Rural New Energy Development and Farmers' Welfare: Mechanisms, Pathways, and Policy Implications for Sustainable Rural Revitalization

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Abstract: This study aims to systematically elaborate on how the development of rural new energy industries in China enhances the welfare effects of farmers. Under the dual strategic background of the national "rural revitalization" and "dual carbon" goals, rural new energy is not only a key area for the transformation of the energy structure but also an important engine for improving farmers 'living standards and increasing their income. The research reviews the mechanisms and pathways through which the development of rural new energy (photovoltaic, wind power, biomass, geothermal) in China enhances farmers' welfare. Through a retrospective analysis of existing empirical studies, the research finds that welfare improvement is mainly achieved through four mechanisms: (1) resource assetization; (2) nearby employment and skills training; (3) clean energy improves the environment; (4) project participation enhances rural governance. The study illustrates the specific benefits of different energy forms through case studies such as photovoltaic in Xinjiang's Tuoli County, wind power in Shandong's Tancheng, biomass in Hebei's Julu, and geothermal in Tianjin's Binhai. Finally, to address challenges such as grid access, technical operation and maintenance, financing channels, and insufficient farmer participation in rural new energy, four countermeasures are proposed: building a multi-energy complementary integrated energy system, strengthening technology and digital management, innovating co-construction and sharing models for business and distribution, and improving differentiated policies while enhancing farmers' capacity building. This aims to maximize the inclusive effects of rural new energy industries and provide references for related decision-making.

Keywords: Rural new energy industries, Farmers' welfare, Renewable energy.

1. INTRODUCTION

As China's economy and society enter a stage of high-quality development, rural revitalization and energy revolution have become two core issues in national development. Rural areas are not only crucial battlegrounds for achieving carbon peak and carbon neutrality goals but also key to improving the well-being of hundreds of millions of farmers. Linking rural new energy industries with household welfare is an important policy practice implemented by the Chinese government in the fields of poverty alleviation and rural revitalization. The pilot exploration centered on photovoltaic poverty alleviation began in 2014 and was fully promoted during the poverty eradication period from 2015 to 2020. After entering the stage of rural revitalization, with the deepening of initiatives such as the "Wind Power Action for Thousands of Towns and Villages," the "Sunshine Action for Thousands of Households," and the clean utilization of biomass energy, the connotation and extension of these efforts have been greatly enriched and expanded. In addition to solar energy, various forms of new energy projects, including wind energy, biomass energy, and geothermal energy, have been widely implemented, presenting a diversified development trend in rural new energy industries [1].

China's rural areas generate approximately 7.3 billion tons of standard coal equivalent in renewable energy annually, which is 12 times the current total rural energy consumption. This abundant resource provides crucial support for rural development and energy integration. The widespread adoption of diverse renewable energy sources has optimized the rural energy structure, transformed energy consumption patterns, and delivered tangible economic benefits to farmers [2].

As an innovative industrial model, rural new energy is driving the deep integration of energy transition and rural revitalization strategies. By revitalizing idle resources, creating employment opportunities, and boosting farmers 'income, it has achieved significant socio-economic benefits [3]. Taking solar energy utilization as an example, by the first half of 2025, China's household photovoltaic installed capacity reached 180 million kilowatts, generating approximately 14 billion yuan in annual income for farmers. With rapid development of distributed new energy in rural areas, the installed capacity of distributed photovoltaic systems is projected to reach 710-850 million kilowatts by 2030, indicating immense development potential. Various new energy projects now cover hundreds of thousands of villages and tens of millions of households, serving as a model pathway for green energy transition in rural areas. Against this backdrop, studying the mechanisms and pathways for enhancing farmers' welfare through rural new energy development holds significant theoretical and practical

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value for promoting energy transformation and achieving comprehensive rural revitalization [4].

"Farmer welfare" is a multidimensional concept encompassing not only income-based economic benefits, but also employment creation, environmental improvement, and capacity-building mechanisms. This study therefore addresses two core questions: What specific mechanisms drive the development of rural new energy industries to enhance farmers' comprehensive welfare? What practical pathways can achieve these welfare effects? Clarifying these questions holds significant theoretical and practical value for formulating more precise and effective rural new energy support policies, and promoting their healthy and sustainable development.

2. THEORETICAL MECHANISM: HOW TO ENHANCE THE WELFARE OF FARMERS IN RURAL NEW ENERGY INDUSTRY

The enhancement effect of rural new energy industry on farmers' welfare can be realized through a series of interrelated mechanisms.

2.1. Direct Effect Mechanism

Economic income and quality of life are the most intuitive and core welfare effects of new energy projects, which are mainly reflected in the growth of economic income and the improvement of quality of life.

2.1.1. Economic Income Growth

New energy projects have opened up stable income sources for farmers outside the traditional agriculture, and improved the economic income of farmers to varying degrees. Transforming resources into assets and farmers into shareholders. Households activate idle assets like rooftops, courtyards, and spare land through leasing to secure steady rental income. By adopting a 'self-consumption and surplus-grid-connected' model, they reduce essential expenses while earning stable electricity sales revenue. The collective village development of new energy projects generates income that benefits all villagers. A new opportunity for 'leaving the land but not the hometown'. The implementation of new energy projects creates full-chain employment opportunities for local farmers, from construction to operation. In addition to labor-intensive positions, as the projects progress, they will also cultivate a group of professional technicians and managers, continuously expanding farmers' employment channels.

2.1.2. Improvement of Quality of Life

Clean and reliable modern energy supply is the basis for improving the quality of life in rural areas [5]. The development of diversified new energy sectors in rural areas has complex implications for the local population. The mechanisms underpinning this relationship are systematized in Table **1**. The Return of Green Mountains and Clear Waters. The rural energy transition is marked by a significant leap in electrification adoption. With clean electricity becoming mainstream and biomass technology enabling waste-to-energy conversion, rural living environments have undergone fundamental improvements, delivering dual benefits of health and ecological sustainability. Through initiatives like the "Bright Future Project", the Chinese government harnesses solar and wind power to supply electricity to remote areas. Today, distributed renewable energy systems ensure stable and reliable power supply in rural regions, completely replacing traditional reliance on coal and firewood. The establishment of "zero-carbon villages" like Xingsheng Village in Ningxia has enabled residents to abandon smoke-filled traditional lifestyles, with living conditions seeing remarkable upgrades. By engaging in new energy projects, farmers enhance their comprehensive skills and self-development capabilities with a long-term perspective. As farmers' participation in organized initiatives grows more widespread and

Table 1: Mechanism of Association between Rural Diversified new Energy Industries and Farmers' Welfar

New Energy Type	Economic Income		Quality of Life
	Economic Benefit Mechanism	Employment Creation Mechanism	Environmental Improvement Mechanism
Photovoltaic power generation	Electricity fee dividends, roof rent, project dividends	Installation, maintenance, and cleaning services	Reduce coal consumption and carbon emissions
Wind power generation	Land lease, shareholding dividend, community fund	Equipment maintenance and monitoring services	Replace fossil fuels and improve air quality
Biomass energy	Raw material sales, processing income, energy saving	Collection, transportation, and processing positions	Replace fossil fuels and improve air quality
Geothermal utilization	Energy saving and hot spring tourism income	Station maintenance and service positions	Reduce coal consumption and improve ecology

profound, rural governance efficiency is simultaneously improved.

3. IMPLEMENTATION PATH: DIVERSIFIED DEVELOPMENT MODEL DRIVEN BY POLICIES

The realization of the welfare effect for farmers cannot be achieved without the combination of top-down policy design and bottom-up diversified practical approaches. Governments at all levels in China have guided and supported the development of rural new energy industries by establishing a three-in-one incentive system of "subsidies + taxes + finance" [6].

3.1. Top-Level Design: A Three-in-one Policy Toolkit

In accordance with the spirit of the 2021 National Guidelines on Rural New Energy Development and other programmatic documents, a set of combined incentive policy frameworks has been formed at the national and local levels.

Fiscal subsidies (direct incentives): These were the primary drivers for early-stage industrial development, including feed-in tariff (FIT) subsidies and initial investment grants. While national-level FIT subsidies have been gradually phased out in recent years, local governments have introduced supplementary subsidy policies tailored to their fiscal capacities. For instance, the "Notice on Biomass Power Generation Tariff Subsidies for 2023" issued by the Shandong Provincial Development and Reform Commission on December 10,2022, stipulates subsidy rates of 0.25 yuan per kilowatt-hour for agricultural and forestry biomass power projects, and 0.1991 yuan per kilowatt-hour for biogas power projects.

Tax incentives (burden reduction): Primarily implemented through corporate income tax reductions and VAT refunds to lower project development and equipment procurement costs. For instance, according to policies issued by the Yunnan Provincial People's Government, enterprises purchasing and using environmental protection or energy-saving/water-saving equipment listed in the "Corporate Income Tax Incentive Catalog for Environmental Protection Equipment" and "Corporate Income Tax Incentive Catalog for Energy-Saving/Water-Saving Equipment" can deduct 10% of the equipment investment amount from their annual corporate income tax liability.

Financial Support (Leverage Mechanism): Through programs such as the "Rural New Energy Project Loan Interest Subsidy," policy banks or local credit cooperatives provide preferential loans at rates below market levels. Article 17 of the Ministry of Finance's "Interim Measures for the Administration of Renewable Energy Development Special Funds" specifies that the special funds may be used for interest subsidies on loans, with subsidy periods ranging from 1 to 3 years and annual subsidy rates capped at 3%.

3.2. Practice Path: Three Typical Project Implementation Models

Under policy incentives, various regions have developed tailored project implementation models for different scenarios and objectives. Government-led model (Photovoltaic Poverty Alleviation Model): This policy-driven approach primarily serves targeted poverty alleviation and rural revitalization. Key stakeholders include local governments, poverty alleviation offices, power grid companies, village collectives, and registered impoverished households. Funding structure combines national poverty alleviation funds, local fiscal matching funds, and corporate social responsibility donations. Implementation pathway: By constructing centralized photovoltaic power stations at the village level with property rights owned by village collectives, the model allocates profits to impoverished households and village collectives according to specified ratios, achieving a win-win outcome for poverty alleviation and collective economic development.

Enterprise-led (market-driven development model): This model prioritizes commercial interests, focusing on large-scale and specialized operations. Key stakeholders include new energy enterprises, equipment suppliers, financial institutions, local governments, and farmers. Financing structure: Primarily relies on corporate equity and commercial bank loans, with some large-scale projects potentially adopting Public-Private Partnership (PPP) models. Implementation approach: Enterprises develop large-scale rooftop resources or rural wastelands and tidal flats through lease agreements. The company assumes full responsibility for investment, construction, and operation, while sharing a portion of the generated electricity revenue with farmers.

Farmhouse Autonomy (Distributed Self-Use Model): This model positions farmers as both investors and beneficiaries, enabling them to meet their energy needs while generating additional income. Key stakeholders include farmers, local installers, and grid companies. Financing structure: Primarily relies on farmers' own funds, supplemented by financial products like photovoltaic loans from banks. Government subsidies or electricity price incentives serve as crucial motivators. Implementation approach: Farmers independently install small-scale photovoltaic systems on their rooftops, adhering to the principle of "self-consumption with surplus power fed into the grid," thereby directly benefiting from dual advantages of electricity cost savings and revenue from power sales.

4. TYPICAL MODELS OF NEW ENERGY INDUSTRY DEVELOPMENT IN CHINA'S RURAL AREAS

4.1. Photovoltaic Assistance Model

The photovoltaic poverty alleviation model is a key national initiative that leverages solar energy projects to lift rural impoverished communities out of poverty [7]. Xinjiang's Tuoli County exemplifies this approach, having invested 51.6 million yuan to establish 11 photovoltaic power stations with a total installed capacity of 10,109 kilowatts. These facilities serve 1,949 households in 22 villages across 7 townships. As of July 2025, the county has collected 56.944 million yuan in photovoltaic revenue, which has been used to create over 1,700 public welfare jobs, pay 31.616 million yuan in wages, and provide 1.89 million yuan in living subsidies to disadvantaged groups. The model's success stems from its precise allocation mechanism and comprehensive management system. Tuoli County allocates 60% of revenues to public welfare subsidies, 30% to support village collective economies, and 10% for emergency relief and rewards. The management framework follows a "county-level dedicated account, township-specific ledger, village-level administration, and township oversight" model, ensuring transparent fund flows and standardized operations [8].

4.2. Wind Power Benefit Model

In regions abundant in wind energy resources, the wind power benefit model has become a crucial form of rural new energy development. Tancheng County is leveraging the wind power industry as a bond to establish a "village-enterprise cooperation, co-construction and sharing" benefit model, with green dividends clearly demonstrated through concrete data. In collaborative development, 15 villages in Quanyuan Town have invested resources into the Youneng Boyuan Wind Power Project, each receiving a stable annual dividend of 5,000 yuan. The 99-megawatt Weisheng Wind Power Project in Honghua Town, with a total investment of 940 million yuan, covers 3 townships and over 20 villages, generating annual tax revenue of approximately 16 million yuan, while Quanyuan Town's wind power industry contributes over 6 million yuan in annual tax revenue. Regarding income distribution, after developing clean energy on 800 mu of barren hills in Huangquan Village, farmers have seen an annual income increase of over 300,000 yuan. Compared to photovoltaic benefits, wind power projects can achieve annual income growth of thousands of yuan per land tenant. In terms of ecological and developmental win-win outcomes, the Weisheng Project generates 248 million kWh of electricity annually, reducing coal consumption by 74,400 tons while creating employment opportunities in equipment maintenance, providing a quantifiable practical model for county-level wind power benefit initiatives.

4.3. Biomass Recycling Model

The biomass recycling model represents an innovative approach that achieves dual benefits of energy production and environmental protection through the resource utilization of agricultural waste. In Julu County, Hebei Province, a biogas industrialization project has been established [9]. Upon full operation of all 14 projects, the facility will annually process 336,000 tons of crop straw, 84,000 tons of livestock manure, and 200,000 tons of toilet waste. The project produces 50.4 million cubic meters of biogas or generates 238 million kWh of electricity annually, while also producing 168,000 tons of organic fertilizer. It generates approximately 40 million yuan in tax revenue and replaces about 65,000 tons of coal annually. In 2018, the company introduced dry anaerobic fermentation technology from Finland and later collaborated with a research team from Tongji University to develop a new process. This advancement increased biogas yield per ton of straw from 300-350 cubic meters to 400 cubic meters, with 400 cubic meters of biogas capable of producing 200 cubic meters of biogas. The fermentation time was accelerated from one month to just seven days. The resulting digestate and liquid are processed into organic fertilizer, replacing chemical fertilizers to improve soil structure and enhance agricultural product quality.

4.4. Integrated Geothermal Development Model

In regions with abundant geothermal resources, the integrated geothermal development model has emerged as a distinctive approach for rural new energy utilization. Tianjin's Binhai New Area has established a diversified utilization system combining "combined heat and power + hot spring agriculture + health tourism" through geothermal resources. The geothermal reserves within 4,000 meters in Binhai New Area amount to 2.7×10^17 kJ, with an estimated exploitable capacity equivalent to 150,000 tons of standard coal over 100 years, contrary to the 260 million tons claimed by users. According to Tianjin's Mineral Resources Plan (2000-2010), the three geothermal fields of Wanglanzhuang, Shanlingzi, and Binhai collectively demonstrate recoverable underground hot water reserves of 49.7 million cubic meters per year, equivalent to approximately 500,000 tons of standard coal annually. The project employs a "tiered utilization" technology: high-temperature geothermal water is first used for power generation, medium-temperature water for heating and greenhouse cultivation, while low-temperature water is utilized for hot spring therapy and tourism development. This model not only meets the clean heating needs of over 5,000 local households but also fosters hot spring agricultural parks, boosting the development of rural tourism in the area.

5. ANALYSIS OF WELFARE EFFECTS OF RURAL NEW ENERGY INDUSTRY

5.1. Revenue Enhancement: Diversification of Revenue Sources

The rural new energy industry generates income for farmers through multiple channels, forming a diversified income structure with strong stability and sustainability. First, direct energy revenue serves as the primary income source. For instance, the "Thousand Villages Photovoltaic" power generation project in Suide County, with a total investment of 60.8 million yuan, covers 95 administrative villages and has a total installed capacity of 19 megawatts. It is expected to generate stable annual income of hundreds of thousands of yuan for each village collective. Second, resource transfer income provides additional benefits. Wind farm projects enable farmers to obtain stable rental income through land leasing. Third, project dividend income further increases farmers 'earnings. By adopting the "joint village construction and equity-based dividends" model, shares are evenly distributed among participating households regardless of village size or land quantity, ensuring fair profit distribution. State Power Investment Corporation's Gansu Company has implemented household distributed photovoltaic projects in five regions: Henan, Hebei, Shanxi, Jilin, and Gansu. In the first half of 2025, it distributed rental income totaling 2.3113 million yuan, benefiting 1,480 households. Participating farmers saw average annual income increases ranging from 1,200 to 6,200 yuan. These projects not only provide reliable economic sources for rural families but also effectively enhance their sense of fulfillment and happiness [10].

5.2. Employment Effect: Local Employment and Skill Upgrading

The rural new energy industry has created substantial local employment opportunities, effectively alleviating the surplus labor issue in rural areas [11]. Toli County utilized photovoltaic revenue funds to develop over 1,700 public welfare positions, including garbage collection, sanitation maintenance, forest fire prevention, road maintenance, public security patrols, and power station management. These positions were specifically designed for rural workers with limited or partial labor capacity, achieving "position-specific roles, one person per position, practical alignment, and suitability between individuals and positions." In terms of salary structure, an innovative model combining base wages with performance-based incentives was adopted. Base wages were determined based on job performance and inspection results, while performance bonuses were calculated by comprehensively evaluating personal and household sanitation, attendance, and compliance with arrangements, effectively boosting the work enthusiasm of poverty-alleviated workers. This employment mechanism not only provides income sources but, more importantly, enhances farmers' employability and self-development capabilities through skill training and on-the-job experience.

5.3. Ecological Effects: Improvement of Living Environment and Health

The development of rural new energy industries has brought significant ecological and environmental benefits. Biomass energy projects, through the resource utilization of agricultural waste, have reduced environmental pollution caused by straw burning. The use of geothermal energy has replaced scattered coal heating, improving air quality during winter. Wind and solar power projects have reduced fossil fuel consumption and lowered greenhouse gas emissions. Taking State Power Investment Corporation's Gansu Company as an example, its managed household distributed photovoltaic systems have a total installed capacity of 50.56 megawatts, reducing annual carbon dioxide emissions by 60,600 tons. These environmental benefits ultimately translate into health improvements. Research shows that after project implementation, the incidence of respiratory diseases in the local area decreased by 15% to 20%.

5.4. Community Governance Effect: Village Collective Economic Development and Governance Capacity Improvement

The rural new energy industry has significantly strengthened the collective economic strength of villages, providing a material foundation for rural community governance. Toli County has incorporated part of photovoltaic revenue into the village collective economy, effectively enhancing the village's capacity to assist poverty-alleviated residents. Through the "Four Deliberations and Two Public Announcements" democratic decision-making process, villages provide living subsidies to elderly, frail, or disabled households that have escaped poverty, helping low-income families and those receiving minimum living allowances increase their income. New energy projects have also promoted innovation in rural governance mechanisms. During revenue distribution, the principle of "transparency, fairness, and equity" is upheld. Village revitalization specialists compile lists of beneficiaries, which undergo preliminary review by the village "two committees" and the "Visit, Benefit, and Gather" task force. After approval and public announcement by townships, the process remains subject to supervision by the public and poverty-alleviated residents. This transparent decision-making process has strengthened villagers' trust in grassroots organizations and improved the governance efficiency of rural communities.

6. CHALLENGES FACING THE DEVELOPMENT OF RURAL NEW ENERGY INDUSTRY

6.1. Infrastructure and Grid Access Bottlenecks

The development of rural new energy faces a critical constraint: insufficient grid capacity. Most existing rural power grids were designed for traditional energy models, making them ill-suited for integrating distributed energy sources. Dai Hongcai, Director of the New Energy Research Institute at State Grid Energy Research Institute, pointed out that as distributed renewable energy installations rapidly expand, local grids are under significant absorption pressure. Accelerating the intelligent transformation of distribution networks has become a key solution to this challenge. In some regions, outdated grid infrastructure prevents newly built renewable energy projects from being connected to the grid in time, which negatively impacts both project profitability and farmers' income [12].

6.2. Technical Compatibility and O&M Management Issues

New energy technologies demonstrate varying applicability and reliability in rural areas [13]. The construction of rural photovoltaic systems lacks unified quality standards and planning benchmarks. Solar and wind power generation remain highly weather-dependent, resulting in unstable power supply. Biomass energy projects face technical challenges in raw material collection and storage, while geothermal utilization requires specialized technical support and maintenance management. The shortage of skilled professionals in rural regions leads to high operational costs and complex maintenance requirements, ultimately compromising the long-term stability of these projects [14].

6.3. Financing Mechanism and Income Stability

Rural renewable energy projects face dual challenges of limited financing channels and uncertain returns. On one hand, the substantial initial investment and lengthy payback period make it difficult for farmers to cover costs with their own funds. On the other hand, financial institutions maintain cautious risk assessments and impose stringent loan conditions. Furthermore, fluctuations in green certificate trading prices and an underdeveloped cost-sharing mechanism for energy storage systems further undermine project profitability and stability.

6.4. Insufficient Farmer Participation and Capacity-Building

In the current development of rural new energy, two prominent issues stand out: limited farmer participation and insufficient capacity building [15]. In most projects, farmers are merely passive resource providers, making it difficult for them to benefit from high-value-added segments of the industrial chain. Moreover, due to a lack of professional technical expertise and management knowledge, farmers' involvement in project operations and maintenance remains low, which restricts their ability to enhance long-term profitability [16].

7. PATHS AND POLICY SUGGESTIONS FOR OPTIMIZING THE WELFARE EFFECT OF RURAL NEW ENERGY INDUSTRY

7.1. Building a Comprehensive Energy System with Complementary Energy Sources

To address the technical characteristics of various renewable energy sources, we should establish a rural integrated energy system featuring multi-energy complementarity and system optimization [17]. By implementing complementary wind-solar integration, integrated photovoltaic-storage solutions, and biomass energy regulation, we can enhance the stability and reliability of renewable energy. For instance, promoting the "photovoltaic + wind power + energy storage" model in rural areas allows surplus electricity generated by wind and solar power to be stored in batteries when output is sufficient [18]. When wind or solar power generation falls short, the energy storage system can release stored electricity. Additionally, developing "biomass + solar" combined heat and power (CHP) models can meet the diverse energy demands of rural communities [19].

7.2. Strengthening Technical Adaptation and Innovative Applications

Enhancing the technical adaptability and integration capabilities of rural new energy industries is a crucial pathway to strengthen welfare effects. First, develop compact and modular new energy equipment tailored to rural needs, reducing installation and maintenance barriers. Second, foster cross-sector innovations by integrating new energy with agricultural technologies, such as photovoltaic agriculture and smart wind-solar hybrid water-saving irrigation systems. Third, promote digital technology applications in rural energy sectors through establishing smart energy management platforms to improve energy utilization efficiency.

7.3. Innovative Business Model and Revenue Distribution Mechanism

To overcome commercial bottlenecks in rural new energy development, innovative business models and revenue-sharing mechanisms are essential [20]. First, promote the "co-construction and sharing" model through cooperative partnerships and collective equity participation, enhancing farmers 'involvement and profit-sharing. Second, explore the "energy services + value-added services" model by integrating energy production with agricultural and tourism services, fostering integration of primary, secondary, and tertiary industries while diversifying revenue streams. For profit distribution, establish a contribution-based mechanism to ensure fair returns for resource providers, investors, and managers. State Power Investment Corporation's Gansu Branch has implemented clear rent distribution standards, procedures, and supervision mechanisms to guarantee precise payments directly to farmers' accounts. Leveraging the "Guangxiangfu" digital management system, the company achieves end-to-end online processing from fund allocation to accounting, ensuring traceable and verifiable fund flows. This approach not only eliminates intermediary oversights but also safeguards fund security and transparency in distribution.

7.4. Improve the Policy System and Implementation Mechanism

To establish a coordinated and efficient policy framework and implementation mechanism, the "Implementation Opinions on Accelerating Rural Energy Transformation and Supporting Rural Revitalization" jointly issued by the National Energy Administration, Ministry of Agriculture and Rural Affairs, and National Rural Revitalization Administration outlines three key objectives: By 2025, a series of green and low-carbon rural energy pilot projects will be established, with wind, solar, biomass, and geothermal energy continuing to increase their share in rural energy consumption. The new energy industry is positioned as a vital supplement to the rural economy and a key source of income growth for farmers. The plan proposes three measures: First, developing differentiated support policies tailored to local resource endowments and development conditions; Second, enhancing interdepartmental coordination to integrate energy, agricultural, and environmental protection policies for synergistic effects; Third, establishing a full-process supervision mechanism to ensure standardized project implementation and equitable benefit distribution.

7.5. Strengthening Capacity-Building and Social Participation

Enhancing energy literacy and participation capacity among farmers and rural communities is crucial for ensuring the sustainability of renewable energy's welfare benefits. First, implement training programs in renewable energy technologies and management to cultivate local technical and managerial talent. Second, support the development of farmer cooperatives to strengthen organizational structures and negotiation capabilities. Third, intensify public education campaigns to raise awareness and acceptance of renewable energy among rural residents.

8. CONCLUSIONS AND ENLIGHTENMENTS

Rural energy sector is projected to reach carbon peak earlier than the national target. As a crucial bridge connecting the "dual carbon" goals with rural revitalization, the development of rural new energy industries demonstrates significant potential in enhancing household welfare. Through diversified models including photovoltaic assistance programs, wind power for public benefit, biomass recycling, and geothermal integrated development, these initiatives have created multiple welfare effects: economic returns, job creation, environmental improvement, and capacity building. They provide farmers with stable income channels, local employment opportunities, ecological enhancement, and strengthened community governance capabilities.

In the future, the rural new energy industry will exhibit three major development trends: First, diversified development, where solar, wind, biomass, and geothermal energy will develop differently based on resource endowments; Second, integrated innovation, with new energy deeply integrating with agricultural production, rural tourism, and rural elderly care to form "energy+" composite industries; Third, intelligent upgrading, through the widespread application of digital technology, energy storage technology, and smart grid technology to enhance the intelligence level of rural energy systems. Through the coordinated efforts of these multidimensional approaches, the rural new energy industry will become a crucial engine for rural revitalization, bringing more sustainable, stable, and diversified welfare effects to farmers, promoting common prosperity and sustainable development in rural areas, and contributing key efforts to realizing prosperous, healthy, and beautiful China villages.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

All authors agree to the publication of this manuscript.

AVAILABILITY OF DATA AND MATERIALS

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

COMPETING INTERESTS

The authors declare no competing financial interest.

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AUTHORS' CONTRIBUTIONS

Conceptualization, Y.S. methodology, software, Y.S. and C.Y.M., validation, Y.S. and X.C writing—original draft preparation, X.C. and C.Y.M. writing—review and editing, Y.S. All authors agreed to the manuscript.

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