmental and economic benefits	
Economic analysis of rooftop distributed photovoltaic application scenarios in the entire county[33]	Li (2023)	Distributed photovoltaic system on the roof of the entire county	Economic analysis in different application scenarios	
Analysis of the Development Status and Prospects of New Energy Vehicles[34]	Zhai (2023)	New energy vehicles	Development status and prospects	
Development and Analysis of Carbon Inclusion and Emission Reduction in Distributed Photovoltaic Projects[35]	An et al. (2023)	Distributed photovoltaics	Current situation, significance, and prospects	
Research on the Development of New Energy Vehicle Technology under the Background of Integration in the New Era[36]	Wang (2023)	New energy vehicle technology	The significance and strategies of integrated development	
Discussion on the Application Status and Development of New Energy Vehicle Power Batteries[37]	Chen (2023)	New energy vehicle power battery	Current situation and development suggestions	

3.2. Analysis of synergistic effects

In the context of dual carbon, the development of distributed photovoltaics in rural areas and the introduction of new energy vehicles to rural areas can achieve synergistic effects, mutually promoting sustainable development and energy transformation, with the following synergistic effects.

3.2.1. Shared clean energy

Distributed photovoltaic and new energy vehicles in rural areas can achieve shared clean energy, thereby promoting sustainable development and energy transformation. Widely install photovoltaic power generation equipment in rural areas to convert solar energy into electricity and supply it to local residents and enterprises. This model can convert clean solar energy resources into electricity, reduce dependence on traditional sources, and reduce carbon dioxide emissions. At the same time, bringing new energy vehicles to the countryside refers to promoting and popularizing the use of new energy vehicles in rural areas, that is, using electric energy as the power source of vehicles. These vehicles can obtain electricity through charging stations for charging. If there are distributed photovoltaic power generation facilities in rural areas, the electricity generated can be used to provide clean energy charging for new energy vehicles. This not only reduces dependence on traditional fuels, but also reduces car exhaust emissions.

Rural distributed photovoltaic and new energy vehicles can achieve the sharing of clean energy. As shown in **Figure 2**, photovoltaic power generation facilities can directly supply the generated electricity to local residents for use, while also providing clean energy charging services for new energy vehicles, making more full use of solar energy resources. Photovoltaic power generation facilities can directly supply the generated electricity to local residents for use, while also providing clean energy charging services for new energy vehicles, making more full use of solar energy resources[38]. Sharing clean energy can help reduce carbon emissions and environmental pollution, improve energy utilization efficiency, and facilitate the sustainable development of rural areas towards energy. In addition, this sharing model can also promote the development of related industries, bringing economic growth and employment opportunities to rural areas[39].

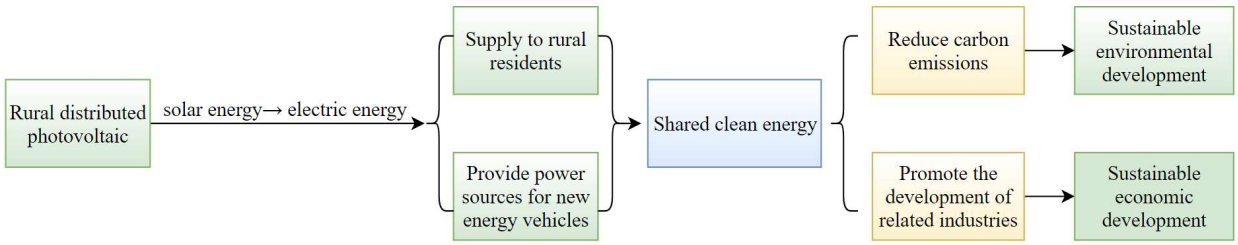

Figure 2. Shared clean energy.

In order to achieve the sharing of clean energy between distributed photovoltaic and energy vehicles in rural areas, the government needs to formulate supporting policies and measures, encourage and support the construction of photovoltaic power generation facilities, and provide improvement and subsidy policies for charging infrastructure. At the same time, it is also necessary to strengthen energy management and monitoring systems to ensure the reliability of energy supply and the convenience of charging facilities. Only with the joint efforts of the government, enterprises, and various sectors of society can we promote the transformation of green energy and transportation in rural areas, and achieve the goal of shared clean energy for distributed photovoltaic and new energy vehicles in rural areas.

3.2.2. Complementary energy conservation and emission reduction

Distributed photovoltaic power generation in rural areas can reduce reliance on traditional electricity and save energy consumption. The use of new energy vehicles can replace traditional fuel vehicles and reduce exhaust emissions. The combination of the two can achieve complementary energy-saving and emission reduction effects, further reducing carbon emissions and environmental pollution.

The complementary use of distributed photovoltaics and new energy vehicles in rural areas can achieve the goal of energy conservation and emission reduction. **Figure 3** provides a clear explanation of the complementary energy-saving and emission reduction effects of the collaborative development of distributed photovoltaic and new energy vehicles in rural areas. Firstly, the development of distributed photovoltaics in rural areas can convert solar energy into electricity, providing clean electricity for local residents and industries, and reducing dependence on traditional energy. Solar energy is a renewable energy source, and photovoltaic power generation does not generate greenhouse gases such as carbon dioxide and does not cause air pollution. Through photovoltaic power generation, the carbon emissions generated by traditional power generation methods can be reduced, achieving the effect of reducing greenhouse gas emissions[40]. Then, moving new energy vehicles to the countryside can reduce the demand for traditional fuel, as new energy vehicles mainly use electric energy to drive. Compared to traditional fuel vehicles, new energy vehicles reduce exhaust emissions, air pollution, and greenhouse gas emissions during use. Moreover, new energy vehicles also have higher energy efficiency, with longer driving distances under the same energy source, thereby reducing energy consumption. The complementary use of distributed photovoltaic development in rural areas and new energy vehicles in rural areas can form a closed-loop system. The electricity generated by photovoltaic power generation can be supplied to new energy vehicles for charging, and the demand for new energy vehicles can also promote the utilization rate of photovoltaic power generation. This complementary usage model can achieve effective energy utilization and minimize energy consumption and carbon emissions[41]. In addition, the development of distributed photovoltaics in rural areas and the introduction of new energy vehicles to rural areas can also promote sustainable development in rural areas. The promotion of photovoltaic power generation and new energy vehicles can drive the development of related industries, promote employment growth and economic development. At the same time, reducing the demand for traditional energy can also reduce energy costs and improve energy security[42].

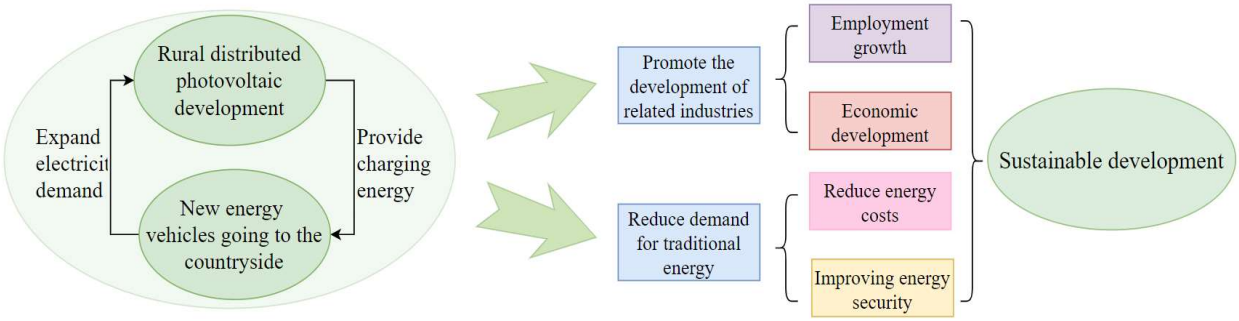

Figure 3. Complementary energy conservation and emission reduction.

In short, the complementary use of distributed photovoltaics and new energy vehicles in rural areas can achieve the goal of energy conservation and emission reduction, promoting sustainable development and energy transformation in rural areas. The government, enterprises, and all sectors of society should work together to provide support policies and promotion measures to promote the implementation of this complementary model.

3.2.3. Optimize energy consumption structure

The construction of distributed photovoltaic power generation facilities in rural areas can promote the increase in the proportion of renewable energy in the energy consumption structure. At the same time, promoting new energy vehicles can reduce dependence on traditional fuels and play an important role in optimizing the energy consumption structure, so as to realize the sustainable development of energy.

The promotion and application of distributed photovoltaics and new energy vehicles in rural areas can optimize the energy consumption structure in rural areas, achieve efficient energy utilization and sustainable development. Firstly, the development of distributed photovoltaics in rural areas can convert solar energy into electricity, providing clean and renewable electricity for rural areas. This type of electricity can not only meet the needs of local residents and agricultural production, but also drive new energy vehicles for charging, achieving energy sharing and utilization. Photovoltaic power generation can reduce dependence on traditional energy, reduce carbon emissions and air pollution, and thus optimize the energy consumption structure[43]. Secondly, the promotion of new energy vehicles in rural areas can also change the energy consumption structure in rural areas. New energy vehicles mainly rely on electricity as the power source, which has higher energy efficiency and lower carbon emissions compared to traditional fuel vehicles. By promoting new energy vehicles, the demand for traditional fuels such as oil can be reduced, energy consumption and environmental pollution can be reduced. At the same time, the charging demand of new energy vehicles can be combined with rural distributed photovoltaic power generation facilities to achieve complementary utilization of clean energy and provide a sustainable energy consumption structure for rural areas[44]. The optimized energy consumption structure of rural distributed photovoltaic and new energy vehicles can also bring a series of economic and social benefits. Firstly, reducing dependence on traditional energy can reduce energy costs and improve the quality of life for rural residents. Secondly, promoting and applying new energy technologies will also promote the development of related industries and bring new employment opportunities to rural areas. In addition, optimizing the energy consumption structure also helps to reduce energy waste, improve energy utilization efficiency, and promote sustainable development in rural areas.

In summary, the promotion and application of distributed photovoltaics and new energy vehicles in rural areas can optimize the energy consumption structure in rural areas. This approach not only reduces energy consumption and carbon emissions, but also brings economic and social benefits, promoting sustainable development in rural areas. The government, enterprises, and all sectors of society should encourage and support this development model, and formulate corresponding policies and measures to promote the optimization of energy consumption structure.4. Integrated development of digital green innovation

3.2.4. Economic development and employment opportunities

The implementation of distributed photovoltaic development in rural areas and the policy of bringing new energy vehicles to the countryside will drive the improvement and development of the industrial chain, promote the development of related enterprises, and create employment opportunities. The construction of photovoltaic power generation facilities, charging pile construction, new energy vehicle manufacturing and maintenance, and other industries will be promoted, providing support for economic growth and employment in rural areas.

The promotion and application of distributed photovoltaic new energy vehicles in rural areas can promote economic development and create employment opportunities. Firstly, the development of distributed photovoltaics in rural areas can drive the rise of related industries. The photovoltaic power generation industry covers multiple fields such as photovoltaic cells, inverters, and brackets. Its construction and operation and maintenance process require a large amount of human resources and technical support, providing development

opportunities for local manufacturing, installation, and maintenance enterprises, and promoting economic development. Meanwhile, photovoltaic power generation can provide clean electricity for rural areas, meet agricultural production and residents' living needs, and further promote the development of the local economy[24]. Secondly, the promotion of new energy vehicles in rural areas can also lead to the development of related industries. New energy vehicles cover multiple fields such as battery motors and charging stations. Compared to traditional gasoline vehicles, the production and maintenance process of new energy vehicles requires more professional talents in the fields of electronics and electricity[45]. Therefore, the promotion of new energy vehicles can drive the development of the new energy vehicle industry chain, including battery manufacturing, motor control systems, electric vehicle charging facilities, etc., thereby creating more job opportunities and enhancing local economic vitality[46]. In addition, the promotion of distributed photovoltaics and new energy vehicles in rural areas can also bring a series of industrial chain cooperation opportunities. For example, photovoltaic power generation can provide electricity for new energy vehicles and achieve complementary utilization of clean energy. In rural areas, photovoltaic power stations and new energy charging stations can be built to form a linkage between photovoltaic power generation and new energy vehicle charging facilities. Such a cooperation mode can be conducive to the coordinated development of different industries, form a more competitive and innovative industrial ecosystem, and further promote economic growth and create employment opportunities.

In short, the promotion and application of distributed photovoltaics and new energy vehicles in rural areas can bring economic development and employment opportunities to rural areas. By promoting the development of related industries and creating new job opportunities, as well as promoting industrial cooperation and synergy, the economic vitality and sustainable development level of rural areas can be enhanced. The government, enterprises, and all sectors of society should strengthen cooperation, formulate relevant policies and measures, promote the development of the photovoltaic and new energy vehicle industries in rural areas, and achieve economic growth and employment opportunities.

3.2.5. Improving the quality of life in rural areas

Distributed photovoltaic power generation and new energy vehicles in rural areas can improve the living conditions of rural residents. Photovoltaic power generation can provide stable power supply for rural areas and solve power consumption problems. Moving new energy vehicles to the countryside can enhance the convenience of rural residents' travel and improve transportation conditions. In summary, the development of distributed photovoltaics in rural areas and the introduction of new energy vehicles to rural areas can achieve a synergistic effect of energy complementarity, energy conservation and emission reduction, optimization of energy consumption structure, promotion of economic development, and improvement of rural quality of life[47]. The government can formulate relevant policies and measures to encourage and support the coordinated development of the two, and promote the transformation of green energy and transportation in rural areas.

As shown in **Figure 4**, the development of distributed photovoltaics and new energy vehicles in rural areas can significantly improve the quality of life in rural areas, mainly reflected in four aspects: increasing farmers' income, improving living conditions, promoting agricultural production, and protecting the ecological environment and residents' health. Firstly, the energy supply is reliable, and distributed photovoltaic systems can provide reliable electricity supply for rural areas. Traditional rural areas often face problems of unstable or insufficient electricity supply, while photovoltaic power generation systems can stably provide clean electricity by utilizing solar energy resources. This means that rural residents can enjoy continuous and reliable electricity supply, improve their quality of life, and have better access to electricity equipment, improving their comfort level. The second is to reduce energy costs, and the use of distributed photovoltaic systems and new

energy vehicles can significantly reduce energy costs. Photovoltaic power generation systems can significantly reduce dependence on traditional grid power, and reduce electricity bills for households and rural enterprises through spontaneous self-use and surplus electricity grid connection. At the same time, using new energy vehicles instead of traditional fuel vehicles can reduce the cost of transportation for farmers. This allows rural residents to save more costs to improve other quality of life, such as education, healthcare, and entertainment. Thirdly, the use of distributed photovoltaics and new energy vehicles is more environmentally friendly. Photovoltaic power generation is a clean energy source that does not generate pollutants or greenhouse gas emissions when used, which helps to improve air quality and ecological environment in rural areas[48]. New energy vehicles use electricity as their power source, without exhaust emissions, reducing air pollution and noise pollution. These environmental advantages are of great significance for ecological protection and residents' health in rural areas[49]. The fourth is to promote agricultural development. The development of distributed photovoltaic and new energy vehicles can effectively drive the healthy development of agriculture in rural areas. Photovoltaic power generation systems can provide cheap electricity for agriculture, promote the development of agricultural intelligence, facility agriculture, and agricultural product processing industry in rural areas, and improve the efficiency and quality of agricultural production[50]. At the same time, new energy vehicles can be used in agricultural production processes such as farmland irrigation and agricultural product transportation, improving farmers' labor efficiency and economic benefits. The construction and development based on distributed photovoltaic and new energy vehicles in rural areas will bring better living conditions and quality to rural residents, improve the overall development level and sustainability of rural areas.

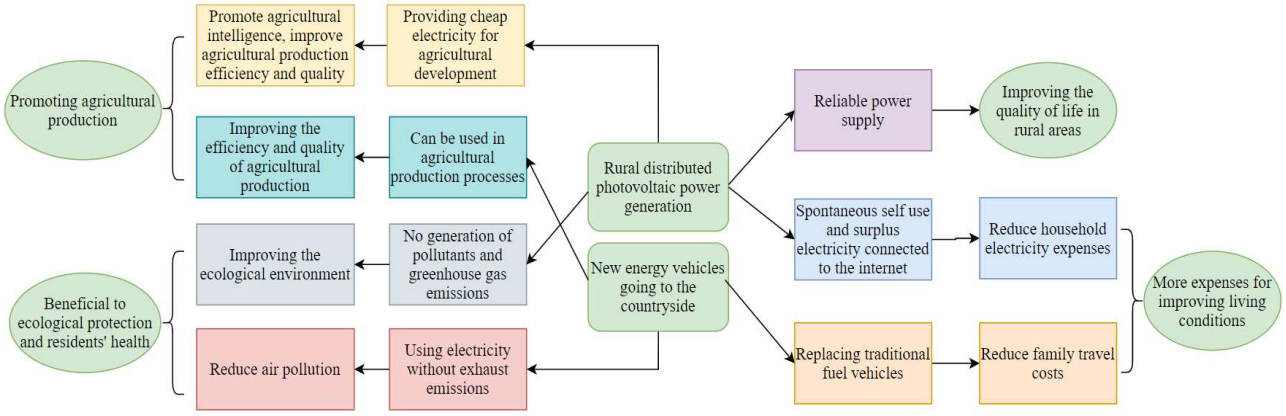

Figure 4. Improving the quality of life in rural areas.

4. Conclusion and prospect

4.1. Conclusion

In the context of dual carbon, the development of rural distributed photovoltaic and new energy vehicles in the countryside are full of opportunities and challenges. Their coordinated development has a significant synergistic effect of sharing clean energy, complementing energy conservation and emission reduction, optimizing the energy consumption structure, promoting economic development, increasing employment opportunities and improving the quality of rural life. Therefore, it is of great significance to promote sustainable development and energy transformation in rural areas. Taking effective measures to maximize its synergy is conducive to promoting the realization of the dual carbon goal.

4.2. Challenge and prospect

4.2.1. Photovoltaic panel recycling

In the process of rural distributed photovoltaic development, the disposal of waste photovoltaic panels has become increasingly prominent. Waste solar panels contain rare metals and harmful substances. If they are discarded or incinerated at will, they will cause serious pollution to the environment. Actively promote the recycling of scrapped photovoltaic panels. Through scientific management and environmental protection, rare metals can be re extracted and utilized, which can not only solve the problem of waste photovoltaic panels, but also contribute to the development of green energy and reduce the negative impact on the environment and resources. Through scientific and technological means and management innovation, we can further improve the recycling efficiency and environmental protection level of waste photovoltaic panels, so as to make greater contributions to the development of green energy and the realization of the dual carbon goal. Japan's Xinjian solar energy company will put a pyrolysis device that can recover about 95% of the solar panels into practical use. As an environmental protection device that does not emit carbon dioxide, it is expected to meet the needs of industrial waste treatment companies and other companies. Scientists at the Institute for advanced materials at Deakin University in Australia have also developed a sustainable method to extract silicon from solar panel waste and reconfigure it into nano silicon, which can then be used to manufacture high-energy anodes for lithium-ion batteries. Korean researchers have also developed a non-destructive technology, which can recover undamaged and damaged battery panels at the same time, so that the recovery rate of glass components can reach 100%. About 80% of other materials can be recycled and made into high-performance solar cells.

4.2.2. Technological innovation

The technological innovation and development direction of distributed photovoltaic mainly focus on improving the energy conversion efficiency of photovoltaic system, enhancing energy storage technology, intelligent management and intelligent control, realizing photovoltaic energy storage complementarity, promoting the construction of grid interconnection and energy Internet, while also paying attention to environmental protection and sustainable utilization of resources. The continuous progress of these technologies will promote the popularization and application of distributed photovoltaic systems and contribute to the realization of sustainable energy development goals. With the growth of distributed renewable power generation, the impact on the power grid is increasing. At the technical level, the most important impact is the thermal overload of power grid equipment, breaking the voltage limit and reverse power transmission. Smart grid is a good exploration. Smart solutions are based on the use of smart grid components, which can stimulate system flexibility. Distributed energy storage can solve power transfer, ancillary services, congestion management and other problems. There are three different business models for the development of distributed renewable energy in Germany, and different regulatory methods are used to stimulate its flexibility. By the end of 2021, Germany has installed a total of about 1.4 GW batteries with a capacity of 4.5 GW, of which household energy storage accounts for the main part.

4.2.3. Charging infrastructure to the countryside

In the face of the huge increase brought by new energy vehicles to the countryside and the scattered characteristics of rural population and vehicles, on the whole, the current rural charging infrastructure construction is lagging behind. The public charging infrastructure construction in rural areas lacks layout planning, the overall number is small, and the distribution is uneven and the layout is unreasonable. The rapidity and convenience of new energy vehicle charging need to be improved. At the same time, the relevant new energy vehicle operation, repair and maintenance services are not perfect enough to meet the after-sales needs of rural users. It is necessary to focus on the prominent bottleneck restricting the deployment of new

energy vehicles to the countryside, build charging infrastructure moderately ahead of schedule, innovate the construction, operation and maintenance mode of charging infrastructure, and ensure that it is "constructed, managed and sustainable". At the same time, accelerate the transformation of the construction conditions of charging facilities in existing rural residential communities according to local conditions, implement the requirements for the construction of charging infrastructure in new residential communities, and continue to promote the sharing of charging infrastructure construction.

4.2.4. Financial support

The coordinated transformation of rural distributed photovoltaic development and new energy vehicles to the countryside faces common challenges, such as the pressure of county-level financial funds, limited development strategies, lagging infrastructure, adverse external environment, lack of capacity-building and tighter land use policies. To solve the problem of lack of funds and talents and effectively promote the green transformation and low-carbon development in rural areas, we need to combine low-carbon emission reduction with investment promotion. We should combine front-end research, back-end project planning and implementation, and combine investment attraction and talent recruitment with low-carbon emission reduction, so as to enhance the initiative and enthusiasm of rural distributed photovoltaic development and new energy vehicles to the countryside.

Data availability statement

The data presented in this study are available on request from the corresponding author.

Author contributions

Conceptualization, SY and LL; validation, LL; writing—original draft preparation, LL, SY, JL and RJ; writing—review and editing, SY and TM. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

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