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Article

International rural new energy industry innovation development and benefit-linkage practices

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Abstract: The rural new energy industry is a crucial area for promoting green transformation and achieving sustainable development, significantly contributing to improvements in energy structure and environmental protection. While China's rural new energy industry has made substantial progress due to policy support and technological advancements, it still faces numerous challenges in practical development. This paper aims to compare and analyze the experiences and practices of various countries and regions—including the United States, the European Union, Brazil, and China—to identify their primary benefit-linkage mechanisms, policy support systems, and overall performance. Based on this analysis, the paper will provide policy recommendations and improvement measures for the innovative development of China's rural new energy industry. The research findings indicate that (1) different countries and regions employ various benefit-linkage mechanisms in the rural new energy sector, including cooperative models, public-private partnerships, and community participation models. Each mechanism has its unique advantages and disadvantages in facilitating project development and benefit linkage. (2) Although all countries have established comprehensive policy support systems, there are notable differences in the introduction and implementation of market mechanisms. The European Union and the United States possess relatively mature market mechanisms for carbon emission trading and green certificate trading, whereas the market mechanisms in China and Brazil are either new or not sufficiently developed. (3) The United States and the European Union demonstrate strong performance in technological advancement and market operations, yielding significant economic and environmental benefits. In contrast, China and Brazil have made progress in policy support and technology adoption but need to enhance their market mechanisms and international cooperation. (4) Social participation and community support yield important social benefits in new energy projects across various countries and regions, particularly the community participation model, which positively impacts community cohesion and project development.

Keywords: green and low-carbon; rural new energy industry; innovative development; benefit-linkage; policy analysis

1. Introduction

With the intensification of global environmental issues and the scarcity of energy resources, green and low-carbon development has become a global consensus and action goal. The increase in greenhouse gas emissions and the impact of climate change on the environment have prompted countries to accelerate their transition and seek sustainable energy solutions [1]. In this context, the development and utilization of new energy, especially the development of the rural new energy industry, have become important avenues for promoting green transformation and achieving sustainable development [2]. In China, the innovative development of the rural new

energy industry is considered an important component in achieving carbon neutrality goals and advancing rural revitalization strategies. With continuous technological advancements and policy support, the rural new energy industry plays a crucial role in promoting economic development, enhancing energy self-sufficiency, and improving environmental quality [3]. However, different countries and regions have varied experiences and challenges in the development of the rural new energy industry, providing us with valuable lessons and insights.

With the strengthening of global climate policies and the rapid development of renewable energy, countries worldwide are formulating and implementing strategies to combat climate change. These efforts are driving the reduction of greenhouse gas emissions and the transition towards more sustainable energy systems [4]. The Paris Agreement sets forth global targets for controlling temperature rise and encourages countries to adopt more proactive emission reduction measures [5]. Advancements and cost reductions in solar, wind, and energy storage technologies have gradually increased the market share of renewable energy [6]. Global investment in green energy and technological innovation is driving the widespread adoption of renewable energy. Green finance has become an integral part of the global financial market, with investors and financial institutions increasingly focusing on environmental, social, and governance (ESG) factors [7]. The rise of financial instruments such as green bonds and green funds has facilitated the financing and development of green and low-carbon projects. The application of technologies like smart grids, the Internet of Things (IoT), and big data has enhanced energy management and optimization. The integration of digital technologies in energy production, transmission, and consumption helps improve energy efficiency and reduce resource waste [8].

The development of the rural renewable energy industry is beneficial for promoting rural revitalization. It helps increase rural economic income, improve infrastructure, and drive comprehensive and sustainable development. By leveraging renewable energy sources such as solar, wind, and biomass, the rural renewable energy industry reduces dependence on traditional fossil fuels, improves the energy mix, and enhances energy security [9]. Moreover, rural renewable energy projects can effectively reduce greenhouse gas emissions and environmental pollution, improve rural environmental quality, and promote ecological conservation [10]. In addition, the implementation of rural renewable energy projects can create job opportunities, enhance residents' living standards, and promote harmonious social development.

Current literature on the rural renewable energy sector exhibits several significant shortcomings. Firstly, methodological limitations are prevalent, as most research tends to adopt a singular approach—either quantitative analysis or case studies—while neglecting the benefits of a mixed-methods strategy. This restricts the generalizability and applicability of the findings. Furthermore, many studies fail to adequately consider local characteristics, such as regional policies, socioeconomic contexts, and cultural differences, which can significantly influence the implementation of rural renewable energy initiatives. Lastly, there is a gap in addressing the integration of technological innovations with supportive policy

frameworks, as existing literature often highlights advancements in technology without systematically analyzing their promotion alongside policy support.

To address these literature gaps, this study offers several important contributions. First, by systematically collecting and analyzing data from diverse countries and regions, this research provides a comprehensive understanding of the rural renewable energy sector, revealing critical success factors and challenges encountered in real-world applications. Second, this study employs a mixed-methods approach, combining both quantitative and qualitative analyses to capture the complexities of rural renewable energy projects, thereby enhancing the depth and breadth of the research. Third, the study offers localized policy recommendations tailored to specific regional characteristics and needs, ensuring their feasibility and effectiveness across different socioeconomic contexts. Finally, by emphasizing the interaction between technological innovation and policy support, this research proposes effective benefit-linkage mechanisms that foster coordinated development within the rural renewable energy industry. Drawing on international experiences, this study aims to provide valuable insights for the innovative application of renewable energy technologies in China, contributing to the country's carbon neutrality goals and rural revitalization strategies.

2. Literature review and theoretical foundation

2.1. Green low-carbon and rural renewable energy industry concepts

Green low-carbon development refers to achieving sustainable economic, social, and environmental progress by enhancing resource efficiency, reducing greenhouse gas emissions, and minimizing environmental pollution. This concept emphasizes balancing economic growth with environmental protection and climate change mitigation, driving a societal transition toward low-carbon, eco-friendly, and resource-efficient practices [11]. Green development emphasizes reducing the consumption of natural resources and minimizing environmental impacts in economic activities. It achieves sustainable economic growth through the advancement of green technologies and the development of green industries [12]. A low-carbon economy focuses on reducing carbon dioxide and other greenhouse gas emissions, promoting the use of low-carbon energy sources and technologies to slow the pace of climate change.

The rural renewable energy industry involves the development and utilization of renewable energy resources in rural areas, such as solar, wind, biomass, and geothermal energy. These resources are characterized by their renewability, cleanliness, and environmental friendliness, helping to reduce reliance on traditional fossil fuels, achieve energy self-sufficiency, and promote environmental protection [13]. The rural renewable energy industry encompasses not only the research and application of new energy technologies but also the entire process of energy production, storage, distribution, and consumption. Its goal is to enhance energy efficiency and drive rural economic development by promoting the adoption of renewable energy technologies in rural areas.

2.2. Global development status of the renewable energy industry

Globally, the renewable energy industry has progressively become a crucial driver of economic growth. Advances in technologies such as wind, solar, biomass, geothermal, and hydrogen energy have led to continuous breakthroughs, decreasing costs, and expanding application ranges. According to data from the International Energy Agency (IEA), global investment in renewable energy has steadily increased in recent years, with wind and solar energy emerging as primary focus areas. Concurrently, the rapid development of electric vehicles and energy storage technologies has further enhanced the renewable energy industry chain, leading to a more integrated and mature industry ecosystem [14]. Global solar photovoltaic (PV) installed capacity has been steadily increasing, particularly in China, the United States, and European Union countries. Technological advancements and economies of scale have significantly reduced the cost of solar power generation. The wind energy market has seen rapid development in Europe and North America, with technological innovations driving down wind power costs. Offshore wind energy is emerging as a new growth area within the sector [15]. Although the development of biomass and geothermal energy has been slower compared to solar and wind energy, their utilization is gradually increasing in certain countries and regions, particularly those rich in agricultural and forest resources.

The rural renewable energy industry is gaining increasing attention globally, with many countries implementing policy support and market mechanisms to promote renewable energy development in rural areas. In the United States, both federal and state-level policies, such as tax incentives and subsidies, have driven the growth of solar and wind energy projects in rural regions [16]. The European Union encourages the adoption of renewable energy in rural areas, fostering the development of community energy projects and green energy cooperatives. In China, national policies and subsidies have driven the implementation of rural renewable energy projects, achieving significant results, particularly in the fields of solar photovoltaics and wind energy.

2.3. Benefit-linkage mechanisms in rural renewable energy industries

Benefit-linkage mechanisms refer to the cooperation and coordination methods among different stakeholders in renewable energy projects, aimed at achieving resource sharing, risk distribution, and equitable benefit-sharing [17]. Benefit-linkage mechanisms in renewable energy projects can be categorized into several models.

(1) Cooperative Model. Farmers collectively invest in, build, and operate renewable energy projects through cooperatives. They share both the benefits and risks associated with the projects. While this model promotes farmer participation and equitable benefit distribution, it may encounter challenges related to management and operational efficiency [18].

(2) Enterprise + Farmer Model. Enterprises take the lead in investing in and developing renewable energy projects, while farmers contribute land or labor. Both parties share the generated benefits. This model can significantly boost rural economic development but requires well-defined agreements to manage risk

distribution and benefit-sharing.

(3) Public-Private Partnership (PPP) Model. This model involves collaboration between government entities and private companies to jointly invest in and manage renewable energy projects. The success of this model depends on effective cooperation between the public and private sectors, highlighting the importance of strong partnership mechanisms for project success [19]. These are frameworks designed to ensure that the economic, social, and environmental benefits of renewable energy projects are equitably distributed among all stakeholders, including local communities, project developers, and governments. Effective benefit-sharing mechanisms are crucial for the success and sustainability of rural renewable energy projects. They help to align the interests of various stakeholders, foster community support, and ensure that projects contribute positively to local development.

2.4. Theoretical foundation

Based on cooperation theory, benefit-sharing mechanisms coordinate the interests of different stakeholders to create mutually beneficial outcomes. Cooperation theory emphasizes that by building trust and sharing resources, the success rate and overall benefits of projects can be enhanced [20]. Game theory is used to analyze the behavior and strategies of various stakeholders in renewable energy projects, helping to understand the impact of different benefit-linkage mechanisms on each party. Policy tools theory explores the role of government in promoting green low-carbon development, including incentives, regulations, and market mechanisms. In green low-carbon policies, the government can drive the development of green technologies and industries through financial incentives, technical support, and regulatory constraints [21]. Multilevel governance theory emphasizes the interactions and cooperation among various levels of government, markets, and society in global climate governance. In the context of rural renewable energy industries, this theory helps to understand the roles and coordination mechanisms of local governments, central governments, and international organizations. It highlights the importance of collaborative efforts across different governance levels to effectively manage and advance renewable energy initiatives.

3. Evolution of benefit-linkage mechanisms in China's rural renewable energy industry

3.1. Development progress

Emergence Stage (Around 2000): The rural renewable energy industry began to attract attention, with the promotion of renewable energy sources such as biogas, solar water heaters, and small hydro power stations in rural areas.

Preliminary Development Stage (2000–2010): The government started to implement relevant policies to support the construction and promotion of renewable energy projects, such as the "Renewable Energy Law." Advanced foreign technologies were introduced, and demonstration projects were launched to accumulate experience.

Rapid Development Stage (2010–2020): Large-scale promotion of solar photovoltaics, wind energy, and biomass energy projects in rural areas. The variety and application scope of renewable energy continued to expand, covering agricultural production, daily energy supply, and more.

Innovation Development Stage (2020–Present): Ongoing advancements in renewable energy technology to improve energy efficiency and economic benefits. Exploration of various benefit-sharing models, such as agro-solar complementary and agro-wind complementary, to enhance endogenous economic development in rural areas.

3.2. Major innovative models and mechanisms

Regarding the models, the cooperative model organizes farmers into cooperatives to participate in new energy projects and share the benefits. The enterprise + farmer model involves enterprises investing in the construction of new energy projects, while farmers contribute land and labor, resulting in mutual benefits. The government guidance model entails the government directing farmers and enterprises to engage in new energy projects through policy support and subsidies.

In terms of mechanisms, market-oriented approaches are employed to attract social capital for the construction and operation of rural new energy projects. A technical service system is established to provide technical support and training for these projects. Additionally, diversified financial products and services are developed to facilitate the financing of new energy projects in rural areas.

3.3. Policy support and complementary measures

In terms of policy support, the Renewable Energy Law offers legal protection for the development of the new energy industry. The government provides financial subsidies to lower the costs of participation in new energy projects for both farmers and enterprises. Preferential tax policies will be implemented to encourage investment in and operation of these projects.

Regarding supporting measures, there will be increased investment in the construction of rural power grids, roads, and other infrastructure to support new energy projects. Technical training programs will be conducted to enhance the technical skills and management capabilities of farmers and enterprises. Additionally, support will be provided for the development of demonstration projects, with successful experiences and models promoted to guide further initiatives.

3.4. Current status and challenges

Currently, the scale of rural new energy projects is steadily expanding, with applications becoming increasingly diverse. These projects have stimulated rural economic development, enhanced farmers' incomes, reduced environmental pollution, and advanced ecological protection. However, challenges remain: the low level of technology in some areas affects project efficiency; substantial investment requirements highlight a notable shortage of funds; insufficient management capacity impacts the long-term viability of projects; and inadequate policy implementation in some regions hampers progress. In summary, while China's rural new energy

industry has made significant strides through policy support and technological innovation, it continues to face challenges related to technology, capital, and management.

4. Lessons from international experience in rural renewable energy

4.1. United States practices in rural renewable energy development

4.1.1. Historical evolution

The development of rural renewable energy in the United States has evolved significantly over the decades. During the early development phase (1970s–1990s), the energy crisis of the 1970s prompted a focus on renewable energy, with pilot projects for solar, wind, and biomass technologies starting in rural areas. The rapid development phase (2000s–2010s) saw significant advancements in photovoltaic, wind, and biomass technologies, leading to substantial cost reductions and broader adoption. This period was marked by strong policy support from federal and state governments, including the Energy Policy Act and the American Recovery and Reinvestment Act, which facilitated the expansion of rural renewable energy projects. In the diversified development phase (2010s-Present), the range of renewable energy applications in rural areas has expanded to include distributed photovoltaic systems, wind power, and biogas projects. Innovative benefit-sharing models have emerged, enhancing the integration of renewable energy with rural economic development.

4.1.2. Support mechanisms

At the federal level, support includes direct financial subsidies, tax credits, and favorable loans to reduce investment costs for rural renewable energy projects. Funding is also provided for research and demonstration projects to drive technological advancements. At the state level, requirements for utility companies to obtain a certain percentage of their power from renewable sources stimulate market demand. Dedicated green banks offer low-interest loans and venture capital to support rural renewable energy projects. Market mechanisms include the establishment of carbon trading markets to encourage companies to reduce carbon emissions and invest more in renewable energy. Additionally, long-term power purchase agreements between companies and farms ensure sustained project revenue.

4.1.3. Benefit-linkage models

In the Cooperative Model, rural renewable energy cooperatives organize farmers to jointly invest in, build, and operate renewable energy projects, sharing the profits and reducing the investment risk for individual farmers.

In the Enterprise + Farmer Model, enterprises invest in the construction of rural renewable energy projects, while farmers provide resources such as land and labor. The profits are shared between the two parties according to an agreed-upon ratio.

In the Community Supported Agriculture (CSA) Model, community members pre-purchase products or services from renewable energy projects, providing financial support while enjoying the economic and environmental benefits generated by the projects.

4.1.4. Performance trends

In terms of economic benefits, rural renewable energy projects have significantly increased income in rural areas and stimulated local economic development. The expansion of these projects has also driven the growth of related industries, creating additional job opportunities.

From an environmental perspective, the large-scale adoption of renewable energy has reduced reliance on fossil fuels and lowered greenhouse gas emissions. This shift has improved the ecological environment in rural areas and promoted sustainable development.

Socially, renewable energy projects have enhanced the quality of life for rural residents by providing more reliable and cleaner energy supplies. The promotion of these projects has also strengthened community cohesion and supported the autonomous development of rural areas.

4.1.5. Policy insights

The U.S. experience underscores the importance of continuous policy support for rural renewable energy development, including financial subsidies, tax incentives, and research funding. This suggests that other countries should ensure the continuity and systematic nature of their policies. Additionally, the U.S. employs a multi-layered support system involving federal, state, and local governments, demonstrating that a multi-tiered, multi-channel approach can more effectively advance rural renewable energy projects. Market mechanisms, such as carbon trading markets and power purchase agreements, play a decisive role in resource allocation and promote sustainable development. Innovative benefit-linkage models, such as cooperative and community-supported agriculture models, have integrated rural economies with renewable energy sectors, providing a valuable reference for other nations to stimulate endogenous growth in rural areas. In summary, continuous policy support, multi-layered mechanisms, market-oriented operations, and innovative models are crucial for the successful development of rural renewable energy industries.

4.2. EU practices in rural renewable energy development

4.2.1. Historical evolution

In the early 1990s, the EU began focusing on climate change and gradually introduced renewable energy policies, with the 1997 Energy White Paper marking the first formal commitment to renewable energy targets. During the mid-2000s to early 2010s, the Renewable Energy Directive of 2001 set development targets for member states, and funding programs such as the Sixth and Seventh Framework Programmes (FP6, FP7) supported research and application of new energy technologies. The rapid development phase from the mid-2010s to early 2020s saw the 2010 Climate and Energy Package establish ambitious targets for renewable energy, greenhouse gas reduction, and energy efficiency by 2020. Technological advancements in photovoltaic and wind energy significantly lowered costs, leading to widespread adoption in rural areas. Since 2020, the European Green Deal has set a goal for carbon neutrality by 2050, and post-COVID-19, the EU has significantly invested in green energy projects through the Recovery and Resilience Facility,

further driving energy transformation in rural regions.

4.2.2. Support mechanisms

At the EU level, the Renewable Energy Directive and the Climate and Energy Package establish clear targets and requirements for renewable energy development. Multiple funding programs, such as Horizon 2020, the Innovation Fund, and the Structural and Investment Funds, support research, demonstration, and promotion of rural renewable energy projects. At the national level, member states develop their own renewable energy plans and policies in accordance with EU guidelines, offering various economic incentives like financial subsidies, tax breaks, and low-interest loans to encourage rural renewable energy projects. Market mechanisms, including the carbon emission trading system and the renewable energy certificate (green certificate) trading system, further promote investment and application in renewable energy by increasing market transparency and supporting sector growth.

4.2.3. Benefit-linkage models

Cooperative Model: In this model, farmers and community residents jointly invest in, build, and operate renewable energy projects, such as wind farms and photovoltaic stations. They share the benefits and enhance community cohesion.

Public-Private Partnership (PPP) Model: This model involves collaboration between the government and private enterprises to jointly invest in and manage rural renewable energy projects. It aims to improve the sustainability and economic efficiency of the projects.

Energy Community Model: Community members participate together in the planning, construction, and operation of renewable energy projects. Through democratic decision-making mechanisms, they achieve shared benefits and promote collective development.

4.2.4. Performance trends

Technological advancements and economies of scale have significantly reduced the costs of renewable energy projects such as photovoltaics and wind power, enhancing their economic benefits. The promotion of renewable energy projects has also stimulated the development of related industry chains and increased employment opportunities in rural areas.

The large-scale adoption of renewable energy has reduced the use of fossil fuels and lowered greenhouse gas emissions, contributing to climate change mitigation. The expansion of renewable energy projects has also supported ecological conservation in rural areas and reduced environmental pollution.

In rural areas, the development of renewable energy has improved energy self-sufficiency and reduced reliance on external energy sources. Cooperative and energy community models have enhanced residents' sense of participation and responsibility, fostering community development.

4.2.5. Policy insights

In terms of comprehensive policy systems, the European Union has ensured the stable development of rural renewable energy industries by establishing a thorough legal framework and policy objectives. This suggests that other countries should consider developing systematic and comprehensive policy frameworks when

formulating renewable energy policies. Regarding multi-layered support mechanisms, the EU's approach spans multiple levels, including EU-wide, national, and local supports, effectively advancing rural renewable energy projects through diverse and multi-channel support. Other countries can adopt such multi-layered support mechanisms to enhance policy implementation effectiveness. In terms of market operations and innovation, the EU promotes renewable energy development through market-based approaches like carbon trading and green certificate trading, while innovative models such as cooperatives and energy communities enhance the sustainability of rural renewable energy projects. Other nations could leverage these market-based operations and innovative models to stimulate market vitality. Lastly, the EU emphasizes community involvement and shared benefits through models like cooperatives and energy communities, which boost residents' sense of participation and responsibility. This highlights the importance of stimulating community engagement to ensure the sustainable development of rural renewable energy projects. Overall, the EU's integrated policy system, multi-layered support mechanisms, market-based operations, innovative models, and focus on community participation and shared benefits provide a robust framework for advancing the healthy development of rural renewable energy industries.

4.3. Brazil practices in rural renewable energy development

4.3.1. Historical evolution

In the early development phase (1970s–1990s), Brazil began seeking alternative energy sources due to the 1970s oil crisis, leading to the gradual rise of ethanol fuel projects. During this period, rural areas started to pilot and promote renewable energy projects such as small hydropower, wind energy, and solar energy. In the policy guidance phase (early 2000s to early 2010s), Brazil enacted the Electricity Law in 2002 and related policies to encourage the development of renewable energy. The Renewable Energy Incentive Program (PROINFA) launched in 2002 aimed to promote the growth of wind energy, small hydropower, and biomass energy. The rapid development phase (mid-2010s to early 2020s) saw significant advancements in photovoltaic and wind energy technologies, with costs decreasing substantially, leading to widespread adoption of rural renewable energy projects. Brazil actively engaged in international renewable energy cooperation, importing advanced technologies and funding to accelerate the development of rural renewable energy projects. In the comprehensive development phase (2020–present), Brazil set ambitious goals to significantly increase the proportion of renewable energy by 2030 in its National Energy Plan, further advancing the rural renewable energy industry. Following the COVID-19 pandemic, Brazil has intensified investment in rural renewable energy projects through a green recovery plan, promoting economic recovery and sustainable development.

4.3.2. Support mechanisms

In terms of policy support, laws such as the Electricity Law and the Renewable Energy Law provide policy guarantees and clearly define the goals and requirements for renewable energy development. Financial subsidies, tax incentives, and low-interest loans are offered to reduce the investment costs of rural renewable energy

projects and encourage the development of renewable energy in rural areas. For funding support, low-interest loans and financing assistance are provided through the National Development Bank to help finance rural renewable energy projects. Additionally, international aid and cooperation are actively sought to attract foreign investment and technology, promoting the development of rural renewable energy projects. In terms of market mechanisms, electricity auction mechanisms are used to determine the prices of renewable energy projects, promoting market competition and improving project efficiency. Participation in international carbon trading markets allows for funding support through carbon trading, further advancing the development of renewable energy.

4.3.3. Benefit-linkage models

In the cooperative model, farmers form energy cooperatives to jointly invest in, build, and operate renewable energy projects, sharing the profits and reducing individual investment risks.

In the public-private partnership (PPP) model, the government collaborates with private enterprises to jointly invest in and manage rural renewable energy projects, enhancing the sustainability and economic benefits of the projects.

In the community support model, community residents are encouraged to participate in the planning, construction, and operation of renewable energy projects, using democratic decision-making mechanisms to achieve shared benefits and mutual development.

4.3.4. Performance trends

In terms of economic benefits, advancements in photovoltaic and wind energy technologies have significantly reduced project costs, improving their economic viability. The development of rural renewable energy projects has stimulated the growth of related industry chains and created additional employment opportunities in rural areas.

Regarding environmental benefits, large-scale application of renewable energy has reduced dependence on fossil fuels and lowered greenhouse gas emissions. The promotion of renewable energy projects has also contributed to ecological protection and reduced environmental pollution in rural areas.

In terms of social benefits, developing renewable energy has enhanced energy self-sufficiency in rural areas and reduced reliance on external energy sources. Cooperative and community support models have increased residents' sense of involvement and responsibility, promoting sustainable community development.

4.3.5. Policy insights

In terms of multi-layered support mechanisms, Brazil has advanced rural renewable energy projects through a combination of national, local, and international support channels. Other countries can adopt this multi-layered approach to enhance policy implementation effectiveness. For market-based operations, Brazil has used mechanisms like power auctions and carbon trading to promote renewable energy, increasing project efficiency and economic benefits. Other countries can replicate this market-driven model to invigorate market activity. Regarding social participation and shared development, Brazil emphasizes community involvement

through cooperatives and community support models, enhancing residents' sense of participation and responsibility. This suggests that other countries should focus on stimulating community engagement to promote the sustainable development of rural renewable energy projects. Additionally, Brazil's success in developing rural renewable energy projects through international cooperation and technology importation provides a valuable example for other nations to strengthen international partnerships, acquire advanced technologies and funding, and accelerate renewable energy growth. Overall, Brazil's approach—combining multi-layered support mechanisms, market-based operations, community involvement, and international cooperation—demonstrates an effective strategy for fostering the healthy development of the rural renewable energy sector.

5. Comparative analysis of rural renewable energy development practices

5.1. Similarities and differences in benefit-linkage mechanisms

Table 1 is the similarities and differences in benefit-linkage mechanisms.

(1) Similarities: The Cooperative Model is utilized in Brazil, the United States, the EU, and China, where farmers form cooperatives to jointly invest in, construct, and operate renewable energy projects. This model enables them to share profits and mitigate individual investment risks. The Public-Private Partnership (PPP) Model is employed by Brazil, the United States, and the EU, involving collaboration between governments and private enterprises to invest in and manage rural renewable energy projects, thereby enhancing their sustainability and economic benefits. Additionally, the Community Participation Model is encouraged in the United States, the EU, and Brazil, where community members are involved in the planning, construction, and operation of renewable energy projects through democratic decision-making processes, fostering shared benefits and collective development.

(2) Differences: The Enterprise + Farmer Model is particularly prevalent in China, where enterprises invest in renewable energy projects while farmers contribute land, labor, and other resources, sharing the benefits. This model is less common in other countries and regions. In contrast, the Energy Community Model is widely applied in the EU, where community members collectively engage in renewable energy projects. This model enhances community cohesion and self-development capabilities, reflecting a distinct approach compared to the models used in other regions.

Table 1. Similarities and differences in benefit-linkage mechanisms.

Mechanism	Brazil	United States	EU	China
Cooperative model	Yes	Yes	Yes	Yes
Public-private partnership (PPP)	Yes	Yes	Yes	No
Community participation	Yes	Yes	Yes	No
Enterprise + farmer model	No	No	No	Yes
Energy community model	No	No	Yes	No

5.2. Similarities and differences in policy support

Table 2 is the similarities and differences in policy support.

(1) Similarities: Brazil, the United States, the EU, and China have all established comprehensive legal frameworks through legislation to support renewable energy development goals and policies. Governments in these regions provide various financial incentives, such as subsidies, tax benefits, and low-interest loans, to lower investment costs in rural renewable energy projects. Additionally, they fund research and demonstration projects for renewable energy technologies, fostering technological advancement and innovation.

(2) Differences: The United States and the EU have extensively implemented market mechanisms such as carbon emission trading systems and green certificate trading mechanisms, which promote market competition and enhance project efficiency. In contrast, China and Brazil have less developed market mechanisms; China primarily depends on national policies and subsidies, while Brazil incorporates these mechanisms to a lesser extent. Additionally, Brazil actively seeks international assistance and cooperation to attract foreign investment and technology for its rural renewable energy projects. China, although also engaged in international cooperation, primarily relies on domestic resources and technology, promoting renewable energy projects through its "Belt and Road" initiative.

Table 2. Similarities and differences in policy support.

Policy support aspect	Brazil	United States	EU	China
Comprehensive legal framework	Yes	Yes	Yes	Yes
Financial incentives (subsidies, tax benefits)	Yes	Yes	Yes	Yes
Funding for research and demonstration projects	Yes	Yes	Yes	Yes
Market mechanisms (carbon trading, green certificates)	Limited	Extensive	Extensive	Limited
International assistance and cooperation	Active seeking foreign investment	Limited	Limited	Engaged in but resource-reliant
Domestic resource utilization	Moderate reliance	High reliance	Moderate reliance	High reliance

5.3. Performance and trend comparisons

Table 3 is the similarities and differences in policy support.

(1) Performance Comparison: In the United States and the EU, advanced market mechanisms and technological progress have significantly reduced project costs, resulting in high economic benefits. Conversely, China and Brazil, despite achieving cost reductions, experience relatively lower economic benefits due to less mature market mechanisms. Environmentally, the EU has realized substantial reductions in greenhouse gas emissions and pollution through stringent policies and carbon limits. While the United States, China, and Brazil also see notable environmental benefits, their policies' enforcement and effectiveness vary compared to the EU. Socially, the United States and the EU have fostered greater community involvement and responsibility through community participation models, promoting sustainable development. In contrast, China and Brazil primarily reflect social benefits in improved rural living standards and energy independence, with relatively less

emphasis on community engagement.

(2) Trend Comparison: Technologically, the United States and the EU lead in advancements in photovoltaic, wind, and energy storage technologies. China is rapidly advancing, particularly in photovoltaics and wind energy, but still has room for growth in high-end technologies and innovations. Brazil's technological focus is mainly on biomass and wind energy, balancing technology importation with local development. Policy-wise, the United States and the EU are shifting from subsidies and incentives to market mechanisms like carbon trading and green certificates. In China and Brazil, policies remain largely subsidy-driven and government-led, with gradual introductions and refinements of market mechanisms. On the international stage, the United States and the EU actively promote global cooperation through technology exports and project investments, expanding their influence. China enhances its international impact through the "Belt and Road" initiative, while Brazil is increasing its role in renewable energy cooperation within Latin America and gradually expanding its international collaboration.

Table 3. Similarities and differences in policy support.

Aspect	United States	EU	China	Brazil
Performance: economic benefits	High due to advanced mechanisms.	High due to advanced mechanisms.	Lower due to less mature mechanisms.	Lower due to less mature mechanisms.
Performance: environmental benefits	Notable reductions but variable enforcement.	Substantial reductions via stringent policies.	Notable benefits, variable enforcement.	Notable benefits, variable enforcement.
Performance: social benefits	Greater community involvement.	Greater community involvement.	Improved rural living standards.	Improved rural living standards.
Trend: technological advancements	Leading in PV, wind, and storage.	Leading in PV, wind, and storage.	Rapid advances in PV and wind.	Focused on biomass and wind.
Trend: policy direction	Shifting to market mechanisms.	Shifting to market mechanisms.	Largely subsidy-driven.	Largely subsidy-driven.
Trend: international cooperation	Actively promoting global cooperation.	Actively promoting global cooperation.	Enhanced impact via belt and road.	Increasing role in Latin America.

6. Insights and policy recommendations

6.1. Insights for China's rural renewable energy industry

To foster the innovative development of China's rural renewable energy industry, it is crucial to establish a comprehensive policy system. (1) Establish a Comprehensive Policy System. To drive the innovative development of China's rural renewable energy industry, it is essential to establish a comprehensive policy framework. China should learn from the EU and the United States by setting clear medium- and long-term development goals and roadmaps to ensure policy coherence and stability. This includes refining the "Renewable Energy Law" and related legislation, as well as defining specific renewable energy targets for rural areas to guide implementation effectively. (2) Implement Multi-Level Support Mechanisms. A robust multi-level support mechanism is crucial for lowering investment costs and enhancing the feasibility of renewable energy projects. By providing various economic incentives, such as subsidies, tax benefits, and low-interest loans, China can create an environment conducive to the growth of its rural renewable energy

sector. Additionally, introducing market-based approaches like carbon trading and green certificates, modeled after successful strategies in the U.S. and EU, will further enhance economic benefits and market competitiveness. (3) Promote Technology Innovation and Community Engagement. Strengthening technology innovation and community involvement is vital for enhancing China's competitiveness in renewable energy. Increasing funding for research and development, particularly in emerging technologies like energy storage and smart grids, will improve technological standards. Moreover, encouraging international cooperation to attract advanced technologies and fostering community participation in renewable energy projects will enhance public support and promote sustainable development.

6.2. Improving benefit-linkage mechanisms in rural renewable energy

To improve benefit-linkage mechanisms in rural renewable energy, developing cooperative models is key. (1) Develop Cooperative Models. To improve benefit-linkage mechanisms in rural renewable energy, developing cooperative models is key. Supporting the establishment of renewable energy cooperatives where farmers jointly invest in, build, and operate projects will enable them to share both benefits and risks. By providing policy support and training, cooperatives can enhance their management and operational capabilities, ensuring the sustainability of their projects. (2) Optimize Enterprise + Farmer Models. Optimizing the enterprise + farmer models is essential for protecting the interests of both parties. This can be achieved by clearly defining cooperation terms and benefit-sharing methods, which will help prevent disputes. Strengthening supervision of these cooperations will further safeguard farmers' rights by preventing unfair contracts and unreasonable benefit distribution, ensuring equitable outcomes for all stakeholders involved. (3) Promote Public-Private Partnerships and Energy Community Models. Promoting Public-Private Partnership (PPP) models is crucial for leveraging the strengths of governments and private enterprises in the investment and management of rural renewable energy projects. Establishing clear policy frameworks and cooperation norms will facilitate smooth implementation and project sustainability. Additionally, implementing energy community models that allow communities to participate in renewable energy projects through democratic decision-making will increase community involvement and responsibility, ensuring successful project outcomes.

6.3. Policy recommendations

To advance the rural renewable energy industry, several policy recommendations should be considered. (1) Formulate and Refine Policies. To advance the rural renewable energy industry, it is crucial to formulate and refine comprehensive policies. Developing a national "Rural Renewable Energy Development Plan" will outline clear development goals, policy measures, and implementation steps. Additionally, creating "Rural Renewable Energy Project Management Measures" will regulate project planning, construction, and operation to ensure quality and effectiveness, providing a solid framework for project success. (2) Enhance Financial Support and Introduce Market Mechanisms. Enhancing financial support through the establishment of a special fund for rural renewable

energy will facilitate research, construction, and operational activities. Optimizing subsidy policies based on project types and regional characteristics will improve targeting and effectiveness. Furthermore, introducing market mechanisms, such as a national carbon trading market and renewable energy certificate trading, will encourage investment, increase market transparency, and create a more competitive environment for renewable energy projects. (3) Promote International Cooperation and Social Participation. Promoting international cooperation by engaging in global renewable energy projects will facilitate technology transfer and enhance domestic competitiveness through the introduction of advanced technologies and management practices. Additionally, fostering social participation by encouraging rural communities to engage in renewable energy projects will drive community development and yield social benefits. Strengthening public awareness and education on renewable energy will further improve recognition and support for the industry. Through these measures, China can enhance benefit-linkage mechanisms, improve policy effectiveness, and drive innovative development toward sustainable goals.

7. Conclusion

The study concludes as follows: Countries and regions demonstrate diverse practices in rural renewable energy benefit-linkage mechanisms. The United States and the EU widely employ cooperative and community support models; Brazil emphasizes enterprise-farmer collaboration, while China primarily relies on enterprise-led and government-supported models. These various models contribute differently to the promotion of rural renewable energy projects. In terms of policy support, systematic legal frameworks and financial incentives are established across countries, but the extent and methods of introducing market mechanisms vary. The EU and the United States have developed mature market mechanisms for carbon and green certificate trading, whereas China and Brazil have less developed or newer market mechanisms.

Performance differences are evident, with the United States and the EU leading in technological advancement and market-based operations, demonstrating significant economic and environmental benefits. China and Brazil have made notable progress in policy support and technology introduction but require further development in market mechanisms and international cooperation. Social participation and community support have shown substantial benefits globally, with the EU's energy community model and the United States' community participation model effectively enhancing community cohesion and project sustainability. This study's focus on select countries and regions may overlook unique practices and policies in others, potentially leading to an incomplete understanding of global rural renewable energy development. Future research should encompass a broader range of countries and regions, including developing nations and emerging markets, to offer a more comprehensive global perspective on rural renewable energy industry development.

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