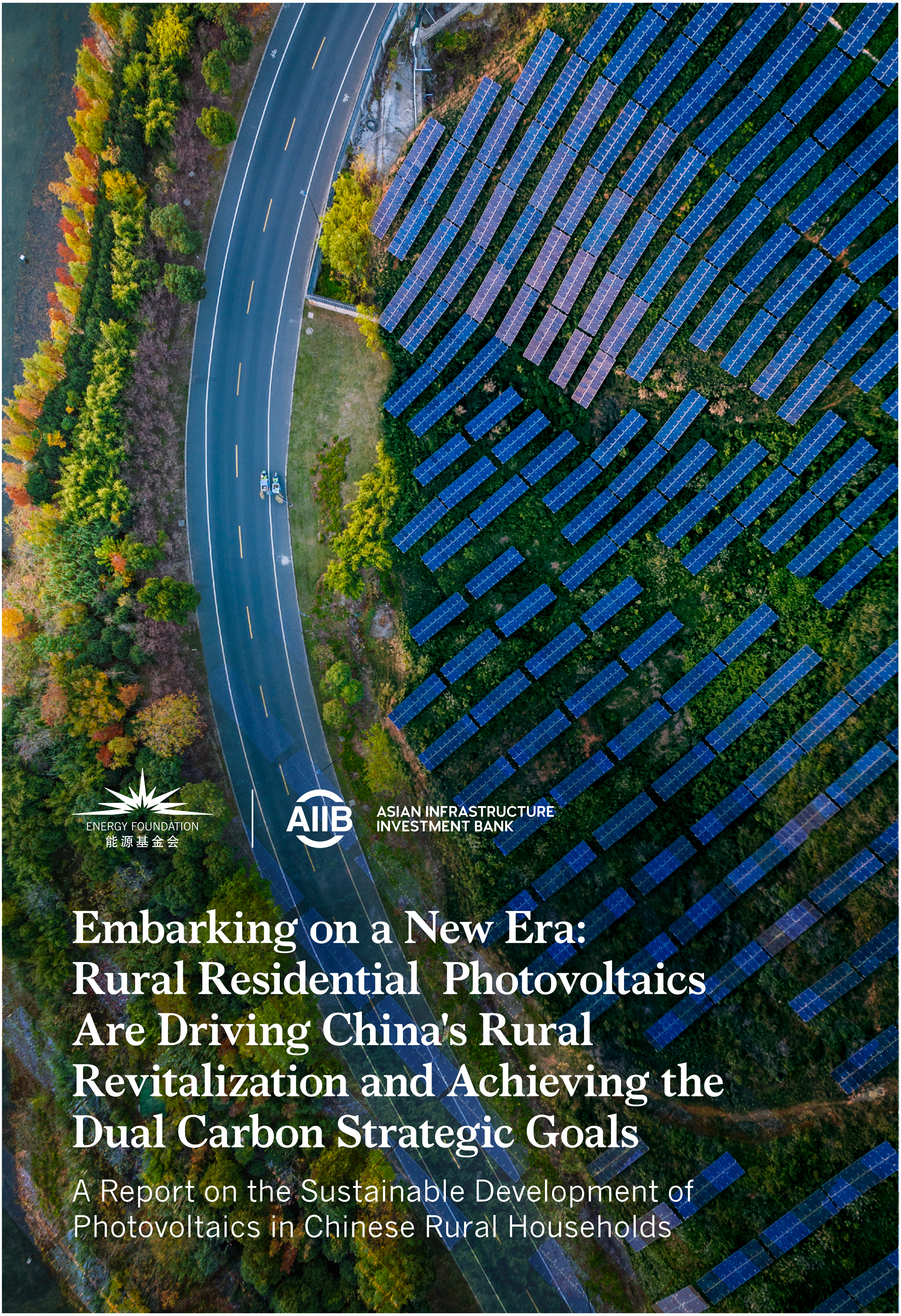

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Embarking on a New Era: Rural Residential Photovoltaics Are Driving China's Rural Revitalization and Achieving the Dual Carbon Strategic Goals

A Report on the Sustainable Development of Photovoltaics in Chinese Rural Households

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[1] Previously known as Banking Department Region 2

[2] Previously known as Operational Services Department

Contents

Preface

In September 2020, China officially announced its Dual Carbon goals at the 75th UN General Assembly (UNGA). These two goals call for China to achieve peak carbon emissions by 2030 and carbon neutrality by 2060. These ambitious goals have accelerated the pace of the country's energy transition, with the traditional fossil fuel-based energy system gradually being replaced by a green and low-carbon system of renewable energy. The development and promotion of key renewable energy forms have become top priorities for the present and for the future energy transition. This involves both the exploration of critical technologies as well as a meticulous examination of efficient and sustainable business models and the roles of stakeholders in comprehensive solutions. Each part of this process has an undeniable impact on economic development and people's lives.

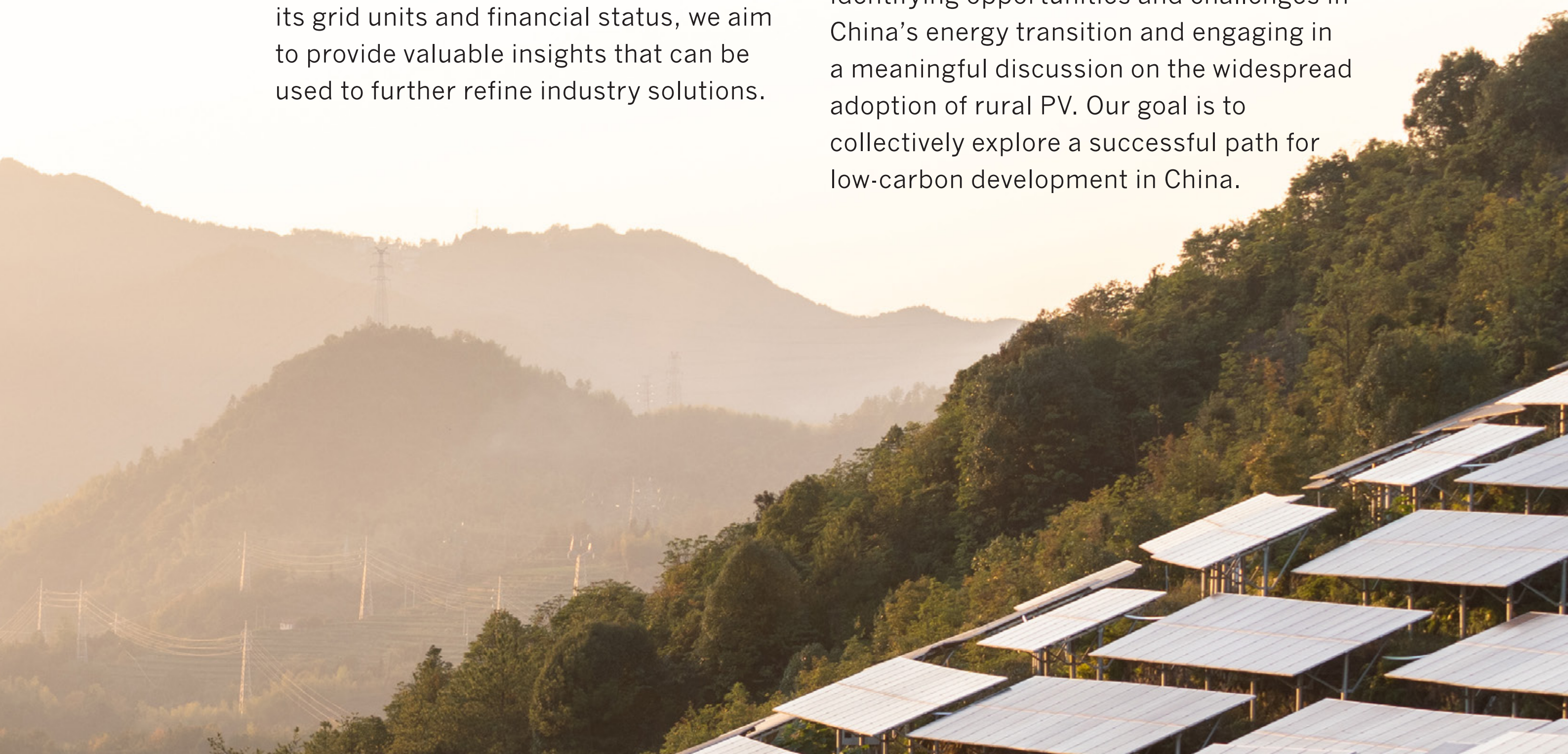
To achieve carbon neutrality by 2060, renewable energy must account for 80% of total electricity generation. Among renewal energy types, photovoltaic (PV) power has a crucial role to play in realizing the Dual Carbon goals by virtue of its low carbon footprint, ease of promotion, and economic stimulation effect. It is anticipated that the proportion of China's electricity generated by PV will gradually increase from 5% in 2022 to 45% in 2060. Distributed solar PV, characterized by its small scale and high construction flexibility, will become a vital engine for rural areas to achieve both decarbonization and income growth. In this context, we will closely examine the status quo of distributed PV in rural areas, the challenges it faces, the design of business models and solutions, and typical pilot cases. We hope that this will offer a fresh perspective for the strategic design and widespread implementation of distributed PV in rural areas.

We realize that despite the vast prospects for the development of distributed PV in rural areas, it currently faces significant challenges. These include the low levels of rural electricity consumption, the transition of residential PV to the subsidy-free era, challenges in implementing policies due to low willingness to participate on the part of various stakeholders, and the complex and dynamic rural market environment. Under the existing rooftop leasing and self-financing & self-ownership business models, stakeholders are actively innovating business models to encourage the development of rural distributed PV in a market-driven manner and help overcome the various bottlenecks the market faces. We propose that local governments, schools, local businesses, financial institutions, and other stakeholders should simultaneously enhance education on rural distributed PV and improve the assessment mechanism for guarantee providers to safeguard the interests of rural households, thereby encouraging the widespread adoption of PV.

To better assist policymakers and industry leaders, we try to identify the pillars supporting the long-term development of rural distributed PV systems. We believe the following six pillars are indispensable for the long-term development and innovation of rural distributed PV: reduced station establishment costs and increased willingness to invest; optimized station ownership models and power generation frameworks; increased rural power consumption capacity; balanced power supply and demand based on energy storage technologies; usage of grid regulatory and trading capabilities; and improved grid and supporting infrastructure. We are encouraged by the fact that, across the various development trends we observed in rural distributed PV, these six pillars have entered different stages of practical implementation, and numerous promising attempts at relevant solutions have emerged around them. We conducted an in-depth analysis of the representative solution “PEDF—Photovoltaic-Energy Storage-Direct Current-Flexibility” (integrating solar PV, distributed energy storage, direct current distribution, and flexible power consumption). By analyzing its grid units and financial status, we aim to provide valuable insights that can be used to further refine industry solutions.

Looking ahead, the new rural PV systems of the future, will not only meet the electricity needs of rural households but also have the ability to further support the power needs of surrounding industries, creating a new integrated energy landscape for rural PV. We expect to see a variety of business models for rural PV evolve in the future, offering significant potential benefits for rural revitalization. However, such a societal transformation is a gradual process and cannot rely solely on the efforts of one party. We anticipate a more significant role for the government in this new power system by enabling the construction of distributed energy facilities and mobilizing funds and resources. The delineation of powers and responsibilities among various stakeholders in the rural PV ecosystem also warrants further exploration in the future.

Energy Foundation China is committed to promoting sustainable energy for the prosperity and climate security of China and the world. It also looks forward to contributing valuable perspectives to the development of rural PV in China. We provide this report for the purpose of identifying opportunities and challenges in China’s energy transition and engaging in a meaningful discussion on the widespread adoption of rural PV. Our goal is to collectively explore a successful path for low-carbon development in China.



Executive Summary

Guided by "Dual Carbon" Goals, the Future is Full of Promise

Guided by the Dual Carbon goals, China's power and energy structures are swiftly transitioning from a fossil fuel-dominated system to a new era of green, low-carbon, and renewable energy. In 2022, China's cumulative installed capacity for wind and solar power reached 760 million kW, with non-fossil energy accounting for 36.2% of the total power generation. This means that by 2030, before achieving carbon emissions peaking, China's wind and solar capacity will have to grow to at least twice its 2022 level. To realize carbon neutrality by 2060, renewable energy sources, primarily solar PV, wind, and hydropower, must constitute 80% of total power generation. Among these energy sources, PV power stands out due to its low carbon footprint, ease of deployment, and economic stimulation effect. As the cost of electricity generation gradually decreases and efficiency continues to improve, it is projected that the share of PV power in China's total power generation will increase from 5% in 2022 to 45% by 2060. PV power will become a crucial driver in achieving the Dual Carbon goals.

In the field of PV power generation, residential PV systems feature small-scale capacity and high construction flexibility. The generated electricity can be directly used on-site, contributing to the transformation of energy consumers into producers, storers, and consumers all at once. As of 2022, newly installed residential PV capacity reached 28% of China's total PV capacity. With continuous improvements in supporting equipment such as energy storage and electrification equipment, the energy utilization efficiency of residential PV will continue to rise. This will provide users with efficient and low-cost electricity while facilitating effective collaboration with the overall power grid system. Taking a micro perspective, if each rural household installs a PV system of more than 20 kW on their rooftop, it could theoretically meet all their electrical needs, including winter heating (for a 50-square-meter main room) and cooking, as well as charging various types of vehicles. If residential PV is further combined with energy storage technology and other flexible resources to form a new power system, the use of coal for heating and cooking in rural households could be entirely replaced by solar energy, significantly reducing greenhouse gas emissions from rural buildings. Taking a macro perspective, China's rural areas boast abundant roof resources, with increasingly clear property rights. The current rooftop area of rural buildings in China has reached a staggering 27.3 billion square meters. Using this as the basis for calculation, the potential installed capacity of residential PV is nearly 2 billion kW, with an annual electricity generation potential exceeding 2.5 trillion kWh. This amount represents nearly one-third of total national electricity consumption measured at over 8.6 trillion kWh in 2022.Currently, rural households consume approximately 350 billion kWh of electricity annually for daily life, and the agriculture, forestry, and animal husbandry sectors consume around 200 billion kWh for production. If a comprehensive electrification strategy is implemented, covering residential, production, and transportation energy needs, rooftop PV alone could meet the demands of the rural population. Rural residential PV not only holds environmental value but also commercial and investment potential, serving as a crucial force in supporting China's rural revitalization strategy. In recent years, the rural residential PV sector has attracted investment from many types of institutions, including private equity firms, multilateral investment banks, large state-owned central energy enterprises, and foreign energy companies. Currently, the ROI for residential PV power generation remains stable at 8% to 10%, offering a higher and more stable return compared to other financial products. The construction, installation, and ongoing maintenance of PV stations have also created employment opportunities in rural areas, ranging from basic installation, cleaning, and transport to specialized positions such as front-end sales, construction, and regular maintenance.

The decision to adopt the Dual Carbon strategy is a significant move by China, showing its proactive stance in taking on global responsibilities and striving to build a community with a shared future for humanity. Utilizing new energy resources not only involves technological and economic development but is also intricately linked with the well-being of the nation and its people. In this process, residential PV is set to become a key driver for rural areas to achieve both decarbonization and increased income. Its development is a significant manifestation of the successful implementation of the Dual Carbon strategy, and it holds the promise of vast future prospects.

Amidst Challenges, Opportunities Abound

The widespread adoption of rural residential PV faces its share of challenges. First, rural regions exhibit low power consumption levels, yet they boast considerable grid-integrated power generation capabilities. However, the limited distribution network capacity necessitates significant financial backing for further system renovation, highlighting the importance of local consumption, adaptive regulation, and energy storage solutions. Second, with the ending of subsidies, residential PV entered the subsidy-free era as of 2022. This shift demands that stakeholders along the value chain explore innovative avenues for profit generation and also poses the pressing need to accelerate the development of carbon trading markets. Third, the implementation of policies such as "county-wide advancement" and incremental distribution networks has encountered hurdles, which may impact the effectiveness of these policies and engagement among stakeholders. Fourth, the rural market presents a dynamic and intricate landscape characterized by distinct regional variations, challenges in customer acquisition, dispersed business operations, and low levels of sustained interest among rural households.

China's business models for residential PV are rooted in property ownership and profit distribution strategies. They can be divided into two main types: **self-financing & self-ownership** and rooftop leasing. These models can be further categorized based on consumption patterns into "full grid feeding" and "self-generation and self-consumption with surplus grid feeding". Power station investors and end-users typically determine property rights and consumption models based on factors such as their own electricity consumption patterns and local electricity rates and pair them with various metering and settlement methods. Given the current landscape of these two primary business models and the electricity system structure, stakeholders can explore short-term solutions to address the challenges faced by rooftop PV in rural China. These solutions include innovative grid integration models, the exploration of green credit mechanisms, and the development of PV insurance products.

The **rooftop leasing model** has been widely adopted in the rural residential PV market in China and features unique Chinese characteristics. Against the backdrop of "county-wide advancement" of PV, rooftop leasing accounts for over 80% of the entire residential PV market. Such a remarkable market share presents development opportunities for stakeholders along the value chain.

For power station developers, securing rural customer base is pivotal. Investors or developers with local customer acquisition channels and market familiarity gain a substantial advantage in the highly homogenous competition within the rural residential PV market. First, these developers can broaden their avenues of customer acquisition by combining user segmentation and sales channels. Second, they can utilize innovative rural residential PV grid integration models (e.g., the new "village-level aggregation" grid integration solution) to alleviate grid integration pressures. Third, they can actively explore green credit models, leveraging national incentives for green finance to create innovative financing models and address the financing challenges faced by rural residential PV projects.

Local organizations such as local governments, schools, and regional enterprises can contribute to achieving energy efficiency, reducing carbon emissions, and enhancing rural household well-being. In the short term, they can conduct PV knowledge education initiatives for rural households, increasing their understanding of benefits and responsibilities. This will help lower households' risk of legal disputes and encourage long-term self-ownership.

In the self-financing & self-ownership model, the rooftop owner bears the construction cost of the power station, collects the income generated, and retains ownership of the station. This model is prevalent in areas not covered by "county-wide advancement" initiatives or among rural households with a certain understanding of PV benefits and higher expectation for revenue. Rural households, either through full payment or financing tools (such as loans), purchase or lease PV system equipment and handle the installation. The self-financing & self-ownership model yields a higher internal ROI (13% to 15%). Therefore, as people's awareness of PV power stations and disposable income increase, the household market is likely to shift from an investment-oriented to a consumer-oriented focus in the long run, driving growth in demand.

However, under this model, rural households are susceptible to natural disasters and other force majeure factors that can cause loss of power station assets, and may also face reduced electricity revenue and increased station wear and tear due to poor operation and maintenance. Moreover, most rural households currently lack awareness of insurance products, with only 36% of power stations having commercial insurance. Insurance companies can create innovative insurance products tailored specifically for rural households who own distributed PV stations, including property insurance, third-party liability insurance, and quality assurance insurance. Raising rural households' awareness as regards insurance through educational campaigns will strengthen their risk management capabilities.

Financial institutions can establish a sound guarantee assessment mechanism, focusing on the qualifications, historical operational performance, insurance coverage, and product quality control of power station developers. This optimization of the market environment will safeguard rural household interests and prevent disorderly practices in the PV loan market from disrupting the financial market order in the PV industry.

Six Pillars for Accelerated Progress

In the long run, in order to align with our country's medium- and long-term Dual Carbon goals and to establish a pioneering power system grounded in clean energy, the continued expansion and innovation of China's rural residential PV sector urgently require support from the following six key pillars:

Pillar 1: Reduced station establishment costs and increased willingness to invest. The relentless progress in PV cell manufacturing technologies is set to drive steady enhancements in power generation efficiency. According to industry experts, by 2035, the cost per kilowatt-hour of PV power could potentially decline by 35% to 40%. Moreover, continued strides in manufacturing processes will further cut down installation and operational expenses, and inventive business models also have the potential to reduce customer acquisition costs for distributed PV power stations. Furthermore, groundbreaking one-stop Internet platform models like those found overseas will reduce customer acquisition costs by 20% to 30%, building on the foundation of the conventional ground promotion model. Leveraging China's well-established Internet business ecosystem, the rural rooftop PV sector stands ready for sustained innovation in customer outreach strategies.

Pillar 2: Optimized station ownership models and power generation frameworks. At present, the promotion of rural residential PV predominantly leans on the rooftop leasing and full grid feeding model, known for its manageable risk profile and comparatively straightforward profit predictions. However, with rural users' increased awareness of PV power stations, more individuals are anticipated to participate in the self-financing & self-ownership with self-generation and self-consumption model of station construction. On the one hand, this model offers increased flexibility. Households seeking higher returns on investment and with the capability to shoulder construction expenses stand to see greater economic gains. Evaluations indicate that, assuming full grid feeding for a 10-kW residential PV system, the income for the self-financing & self-ownership model will be three times that of the rooftop leasing model. On the other hand, with increased tangible benefit for rural users, the widespread adoption of PV power stations will gather momentum. This ripple effect will foster diversified involvement in rural residential PV, while concurrently curbing the risk of asset concentration in the hands of state-owned investment enterprises and other major players.

Pillar 3: Increased rural power consumption capacity. In rural China, electricity consumption is relatively low, and the level of electrification is not particularly high. Local energy consumption only accounts for approximately 10% of the theoretical PV generation potential of rural households. As distributed PV becomes more deeply integrated into the grid, rural distribution systems will face growing pressure for power consumption. Addressing this challenge entails enhancing local and nearby consumption capabilities. This strategy not only alleviates the strain on rural grids, but also improves rural quality of life in practical ways. On one hand, by continuously improving rural electrification levels, it fosters and expands the market for residential power use in rural areas, thus enhancing local consumption. From 1992 to 2020, the electrification of cooking activities (by average time proportion) gradually increased from below 10% to nearly 80%. In parallel, the electrification ratio for heating activities rose from below 5% to nearly 70%, with six provinces exceeding 80%. On the other hand, integrating local energy layouts with regional industrial and economic growth and making the most of local resource potential can boost the development of energy-consuming industries in villages and towns, thereby bolstering nearby consumption capabilities.

Pillar 4: Balanced power supply and demand based on energy storage technologies. Household energy storage is a versatile tool for regulating power, yet its cost-effectiveness remains an obstacle to broader adoption. Given the relatively modest residential power prices in China, incorporating energy storage could potentially prolong the investment payback period for residential PV by approximately six years. Consequently, energy storage might find more relevance in the commercial and industrial PV sector, which are characterized by higher power prices, notable peak-to-off-peak price differentials, and substantial self-consumption rates. Nevertheless, the past decade has seen a steady decline in energy storage costs in the Chinese market. By 2025, prices might experience another 50% reduction compared to 2020 figures. With residential tiered pricing and peak-to-off-peak price differentials potentially offsetting the per-kWh cost of a single battery charge and discharge cycle, residents are likely to show greater interest in investing in energy storage devices. Additionally, a variety of innovative and cost-competitive energy storage solutions continue to emerge, including bidirectional electric farming equipment capable of charging and discharging, and energy storage-equipped electric vehicle charging stations.

Pillar 5: Usage of grid regulatory and trading capabilities. In order to navigate the many types of distributed generation assets, the grid needs to fine-tune its coordination abilities while bolstering its regulatory functions. In certain regions, local grids are harnessing virtual power plant technology to streamline power distribution in a cohesive manner. On the consumption end, this approach allows for participation in real-time power trading, offers supplementary services, and improves bilateral transactions for revenue sharing. This strong foundation of grid regulation is laying the groundwork for power trading to become an emerging focus. Market-driven point-to-point trading will facilitate localized power circulation, empowering users to directly conduct power transactions. This pricing model strikes a balance between grid power rates and residential rates, benefiting both stakeholders.

Pillar 6: Improved grid and supporting infrastructure. China's Central Document No. 1 proposed the intensification of rural grid construction, with the National Development and Reform Commission (NDRC) establishing "two priorities" for rural PV development. These prioritize support for rooftop distributed PV power generation with the generated power supplied to grids, and grid companies should prioritize acquiring this generated power, paving the way for the upgrade and renovation of rural grids. Concurrently, local governments are progressively introducing incentives for PV energy storage, thereby working to bring down the cost of energy storage technology. A wide range of stakeholders, including PV companies and local banks, are engaging in green and low-carbon financial products. Notably, PV loan products have set a benchmark for the market. As the national-level power trading market gradually takes form, the curtain is rising on power market reforms. From central guidelines to local policies, from financial products to the establishment of public trading platforms, a policy framework and market mechanisms tailored to distributed PV are gradually taking shape.

At present, the six pillars above have entered the stage of practical implementation, with various regions embarking on valuable explorations involving comprehensive solutions. Among them, PEDF technology, as a new zero-carbon electricity solution, facilitates the exploration of the "self-owned power station + electrification consumption + energy storage + flexibility control" model and can effectively promote the integration of "production, consumption, storage, and interaction".

PEDF Model Innovation

PEDF is a novel model built on four key technologies: Photovoltaic (PV), Energy storage, Direct current distribution, and Flexibility in power usage. Through the overlapping and integrated use of multiple technologies, the traditional "source following the load" model that requires a high degree of coordination on the part of the grid is transforming into a grid-friendly "load following the source" approach. This change effectively consumes PV energy, achieving energy-efficient and low-carbon power system operations. Currently, PEDF technology is primarily applied in building scenarios, with initial estimates indicating a potential carbon reduction of approximately 25% in building operations.

In the context of PEDF, new direct current grids will consist of two types of units:

First, there are household units. Due to increasing electrification levels and the promotion of direct current appliances, the electricity generated by residential PV can fully cover domestic electricity needs. Additionally, the bi-directional charging and discharging functionality of electric farm machinery allows it to serve as cost-effective energy storage devices. For example, during the day, the PV charging system charges agricultural equipment, and the surplus electricity can power the household during the night or on cloudy days. Excess power is sent to the microgrid for trading, generating income from electricity sales. In this scenario, due to the considerable profits brought by the self-financing & self-ownership plus self-generation and self-consumption model, and with household electricity needs increasing with electrification, rural households that have/can borrow the necessary funds and are willing to assume certain investment risks can actively participate in the construction of power stations and microgrids.

Second, there are village-level public units. These units are constructed on public buildings such as village government offices or village-operated schools, or they can be distributed PV stations scattered across open spaces. These public units not only support the electricity needs of the buildings themselves but also facilitate public area lighting and solar power storage and charging stations. Such units provide a green energy supply at the village level. Within the same direct current microgrid, users can freely trade electricity. If the village has poultry farms, agricultural processing plants, or other community-run industries with significant daily electricity demands, the industry owners can enter power purchase agreements with local PV-generating rural households within the microgrid to compensate for any electricity shortfalls. They pay a grid integration fee to the grid and conduct electricity transactions at intermediary prices, increasing the proportion of locally consumed electricity. Furthermore, by utilizing energy storage facilities, a continuous power supply can be ensured day and night for village-run industries.

Due to the initial investments in hardware facilities and renovations for the PEDF project, including energy storage, direct current microgrids, direct current household appliances, and other investments, the construction cost per watt was RMB 4.6, approximately 30% higher than typical residential PV station construction costs of about RMB 3.2 per watt. Consequently, the overall project payback period is longer, currently nearing 15 years, twice as long as regular projects. However, rural PEDF systems can help reduce the investment required for upgrading rural power grids and projects such as coal-to-electricity and coal-to-gas heating. If a new type of direct current microgrid PV system is established with well-designed energy storage systems and government financial support, households will have the opportunity to trade electricity. They will be able to actively participate in peak shaving support markets and carbon trading to directly earn income. According to calculations, in this new system, the returns for households investing in PV systems would be 1.5 times higher compared to the self-financing and self-ownership model.

A New System to Power the Voyage Ahead

In the near future, the new rural PV system—with its holistic ecosystem encompassing station construction, power generation, consumption, energy storage, and trading—will not only fulfill the power demands of rural households but also underpin the industrial power supply in surrounding regions. While upholding the principle of household power autonomy, this new system constructs an integrated energy landscape for rural residential PV. It not only tangibly enhances the power infrastructure and fosters a fair distribution of benefits, but also effectively improves power utilization. As a multitude of new PV systems take root across rural China, a network is gradually emerging, connecting isolated points to form interconnected nodes and then evolving into a comprehensive framework of distributed energy. This network will improve the quality of life of rural residents and contribute to achieving the Dual Carbon goals.

Looking ahead to the next 10 to 30 years, we anticipate that these new rural PV systems will mature. The economic viability of residential PV stations will continue to improve, and the ownership models will become more diverse. Households will be able to opt for self-owned stations or generate power sales revenue through participation in collective rural projects, each with its distinct sales model. Reliable and cost-effective power will allay concerns about power consumption, thereby augmenting power utilization efficiency. Even in remote areas, villages can attain energy self-sufficiency through residential PV installations without relying on grid integration. Excess power that large generators cannot immediately consume can be efficiently stored in centralized or distributed energy storage devices and coordinated through local scheduling for nearby consumption. This could include supplying neighboring rural households or catering to the industrial and commercial power needs within the village, supplying power for nighttime domestic use, or feeding into the broader grid. Such measures would not only support surrounding industries but also propel rural revitalization forward.

The government assumes a pivotal role in this emerging power landscape. At the rural and township levels, local governments can serve as coordinators, facilitating collective village involvement in distributed energy projects, as well as mobilizing funds and resources. They can also function as asset management entities, effectively consolidating dispersed generation assets within villages to boost the income of local residents. The responsibilities of county-level governments include efficient service delivery, increasing participation of local governments and residents, facilitating administrative procedures, and helping establish microgrid systems. Empowered by robust policies aimed at revitalizing rural economies and combined with market-driven strategies, villagers, as asset owners, can proactively engage in the new rural power system. As we look ahead, a deeper exploration of participation strategies and a clear definition of roles and responsibilities among stakeholders will become crucial. Governments can provide subsidies, or invest and participate in the operation of local control and coordination centers, thereby fully utilizing the local distributed power system. Alternatively, they can establish policies to manage and regulate the transmission capacity of village-level networks connected to the broader grid.

As things stand at present, stakeholders involved in or observing the distributed PV sector must thoughtfully consider entry points and commercial strategies within the residential PV value chain based on strategic positioning, business layout, and industry resources. Casting our gaze into the future, we foresee the establishment of a rural PV power system that substantially refines the power infrastructure, balances the distribution of benefits, and optimizes power consumption. Through the collective endeavor of society as a whole, the unlimited sunlight we enjoy will generate increasing value for rural China, propelling rural revitalization forward.

At the same time, drawing inspiration from China's experience, emerging economies and developing nations can harness their own resources and capabilities to cultivate an operational environment to enable residential PV by leveraging policies, technologies, industrial configurations, and financial support. They can select new business models and foster innovation to achieve the transition towards low-carbon development.

01 Significance, Positioning, and Prospects of Residential PV under the Dual Carbon Goals

1.1 Distributed PV: A key catalyst for carbon reduction in the power system

On September 22, 2020, President Xi Jinping expressed China's Dual Carbon goals during the General Debate of the 75th Session of the United Nations General Assembly, saying "We aim to have carbon emissions peak before 2030 and achieve carbon neutrality before 2060". Currently, nearly 90% of China's greenhouse gas emissions originate from the energy sector[1], with the power industry accounting for nearly half of the carbon dioxide emissions of the energy system[2]. To realize the Dual Carbon goals, China must undertake substantial adjustments to its current electricity generation framework. This necessitates a shift from centralized, planned, and fossil fuel-centric energy systems towards distributed, market-driven, efficient, and environmentally sustainable alternatives.

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[1] International Energy Agency (2021), An Energy Sector Roadmap to Carbon Neutrality in China, https://www.iea.org/reports/an-energy-sector-roadmap-to-carbon-neutrality-in-china/executive-summary?language=zh

[2] International Energy Agency (2021), Enhancing China's ETS for Carbon Neutrality: Focus on Power Sector, https://www.iea.org/reports/enhancing-chinas-ets-for-carbon-neutrality-focus-on-power-sector/executive-summary?language=zh

The expansion of electricity generated by renewable energy holds the potential to drastically curtail China's carbon emissions and bring about China's carbon emissions peak before 2030. Moreover, the zero emissions of renewable energy electricity positions it as an alternative to various existing demand-side energy sources, making it a primary tool for achieving carbon neutrality.

In December 2020, China established a target to install over 1.2 billion kW of solar and wind power capacity by 2030. In 2021, the State Council released the Guidelines on Implementing the New Development Concept and Advancing Efforts for Peak Carbon Emissions and Carbon Neutrality, which underscored the importance of raising the share of non-fossil fuels in primary energy consumption above 80% by 2060. As of 2022, coal-fired power accounted for roughly 60% of China's total electricity generation[3]. According to estimates from the International Energy Agency (IEA), this proportion needs to fall to 5% by 2060, when coal-fired power will assume a more flexible role in tandem with carbon capture and storage technologies[4]. Additionally, forecasts from reputable energy agencies and universities worldwide indicate that renewable energy generation, led by solar PV, wind, and hydroelectric sources, will gradually replace a substantial portion of current fossil fuel-based electricity. By 2050 and 2060, these renewables are anticipated to account for a significant 80% of the overall electricity generation[5] (see Figure 1.1). Nevertheless, China's current energy and power structure still falls short of the vision behind the Dual Carbon goals. In 2022, China's total installed capacity of wind and solar power amounted to 760 million kW, accounting for 36.2% of the total electricity generation from non-fossil sources[6]. This suggests that, to reach peak carbon emissions by 2030, China needs to nearly double its installed wind and solar capacity from its 2022 levels. By 2060, the total share of renewable energy generation needs to grow by approximately 1.2x the 2022 figures. Amid this momentous transformation in energy and power structures, a green and low-carbon transition is the only viable route. China must expedite the development of renewable energy electricity while continuing to seek new opportunities for economic growth and industry transformation driven by new energy sources.

Among these energy sources, solar photovoltaics (PV), as the primary means of renewable energy generation, has emerged as an indispensable catalyst for realizing the Dual Carbon goals, driving energy transformation, and spurring local economic development. With the gradual reduction in the cost of solar PV generation and the sustained enhancement of its efficiency, China is poised to raise the share of solar PV in its total electricity generation portfolio from a modest 5% in 2022 to a robust 45% by 2060. In the context of the Dual Carbon vision, solar PV is set to assume a prominent role in shaping China's electricity landscape. Consequently, a robust expansion of solar PV generation is a necessary path for China as it builds a new power system.

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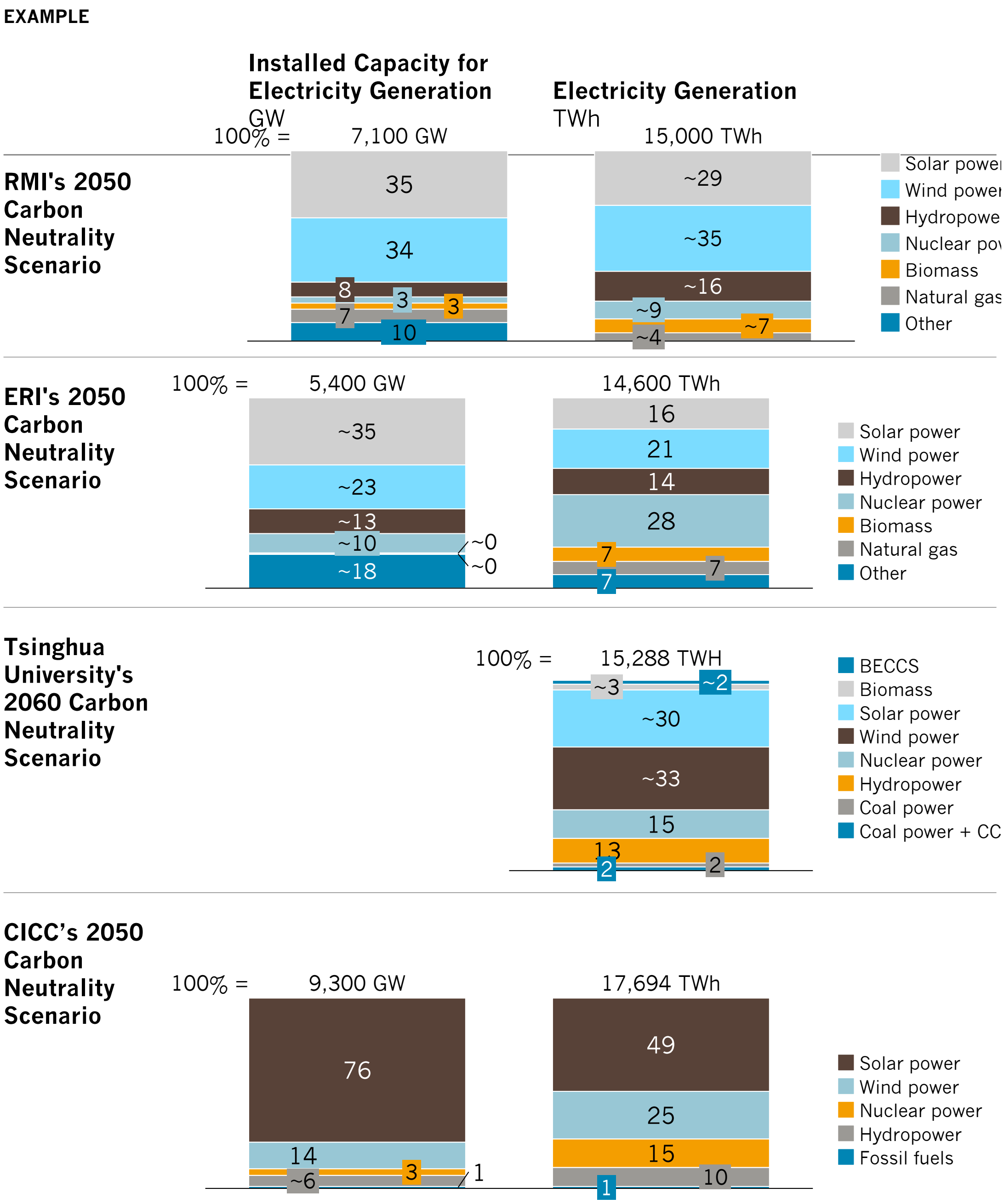
[3] China Electricity Council, 2022 Economic Operation Report for China's Electricity Industry, http://lwzb.stats.gov.cn/pub/lwzb/fbjd/202306/W020230605420997463323.pdf

[4] International Energy Agency (2021), An Energy Sector Roadmap to Carbon Neutrality in China, https://www.iea.org/reports/an-energy-sector-roadmap-to-carbon-neutrality-in-china/executive-summary?language=zh

[5] International Energy Agency (2021), An Energy Sector Roadmap to Carbon Neutrality in China, https://www.iea.org/reports/an-energy-sector-roadmap-to-carbon-neutrality-in-china/executive-summary?language=zh

[6] China Electricity Council, 2022 Economic Operation Report for China's Electricity Industry, http://lwzb.stats.gov.cn/pub/lwzb/fbjd/202306/W020230605420997463323.pdf

Figure 1.1: Power Generation Forecast in 2050 and 2060 Under Carbon Neutrality Scenarios, as projected by RMI, Tsinghua University[7], ERI, and CICC



1. BCG Report predicts zero emissions will be achieved by 2060, with an 80% reduction by 2050.

Data Sources: "China 2050 Outlook: A Fully Developed, Prosperous, Zero-Carbon Economic Entity", "Analysis of Low-Carbon Energy Transition Scenarios under the 2060 Carbon Neutrality Goal", "China's Energy Consumption and Emissions Scenarios for Achieving the Global 1.5° C Target", "China Climate Pathways Report", "How Far Are We from Carbon Neutrality: Energy and Power Sector"

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[7] Institute of Energy, Environment and Economy, Tsinghua University, Analysis of Low-carbon Energy Transition Scenarios under the 2060 Carbon Neutrality Goal, http://www.sxxrny.com/news/news.php?id=891

In contrast to large-scale ground-mounted solar PV facilities primarily situated in the "Three North" regions (Northeast China, North China, Northwest China), distributed solar PV installations are gaining traction due to their lower investment threshold, reduced construction costs, and versatile applications. These advantages have propelled their growth, positioning them as a pivotal force that can ensure China achieves its Dual Carbon goals on schedule. By 2022, centralized PV development had strong momentum, representing 60% of China's cumulative grid-connected PV capacity. At the same time, the share of newly installed capacity from distributed PV continued to climb, accounting for 58% of new grid-connected PV installations in 2022. This trend represents a concurrent and robust expansion alongside centralized PV projects[8]. Among PV installations, household systems contributed 49% of all newly added grid-connected capacity, while commercial and industrial installations accounted for 51%, reflecting a relative balance between the two sectors[9]. Although China's wind and solar resources are primarily concentrated in western regions, electricity demand is heavily centered in the central and southern regions, giving rise to a substantial need for cross-provincial transmission owing to this mismatch between supply and demand. Furthermore, large-scale ground-mounted wind and solar PV facilities feature significant fluctuations, necessitating stringent requirements for supporting infrastructure such as transmission networks and peak-shaving capabilities. Conversely, distributed PV systems, due to their smaller scale, offer greater construction flexibility. Additionally, by generating power in proximity to end-users, distributed PV installations facilitate on-site utilization of the generated electricity. This approach drives more energy and power consumers to become producers, storers, and consumers all at once. Moreover, as distributed PV support mechanisms such as energy storage and electrical consumption equipment continue to advance, they can make renewable energy utilization more efficient and ensure swift, cost-effective electricity supply to society. This will facilitate the coordinated and sustainable development of the power grid system and represents a pivotal direction for the future growth of renewable energy.

1.2 Enormous development potential of rural household rooftop PV

China's rural areas possess a large amount of rooftop space, with clearly defined ownership rights among households. This renders them a pivotal avenue for advancing distributed PV in the densely populated eastern regions. In 2022, the eastern region's[10] annual electricity consumption exceeded 4 trillion kWh[11], yet power generation only reached 3 trillion kWh[12], resulting in a nearly 1 trillion kWh electricity deficit. Since 2020, annual

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[8] National Energy Administration, 2022 Photovoltaic Power Generation Construction and Operation Status, http://www.nea.gov.cn/2023-02/17/c_1310698128.htm

[9] National Energy Administration, 2022 Photovoltaic Power Generation Construction and Operation Status, http://www.nea.gov.cn/2023-02/17/c_1310698128.htm

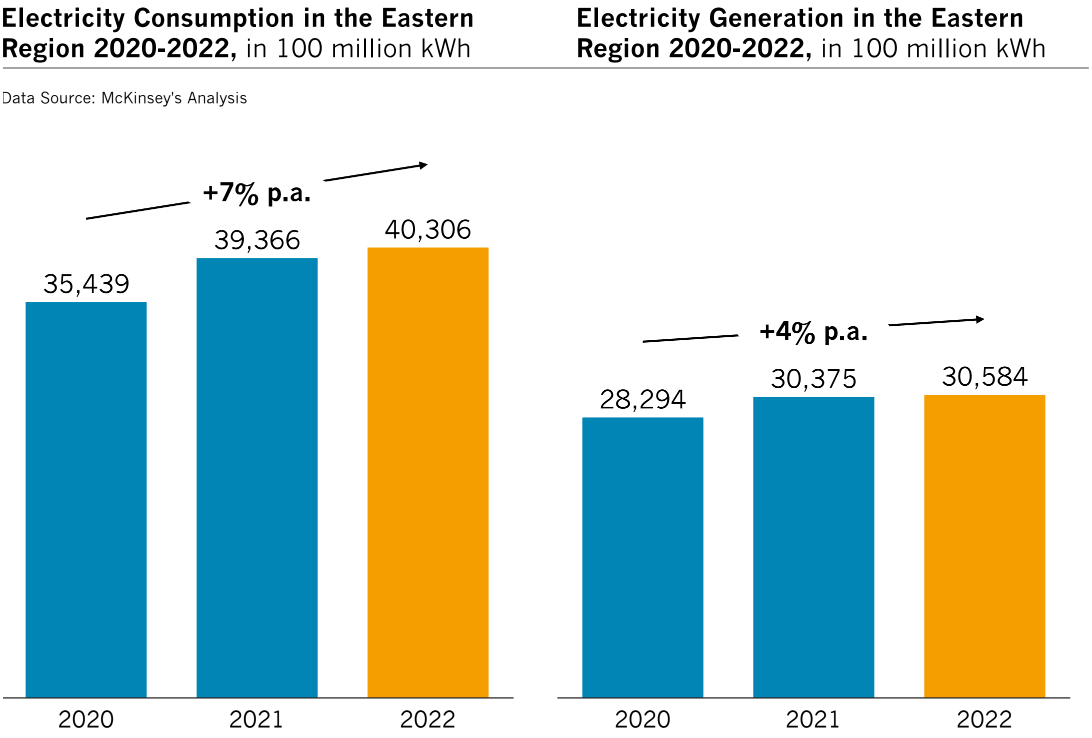
[10] Eastern regions include ten provinces and municipalities: Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan, according to https://m.bjx.com.cn/mnews/20230119/1284047.shtml

[11] China Power Knowledge Thinker, 2022 China Power Consumption Ranking by Province, with Guangdong, Shandong, and Jiangsu Leading the Way!, https://baijiahao.baidu.com/s?id=1771223831993735797&wfr=spider&for=pc

[12] Zhiyan Consulting, Research on the Investment Potential and Development Trends of the Chinese Power Industry from 2023 to 2029, https://www.sohu.com/a/647416029_120961824

electricity consumption in the eastern region has surged by approximately 7%, whereas annual power generation has grown by a mere 4% (refer to Figure 1.2), exacerbating the electricity shortfall. In the context of burgeoning economic and population growth, the eastern region must explore additional power resources. According to data compiled by Tsinghua University's Building Energy Research Center in collaboration with the National Remote Sensing Center of China, rural areas in China possess an aggregate rooftop area of 27.3 billion square meters. Utilizing this figure as a baseline, the potential for rooftop residential PV installations is nearly 2 billion kW, with an annual electricity generation potential exceeding 2.5 trillion kWh. This capacity can fully offset the present electricity deficit in the eastern region. Given the scarcity of land resources in the eastern region, the sustainable, large-scale, and high-speed development of centralized power stations is difficult. Consequently, rural rooftop resources will become the main avenue for distributed PV expansion. With the backdrop of increasing urbanization, the incremental growth of rural rooftops may gradually slow down. The construction of new dwellings will follow the targets outlined in China's 14th Five-Year Plan for new urbanization, which underscores the pivotal role of county towns in driving the development of their surrounding villages. It also requires the establishment of urban clusters to drive the development of surrounding areas and form a new pattern of urbanization. Furthermore, distributed PV technology continues to evolve. Building-integrated PV and potential innovations such as PV curtain walls are not confined solely to rooftop

Figure 1.2: Electricity Demand in the Eastern Region Surpasses Generation, with the Gap Increasing Annually Due to Faster Growth in Consumption



Electricity Consumption in the Eastern Region 2020-2022, in 100 million kWh

Electricity Generation in the Eastern Region 2020-2022, in 100 million kWh

Data Source: McKinsey's Analysis

spaces, but may create fresh market resources for the continued advancement of distributed PV.

The extensive deployment of rural residential PV systems will furnish rural areas with a stable source of clean electricity during the energy transformation. Agriculture represents a significant contributor to greenhouse gas emissions, with data revealing that approximately 15% of China's carbon emissions stem from rural and agriculture-related activities[13]. Agricultural production accounts for half of this total, while the remaining half results from emissions linked to rural living, representing 8.3% of total national emissions.[14] In rural areas, heating and cooking are the primary energy consumption scenarios. Heating predominantly relies on coal, supplemented by firewood and electricity, resulting in considerable carbon emissions[15]. In addition to carbon dioxide, the combustion of coal and firewood creates large amounts of PM2.5 particles, carbon monoxide, sulfur dioxide, and other gases. Given the low source height of these emissions, the pollutants readily infiltrate the human respiratory system, pollute the air in rural areas, and pose health risks to residents. Carbon monoxide poisoning is prevalent in rural regions during the winter months, garnering significant attention from various sectors of society. Moreover, initiatives to promote clean heating, such as transitioning from coal to electricity or gas, face economic constraints and formidable obstacles. The construction of residential PV systems is characterized by low environmental pollution. The electricity generation process is virtually emissions-free, rendering it a potent tool in combating air pollution, promoting energy conservation, and reducing emissions. This technology has the potential to serve as a viable alternative to coal consumption in rural areas. Calculations demonstrate that the installation of PV systems exceeding 2 kW on the roofs of rural houses could theoretically satisfy all of their electricity needs, including winter heating for a 50-square-meter primary room, cooking, and the charging of various vehicles. Further integration with energy storage technologies and other resources would likely entirely replace the coal traditionally used for heating and cooking with solar power in rural areas, significantly curtailing greenhouse gas emissions from rural buildings.

In short, rural residential PV systems possess the capacity to effectively lower electricity costs, stimulate energy conservation, reduce emissions, and offer a practical and economically efficient solution for effecting the transformation of rural energy.

1.3 Rural residential PV: Fueling business investments and rural revitalization

The extensive promotion of rural residential PV as a novel energy investment pathway has given rise to substantial commercial opportunities and attracted a wide range of investors including private equity firms, multilateral investment banks, prominent state-owned energy conglomerates, and foreign energy enterprises. In August 2021, the PV company Chint Anneng secured a strategic investment of RMB 1 billion from IDG

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[13] Rural households' Daily, Carbon Neutrality: Agriculture and Rural Areas Must Keep Pace, https://ieda.caas.cn/xwzx/mtbd/275997.htm

[14] Chinese Academy of Agricultural Sciences, 2023 China's Low-carbon Development Report for Agriculture and Rural Areas, https://mp.weixin.qq.com/s/JUQgnGSg7qENqx-ImdfhBw

[15] China Climate Change Info-Net, One Billion Tons of Carbon Dioxide Emissions in A Year, Urgent Need for Heating Transformation, https://www.ccchina.org.cn/Detail.aspx?newsId=73556&TId=65

Capital and Sequoia China. In November, Asia Clean Capital, in collaboration with a subsidiary of State Power Investment Corporation, signed a strategic financing agreement for distributed PV projects. Notably, in December, the new energy company GCL-Poly obtained HKD 5 billion in financing from a group of investors including Hillhouse Capital. The enthusiastic participation of these investment entities is expediting capital operations within the PV industry[16]. These investors not only stand to gain long-term cash flows and substantial economic returns, but are also actively catalyzing the transformation and upgrade of the energy structure. This endeavor will have a far-reaching impact on diminishing the reliance on fossil fuels and producing a broad and positive impact on society.

Notably, rural residential PV has emerged as a critical instrument by which economically disadvantaged regions can lift themselves out of poverty. In addition to centralized PV stations in specific villages, rooftop residential PV installations are delivering tangible economic benefits directly to rural households. Presently, the return on investment (ROI) for residential PV is relatively stable in the range of 8% to 10%. It offers rooftop owners investment returns that are not only more stable but superior to those of other financial instruments. Moreover, China's PV Poverty Alleviation policy has established solar power as a permanent "sunshine bank" and "iron crop" for impoverished households. This policy has also become a pivotal opportunity for impoverished villages to break free from the cycle of poverty as well as an important means of rural revitalization and poverty alleviation through asset income in various regions. Since the inception of PV poverty alleviation projects (PPAPs) in 2015, the government has issued and executed five batches of specialized PPAP plans up to 2020. Collectively, these initiatives resulted in a total capacity of 26.36 million kW for poverty alleviation, benefiting around 60,000 villages and 4.15 million impoverished households. These projects have yielded consistent annual electricity revenues totaling around RMB 18 billion[17]. The formal confirmation of property rights at the village-level PV poverty alleviation stations showed that average annual income per village saw a stable increase of RMB 200,000[18].

Simultaneously, residential PV has generated employment opportunities for residents unable to leave their villages. The different types of labor required for the construction, installation, and ongoing maintenance of PV systems, including installers, cleaners, transport workers, and maintenance personnel, do not require special skills or certifications. These roles are well within the capabilities of local residents. For instance, in a county-level city planning to install 500 MW of residential PV, this initiative could create about 1,750 local jobs over an estimated 1 to 3-year period from customer acquisition to construction and then over the 25-year lifecycle of PV panels. These job opportunities span customer acquisition, front-end sales, construction, operation and maintenance, providing local residents with a diverse array of employment choices. This, in turn, serves to further invigorate rural economic development and revitalization.

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[16] China Energy News, Easier Financing for the A-share Photovoltaic Industry, https://guangfu.bjx.com.cn/news/20220301/1207135.shtml

[17] People's Daily, Energy Poverty Alleviation at the Household Level, Illuminating the Path to Prosperity for the Masses, http://www.xinhuanet.com/power/2021-02/18/c_1211030404.htm

[18] People's Daily, Energy Poverty Alleviation at the Household Level, Illuminating the Path to Prosperity for the Masses, http://www.xinhuanet.com/power/2021-02/18/c_1211030404.htm

In terms of application scenarios, PV agriculture has evolved into a pioneering approach to comprehensive land utilization. Models like Agriculture-Solar Complementary and Fishery-Solar Complementary combine PV power generation, agricultural production, and agricultural facilities. This approach conserves land while effectively utilizing surplus vertical space, thus boosting village revenue. At present, numerous energy pilot counties and villages in China are pioneering PV-based strategies. Forging their own paths toward rural revitalization based on local attributes such as distinctive industries, climatic conditions, and economic factors, all revolving around the sunshine bank. For instance, in Yunnan Province's Honghe County, collective village power stations have adeptly addressed economic income challenges for roughly 77 village collectives. Additionally, CNNP Rich Energy's 250 MW Livestock-Solar Complementary compound PV project in Hualong Hui Autonomous County, Haidong City, Qinghai has been formally integrated into the grid and gone into operation.

In terms of operational strategies, rural residential PV can be advanced on the basis of a village or township collective, with a unified PV development promotion plan formulated to boost collective income. For example, through the fusion of PV and agriculture, rural households can diversify their income sources. In addition to their revenues from agriculture, they will receive periodic payments of electricity generation revenue. The PV poverty alleviation approach also allows for innovative and adaptable adjustments to the revenue-sharing model, tailored to the actual needs of local village collectives. In addition to securing stable income for rural households, electricity sales can amplify collective economic potential. This not only increases the annual dividends for rural households but also creates new employment opportunities within the PV industry supply chain, promoting true economic revitalization for rural collectives.

In summary, rural residential PV in China, as a crucial avenue for decarbonization and income generation in rural areas, holds significant potential provided it enjoys policy support. With ongoing technological advancements and the maturation of supporting PV industry technologies such as energy storage and adaptive regulation, the overall prospects for rural PV industry deployment are very promising.

02

Current Landscape, Prospects, and Challenges for the Development of Rural Residential PV in China

2.1 Rapid growth and inland expansion of domestic distributed PV

Over the past decade, China's installed PV capacity has witnessed a remarkable expansion. According to data from the National Energy Administration, as of 2023, China's cumulative installed PV capacity reached 608.9 gigawatts (GW), maintaining China's position as the global leader, which it has held for a decade. Of this total capacity, distributed PV installations accounted for 254.4 GW, constituting 42% as the result of its twenty-five-fold surge since 2016. In 2023, the newly added PV grid-connected capacity in the Chinese market reached approximately 216.3 GW. Specifically, distributed PV contributed around 96.3 GW, representing 45% of the total new PV grid-connected capacity. Furthermore, residential PV systems generated approximately 43.5 GW[1], as shown in Figure 2.1.

Additionally, data from the China Photovoltaic Industry Association (CPIA) revealed that China's PV electricity generation in 2022 reached 427.6 billion kWh, a 30.8% year-on-year increase.

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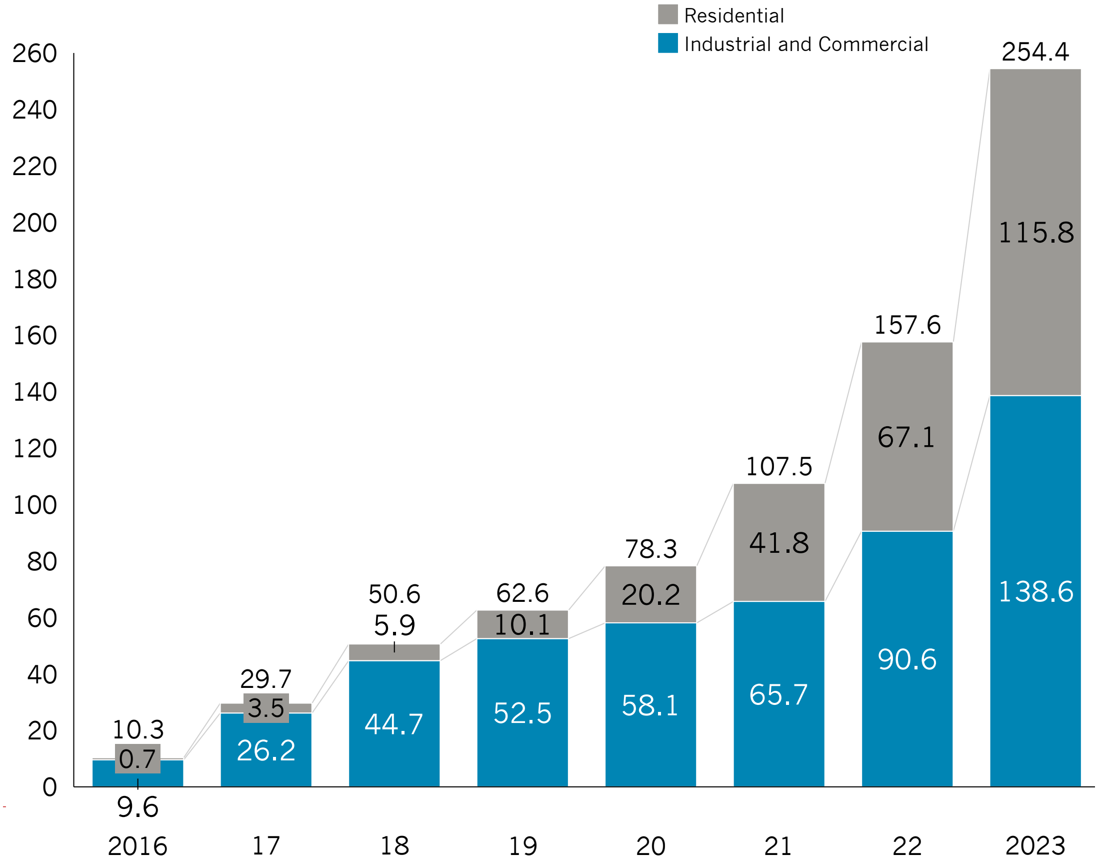
[1] National Energy Administration, 2023 Photovoltaic Power Generation Construction and Operation Status, https://www.nea.gov.cn/2024-02/28/c_1310765696.htm

Figure 2.1 2016~Q3 2023 Total Distributed PV Capacity Installed in China (GW)



Distributed PV electricity generation exceeded 120 billion kWh, growing by nearly 35% year-on-year. In 2022, the national average PV electricity utilization rate stood at 98.3%. Due to the national policy of comprehensive integration of distributed PV into the grid, the abandonment rate for residential PV installations after grid integration approval was a mere 1.7%[2].

Forecasts indicate that, by 2025, China's newly added distributed PV capacity will reach 157 GW, constituting around 42% of total new PV installations. This trajectory could narrow the gap between distributed and centralized PV installations in the future. From 2026 to 2030, projections show that new distributed installations will reach 201 GW, accounting for around 40% of total new PV installations[3], as illustrated in Figure 2.2. By 2030, the annual increase in distributed PV capacity is forecasted to reduce carbon emissions by approximately 430 million tons[4].

Notably, rural residential PV will play a pivotal role in China's overall decarbonization efforts. In recent years, rural areas in China have annually

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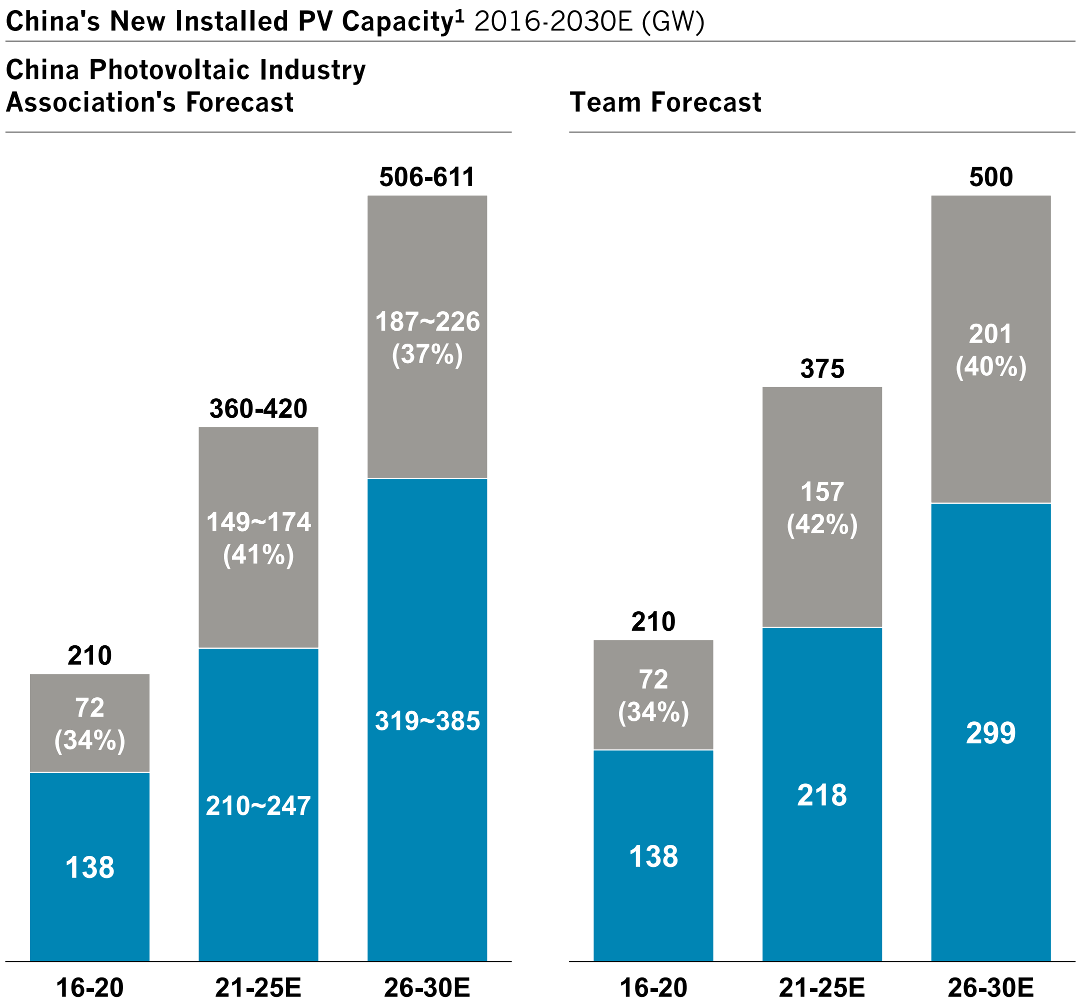
[2] Central People's Government of the People's Republic of China, China's Photovoltaic Power Generation Had An Average Utilization Rate of 98.3% Last Year, https://www.gov.cn/xinwen/2023-02/21/content_5742400.htm

[3] McKinsey Forecast

[4] McKinsey Forecast: Every megawatt of photovoltaic power can reduce 1,200 tons of carbon dioxide equivalents annually.

Figure 2.2 Estimated Growth Rate of Distributed PV Capacity Installed in China



1. In 2021, the share of distributed PV increased to 55% due to a rush to install before the end of subsidies, while centralized installations were lower than normal due to rising silicon wafer prices and a slowdown in the announcement process for the 14th Five-Year Plan. We expect the distributed share to steadily increase in the future.

consumed nearly 350 billion kWh of electricity for domestic purposes, with an additional 150 billion kWh dedicated to production. Together, this totals nearly 500 billion kWh of electricity consumption in rural areas each year. If all rural households in China adopt PV installations, the potential installed capacity could reach nearly 2 billion kW, with an electricity generation potential of approximately 2.5 trillion kWh[5]. This capacity is five times the current electricity consumption in rural areas and could contribute up to 30% of China's total electricity generation in 2021 (8.5 trillion kWh). In this way, rural areas could effectively become massive power plants that meet their own power needs and then supply electricity to a wide range of other consumers. Moreover, the electricity consumption of rural areas is expected to further increase. Currently, daytime electricity consumption by households is limited, and nighttime electricity needs

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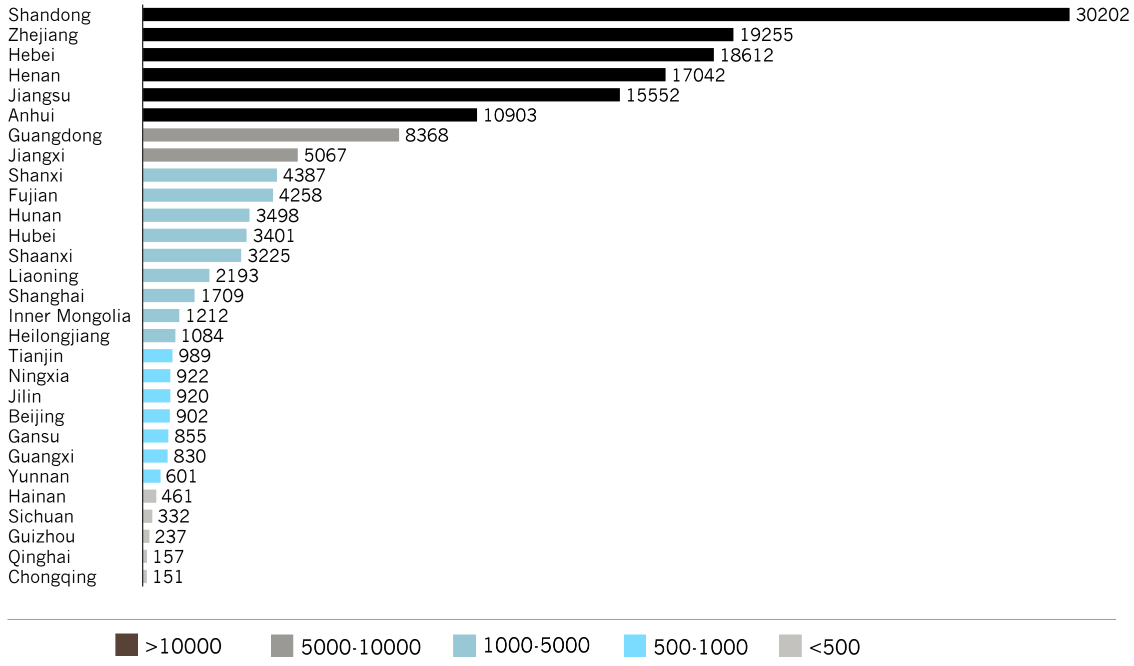
[5] Academician Jiang Yi, Carbon Emission Peak and Carbon Neutrality for China's Buildings, Public Forum of the 17th Tsinghua University Building Energy Conservation Academic Week

are still supplied by the grid due to factors such as ongoing electrification, population migration, and immature energy storage technologies. This results in electricity consumption in rural areas hovering at approximately 10-15% of their potential PV generation capacity. However, with the increasing electrification of activities such as heating, cooking, transportation (including electric vehicles), and agricultural operations (e.g., village-run factories and electrified farm machinery), in conjunction with the gradual maturation of energy storage technologies, rural areas may consume about 25% of their generation capacity if nighttime energy needs can be met by daytime PV generation. Simultaneously, even with the growth in household consumption rates, a 50% to 70% electricity surplus can still be fed back into the grid. This surplus can supply the energy needs of surrounding areas, contributing to energy conservation and emissions reduction on a wider scale.

China's vast expanse and regional disparities in geographical and economic development have given rise to significant differences in the installed PV capacities of different provinces, as shown in Figure 2.3. Consequently, the potential for future installations and electricity generation likewise varies significantly by region. To estimate this potential, we base our calculations on the total area of rural housing in each province as of 2021. Assuming that rural buildings predominantly consist of one to two-story structures with rooftops capable of supporting 120 W/m^2, and accounting for local sunlight resources, we computed the theoretical distributed installed PV capacity and electricity generation potential for each region, as shown in Figure 2.4.

Figure 2.3 Distribution of Distributed PV Capacity Installed in Provinces and Cities

Total solar DG installation capacity, By the end of 2022, MW



Data Sources: National Energy Administration; expert interview; team analysis

Figure 2.4 Theoretical PV Generation Potential Calculated for Rural Areas of Various Provinces and Cities

Province (District, City)	Total Village Housing Area (Including Public Buildings and Rural Production Buildings, in 100 million m^2)	Installation Potential (GW)	First-Year Hours for Electricity Generation	Electricity Generation Potential (in 100 million kWh)
Henan	24.55	150	1095	1645
Sichuan	23.20	142	1205	1712
Shandong	21.27	130	1236	1609
Hunan	20.99	128	885	1137
Jiangsu	18.28	112	1138	1273
Anhui	16.23	99	1062	1055
Guangdong	15.34	94	1043	979
Guangxi	14.83	91	974	884
Hebei	14.77	90	1360	1229
Yunnan	14.54	89	1300	1157
Jiangxi	13.89	85	995	845
Zhejiang	13.29	81	1051	855
Hubei	13.17	81	964	777
Guizhou	11.46	70	837	587
Shaanxi	10.63	65	1171	762
Fujian	9.57	59	1076	630
Shanxi	8.70	53	1319	702
Chongqing	8.10	50	799	396
Gansu	6.24	38	1536	587
Liaoning	4.81	29	1340	395
Heilongjiang	4.38	27	1346	361
Inner Mongolia	4.19	26	1605	411
Jilin	3.55	22	1334	290
Beijing	2.64	16	1340	216
Hainan	1.87	11	1223	140
Shanghai	1.80	11	1074	119
Ningxia	1.43	9	1482	129
Qinghai	1.23	8	1684	127
Tianjin	1.04	6	1308	83

[8]

In addition to factors such as roof size and sunlight conditions, regional electricity prices are a significant driver for developing distributed PV markets across diverse areas. On one hand, as selling electricity to the grid remains the primary revenue stream for residential PV power stations, the local benchmark on-grid electricity price for coal-fired power serves as a predictive gauge for the economic viability of investments in power stations in the region. The higher the on-grid electricity price, the greater the revenue generated per kilowatt-hour. On the other hand, when evaluating the development potential of the PV market, it is essential to consider the existing installed capacity of distributed PV within each province (see Figure 2.5). Provinces with limited installed capacity may face certain early-stage constraints that hinder the growth of the PV industry. Conversely, provinces with substantial installed capacity may encounter slower near-term growth due to grid capacity limitations or because they are approaching installation saturation.

Taking into consideration factors like available roof space in rural residences, sunlight conditions, and electricity price levels across provinces in 2021, the potential installed capacity for residential PV in rural areas[6] can be broadly categorized into three potential zones: (1) High Potential Zone: Including provinces such as Jiangsu, Henan, Shandong, and Anhui, this zone is characterized by both a high installation potential and elevated electricity price levels. (2) Medium Potential Zone: Including provinces such as Jiangxi, Hubei, and Fujian, this zone has a moderate installation potential. (3) Low Potential Zone: Including provinces such as Qinghai and Ningxia, this zone has a low installation potential and relatively low electricity price levels (see Figure 2.6). However, the actual regional development of distributed PV must also consider non-quantifiable factors such as local resource endowments, grid integration conditions, and regional policies related to new energy. Consequently, provinces in these categories should conduct thorough analyses based on their unique circumstances.

Taking into account the diverse natural, social, and economic conditions mentioned above, using the theoretical residential PV installed capacity in rural areas as our base framework, and also considering grid integration conditions, resource endowments, and policy inclinations in different regions, China's rural residential PV market potential can be classified into three primary tiers during the 14th Five-Year Plan period, with provinces and municipalities as the basic units.

In first-tier provinces and cities, rooftop PV exhibits significant potential owing to the ample available roof space, high installation capacity, relatively high electricity prices, favorable sunlight conditions, and substantial grid integration infrastructure. These regions, including Jiangsu, Anhui, Zhejiang, and Guangdong, are actively promoting distribution grid upgrades and have already introduced clear-cut policies to encourage PV adoption. Jiangsu Province provides a case in point. There, electricity prices hover around RMB 0.38/kWh, and solar power generation hours exceed 1,100 per year. Jiangsu is proactively transforming its power grid through digitization and dynamic capacity augmentation in transmission channels, fostering a conducive environment for the growth of distributed PV. In addition to the natural factors at play, policy incentives also play a pivotal role. For instance, in May 2023, the Guangdong

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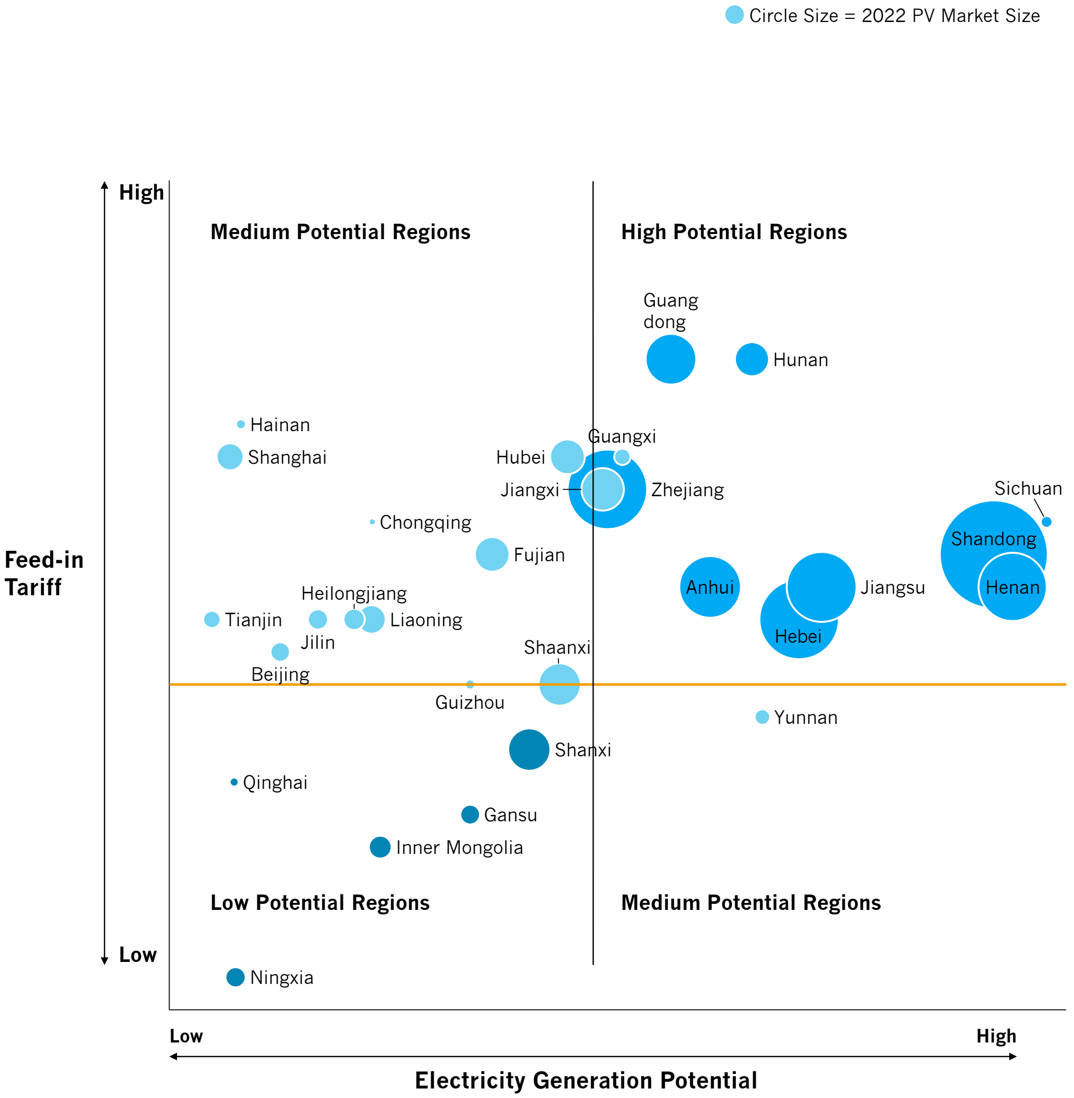
[6] The term "potential" here refers to the total potential for installations, derived from the roof area multiplied by a certain coefficient.

Figure 2.5 Benchmarks for On-Grid Electricity Prices in Coal-fired Power Generation and the Installed Capacity of Distributed PV in Provinces and Cities

	Cumulative Grid Connection Capacity as of the End of June 2023			
Province (District/City)	**Total Distributed PV**	**Residential PV**	**Industrial & Commercial PV**	**Benchmark Coal Power Price (RMB/kWh)**
Total	**19822.8**	**9502.4**	**10320.4**	
Beijing	96.7	30.2	66.5	0.3598
Tianjin	134.3	30.1	104.2	0.3655
Hebei	2074.2	1600.1	474.1	0.3682
Shanxi	520.9	350.8	170.1	0.332
Shandong	3571.6	2322.1	1249.5	0.3949
Inner Mongolia	143.8	65.4	78.4	0.2932
Liaoning	300.2	137.1	163.1	0.3749
Jilin	100.4	26.5	73.9	0.3731
Heilongjiang	131.8	20.3	115.5	0.374
Shanghai	195.3	20.3	175	0.4155
Jiangsu	2071.4	511.8	1559.6	0.391
Zhejiang	2222.3	335.4	1886.9	0.4153
Anhui	1539.6	743.3	796.3	0.3844
Fujian	609.9	254.1	355.8	0.3932
Jiangxi	757.9	350.8	407.1	0.4143
Henan	2448.5	1866.1	582.4	0.3779
Hubei	471.6	138.3	333.3	0.4161
Hunan	488.7	210.7	278	0.45
Chongqing	36.4	3.6	32.8	0.3964
Sichuan	37.6	12.8	24.8	0.4012
Shaanxi	359.1	138.7	220.4	0.3545
Gansu	15.8	10.9	4.9	0.3078
Qinghai	114	2.5	111.5	0.3247
Ningxia	17.6	101.4	N.A.	0.2595
Guangdong	1063.3	169.8	893.5	0.453
Guangxi	105.4	16	89.4	0.4207
Hainan	84.4	14.9	69.5	0.4298
Guizhou	26	2.2	23.8	0.3515
Yunnan	81.6	14.3	67.3	0.3358

Figure 2.6 Regional Potential Map of Theoretical Residential PV Installed Capacity in Rural Areas



Provincial Energy Bureau introduced the Implementation Plan for Promoting High-Quality Energy Development in Guangdong Province (2023-2025), which proposes robust support for "residential PV + rural revitalization". This initiative emphasizes the need to align distributed PV development with local conditions and provides explicit policy backing.

Within the first tier, some provinces and municipalities boast a considerable PV market size, theoretically abundant sunlight resources, expansive rooftop space, and high electricity prices, making them high-potential areas for residential PV development. Nevertheless, due to policies such as "county-wide advancement", these regions have attracted a multitude of stakeholders and, given the current status of the distribution network, their remaining capacity for grid-connected distributed PV is approaching saturation. Provinces like Shandong, Henan, and Hebei are major areas of PV development, but may witness restrictions in future development. For instance, in 2021, Shandong added 7.63 GW of residential PV installations for a total installed capacity of 15.93 GW, a remarkable 91.9% year-on-year increase. This enabled Shandong to rank first in both annual growth and total installed capacity nationwide[7]. However, according to estimates from a Yantai-based dealer in Shandong, "if the existing transformer capacity in Shandong remains unchanged, and no new policies are introduced, our company's market research suggests that residential PV installations in Shandong have, at most, another three years of development potential. In certain densely developed areas, saturation may even occur within the coming year"[8]. Grid integration constraints loom as the foremost impediment to residential PV expansion. At the same time, Sichuan Province, theoretically classified within the first tier, has distinctive characteristics. Despite its high feed-in tariffs, expansive rural rooftop acreage, and high average annual sunlight hours that would theoretically allow it to be a major PV region, Sichuan experiences a profound imbalance in the distribution of solar resources. The western plateau and southwestern mountainous regions enjoy a wealth of solar resources due to their long dry seasons. However, due to the high altitude, the population is sparse in these areas. Most rural rooftop resources are concentrated within the Sichuan Basin, characterized by a damp and rainy climate and sub-optimal sunlight conditions. Consequently, the province continued to emphasize the development of high-altitude centralized PV power stations.

Among second-tier provinces and cities, substantial potential for residential PV installations exists, with electricity prices situated at moderate levels. While these regions may have less favorable natural conditions compared to their first-tier counterparts, rooftops with ample space, favorable orientations, and suitable slopes are gradually being developed. This, combined with policy initiatives and measures such as grid upgrades, indicates future growth prospects for rural PV installations. Representative provinces within this category are Hubei, Jiangxi, Fujian, Shaanxi, and Liaoning. Although regions such as Hubei and Jiangxi may have only average sunlight conditions, they boast expansive rooftop areas and competitive electricity prices. Several enterprises have already commenced market exploration based on their existing installation capacities. In addition, the market outlook is further improved by supportive policies. For example, in June 2021, Hubei introduced the *Hubei Province New Energy Project Construction Plan for 2021 (Draft for Comment),* advocating the comprehensive promotion of residential PV power generation throughout the province. The plan also emphasizes the development of the carbon market to facilitate overall emissions reduction and drive the province's Dual Carbon goals. In its *14th Five-Year Plan of Liaoning Province for Ecological Economic Development* released in January 2022,

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[7] Dazhong Daily, Shandong Leads in Both Growth and Scale of Household Photovoltaic Installations Nationwide, http://nyj.shandong.gov.cn/art/2022/1/25/art_253733_10291562.html

[8] Century New Energy Network, How Much Space is Left for Household Photovoltaics in Shandong, https://www.ne21.com/news/show-168579.html

Liaoning Province vigorously promotes the diversified utilization of solar energy and the establishment of village-level PV power stations. It is expected that, as the PV market in first-tier provinces and municipalities continues to reach saturation, rapid development in the sector will pass to second-tier regions for a time.

In the third-tier provinces and cities, despite advantageous electricity prices and hours of sunlight, several factors, including significant terrain variations, dispersed rural rooftops, high customer acquisition costs for developers, and the need for time-consuming grid upgrades, curtail the economic viability of local distributed PV projects. As a result, residential PV has not been widely promoted in these regions, which include provinces such as Ningxia and Gansu. Both Ningxia and Gansu have approximately 1,500 hours of first-year electricity generation, yet challenges such as scattered rural residences, relatively poor rooftop conditions, mediocre grid integration, and high customer acquisition costs limit the potential for distributed PV development. Therefore, utility scale PV stations are more prevalent in these two provinces. Shanxi Province in the third tier, while theoretically falling into the low-potential installation category due to limited rooftop availability and lower electricity pricing, has a unique trajectory. A traditional fossil fuel-dependent province, the Shanxi Government has introduced an array of PV support policies under the pollution reduction and carbon reduction mandate. These policies aim to enhance rural grid structures, improve rural electrification levels, and stimulate distributed PV development. As a result, Shanxi is anticipated to have certain development potential in the future.

With the continuous rise in urbanization rates and the gradual decrease in rural population, the yearly growth in new housing construction in rural areas has steadily fallen. During the 14th Five-Year Plan period, it is predicted that the total available rooftop space in rural areas will remain relatively stable. According to data from the Seventh National Population Census, the rural population in China stands at 509.79 million, a decrease of 164.36 million compared to 2010. Concurrently, the completed construction area of rural residential buildings had contracted from 878 million square meters in 2012 to 480 million square meters in 2020. This significant reduction in newly constructed rural residential areas signals a corresponding decline in available rooftop space. For a certain period, the theoretical installed capacity and electricity generation potential of China's rural PV market will hover around 2 billion kW and 2.5 trillion kWh, respectively. However, as of 2021, the total installed capacity of residential PV in China amounted to 67 GW, only 4% of the total potential installed capacity in the rural PV market. A collective effort from all sectors of society is needed to significantly boost rural PV coverage.

2.2 Technological advancements, financial support, and socioeconomic improvements fuel the comprehensive growth of the distributed PV market

With continuous innovations in solar technology and steady improvements in the conversion efficiency of PV modules, the economic viability of solar power has significantly increased. Over the past decade, the levelized cost of electricity (LCOE) for residential and commercial solar PV has seen a notable drop of approximately 30%[9]. The gradual adoption of time-of-use electricity pricing mechanisms further highlights the economic advantages of solar energy. Some provinces and municipalities have increased their peak-to-valley electricity price differentials by as much as 70%[10], favoring distributed PV generation during periods of high electricity prices and thereby increasing overall electricity revenue. Furthermore, 29 provinces and municipalities in China have transitioned away from fixed electricity price catalogs for industrial and commercial users, moving toward a more market-oriented pricing structure. In addition, carbon emission trading has become an important factor when evaluating the future economic feasibility of PV, and the opening of a carbon emission trading market is now on the agenda. In April 2023, the Ministry of Ecology and Environment issued a *Public Invitation for Proposals Regarding Methodologies for Voluntary Greenhouse Gas Emission Reduction Projects*, soliciting suggestions from the general public. During a routine press conference in June 2023, the Ministry of Ecology and Environment unveiled plans to expedite the establishment of various systems and infrastructure, with the goal of initiating a national voluntary trading market for greenhouse gas emissions as early as within the year. This signifies a reactivation of the China Certified Emission Reduction (CCER) mechanism. Concurrently, the approval of the *Green Electricity Trading Pilot Program* has created a conducive environment for solar PV projects to participate in domestic carbon certification and trading. The National Energy Administration is actively exploring the incorporation of residential PV into the green electricity and green certificate trading markets. In April 2023, the Administration issued the *2023 Energy Work Guidance*, which clearly states the need to robustly promote the construction of distributed PV projects, advance comprehensive green certificate issuance, and ensure seamless integration with carbon trading. These efforts are expected to effectively enhance electricity generation revenues and build enthusiasm for the development of distributed PV.

The PV sector is constantly taking in financial resources, making it possible to extend financing and loan support for residential PV development. As commercial banks increasingly recognize the value of PV assets, they are exploring various market-driven financial instruments to increase the supply of loans. Some commercial banks have adopted multiple guarantee models for residential PV projects. These include unconventional collateral, such as movable property mortgages and

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[9] Wood Mackenzie, A Deep Dive into China's Renewables Landscape, https://www.woodmac.com/our-expertise/focus/Power--Renewables/a-deep-dive-into-chinas-renewables-landscape/

[10] Hebei Provincial Development and Reform Commission, Peak and Off-peak Electricity Prices Fluctuate by 70%! China Southern Power Grid in Hebei Adjusts Time-of-Use Electricity Price Policy for Commercial and Other Users, https://news.bjx.com.cn/html/20221031/1264783.shtml

the pledging of electricity fee collection rights, to obtain financial support for residential PV initiatives. Simultaneously, the government is actively promoting innovative PV loan models. On July 2, 2021, the National Development and Reform Commission released the *Notice on Further Improving the Pilot Work of Real Estate Investment Trusts (REITs) in the Infrastructure Sector* (referred to as “Document 98”). This document states that solar PV projects could now apply for REITs across regions and projects in pilot cities, introducing a novel financing model for residential PV projects spanning entire counties. In December 2022, the Special Support Plan for State Power Investment Corporation - Chongqing Electric Power’s Energy Infrastructure Investment in residential PV Green Assets (quasi-REITs) was successfully launched at a scale of RMB 1.4 billion. This instrument serves the rural revitalization and the Dual Carbon strategy, marking the introduction of China’s first residential PV infrastructure REITs. It represents a significant step forward in enhancing the accessibility of financial resources for rural distributed PV.

Furthermore, the thriving technological R&D environment is propelling advances in talent and technology within the residential PV market. In 2021, the Ministry of Industry and Information Technology unveiled the *Action Plan for Innovative Development of the Intelligent Photovoltaic Industry*, which encourages accelerated technological innovation in the PV sector, increases smart manufacturing capabilities, and reinforces talent development within the PV field. In 2022, nine government departments, including the Ministry of Science and Technology, jointly issued the *Implementation Plan for Technological Support for Carbon Emissions Peaking and Carbon Neutrality (2022-2030)*. This plan promotes active research and development in cutting-edge technologies, including floating PV systems, key equipment and flexible technologies for power supply and distribution in the Photovoltaic-Energy storage-Direct current-Flexibility (PEDF) model, technology systems for building integrated PV (BIPV), and source-grid-load-storage technologies and equipment for regional-building energy systems.

In addition, the concept of sustainable social development continues to deepen, influencing a wide array of stakeholders to actively engage in the construction of the residential PV market. Enterprises are increasingly embracing the idea of energy conservation and emissions reduction, leading to heightened interest in green investment opportunities. Individual consumers, inspired by global climate change and the principles of sustainable development, demonstrate a preference for green and low-carbon products in their consumption patterns. This trend is evident in their growing interest in new energy vehicles and their heightened awareness of carbon footprints.

2.3 Strong government support drives distributed PV development, actively promoting the realization of the Dual Carbon goals

Carbon emissions peaking and carbon neutrality have been enshrined as important national strategies for China, making promoting the development of distributed PV an important avenue and measure for realizing the Dual Carbon goals. Since 2009, the Chinese government has demonstrated a strong commitment to PV power and progressively guided the maturation and spread of the distributed PV sector through its policy framework.

During the 12th Five-Year Plan period, China clarified the strategic importance of PV by introducing a series of supporting mechanisms and administrative measures. These directives provided explicit regulations concerning grid construction, grid integration procedures, and subsidy frameworks. As the economic viability of PV steadily improved, subsidies for rural residential PV systems began to be gradually reduced, marking the transition toward the era of grid parity. Concurrently, certain regions continued to bolster subsidies for distributed PV development, creating a new competitive landscape in the market.

In 2021, the National Development and Reform Commission released the *Notice on Relevant Matters Concerning the 2021 New Energy Grid Electricity Pricing Policy*, which mandated that central government subsidies would no longer be extended to newly registered industrial and commercial distributed PV projects. Instead, these projects would operate at grid parity, with only limited central government subsidies allocated to residential PV projects. Even though national subsidies were phased out of the market in 2022, some rural residential PV projects still benefit from subsidies offered at the municipal or district level (refer to Figure 2.7). For instance, Leqing City in Zhejiang Province provides a subsidy of RMB 0.1/kWh to distributed PV projects connected to the grid after January 1, 2022. In Ningbo City, Zhejiang Province, residential BIPV projects connected between 2021 and 2025 are granted a subsidy of RMB 0.3/kWh. Similarly, in Xi'an City, Shaanxi Province, distributed PV projects connected between 2021 and 2023 receive a subsidy of RMB 0.1/kWh. Moreover, alongside the provision of local subsidies, several provinces and municipalities are proactively exploring additional policy supports to enhance the economic viability of distributed PV generation and propel the development of the PV industry. Among these initiatives is the *Carbon-Inclusive Trading Management Measures of Guangdong Province* introduced by the Guangdong Provincial Department of Ecology and Environment in 2022. This policy proposed a carbon-inclusive mechanism, enabling distributed PV to apply for certification of carbon-inclusive emission reductions. These reductions can then be traded through methods such as listing and selection, competitive bidding, and agreement transfers.

As the trend of residential PV installations continues to rise, the phased withdrawal of distributed PV subsidies will not severely impact profitability. While the short-term withdrawal of subsidies might decrease profits and lead to industry reshuffling and many enterprises without competitive advantages are expected to exit the market, the shift towards grid parity will compel enterprises to accelerate their transformations. Numerous high-quality PV enterprises are exploring innovative development

Figure 2.7 Overview of Local Subsidy Policies for Distributed PV in China (2021~2022) 1/2

Release Date	Policy Name	Location	Subsidy Format
2021-01	Beijing Xicheng District Administrative Measures to Support and Encourage Energy Conservation and Consumption Reduction (Revised)	Xicheng District, Beijing	Installation subsidy, 30% of total investment
2021-04	Notice on Adjusting the Municipal Financial Subsidies for Distributed Photovoltaic Power Generation Projects for Residents Across the City	Yueqing City, Zhejiang Province	Generation subsidy, RMB 0.1-0.2/kWh
2021-05	Measures of Guangzhou Huangpu District, Guangzhou Economic and Technological Development Zone, Guangzhou High-tech Industrial Development Zone for Promoting Green and Low-Carbon Development	Guangzhou Huangpu District, Guangzhou Economic and Technological Development Zone, Guangzhou High-tech Industrial Development Zone	Generation subsidy, RMB 0.15-0.3/kWh
2021-05	Announcement on Soliciting Opinions on the Continued Implementation of the Administrative Measures for Distributed Photovoltaic Power Generation Projects by Dongguan Development & Reform Bureau	Dongguan City, Guangdong Province	Generation subsidy, RMB 0.1-0.3/kWh
2021-08	Implementation Measures for Relocating Farmhouses to Apartment-Style Settlements in Baibu Town (Trial)	Haiyan County, Zhejiang Province	Installation subsidy, RMB 0.8/W
2021-09	Reply to Proposal No. 20220188 of the First Session of the Second District Political Consultative Conference of Fenghua District People's Government	Ningbo City, Zhejiang Province	Generation subsidy, RMB 0.3/kWh
2021-09	Interim Measures for Promoting Green Development in Jiangning Economic and Technological Development Zone	Nanjing Economic and Technological Development Zone, Jiangsu Province	Generation subsidy, RMB 0.1/kWh; installation subsidy, RMB 0.2/W
2021-10	Action Plan for Energy Conservation and Transformation of Thousand Enterprises in the Manufacturing Industry of Wenzhou City (2021-2023)	Wenzhou City, Zhejiang Province	Generation subsidy, RMB 0.1/kWh
2021-11	Implementation Opinions of Lishui Municipal People's Government on Accelerating the Scale Development of Distributed Photovoltaics	Lishui City, Zhejiang Province	Installation subsidy, RMB 0.6/W, decreasing by RMB 0.1/W annually
2021-11	Notice on the Implementation Plan of Distributed Photovoltaic Scale Development in Wujiang District	Wujiang District, Suzhou City	Generation subsidy, RMB 0.1/kWh

Figure 2.7 Overview of Local Subsidy Policies for Distributed PV in China (2021-2022) 2/2

Release Date	Policy Name	Location	Subsidy Format
2021-12	Public Notice on the Implementation Plan of Rooftop Distributed Photovoltaic Development Pilot Project in Keqiao District	Keqiao District, Zhejiang Province	Generation subsidy, RMB 0.25/kWh
2021-12	Opinions on Supporting Distributed Photovoltaic Power Generation in Taishun County (Draft for Comment)	Taishun County, Zhejiang Province	Installation subsidy, RMB 0.05-0.5/W based on "flat to slope" renovation, installation time, and capacity
2021-12	Several Policies for Promoting High-Quality Development of Manufacturing Industry in Fanchang District to Create a Smart Manufacturing City in Fanchang Block	Fanchang District, Wuhu City, Anhui Province	Installation subsidy, RMB 0.2/W
2022-01	Several Opinions of the People's Government Office of Pinghu City on the New Round of Encouragement for Photovoltaic Power Generation Project Construction	Pinghu City, Zhejiang Province	Installation subsidy, RMB 1/W
2022-01	Several Measures for Promoting Distributed Photovoltaic Power Generation (Draft for Comment)	Shenzhen City, Guangdong Province	Generation subsidy, RMB 0.1-0.3/kWh

models, driving diversified growth at higher levels. The cost reductions resulting from rapid technological iteration will create new profit margins. The gradual reduction of distributed PV subsidies marks a return to conventional commercial logic within China’s distributed PV market. Stakeholders and market players are now required to rely on dependable, top-tier component products and services to generate profits in accordance with the rules of business, instead of depending solely on subsidies for survival. As the era of subsidies gradually winds down, the distributed PV market will continue its orderly expansion in the new development landscape, gradually increasing returns through market-oriented logic.

Government backing will continue to drive the development of rural residential PV during the 14th Five-Year Plan period. Under the impetus of the Dual Carbon goals and the drive to bolster new energy development, the National Energy Administration issued the *Notice on Submission of Pilot Proposals for County (Municipal, District)-Wide Residential PV* in 2021. This document mandates that rural residential rooftops should be equipped with PV installations covering no less than 20% of the total roof area. A total of 676 counties and cities nationwide have been enlisted in the pilot program, constituting one-quarter of China’s over 2,800 counties. Under the “county-wide advancement” policy, state-owned and central enterprises have actively entered the distributed PV sector, propelling large-scale rural residential PV construction. By the end of 2021, State Power Investment Corporation had surpassed 100 target counties spanning 20 provinces and cities. China Energy Investment Corporation had secured contracts with over 33 counties. China Huaneng Group had signed contracts with more than 20 counties. China Datang Corporation and China Huadian Corporation had each signed agreements with more than 10 counties. The collective capacity of all projects is set to exceed 70 GW, with a total project cost surpassing RMB 250 billion. In 2021, government bodies including the National Development and Reform Commission and the National Energy Administration jointly issued the *14th Five-Year Plan for Renewable Energy Development*, introducing the "Bathe Thousands of Homes in Light Initiative". This program, combined with the rural revitalization strategy, coordinates the deployment of distributed PV on rooftops with suitable conditions or collectively arranged areas in rural villages. Its goal is to establish around 1,000 PV demonstration villages in an attempt to enhance rural electrification and expedite the transition toward cleaner energy usage. In May 2022, the National Development and Reform Commission and the National Energy Administration jointly released the *Implementation Plan for Promoting High-Quality Development of New Energy in the New Era*, outlining measures to encourage local governments to support rural households in the installation of residential PV systems on their rooftops and bolster the consumer base for PV electricity generation.

At the same time, the ongoing progress of China's electricity market reforms offers institutional support for the growth of residential PV. As the electricity system reform continues to deepen, equitable grid access is gradually being extended. Entities with distributed power sources are shifting from being solely consumers to prosumers and actively partaking in market competition. In 2022, the National Development and Reform Commission and the National Energy Administration issued the *Guiding Opinions on Accelerating the Establishment of a Unified National Electricity Market System*, which proposes the systematic inclusion of new energy in electricity market transactions while enhancing the adaptability of the electricity market to accommodate a higher proportion of new energy sources. In the same year, the National Development and Reform Commission, along with other ministries, jointly released the *Plan for Promoting Green Consumption*, highlighting the necessity of further stimulating the potential for green electricity consumption throughout society. This involves coordinating the promotion of green electricity transactions and green certificate trading. Additionally, in response to Proposal No. 01691 (Economic Development Category No. 110) from the 5th Session of the 13th National Committee of the Chinese People's Political Consultative Conference, the National Energy Administration stated in October 2022 that they were "actively exploring the integration of residential PV into the green electricity, green certificate, and carbon emission trading markets to further empower the industry". At the beginning of 2023, the Central Document No. 1 titled *Opinions of the Central Committee of the Communist Party of China and the State Council on Advancing Key Work in Comprehensive Rural Revitalization in 2023* explicitly stated the aim of "consolidating and upgrading rural power grids and advancing renewable energy in rural areas", laying the foundation for the development of rural residential PV markets.

2.4 Challenges in scaling up rural residential PV

Despite the current nationwide push for PV industry development and the strategic importance of rural PV within the PV landscape, it is clear that the large-scale expansion of rural residential PV faces several challenges.

2.4.1 Despite low power consumption and considerable power generation grid integration, rural areas face limited distribution network capacity and require substantial funds for upgrades

In rural areas of China, electricity consumption is relatively low, and the level of electrification is not particularly high. Local energy consumption only accounts for approximately 10% of the theoretical PV generation potential of rural households. In 2021, the monthly per capita electricity consumption in China was only about one-third to one-half[11] that of developed countries such as the United States and Canada. The disparity in rural areas is even more pronounced. In the United States, rural areas have a high level of electrification, greater per capita disposable income, and larger per capita housing spaces. Currently, residential PV consumption makes up 50% of the total. However, electricity consumption in rural China is notably low, and there is a substantial difference between daytime and nighttime usage. This mismatch results in an oversupply of PV electricity during the day, necessitating the integration of PV-generated electricity into the grid. Nevertheless, the sporadic grid integrations for residential PV make it challenging to efficiently transmit power at high voltages, leading to voltage and frequency fluctuations in the aging distribution network. This can cause instability in local power supply, highlighting the pressing need for distribution network upgrades and renovations.

The high cost of upgrading distribution networks and the low economic viability of grid upgrade and integration pose significant obstacles to the development of rural residential PV. Grid companies play the roles of both buyers and sellers in promoting distributed PV generation. For grid companies whose performance metrics are based on electricity sales, the cost of new energy generation is higher than traditional energy sources. Additionally, the self-generation and self-consumption model reduces revenue from grid electricity sales. Consequently, grid companies may lack enthusiasm for purchasing new energy electricity. Furthermore, the projected investment in nationwide distribution network upgrades is expected to reach RMB 3 trillion[12]. These projects come with high operating and maintenance costs, and their economic benefits are relatively low. The return on investment in central and western regions and remote areas of China is significantly lower compared to the eastern regions. These projects are characterized by clear public interests but have limited appeal to private capital, resulting in a significant funding shortfall. The constraints within the distribution network have become a bottleneck for the development and grid integration of distributed PV power plants in many regions, especially in major PV provinces. For example, Zaozhuang City in Shandong Province issued the *Zaozhuang Municipal Distributed PV Construction Norms (Trial)* in November 2021, clearly stipulating that distributed PV power

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[11] Statista, Per Capita Electricity Consumption Worldwide 2021, by Selected Country, https://www.statista.com/statistics/383633/worldwide-consumption-of-electricity-by-country/

[12] Expert Predictions from State Grid Energy Research Institute

should be consumed locally or nearby. It further dictates that, in principle, the total installed capacity of various types of PV within a county should not exceed 60% of the region's maximum annual electricity load, so as to avoid the reverse transmission of power to grids operating at 220 kV and above. Following the release of this document, some local authorities suspended the acceptance of applications for development and grid integration, citing the fact that the total PV capacity within the entire county exceeded the local grid's capacity. Similarly, Xingtai City in Hebei Province limits transformers to operate at 80% of their capacity. According to the *Report on Distributed PV Capacity Available for Grid Connection* submitted by State Grid Corporation Xingtai Power Company to the Xingtai Development and Reform Commission in November 2021, as of October 27, 2022, Xingtai City had an available capacity of 303.71 MW for 220 kV substations in six counties and districts, including Xindu District, Xiangdu District, Qinghe County, Ningjin County, Nanhe District, and Shahe City. In contrast, the available capacity for 220 kV substations in other counties and districts was zero. These bottlenecks in the development of distributed PV installations are clearly affecting the province's progress in achieving the "county-wide advancement" goal.

As a result, it is imperative to enhance local power consumption capacity, facilitate residential PV with energy storage solutions, and promote the development of flexible control capabilities in order to develop distributed PV. Improving local consumption capacity is closely tied to the further improvement in the living standards of rural residents. Improving living standards should involve the promotion of comprehensive electrification for all energy needs, including cooking, heating, various forms of transportation, agricultural machinery, and agricultural production. Moreover, the widespread adoption of energy storage solutions requires overcoming current constraints such as high costs, poor economic viability, and significant safety risks.

Challenges and Solutions in the Development of Residential PV in Shandong Province

Shandong Province, driven by its high population and energy demand, finds itself at the cusp of a significant transformation in its energy landscape. As of 2020, the province's total energy consumption stood at 418 million tons of standard coal, ranking first in China[1]. The dominance of traditional energy sources in its energy portfolio presents a formidable challenge to Shandong's energy structure. In response, initiatives focused on reducing coal-fired power generation and expanding clean energy sources, notably PV and wind power, have taken center stage in Shandong's critical low-carbon endeavors.

Recent years have witnessed a remarkable upswing in the adoption of distributed PV across Shandong Province, making it the province with the highest total installed capacity. Shandong boasts abundant

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[1] Natural Resources Defense Council, Research on the Path to Reduce Coal Consumption in Key Coal-Consuming Industries in Shandong Province during the 14th Five-Year Plan Period, http://www.nrdc.cn/Public/uploads/2022-11-02/6361e8831b093.pdf

sunlight resources, a wealth of public infrastructure, industrial facilities, rural housing rooftop space, and competitive benchmark electricity rates for desulfurized coal. Bolstered by the nationwide push for policies promoting distributed PV development and capitalizing on Shandong's unique blend of natural and cultural assets, the province's installed distributed PV capacity surged from a modest 0.38 GW in 2014[2] to 15.93 GW by 2021[3], making it the leading province in distributed PV deployment. Shandong has 70 counties on the 2021 list of 676 counties (cities, districts) for national "county-wide advancement" rooftop distributed PV pilot program, securing the top spot nationwide. As a result, Shandong has embarked on large-scale residential PV development, triggering a surge in new installations.

However, the growth of Shandong's distributed PV industry has gradually slowed due to a series of challenges, including overloaded grid integrations, prevalent issues related to overvoltage at endpoints, disparities in equipment quality, and chaotic O&M management practices. These impediments have emerged as the primary constraints on the continued development of distributed PV in the province.
The extensive grid integration of distributed PV systems has exacerbated the pressure on peak load management, notably evident in problems such as overburdened distribution transformers. As of the first half of 2022, the majority of rural transformers in Shandong were operating at full capacity, with PV capacity accounting for 80% of the local transformer capacity threshold[4]. This has impacted the safety of power supply and the quality of energy. Moreover, quality issues plague the installed distributed PV equipment, including frequent component failures and severe photovoltaic panel aging, resulting in an annual decline in the yield of PV projects. In PV O&M work, issues such as fragmented management and the absence of routine maintenance have negatively impacted the enthusiasm of households to install distributed PV systems.

A potential key to addressing the challenges associated with distributed PV power consumption is the adoption of energy storage solutions. With various regions consistently rolling out subsidies for the use of electrochemical energy storage in peak load regulation and the prospect of diminishing storage costs and ongoing liberalization in the power market, source-grid-load-storage integration presents a potential solution to the challenges in distributed PV power consumption. Zaozhuang City in Shandong has initiated preliminary trials in this area, proposing principles such as the allocation of energy storage facilities for distributed PV on rooftops at a minimum of 15% of installed capacity and minimum discharge

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[2] National Energy Administration, 2014 Photovoltaic Generation Statistics, http://www.nea.gov.cn/2015-03/09/c_134049519.htm

[3] Energy Administration of Shandong Province, Shandong Leads in Both Growth and Scale of Household Photovoltaic Installations Nationwide, http://nyj.shandong.gov.cn/art/2022/1/25/art_253733_10291562.html

[4] PV-info, Wind Vane! Household Photovoltaics in Shandong Dropped from Top Place, https://www.163.com/dy/article/HDI7NNKR0511CVT1.html

duration of two hours[5],encouraging "PV + energy storage" synergy, with the ultimate goal of further propelling the growth of distributed PV.

Furthermore, the integration of distributed PV into grid peak load regulation represents another promising avenue. During the 2022 Chinese Spring Festival, the Shandong Provincial Government proposed that, when conventional methods prove inadequate in meeting the demands of grid peak load regulation, priority should be given to centralized solutions before decentralized ones and non-residential applications before residential ones[6]. This strategic shift seeks to leverage distributed PV stations for peak shaving and valley filling, thereby enhancing the capacity of distributed PV to participate in grid peak load control and demand response.

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[5] Zaozhuang Municipal People's Government, Notice of Zaozhuang Municipal People's Government Office on Issuing the Implementation Plan for Promoting Distributed Photovoltaic Power Generation on Rooftops across the District (City), http://www.zaozhuang.gov.cn/zcwjk/szfbgswj/202202/t20220228_1551004.html

[6] Energy Administration of Shandong Province, Notice on Ensuring Power Supply during the 2022 Spring Festival, Winter (Paralympic) Games, and Two Sessions, http://nyj.shandong.gov.cn/art/2022/1/26/art_59960_10291333.html

2.4.2 Residential PV is entering a comprehensive subsidy-free era and value chain participants need to explore new profit growth points

Since 2022, the residential PV market has experienced central subsidy withdrawal, leaving behind only a few local subsidy programs. This marks a transition towards price parity and market-driven development. Recent years have seen rapid development in the PV industry, with many stakeholders joining the fray and intensifying market competition. The continuous decline in the costs of PV systems has boosted the economic viability of distributed PV in China, making grid parity an inevitable trend. PV subsidies decreased from RMB 0.42/kWh in 2017 to RMB 0.03/kWh in 2021, representing a significant reduction. Concurrently, the cost of residential distributed PV systems has plummeted from around RMB 6/W[13] in 2017 to approximately RMB 3.3/W[14] in 2021. Under the model of full grid feeding, the internal rate of return (IRR) for distributed PV power stations in the current market has largely remained on par with 2017 figures, hovering between 8% and 10%. However, in this era of "comprehensive subsidy-free", the heightened challenge of customer acquisition will undoubtedly present a fresh test for the ability of all value chain participants to reduce costs and enhance efficiency. In the six months following the introduction of the 531 New Policy in 2018, which outlined substantial reductions in PV subsidies, around 638 PV enterprises closed down, representing more than a quarter of all deregistered PV enterprises[15]. Enterprises that had previously relied on policy subsidies to survive now face a bigger challenge

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[13] China Energy Net, Subsidy Reduction: How to Ensure the Return on Investment for Distributed Photovoltaic Projects, https://www.china5e.com/news/news-1017530-1.html

[14] TF Securities, Resurgence of Investment Enthusiasm in Distributed Photovoltaics: How Will the Business Models Evolve, https://pdf.dfcfw.com/pdf/H3_AP202204061557574334_1.pdf?1649259191000.pdf

[15] CITIC Futures, Commodity Perspective on the Photovoltaic Industry: A Series of Topics on Policies · Policy Analysis for Global Photovoltaic Industry, https://pdf.dfcfw.com/pdf/H3_AP202205101564703194_1.pdf?1652196167000.pdf

in identifying new avenues for profit generation. This will put a damper on participants' enthusiasm in the short term.

In the long run, the subsidy reduction will impel enterprises to engage in technological innovation, lower production costs, and boost their profitability. Moreover, market participants will actively explore alternative paths for revenue growth. However, at present, carbon emission trading markets, including green electricity trading and green certificate trading, do not cover residential PV. Participants are unable to independently take part in carbon trading, affecting their ability to gain additional revenue from the carbon market. In a period of diminishing policy and subsidy benefits in the residential PV market, there is increased demand to push forward green equity trading market building.

2.4.3 Challenges in implementing the "county-wide advancement" policy may affect progress and stakeholder engagement

In the context of the 14th Five-Year Plan, the "county-wide advancement" policy has emerged as a pivotal national energy strategy, covering the demand for more than 100 GW in new distributed PV installations. This initiative has brought rural residential PV into the industry spotlight. At its core, within the first batch of 676 selected county-level pilot areas, the policy advocates a coordinated approach to developing distributed PV at the county level and the principle of "construct where feasible". The policy also promotes direct engagement between various investors (including major power companies, foreign energy enterprises, PV manufacturers, and cross-industry participants) and county-level officials. Once granted the development rights for an entire county, these entities undertake the construction of power stations either independently, through collaboration, or via subcontracting. It's important to note that the "county-wide advancement" policy extends beyond rural residential rooftops, covering various rural government buildings such as village committees, hospitals, community centers, and schools, as well as collectively owned rural houses. As of the end of August 2022, among the 676 pilot areas for "county-wide advancement" selected by the National Energy Administration, 140 counties and cities had entered the bidding and tendering phase, accounting for 20.71% of the total list[16].

Nevertheless, the "county-wide advancement" policy, an important guideline for residential PV development during the 14th Five-Year Plan, confronts numerous challenges in practical implementation. The policy is designed to accelerate residential PV development by capitalizing on economies of scale and involving major state-owned enterprises in rural residential PV markets to improve the heterogeneous market environment. However, some regions have mechanically enforced the centralized PV development model, staging a "land enclosure movement." Exclusive measures such as the "one enterprise per county" approach have inadvertently generated confrontations among diverse market participants. Additionally, certain local governments have mandated companies to enter into bundled agreements, necessitating investments in other industrial resources as a condition for obtaining county-wide development rights. Moreover, limitations in grid integration

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[16] National Energy Administration, Notice of the General Office of National Energy Administration on Publishing the List of County-Wide (City-Wide, District-Wide) Pilot Projects for Rooftop Distributed Photovoltaic Development, http://zfxxgk.nea.gov.cn/2021-09/08/c_1310186582.htm

capacity, variations in the quality of rural rooftops, and the difficulties in promoting PV in rural areas present challenges for the “county-wide advancement” policy’s long-term prospects. Consequently, rural residential rooftops have become arenas for conflicts of interests, thereby impacting the healthy development of the rural residential PV market.

2.4.4 Due to complex dynamics of the rural market environment, enterprises face challenges in customer acquisition, fragmented operations, and limited long-term commitments from rural households

The rural market environment in China is inherently complex. Generally, rural residents possess lower levels of education and professional expertise. In terms of residential PV operations, there are uncertainties around customer acquisition, PV installation, maintenance, and long-term ownership. In rural China, social mobility remains low, the social structure is relatively fixed, and the influence of personal relationships is significant. Therefore, local outreach personnel must possess robust local social networks, making it challenging for private enterprises to standardize and streamline customer acquisition processes. Furthermore, due to the diverse conditions of rural rooftops, each installation requires a customized approach, leading to increased design costs. Furthermore, the dispersed nature of rural residential PV installations, coupled with the lack of professional maintenance knowledge among rural homeowners, results in higher maintenance costs during the station’s lifespan. At present, given the prevailing rooftop leasing model in rural areas, power station owners encounter challenges related to the limited long-term commitment from homeowners, changes in property ownership, and the environmental conditions around the stations, all of which impede the efficiency of PV operations.

03

Business and Consumption Models for Rural Distributed PV

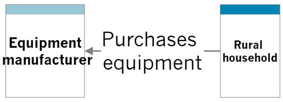
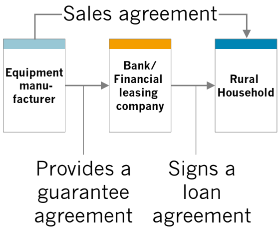
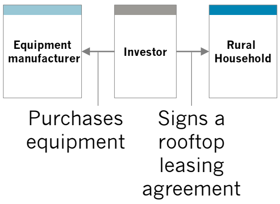
In rural China, residential PV operates under two primary business models: rooftop leasing and self-financing & self-ownership. These models come with distinct ownership structures and profit distribution methods, as illustrated in Figure 3.1. Due to China's relatively lower residential electricity prices compared to more developed countries and its lower level of rural electrification, rural residents have limited awareness of PV technology. Given the context of the "county-wide advancement" policy, the rural residential PV market in China is predominantly dominated by the rooftop leasing model, constituting over 80% of the entire residential PV sector.

The consumption models for residential PV electricity can be categorized as "self-generation and self-consumption with surplus grid feeding" and "full grid feeding". Power station investors and end-users typically choose different consumption models based on factors such as their own electricity consumption patterns and local electricity rates and pair different consumption models with various metering and settlement methods.

In the effort to scale up the development of rural distributed PV, this chapter analyzes the challenges and pain points within the existing business models and offers tailored recommendations for future development at scale.

Figure 3.1 Main Business Models for Distributed Residential PV

🟦 Rural household ⬛ Investor 🟧 Bank/Financial Leasing Company ▧ Equipment Manufacturer

		Business Model Overview	Stakeholders	Revenue Composition for Various Stakeholders	Grid Connection Method	Station Owner
Self-financing & self-ownership ~20%	① **Payment in full**	Rural households independently invest in purchasing PV equipment, handle installation and maintenance, and retain all revenue from electricity generation.		🟦 Electricity revenue	Mainly self-generation and self-consumption with surplus grid feeding	🟦 Rural Household
	② **PV loan model**	Rural households, with the endorsement of dealers or equipment suppliers, enter loan agreements with banks or financial leasing companies. Designated equipment suppliers provide the equipment. Dealers or equipment suppliers also sign additional guarantee agreements with banks or financial leasing companies.		🟦 Post-repayment electricity revenue ▧ Equipment sales revenue	Mainly self-generation and self-consumption with surplus grid feeding	🟦 Rural Household
Rooftop Leasing Model ~80%		Rural households exclusively lease their rooftops to investors. Investors take charge of the entire PV station process, from development to maintenance, and receive the revenue from electricity generation.		🟦 Rooftop leasing fee ⬛ Electricity revenue	Full grid feeding	⬛ Investor

3.1 Rooftop leasing – Full grid feeding

3.1.1 Current landscape: Dominant model under the ‘‘county-wide advancement’’ policy; multiple collaborative models for station development among station investors, developers, and owners

The rooftop leasing model is widely adopted in the rural residential PV market in China and features unique Chinese characteristics. The construction of a residential PV station typically entails an initial investment ranging from RMB 30,000 to RMB 80,000, creating a barrier to entry for regular homeowners. This business model, which can be stated as “you provide the roof, I invest the money, and we build the station together”, has evolved in response.

Under this model, private enterprises and other developers engage with potential rural homeowners through ground promotion and other touchpoints, negotiating agreements to lease underutilized rooftops for PV station construction. They pay a fixed monthly rent based on the rooftop area and PV station capacity. Ownership of the station rests with the developer, while the revenue generated from electricity production goes to the investor. After 20 to 25 years, the station ownership is transferred to the user.

The value chain in the rooftop leasing model comprises four primary stakeholders: rooftop owners, PV station investors, PV station developers, and the final station owner (currently dominated by the “Five Big and Six Small” major state-owned power companies: China Huaneng Group, China Datang Corporation, China Guodian Corporation, China Huadian Corporation, and China Power Investment Corporation, as well as SDIC Power Holdings, Guohua Electric Power, China Resources Power, China General Nuclear Power, CECEP Solar Energy Technology, and China Three Gorges Corporation). In practice, it is common for a single stakeholder to take on multiple roles within the value chain. For instance, a major state-owned power company can serve both as an investor and a final station owner. When its finances permit, a PV manufacturer can simultaneously function as an investor and a station builder.

Within the development value chain, acquiring local customers is a pivotal step for station investors, who often lack promotional channels in rural areas. Developing customers to drive module sales has become the new norm for some PV manufacturers as they venture downstream into the highly competitive rural residential PV market. In this environment, investors or developers with local integrations and market familiarity enjoy a significant advantage.

Stakeholders within the value chain collaborate in station development through partnerships or mergers and acquisitions. Under the partnership model, well-funded investors collaborate with general contractors through tendering and other forms. These investors provide a portion of the funds as a deposit, and the developers undertake specific development tasks. Once the station is constructed, investors acquire it as an asset, paying the remaining amount to the developers. In the acquisition model, stakeholders with comprehensive end-to-end capabilities independently manage county-level development, customer development, and station construction. They either retain the assets for the long term or sell them to backers, including the “Five Big and Six Small” major state-owned power companies. Additionally, PV companies occasionally participate as subcontractors in one or more stages including module supply, construction, and operation & maintenance.

Given the predominant "county-wide advancement" policy in China and the widespread adoption of the rooftop leasing model, most investors favor the full grid feeding model, which offers an easy settlement process. Rural PV station owners often spend their daytime hours engaged in agricultural activities, resulting in lower self-consumption capacity relative to urban areas. Under the full grid feeding model, the PV grid integration point is established at the household's meter, eliminating the need for rural households to personally consume the generated electricity. All electricity generated by the PV system flows directly into the public grid and is billed at a predetermined grid integration price.

Analysis of Economic Viability for the Rooftop Leasing Model

Let us take Mrs. Zhong (alias), a resident of Zhongjiagou Village in Yantai, Shandong, as a case study. An assessment conducted by a PV company reveals that Mrs. Zhong's rooftop has the capacity to accommodate 20 PV panels, totaling 10 kW in capacity. Given the natural conditions of Yantai, the estimated annual solar exposure of the rooftop is approximately 1,400 hours, resulting in a total electricity generation of 14,000 kWh.

Benefits of the rooftop leasing model among different parties

In the event that Mrs. Zhong decides to adopt the rooftop leasing model, at a leasing rate of RMB 8/kW per month, the 10-kW PV panels installed on her rooftop can generate an annual rental income of RMB 960. Over the 25-year lease period, this amounts to a total income of RMB 24,000.

Normally, the return on investment for PV station developers falls within the range of 7% to 9%, depending on factors such as equipment costs (modules, inverters, brackets, and additional auxiliary expenses), engineering, procurement, and construction (EPC) costs, operation & maintenance fees, rental charges, and insurance premiums. Within the rooftop leasing model, there are two main ways PV station developers and investors can work together to construct a PV station on Mrs. Zhong's rooftop. In the collaborative development model, the construction cost for the PV station is RMB 3.2/W, equating to a total cost of RMB 32,000 for a 10-kW station. If the investor furnishes funding at a rate of RMB 3.5/W, the developer stands to gain RMB 35,000 from the investor. In this scenario, Mrs. Zhong's rooftop would bring a profit of RMB 3,000 to the investor. On the other hand, in the merger and acquisition model, developers with adequate cash flow and bargaining power can hold ownership of the station assets for a short period, typically no more than a year, and then transfer the assets at a rate of RMB 3.7/W, resulting in a profit of RMB 5,000. Moreover, when developing on a county-wide scale (generally 50 MW to over 100 MW), PV station developers can bring in profits of RMB 15 million to RMB 50 million from all the projects in the area depending on the scale and development approach adopted.

When taking over assets, PV investors generally anticipate a return on investment exceeding 8%, determined by factors such as acquisition price, electricity generation, corporate operational expenditures, and loan interest rates. Under the rooftop leasing model, investors hold the right to sell electricity. Calculated at an electricity price of RMB 0.395/kWh in Shandong, Mrs. Zhong's household can earn an annual electricity income of RMB 5,530, given an annual electricity generation duration of 1,400 hours. Assuming a 2% annual degradation rate in the initial year, followed by 0.7% from the subsequent year onwards, the overall electricity income over the 25-year lease period totals approximately RMB 123,872. Under the collaborative development model, investors pay a support fee of RMB 3.5/W, resulting in a cost of RMB 35,000. Throughout the station's operational lifespan, investors are obligated to pay an annual operation and maintenance fee of RMB 0.03/W per year, totaling RMB 300 annually and RMB 7,500 over the term of the lease. Additionally, investors are required to provide Mrs. Zhong with an annual rental fee of RMB 960[1], totaling RMB 24,000 over the term of the lease. Over the 25-year lease period, the profit accrued by investors from Mrs. Zhong's rooftop will total RMB 57,372. Calculated with an average discount rate of 4% for state-owned enterprise projects, the net present value of a single project is approximately RMB 24,000. Similarly, on a county-wide level, investors can potentially see a total profit of almost RMB 300 million to RMB 600 million over the span of 25 years, with an overall project net present value of about RMB 120 million to RMB 240 million. Under the merger and acquisition model, investors acquire the entire county's station assets at a rate of RMB 3.7/W. A single station can generate a profit of RMB 55,372 over 25 years, for an estimated total county-wide profit of approximately RMB 280 million to RMB 550 million and a county-wide project net present value of around RMB 110 million to RMB 220 million (see Figure 3.2).

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[1] Rental rates vary by region and are determined by local economic development, electricity prices, and specific local conditions.

Figure 3.2 Estimated Benefits for All Stakeholders under the Rooftop Leasing Model

Baseline Scenario Assumptions

Project Details

End-to-end development charge	3.7	RMB/W
Project scale	10	KW
County-wide scale	50-100	MW

Operational Details

Feed-in tariff	0.395	RMB/kWh

In the M&A model, private enterprises take the lead in financing and developing power stations in a whole village/county. After the power station is completed, efforts are made to secure backing or project takeover by state-owned and central government enterprises and other investors.

Annual generation hours	1400	h/year
Lifecycle years	25	Years
First year degradation		2%
Degradation	0.70	/Year
O&M fees	0.03	RMB/W

Leasing Details

Rent	96	RMB/kW/year
Scale	10	kW/household

Rooftop Leasing: Benefit Calculation for All Parties (M&A Model)

Private enterprises

End-to-end development charge	3.7	RMB/W
End-to-end development cost	3.2	
▪ Non-technical costs (project permits)	0.2	
▪ Customer acquisition costs	0.2	
▪ Equipment costs	2.6	
– Module	1.9	
– Supports and other auxiliary costs	0.7	
▪ Installation costs	0.2	
Profit	**RMB 5,000**	
County-wide revenue	**RMB 30-50 million**	

Rural Household

Rent	96	RMB/kW/year
Scale	10	kW/household
Lifecycle years	25	Year
Total revenue	**RMB 24,000**	

State-owned and central enterprises like the "Five Big and Six Small"

End-to-end development charge	3.7	RMB/W
Project scale	10	KW
Initial project investment	**37,000**	**RMB**
Annual rent	960	**RMB**
Annual O&M fees	300	**RMB**
O&M fees	0.03	RMB/W
Total generation costs	**31,500**	**RMB**
Total revenue from electricity generation	138,250	RMB
Annual revenue from electricity generation	5530	
Annual revenue from electricity generation		
Total electricity generation loss	14,378	
Actual revenue from electricity generation	**RMB 123,872**	
Total profit per project	**RMB 55,372**	
County-wide total profit	**RMB 280-550 million**	
Net present value of county-wide project	**RMB 110-220 million**	

3.1.2 Challenges and strategies for stakeholders: PV station developers, rooftop owners, and financial backers

The rooftop leasing model is a distinctive model for the residential PV market that has emerged in China. Various players in the value chain are continually exploring business models that align closely with conditions in rural China. It is worthwhile to identify the challenges encountered in this process.

3.1.2.1 PV station developers (primarily private enterprises):

Confronting the difficulty in obtaining approval for grid integration and other challenges that limit the expansion of high-quality projects, high initial customer acquisition costs, and difficulty in finding financial backers, developers must prudently assess entry opportunities, explore innovative grid integration models, expand customer acquisition avenues through user segmentation and integrated sales channels, and actively seek out potential financial backers.

Challenge 1: Developers face constraints when it comes to expanding high-quality projects due to the difficulty in obtaining approval for grid integration and other obstacles. Grid integration approval is a crucial initial step in PV station development, usually involving communication between developers and local power grids during the ground promotion process. In certain regions, grid integration approval is difficult to obtain due to factors such as difficulty in consuming electricity and high levels of existing energy generation. In addition, the need for supplementary energy storage installations hinders developers from expanding their projects further. Although there is currently no unified national standard restricting the capacity of grid-integrated transformers, most regions adhere to the guideline that grid-integrated residential PV transformer capacity should not exceed 80% and take a first-come, first-served approach. Consequently, in areas with abundant solar resources, higher economic development levels, and relatively elevated electricity prices, the available grid integration capacity is limited, leading to frequent challenges when seeking approval.

Solution: To ease the pressure on grid integration approvals, developers should create innovative rural residential PV grid integration models. Some provinces and cities have adopted a novel grid integration solution called village-level aggregation to replace the earlier individual household grid integration model that takes natural persons as its basic units. This innovative approach has proved effective in addressing grid integration challenges. In the village-level aggregation model, PV station developers apply for grid integration on behalf of the village as a whole following a standard commercial and industrial model, and then enter into grid integration dispatch agreements with the grid. PV projects are connected to the grid through centralized transformers, following principles such as load reduction and nearby consumption. PV electricity is efficiently distributed to the load end through power lines, enhancing overall efficiency and effectiveness. The village-level aggregation grid integration model reduces the number of grid integration points, which effectively mitigates potential disruptions caused by a large number of dispersed residential PV integrations to the grid and simplifies operations. This model also provides more low-voltage consumption options. However, the model must consider factors such as rural grid capacity and cable voltage drop, and one typical unit for grid integration ranges from 400 kW to 600kW.

Innovative Village-Level Aggregation Grid Integration Model

In the second half of 2021, Zhangjiamiao Village in Linyi County, Dezhou City, Shandong, pioneered the adoption of the village-level aggregation grid integration model. This approach involves villagers leasing their rooftops to PV station developers who, in turn, invest in PV modules, low-voltage collection lines, and step-up transformers. The 117 PV projects in Zhangjiamiao Village with 3 MW in total were divided into seven units, and the electricity generated was centrally collected and directed into seven dedicated step-up transformers. The power was then integrated into the grid via 10 kV lines. Upon project completion, an annual output exceeding 3 million kWh is anticipated, thereby reducing carbon dioxide emissions by more than 2,500 tons. An executive from Shandong Dahai Group Co., Ltd., the PV station developer, outlined that the project would follow conventional commercial and industrial procedures to secure grid integration after completion. They would enter into a grid integration dispatch agreement with the grid and simultaneously furnish the power service command center with station information, ensuring compliance with telemetry, remote signaling, remote control, and other grid requirements.

The village-level aggregation model adopts a high-voltage grid integration approach. The purchase of additional equipment components, such as transformers, grid integration boxes, and cables, increases construction costs by RMB 0.2-0.3/W over the initial average cost of RMB 3.2-3.4/W. Nevertheless, this grid integration model offers two substantial advantages. First, it dramatically alleviates grid integration strain, reducing the likelihood of low-voltage grid integration-related incidents and circumventing grid integration restrictions in specific regions. Second, it simplifies operation and maintenance. By consolidating 117 PV projects into 7 units integrated to the grid, it reduced workload for daily operation and maintenance inspections. Taking a long-term perspective, the incremental costs during the initial phase only have a minor impact on overall project returns, with projects typically maintaining an ROI of over 8%.

Moreover, the village-level aggregation approach, which effectively match with grid construction, obviates the need for investment by the local government or villagers. Also, it doesn't demand local governments to dispense policy subsidies or financial support. This creates a mutually beneficial scenario, delivering advantages across social, economic, and ecological dimensions[1].

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[1] China Electric Power News, Exploring the County-wide Advancement Experience in Dezhou, https://www.cpnn.com.cn/news/hy/202207/t20220718_1534353.html

Challenge 2: The increasing difficulty in front-end customer expansion contributes to higher conversion costs for PV station developers. After a year of implementing the "county-wide advancement" policy, most households with a strong desire to install PV panels have already done so. Regions endowed with abundant and relatively concentrated rooftop resources have reached saturation. Conversely, areas yet to be developed feature dispersed households that are more distant from urban centers. This presents a more challenging market in lower-tier regions, making customer acquisition much more difficult and intensifying the difficulties faced by ground promotion personnel during customer expansion.

Solution: Encourage PV station developers to diversify their customer acquisition channels by combining user segmentation and integrated sales strategies. Throughout the customer expansion phase, developers can leverage a multitude of sales networks. They may recommend different products to households based on factors like economic circumstances and individual preferences. This approach entails user segmentation to improve household conversion rate. For example, Chongho Bridge bolstered its presence in rural areas by offering small-scale credit services. By harnessing its robust user network and the trust established between local staff and villagers, the company was able to gain profound insights into household needs and then tailor their outreach. In the case of the Liaoning Dashiqiao PV Project, Chongho Bridge employed the rooftop leasing model and promoted PV among households made up of older people with unstable income sources, low possibility of property rights change, and limited knowledge of PV. It placed substantial emphasis on the convenience of the rooftop leasing model and the reliable long-term rental income, which yielded a high household conversion rate.

Front-End Customer Acquisition Model in Chongho Bridge's Liaoning Dashiqiao PV Project

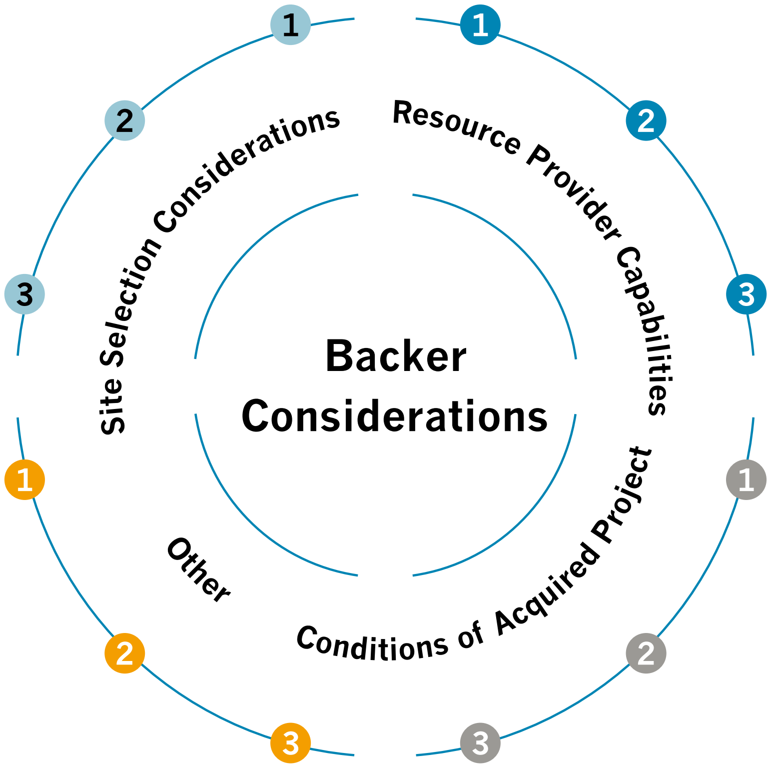
Chongho Bridge, founded in 2008, operates as a comprehensive rural assistance organization dedicated to serving rural clients. Formerly as a part of the China Foundation for Poverty Alleviation's small-scale credit project division, Chongho Bridge currently boasts a customer base of over 400,000 loan clients. Their operations extend across 20 provinces, autonomous regions, and centrally-administered municipality municipalities, covering more than 400 counties and over 100,000 villages. The organization employs a dedicated workforce of over 7,000 direct-sales account managers. In 2021, Chongho Bridge formally established its rural PV business department.

For front-end customer acquisition, Chongho Bridge leverages its existing small-scale credit business network to expand its PV operations. Simultaneously, the organization collaborates with village leaders to organize informal PV promotional events within local communities. They designate PV pilot households as "rural household promotion ambassadors" and conduct PV slogan campaigns and public awareness initiatives within these communities. Account managers in local branches are skilled at communicating with local households and understand their common issues and concerns, and possess strong customer engagement skills and the ability to conclude contracts. Additionally, Chongho Bridge works hard to improve the capabilities of its ground promotion team. Beyond prioritizing the sales and ground promotion experience of their customer managers, the company utilizes its resources and taps into PV knowledge from EPC partners to provide a comprehensive week-long online and offline training program for their staff.

Chongho Bridge's front-end customer acquisition process includes six key steps: initial customer outreach, follow-up customer visits, collection of business documents, initial review, final review, and contract finalization. During the initial customer acquisition phase, ground promotion customer managers make two or three visits to potential PV rural household households. Simultaneously, they evaluate the households based on housing conditions, including accessibility, building structures, construction methods, shading, and personal factors such as age and income. Recommendations are tailored to the unique circumstances of each household. Once mutual cooperation intent is confirmed, local supervisors at Chongho Bridge collect information on property rights and other information from the households for verification in order to ensure compliance. After initial and final document reviews, cooperation agreements are concluded and formally executed between the households and Chongho Bridge.

Challenge 3: Difficulty in securing financing for PV station assets is increasing, coupled with escalating delivery risks for developers. As a result of evolving policies, traditional PV investors and backers, including the "Five Big and Six Small" and other central enterprises, are being more cautious in their investments. They have heightened asset requirements, focusing on site-specific conditions such as local natural factors, consumption capacity, grid electricity pricing, resource-side customer acquisition capabilities, operation and maintenance support, coordination capabilities, and projects' internal rates of return, scale, and compliance (see Figure 3.3). Moreover, most PV station developers have limited self-financing capabilities and a low inclination to hold station assets for a long period, which further exacerbates the risk of asset divestiture difficulties.

Figure 3.3 Concerns for Backers Acquiring Distributed PV Station Assets



1 **Solar resources:** Regions with abundant solar resources, such as the **northeast and northwest**

2 **Consumption capacity:** Areas with well-developed industrial and commercial sectors, exhibiting strong electricity consumption capacity

3 **Feed-in tariff:** Areas with advantageous electricity prices

1 **Grid integration model:** Low-voltage grid connection is preferred, followed by centralized convergence and high-voltage grid connection

2 **Energy storage**: For economic reasons, the industrial and commercial grid connection model tends to avoid the purchase of high-priced energy storage

3 **Local economic conditions and policies:** Preference for areas with a high level of market education, economic development, and high household disposable income

1 **Customer acquisition:** Prefer resource providers with a background in central enterprises, demonstrating strong capabilities in resource expansion and customer acquisition

2 **Coordination ability:** Focus on the coordination and communication abilities between resource providers and local governments, as well as the power grid

3 **O&M support:** Ensure that resource providers can provide local O&M services for 25 years

1 **IRR:** Different backers have different bottom lines, which will be adjusted according to electricity prices, sunlight conditions, and other internal factors

2 **Scale:** The normal scale of projects in the industry is from 50 MW to 100 MW, where larger power plants yield higher returns

3 **Compliance:** Comply with the requirements of the State-owned Assets Supervision and Administration Commission (SASAC), ensuring compliance throughout the acquisition process

Data Sources: Expert interviews; Panel analysis

Solution: Developers should proactively explore a variety of financing channels to alleviate financial pressures associated with PV station projects. To mitigate the risk of asset backers rejecting PV station assets, developers must actively seek alternatives outside of large state-owned central enterprises so as to reduce the burden of holding PV stations. Given considerations such as environmental impact, social influence, and ROI, an increasing number of investors, including multilateral development banks, multinational corporations, and private equity firms, show a growing interest in green assets, with PV stations being a prime example. Efforts could be made to develop such potential investors. Furthermore, driven by ESG considerations, major corporations are demonstrating a stronger inclination to hold green assets. Efforts can be made to bring rural residential PV stations to their attention. For instance, Tencent's 2022 *Tencent Carbon Neutral Target and Action Roadmap Report* announces its "Net Zero" initiative and commits to achieving 100% green electricity usage ("RE100") no later than 2030. The report also outlines measures such as constructing energy storage stations, developing centralized new energy power stations, and exploring integrated source-grid-load-storage pilot projects. The report clearly shows Tencent's increased enthusiasm for green assets. Data from the EACs Marketplace green equity market and trading platform reveals that over 300 domestic and international companies, including Apple's suppliers, Microsoft, and CBRE, have expressed a need for green equity transactions. The platform records an annual trading volume exceeding 10 million green equity certificates. Beyond simply committing to achieve 100% green electricity usage, these companies typically encourage their suppliers by entering into long-term agreements. For example, Apple has led 175 suppliers, including TSMC, Foxconn, ASE Holdings, and Lealea Group, to commit to RE100. Suppliers, driven by the need to fulfill these agreements, are displaying a growing interest in PV station resources.

3.1.2.2 Rooftop owners (rural households):

Rural households have
a limited understanding of profits and responsibilities that may result in legal disputes. This can be addressed by enhanced industry regulation and rural household training.

Challenge: Rural households usually enter into agreements without a comprehensive grasp of the financial gains and obligations involved, leading to legal disputes. In certain instances, dealers entice rural households into accepting residential PV installations by falsely asserting the availability of substantial government subsidies, portraying it as a risk-free, high-yield endeavor. Some rural households, without scrutinizing the contract terms, hastily sign agreements. In fact, many of them lack the ability to distinguish between companies and understand the particulars of contracts. During the operation of PV stations, rural households often discover that the promised benefits remain unfulfilled, leading to frequent legal disputes.

Disputes Arising from Misleading Advertising by a Residential PV Enterprise

A leading enterprise in the PV industry found itself involved in legal conflicts and public controversies during its rapid expansion of residential PV systems, exposing irregularities within segments of the rural PV market. Urgent measures are required to rectify abuses and establish standardized market practices.

During the promotion of its products, this enterprise engaged in exaggerated and deceptive advertising, causing confusion among rural households regarding station ownership and the distribution of responsibilities. Promotional slogans such as “invest at no cost and enjoy easy income for 20 years” were alluring but misleading. The company’s messaging conveyed the impression that PV enterprises would construct stations on rural households’ rooftops, **with the rural households merely acting as lessors** and receiving rent. However, in practice, some agents utilized a “co-development” model where the enterprise registered the station under the rural household’s address, diverting both power-generation and rent income to the PV company, and then the company would pay rent to the rural household. Their statement that they would “repay loans with monthly electricity income and return extra income to rural households, who would only receive profits with zero investment” was nothing more than an empty slogan. Rural households **became the nominal owners of power stations** and were burdened with responsibilities such as roof renovations, expansions, and protection against theft and damage to PV panels.

Apart from misleading advertising, the enterprise exhibited unprofessional conduct when communicating and signing contracts with rural households, indicating regulation oversight. When the company sold residential PV assets to third parties, it often failed to adequately explain contract terms. Rural households, convinced to “sign with a single click”, struggled to safeguard their legal rights. In 2021, after the company sold nearly 500 MW of residential PV assets, rural households were requested to re-sign contracts with agents through a PV system management app. However, upon comparing the new contracts with verbal assurances, SMS notifications, and the original paper contracts, some rural households discovered significant discrepancies, particularly related to cost-sharing for repairs and lease durations. Agents failed to alert rural households to these contract modifications, and the enterprise argued that there were “no audio or video recordings on-site”, indicating absence of specific supervisory measures.

Solution: Regulatory authorities should establish standardized processes and regulations for the industry, identifying key control points for supervision. Best practices within the industry must be identified and disseminated through industry associations. Enterprises should enhance education and evaluations for their field staff to ensure compliance to legal and regulatory standards at all stages. On the rural households' side, government bodies and enterprises should organize more training sessions centered on rural PV knowledge, with the goal of promoting energy efficiency, reducing carbon emissions, and improving rural households' well-being. These sessions can enhance rural households' understanding of residential PV, their responsibilities, benefits, and risks, thereby reducing disputes with investors and developers in rooftop leasing arrangements.

3.1.2.3 Financial backers (financial institutions or other investors):

Financial backers face challenges in risk management, lack of effective collateral, and low project returns in residential PV financing projects. There is a need for innovative green credit models.

Challenge: When financial backers provide financing and loan services to small and medium-sized PV enterprises, they encounter significant challenges including long project cycles, high risks, difficulties in risk management, and relatively low returns. The typical loan term for PV station projects is five to eight years, and the absence of traditional collateral increases project risks. In the seed stage, there is only capital inflow without outflow. As a result, financial backers often exercise caution due to concerns regarding risks and costs.

Solution: To address the financing difficulties faced by rural residential PV enterprises, it is crucial to utilize national green finance incentives and innovate new financing models for rural residential PV projects. While under the pressure of performance assessments, including green loans and green bonds issued by the People's Bank of China (PBOC), financial institutions and other financial backers are encouraged to proactively utilize national green finance incentives. This includes tools such as the PBOC's carbon reduction support that provide effective financial support subsidies to maximize the economic benefits institutions realize from green finance. To effectively address the financing challenges of small and medium-sized PV enterprises, local banks are encouraged to innovate and develop new green finance products, such as specialized guarantee models for distributed PV project loans and financing methods combining working capital loans with domestic letters of credit. Currently, to address the pain point of insufficient effective collateral for small-scale distributed PV projects, some banks have creatively proposed the use of movable mortgages, pledging electricity fee collection rights, and other unique guarantee methods. They are actively exploring more efficient and market-oriented financial support tools.

Bank of Huzhou's Innovative Residential PV Financial Model

The Bank of Huzhou stands out as the nation's first regional bank to develop a comprehensive ESG strategy and management system to incorporate ESG principles into risk management and credit management.

The Bank of Huzhou focuses on innovation in financial products and financial service optimization as a core approach to promote shared green prosperity. In recent years, the bank has introduced multiple green finance products designed to support both individuals and businesses in their endeavors to construct distributed PV power stations. In 2021, the bank launched the innovative Village Empowerment PV Loans aimed at facilitating the rural transition to low-carbon living, infusing financial support into collective economies and increasing rural households' income. At present, this product has reached 89 village collectives across various districts and counties, including Wuxing, Nanxun, and Deqing, with a cumulative credit amounting to RMB 307 million.

The Village Empowerment PV Loans operates on the principle of "village-wide approval" and "batch operation", creating a lending model that involves the government, banks, village collectives, and enterprises together. The Bank of Huzhou collaborates with government bodies, district- and county-level platform companies, village collectives, and other relevant stakeholders. It brings in "village empowerment" companies controlled by county-level platform companies with economic cooperatives at the village level to be responsible for PV project deployment, management, financing, and other aspects. The Bank of Huzhou extends the Village Empowerment PV Loans to these "village empowerment" companies or village-level economic cooperatives. The source of repayment is the income generated from electricity fees related to PV projects, creating a closed-loop credit system.

The Bank of Huzhou only requires a one-tenth payment in the first phase to leverage a substantial credit limit. This is particularly designed to address the circumstances in which village collectives express the willingness to participate but lack funds, while enterprises harbor concerns due to the lack of security. The bank offers credit equivalent to 90% of the total cost of the PV installation project. The "village empowerment" companies or economic cooperatives need only pay one-tenth of the total cost and can receive credit of up to RMB 10 million over a loan term of up to 10 years. Payments are structured as monthly interest payments, effectively alleviating repayment difficulties.

To facilitate the construction of PV power stations by "village empowerment" companies efficiently and in a standardized manner, the Bank of Huzhou has established a fast-track system for credit approval based on three key elements. First, it has devised a set of clear loan business management guidelines, called the *The Bank of Huzhou 'Green Village PV Loan' Business Management Measures*, which establishes well-defined business standards and processing procedures. By adhering to the village-wide approval and batch operation approach, they have formed a standardized lending model that brings together the government, banks, village collectives, and enterprises. This provides the necessary institutional support for replicating the model throughout the entire city. Second, the bank's leadership dispatches specialized teams to visit villages and support enterprises. These teams visit towns and administrative villages, offering detailed explanations and analyses of the Village Empowerment PV Loan business model to individuals interested in green finance. They also provide long-term follow-up services, enabling residents to engage in frequent communication with financial advisers right in their local communities. Third, the bank has streamlined decision-making processes and reduced approval times. By building close relationships with village empowerment companies and village-level economic cooperatives, the bank gets involved in projects before credit approval and conducts business access identification and credit plan development. This has resulted in loan approvals being completed within a single day, with funds disbursed within three days.

In 2022, the Bank of Huzhou introduced the Green Energy Loan, a specialized product for distributed PV. Its primary purpose is to cover the expenses for enterprises to pay for a complete set of PV power generation equipment. The main source of repayment is the income generated once the project is put into operation. By linking together the entire purchase-construction-production-sales chain through financial elements, this product promotes the seamless operation and stability of the PV industry chain. Additionally, it further propels the positive development of the "sunshine economy." This financial product also offers tangible economic benefits to enterprises and positive social impact. For example, through the Green Energy Loan product, one company received a RMB 2.5 million loan from the Bank of Huzhou to construct a 1.2 MW rooftop solar station that generates 1.3 million kWh of electricity annually. This resulted in economic benefits of RMB 810,000 for the company, while also reducing carbon dioxide emissions by 1,094.75 tons annually. Ultimately, it produced a harmonious blend of economic, social, and environmental benefits.

Moreover, to enhance the management of station operations by financial institutions, the financial institutions can collaborate with PV enterprises or grid enterprises in post-loan management. For example, through the Skyworth app or State Grid's "Electricity E-bao", they can monitor power generation and electricity fee settlement data in a timely manner. This gives the operators a more comprehensive understanding of station performance and aids commercial banks in actively extending loans while enhancing their understanding of PV station operations. Looking forward, by using more finance + technology intelligent functions, financial institutions can achieve a more transparent and traceable post-loan management process.

3.2 Self-financing & self-ownership: Self-generation and self-consumption with surplus grid feeding

3.2.1 Current landscape: A higher ROI for end users, still awaiting popularization in rural China

In the self-financing & self-ownership model, the rooftop owner bears the construction cost of the power station, collects the income generated, and retains ownership of the station. This model is commonly found in areas not covered by "county-wide advancement" policies and is suitable for households that have a certain understanding of PV benefits and desire high income from the project. Private developers engage with rural households through ground promotion, offering them the option to purchase or lease PV equipment (including installation) either on their own or with the aid of financial instruments such as loans.

At present, the self-financing & self-ownership model accounts for only around 20% of the rural residential PV market. The primary factors limiting its adoption include the high initial construction costs of PV systems, which put them beyond the reach of most rural households. Moreover, rural households' understanding of the risks and benefits associated with self-financing & self-ownership of PV systems still has considerable potential for improvement.

Households following the self-financing & self-ownership model have two alternatives for power consumption: "full grid feeding" and "self-generation and self-consumption with surplus grid feeding". A majority of rural households favor the latter. In the self-generation and self-consumption with surplus grid feeding model, the PV grid integration point is located on the load side of the user's electricity meter. It requires the installation of an additional meter for measuring the power fed back into the grid, or modification of the existing electricity meter for bidirectional measurement. The power generated by the station is initially consumed by the station owner. Any surplus power that cannot be utilized by the household is sent back to the national grid and sold at a predetermined feed-in tariff. This model is particularly popular in regions with higher electricity prices. The higher the proportion of self-consumed power (for example, increased daytime power usage) and the higher local electricity prices, the more beneficial this approach is to rural households.

Economic Analysis of Self-Financing & Self-Ownership Model

Let's take Mrs. Zhong from Zhongjiagou Village in Yantai, Shandong, as an example again. An assessment conducted by a PV company reveals that Mrs. Zhong's rooftop has the capacity to accommodate 20 PV panels, totaling 10 kW in capacity. Given the natural conditions of Yantai, there is an estimated annual solar exposure of approximately 1,400 hours, resulting in a total electricity generation of 14,000 kWh.

Revenue under the Self-Financing & Self-Ownership Model

Mrs. Zhong, a financially savvy individual with some capital at her disposal, began considering the possibility of putting up all the funding for her self-owned PV station after she was introduced to the self-financing & self-ownership model by sales representatives. Given her specific rooftop setup, Mrs. Zhong's initial investment in a residential PV system totals RMB 35,000, coupled with an annual operation and maintenance cost of RMB 300.

Mrs. Zhong initially considered adopting **full grid feeding** under the self-financing & self-ownership model. By selling all the electricity generated back to the grid at a feed-in tariff of RMB 0.395/kWh, she stands to gain an annual revenue estimated at RMB 5,530 for 14,000 kW per year. Factoring in a degradation rate of 2% in the first year and subsequent annual degradation rate of 0.7%, the cumulative revenue over the 25-year lifespan of the PV system amounts to RMB 123,872.

Mrs. Zhong also considered the **self-generation and self-consumption with surplus grid feeding** approach. Unlike ordinary rural households who are out working in the fields during the day, Mrs. Zhong is retired and spends most of the day at home, taking care of her grandchildren with her husband. Their electricity consumption during the day is relatively high, with a self-consumption ratio close to 20%, totaling around 2,800 kWh annually. Taking this into account, the PV system leads to significant cost savings in her daytime electricity expenditures, estimated at around RMB 1,624/year based on the residential electricity tariff of RMB 0.58/kWh multiplied by 2,800 kWh/year. The remaining surplus electricity is directed back to the grid, generating revenue of RMB 4,424 annually based on 11,200 kWh at a rate of RMB 0.395/kW. When combining the savings from electricity consumption with the revenue generated from surplus electricity sales, Mrs. Zhong's rooftop PV system yields nearly RMB 6,048 per year, RMB 518 more than the revenue from full grid feeding. When factoring in the degradation rate, the self-generation and self-consumption with surplus grid feeding model is projected to generate an income of RMB 136,822 over the 25-year lease term, surpassing the earnings from the full grid feeding model by an additional RMB 12,950 after factoring in electricity expense savings.

Assuming an initial investment of RMB 35,000 and accounting for operational costs and electricity degradation, the payback period for the full grid feeding model is approximately 7 years, whereas the self-generation and self-consumption with surplus grid feeding model offers a payback period of around 6.4 years. The Internal Rate of Return (IRR) for these models stands at 13% and 15%, respectively (see Figure 3.4).

With a rural commercial bank actively promoting PV Loan products in her village, Mrs. Zhong, realizing that the RMB 35,000 investment for a PV system is quite substantial, also expressed interest in a 10-year PV loan product.

The annual interest rate for this 10-year PV loan is set at 9%. With an initial loan amount of RMB 35,000, the cumulative interest payments over the 10-year loan term amount to RMB 13,388. The total repayment, which includes both principal and interest, is RMB 48,388, with annual repayment of RMB 5,334 per year. Assuming Mrs. Zhong adopts the full grid feeding model and, accounting for the degradation rate, the total revenue over the 25-year lease period is estimated at RMB 75,485. This is nearly 40% less than the revenue generated by the self-financing & self-ownership model. For rural households considering the self-financing & self-ownership model, reputable PV loan products undoubtedly alleviate much of the initial financial pressure. However, the existing PV loan products in the market feature a long repayment period. A decade-long repayment plan puts substantial financial strain on rural households and may potentially have adverse effects on their family living standards. From the perspective of rural households, if community cooperative banks and rural microfinance companies could enter the market and play roles in guiding, educating, and supervising rural households, it would reduce their reliance on a single repayment source. By diversifying their income through multiple streams such as animal husbandry, agriculture, and part-time work, rural households

Figure 3.4 Estimated Benefits of the Self-Financing & Self-Ownership Model

Self-financing & Self-ownership: Rural Household Profit Estimation

Project Costs

End-to-end development cost	3.5	RMB/W
Project scale	10	KW
Initial project investment	**35,000**	**RMB**

O&M Costs

Annual O&M fees	300	**RMB**
O&M fees	0.03	RMB/W
Total O&M fees	**7,500**	**RMB**

Borrowing Costs

Loan principal	35,000	RMB
Loan term	10	Year
Loan interest	**13,388**	**RMB**
Annual interest rate	9%	

- **If the initial project investment is financed through a loan, it will result in interest expenses**. Taking a rural commercial bank's "PV loan" as an example, the interest expense amounts to RMB 13,388.
- Compared to payment in full, borrowing to invest reduces project profits by approximately 16% in the full grid feeding model and 14% in the self-generation and self-consumption with surplus grid feeding model.

① Full grid feeding

Feed-in tariff	0.395	RMB /kWh
Annual generation hours	1,400	h/year
Lifecycle years	25	Year
First year degradation	2%	
Subsequent degradation	0.7%	/Year
Total revenue from electricity generation	138,250	RMB
• Annual revenue from electricity generation	5,530	RMB
Total electricity generation loss	14,378	kWh
Actual revenue from electricity generation	**123,872**	**RMB**
Total project revenue	**123,872**	**RMB**
Total project profit	**81,372**	**RMB**

② Self-generation and self-consumption with surplus grid feeding

Electricity revenue	Self-consumption electricity volume	2,800	kWh/year
	Self-consumption ratio	20%	
	Residential electricity price	0.58	RMB/kWh
	Total electricity revenue	**40,600**	**RMB**
Electricity sale revenue	Grid-connected electricity volume	11,200	kWh/year
	Total revenue from electricity generation	110,600	RMB
	Annual revenue from electricity generation	4,424	RMB
	Total electricity generation loss	14,378	RMB
	Actual revenue from electricity generation	**96,222**	**RMB**
Total project revenue		**136,822**	**RMB**
Total project profit		**94,322**	**RMB**

can alleviate the stress of repayment while simultaneously promoting the generation of income from their own property. This suggests more promising prospects for the self-financing & self-ownership model in residential PV markets.

Under the self-financing & self-ownership model, the role of PV system developers in the leasing model shifts towards that of PV system constructors, primarily providing station installation services. Their income generated aligns with the basic revenue model in the rooftop leasing scenario. Mrs. Zhong was charged RMB 3.5/W for the installation of her 10-kW system, resulting in a total bill of RMB 35,000. At present, developers incur construction costs of RMB 3.2/W[1], which would total RMB 32,000 for a 10-kW project. The profit made by the developer from Mrs. Zhong's household would total RMB 3,000.

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[1] This includes non-technical costs (RMB 0.2 for roads), customer acquisition costs (RMB 0.2), equipment costs (RMB 2.6), and installation costs (RMB 0.2), totaling RMB 3.2 in end-to-end development costs.

3.2.2 Challenges and strategies for stakeholders: Financial institutions and rooftop owners

While the self-financing & self-ownership model has yet to become the prevailing choice for promoting rural PV stations in China, there is potential for this model to align with the international market and gain gradual adoption and popularity in the Chinese market, driven by increased public awareness of PV stations and higher disposable incomes. The self-financing & self-ownership model has brought about changes in the roles of various participants in the value chain, presenting distinctive challenges that warrant exploration.

3.2.2.1 Financial institutions (financial leasing companies): Urgent need for well-structured regulation and assessment mechanisms in the financial market due to chaos in PV loans

Challenge: PV loans, designed as operational loans that allow households to purchase PV station equipment, were intended to relieve the financial burden on residential PV consumers and provide the initial capital required for household to generate more income. However, the chaos in the PV loan market has severely disrupted the orderliness of the PV industry's financial market, and some households are scared away at the mere mention of PV projects. Shell companies posing as PV providers that claim to help rural households secure financing for PV station construction have been selling PV modules at high prices under the guise of PV loans. After loan approval, these companies vanish, leaving rural households trapped in a PV loan scam.

PV Loan Chaos

Mr. Li, a low-income resident in the mountainous region of Nanping City, Fujian, heard a PV salesperson's claims to offer bank loans for installation without interest payments that would give him additional monthly income. Enticed by this offer, he obtained a personal loan of RMB 200,000 and installed a 22-kW PV panel on his rooftop, hoping to generate income through solar power to repay his loan. However, within just six months, this PV loan scam began to unravel. Mr. Li realized that the income generated from monthly electricity production was not enough to cover his interest payments. In the first year, he ended up paying RMB 2,000 out of his own pocket, and in the second year, this increased to RMB 4,000. Beyond loan principal and interest, he also had to pay annual maintenance costs totaling over RMB 1,000. In terms of post-loan management, assurances provided by the sales agent, such as compensation for shortfalls due to weather conditions, ceased to be honored a few months after the deal was concluded. The office of the original PV distributor was now deserted, and the PV module manufacturer claimed no responsibility in this case. In the meantime, the loan principal was intentionally misleading. The PV distributor had progressively inflated prices while utilizing the PV loan scheme to sell PV panels. As a result, Mr. Li paid an extra RMB 70,000 for PV panels compared to the prevailing market rates. This overpayment went straight into the pockets of the PV company. Instead of improving their quality of life through solar power, rural households like Mr. Li found themselves burdened with substantial debt[1].

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[1] IFENG.COM, Farmers Trapped in PV: Why Did Free Sunshine Leave Me in Debt to the Bank for RMB 200,000?, https://finance.ifeng.com/c/8AoIUYAIEJ6

Solution: In light of the disarray in the PV loan market, financial institutions should establish comprehensive evaluation mechanisms for guarantors to scrutinize the qualifications, historical operational performance, insurance coverage, and product quality of PV station developers, as well as the qualifications, partnership with station developers, product marketing materials, and historical operational performance of PV station distributors. Rigorous oversight in these areas will help mitigate associated risks, protect the interests of rural households, and enhance the confidence of rural households in the PV industry. In response to the growing demand for PV loans in recent years, major banks have joined

Longi Sunflower: A One-Stop Solution

On June 23, 2022, LONGi Green Energy Technology Co., Ltd. (LONGi), a leading PV enterprise, officially launched the industry's first one-stop solution for residential PV: Longi Sunflower. Through this initiative, LONGi collaborates with major banks and branded distributors, aiming to create a convenient, efficient, and reliable system. Large banks partnering with LONGi will provide loan services to users purchasing LONGi's PV equipment. LONGi will offer continuous high-quality technical support, module supplies, and security deposits to ensure the model operates seamlessly.

To guarantee the station's safety and reliability, installers providing operation and maintenance services must meet LONGi's rigorous selection criteria. Additionally, LONGi educates rural households about the relationship between loans and PV stations and the concepts involved, ensuring rural households understand that, under the PV loan model, the station belongs to them. LONGi ensures that rural households voluntarily sign contracts that they fully understand, in order to maximize the benefits for rural households.

forces with leading PV companies to introduce PV loan products. These loans, with large PV companies serving as guarantors, enable rural households to access loans, effectively turning residential PV into a "sunshine bank" for rural households.

3.2.2.2 Rooftop owners (rural households): Insurance awareness gap, vulnerability of station assets, and a need for enhanced awareness of risk prevention

Challenge: In the context of the self-financing & self-ownership model, residential PV stations function as personal assets for rural households and the equipment status directly influences the income from electricity generation. Nevertheless, a significant portion of rural households currently lacks awareness of the need for insurance, rendering them susceptible to force majeure events such as natural disasters. This susceptibility exposes their PV station assets to potential losses. Furthermore, inadequate maintenance practices can lead to reduced electricity revenue and increased wear and tear on the station. A study conducted by Hebei Yinneng Technology Co., Ltd., which covered six provinces and cities including Shandong, Shanxi, Henan, Hebei, Beijing, and Tianjin revealed that only 36% of residential PV stations had invested in commercial insurance. Owners generally exhibit a weak understanding of insurance. Inspectors noted, "From the initial desire to install a residential PV system to successful installation and electricity generation, many owners are barely exposed to insurance options and are largely unaware of its significance. However, when issues arise with the station and they face maintenance costs, it's often too late."[1]

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[1] China Energy News, Emerging Residential PV Station Insurance Market, https://guangfu.bjx.com.cn/news/20210414/1147322.shtml

Solution: In the process of ground promotion and subsequent communication with rural households, project developers should introduce the concept of insurance to address the prevailing knowledge gap among rural households. They may even directly cooperate with reputable insurance companies and financial institutions to offer high-quality insurance product choices to rural households. This will help alleviate concerns about station operation, ultimately improving contract success rates. Furthermore, there is a need to encourage insurance companies to create innovative insurance products tailored specifically for rural households who own distributed PV stations, including but not limited to property insurance, third-party liability insurance, and quality assurance insurance. Raising rural households' awareness as regards insurance through

PV Insurance Market Development and Claims

When it comes to PV stations, which are revenue-generating assets that require upfront investment and ongoing maintenance, users are naturally concerned about the associated risks. Consequently, leading insurance companies began to develop relevant products during the early stages of distributed station promotion in China. Notably, in October 2012, Yinda Taihe Property Insurance introduced the first 25-year PV module insurance product. This product ensures that even if the PV module company faces bankruptcy during the contract's validity period, the interests of buyers remain protected. This marked an important step in integrating domestic insurance products into the PV industry and kickstarted the drive towards higher value, enhanced standardization, and regulation within the domestic PV industry. In early June 2014, AnBang Property and Casualty Insurance launched the first insurance product covering operational losses for PV stations in China, becoming a critical means for accessing bank loans to finance distributed PV projects. In the same year, GCL New Energy Holdings signed an agreement with Swiss Re and Alltrust Insurance for a solar radiation power generation index product, pioneering the use of solar radiation indices to secure PV station income in China.

In recent years, as the PV industry has gradually matured, insurance companies have continued to introduce innovative insurance solutions tailored to the PV sector. For instance, in 2023, PICC introduced a multi-level, end-to-end green insurance solution for the PV industry. This comprehensive solution covers various stages including upstream procurement (supply performance guarantee insurance), midstream module sales (long-term quality and power guarantee insurance for PV modules, along with product liability insurance), and downstream station development and construction (performance guarantee insurance for construction projects). In addition to covering situations where assets sustain damage due to natural disasters and external factors, the market now offers insurance types that address insufficient electricity generation. In 2022, China Continent Insurance pioneered compensation insurance for the drop in generated electricity of distributed rooftop PV stations. This insurance provides coverage for factors that affect the efficiency and electricity generation of PV systems, such as insufficient solar radiation, abnormal energy conversion within PV systems, and irregular maintenance. All of this is facilitated through the advantages of IoT technology, enabling remote monitoring and indicator tracking for distributed stations and allowing for proactive intervention by offline maintenance teams when risk factors are anticipated.

In general, the insurance investment for PV stations represents around 0.5% of the total project investment. For example, consider a 10-kW residential PV station. Assuming a project investment of RMB 35,000, the annual premium will typically be about RMB 180. Over 25 years, this results in an additional expenditure of approximately RMB 4,500. While this extends the payback period by roughly two months and reduces the IRR by 0.5%, PV insurance has little impact on the overall ROI and can be instrumental in mitigating financial losses in the case of natural disasters and other events. For instance, in July 2016, Mr. Lu from Yancheng, Jiangsu, spent RMB 50 to insure his 3-kW residential PV station. In September of the same year, one PV panel in the station sustained damage due to an unexpected accident. The insurance company promptly conducted a damage assessment the same week and determined that the panel was not salvageable. Given that the unit price of the panel was RMB 2,200, and the damage occurred after a year of operation, the assessed loss amount was RMB 2,000. The insurance policy included a deductible of RMB 1,000, resulting in a final compensation of RMB 1,000 to Mr. Lu based on (loss amount - salvage value) * insured ratio - deductible = (2,000 - 0) * 100% - 1,000.

comprehensive awareness campaigns will strengthen their overall risk management capabilities. Generally, over the past decade, the domestic PV insurance sector has witnessed the adoption of innovative business models and technological advances, playing a significant role in supporting national energy transition and promoting low-carbon technologies.

Given current business models and electricity system framework, this chapter provides specific, short-term solutions to tackle the challenges faced by rural rooftop PV systems in China (as illustrated in Figure 3.5). However, in the long run, in order to further advance the development of rural residential PV and aid in the realization of China's 30/60 Dual Carbon goals, the residential PV market must undergo a substantial shift from being enterprise-driven to consumer-driven, achieving growth through demand stimulation. Although the self-financing & self-ownership model is more sustainable in comparison to other models, the transition to market-driven household models won't occur overnight due to various factors such as the need for market education, low rural household acceptance, and high consumer spending levels. The ultimate shift towards the self-financing & self-ownership model will still be market-driven. Consequently, all stakeholders need to actively explore novel rural PV ecosystem solutions centered on collaborative development. Furthermore, in its capacity as a responsible rising power, China can collaborate and

Figure 3.5 Challenges and Solutions for Value Chain Participants in Two PV Models in the Near-to-Mid Term

	Stakeholders	Challenges	Solutions
Rooftop leasing – Full grid feeding	**Station developers**	The difficulty in obtaining approval for grid connection and other obstacles constrains the expansion of high-quality projects.	Create innovative rural Residential PV grid connection models such as village-level aggregation grid connection to ease the pressure on grid connection approvals.
		The increasing difficulty in front-end customer expansion drives up conversion costs.	Encourage PV station developers to diversify their customer acquisition channels by combining user segmentation and integrated sales strategies.
		It is becoming increasingly difficult to secure financing for PV station assets and station handover risks are rising.	Actively explore diverse financing methods, including multilateral development banks, multinational companies, and private equity firms, to alleviate financial pressure on project developers.
	Rooftop owners (rural households)	Rural residents can become involved in legal disputes without a comprehensive grasp of the financial benefits and obligations.	In the short term, actively encourage local governments, schools, local enterprises, and other organizations to conduct solar knowledge education for rural households with the goal of achieving energy saving, carbon reduction, and enhancing rural well-being. In the long term, encourage rural households to take ownership of solar projects.
	Financial support providers	There are significant challenges including long project cycles, high risks, difficulties in risk management, and relatively low returns when financial backers provide financing and loan services to small and medium-sized PV enterprises.	Actively explore green credit models, utilize national green finance incentives, and innovate new financing models for rural Residential PV projects to address the financing difficulties faced by rural Residential PV enterprises.
Self-financing & self-ownership – "Self-generation and self-consumption with surplus grid feeding"	**Rooftop owners (rural households)**	A significant portion of rural households currently lacks awareness of the need for insurance, rendering them susceptible to force majeure events such as natural disasters. This exposes their PV station assets to potential losses. Furthermore, inadequate maintenance practices can lead to reduced electricity revenue and increased wear and tear on the station.	Encourage insurance companies to create innovative insurance products tailored specifically for rural households who own distributed PV stations, including property insurance, third-party liability insurance, and quality assurance insurance. Raise the insurance awareness of rural households through educational campaigns to strengthen their risk management capabilities.
	Financial institutions	The chaos in the PV loan market has severely disrupted the orderliness of the PV industry's financial market.	Establish a sound guarantee assessment mechanism, focusing on the qualifications, historical operational performance, insurance coverage, and product quality control of power station developers. Clean up the market environment to eliminate chaos, and safeguard the interests of rural households.

communicate with emerging economies and other developing countries to share their respective experience in residential PV development, thereby promoting global efforts to achieve carbon peaking and carbon neutrality goals. Via an analysis of different commercial models for rural distributed PV in China, several fundamental elements are essential for the sustainable development of the residential PV market:

First, resource endowment. Given the current heavy reliance on fossil fuels, there is a compelling need to transition to renewable energy sources. Additionally, local solar resources are abundant and highly conducive to the development of solar PV operations. Take Uzbekistan for example, where energy consumption currently outstrips energy supply, leading to severe daytime and seasonal energy shortages. It has a strong need for energy. Approximately 90% of Uzbekistan's electricity generation comes from natural gas and coal, with renewable energy sources accounting for a mere 10%. Of this 10%, hydropower accounts for 80%, and solar and wind energy generation are negligible. However, Uzbekistan boasts exceptional sunlight conditions, with potential solar resources totaling four times the sum of its current primary energy consumption. This makes it well-suited for the development of solar PV generation.

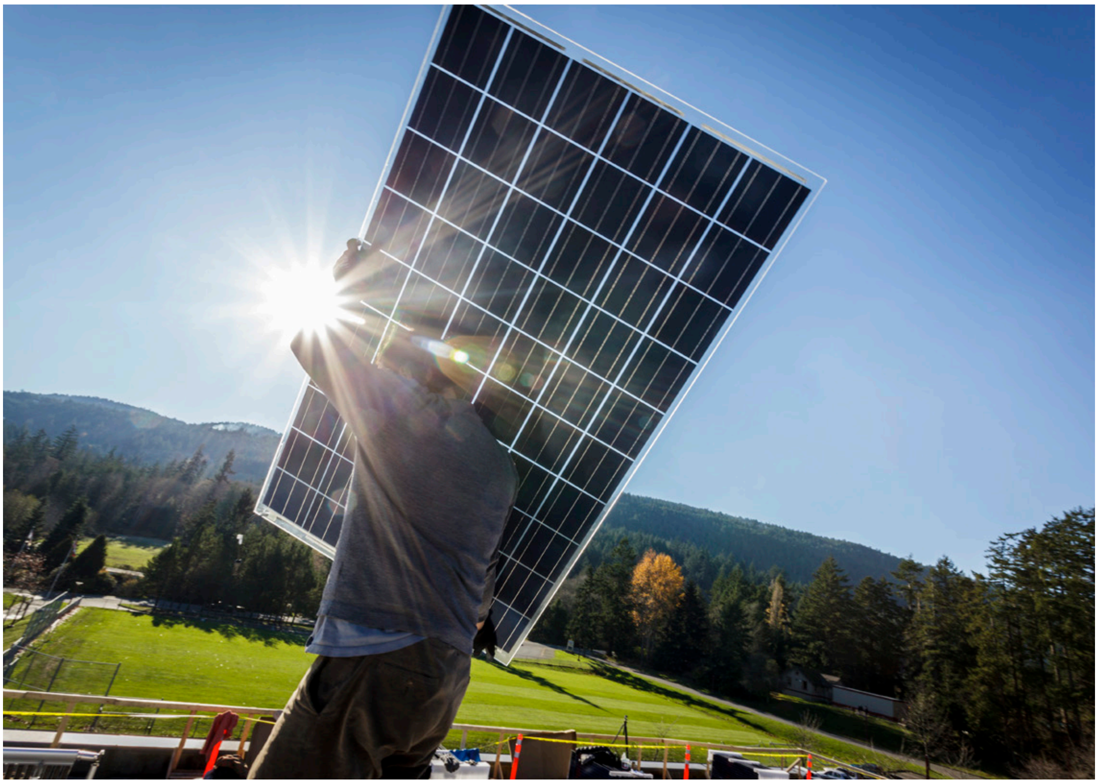
Second, strategic vision. A national-level energy transition strategy should be formulated to provide a clear trajectory for renewable energy development. For example, China has historically relied on coal as its primary energy source, resulting in significant greenhouse gas emissions. However, in 2020, China made a clear commitment to achieve carbon peaking and carbon neutrality. PV, with its low cost, environmental friendliness, and renewable characteristics, aligns with China's national energy strategy and transition goals. Consequently, the PV industry has experienced rapid development. Furthermore, the government should implement a series of specific industry support policies, including financial subsidies, tax incentives, encouragement of grid integration optimization, and green equity mechanisms. It should also initiate regional pilot programs for new models and make timely policy adjustments as needed.

Third, support from scientific research. Encouraging technology transfer and new technology research is essential. One of the key conditions for large-scale PV deployment is the continual reduction of costs. This includes both fostering independent R&D and collaborating with leading production companies. Collaboration with domestic and international research institutions and peer enterprises can drive joint research and production efforts. Facilitating the rapid acquisition of cutting-edge PV technology can also be achieved through support for local operations of advanced foreign companies. China is the leader in PV product research and technological breakthroughs. Countries along the Belt and Road Initiative can actively collaborate with China to drive the green and low-carbon transformation of national energy structures.

Four, economies of scale. Establishing a complete local PV industry chain can further reduce product and electricity generation costs, avoiding the higher costs associated with large-scale purchases of foreign products. Encouraging the development of business models suitable for local conditions ensures the benefits of all parties involved. Common models in global PV markets include station self-ownership or third-party ownership and involve participants such as equipment manufacturers, developers, installers, financial institutions, and users. Due to the unique circumstances in China, large state-owned power companies and local governments play significant roles as well.

Five, credit instruments. Capital infusion and effective financing instruments are indispensable. Capital injection signifies investments to expand production capacity, increased R&D investment, favorable sentiment in capital markets, job creation, and talent attraction. It is imperative to promote domestic investment from individual investors, institutional investors, private equity funds, and mutual funds, while also attracting foreign investors. The initial funding requirements for station ownership require diverse funding methods, offering companies a range of channels for capital acquisition.

Taking inspiration from China's experience, other emerging economies and developing countries can leverage their own resource endowments and capabilities. This can be achieved by shaping policies, technology, industrial layouts, and financial support measures to create a conducive operational environment for sustainable PV market development. These countries can select and pioneer new business models that align with their unique circumstances, while continuously adapting, optimizing, and upgrading them. Furthermore, China can actively contribute as a leader in the fight against climate change, providing support and assistance to less developed countries, African nations, island nations, and neighboring Southeast Asian countries in their efforts to combat climate change, gradually transition toward low-carbon development, and undertake climate adaptation initiatives.

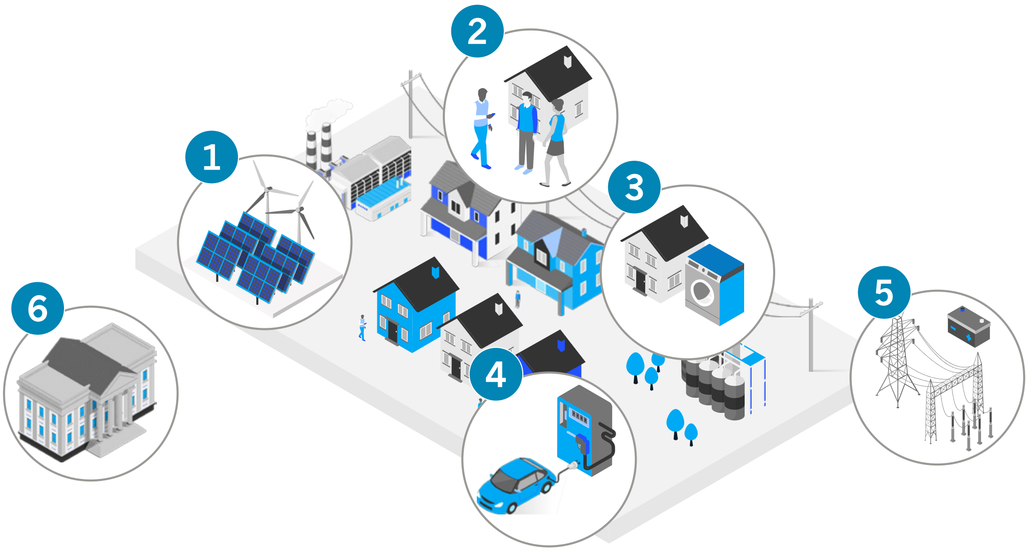


04 Trends and Future Prospects in the Evolution of the New Rural PV Ecosystem in China: An Exploration of Business Models

As we witness the rapid expansion of distributed PV systems in rural China, it has become increasingly evident that existing rural PV systems face certain developmental limitations. Challenges related to PV station efficiency, technical bottlenecks in energy storage, the level of rural electrification, and the economic viability of residential PV installations demand our attention. Furthermore, enhancements are required for supporting systems such as grid infrastructure upgrades and electricity trading platforms. To align with the national Dual Carbon goals and transit from fossil fuel-dependent traditional energy structures to zero-carbon energy systems grounded in renewable sources, it is crucial to overcome the numerous obstacles present in the current rural residential PV market. All this is of the utmost importance for establishing a new electricity system in the medium to long term.

In a broader context, the establishment of a novel rural residential PV ecosystem will be driven by six key factors that represent future trends (see Figure 4.1):

Figure 4.1 Key Drivers of the Future Rural Residential PV Ecosystem



1 Station Construction

Further reduction in PV construction costs: Leveraging technological breakthroughs to continuously improve power generation efficiency and utilizing innovative methods such as the internet to lower customer acquisition costs

2 Ownership Models

Optimize ownership and generation structures based on actual power consumption: Transitioning from the dominant model of rooftop leasing and full grid feeding to a dual approach combining the rooftop leasing and the self-financing & self-ownership models

3 Electricity Consumption

Simultaneously meet rural demand and support surrounding industries: The power consumption capacity in rural areas increases with the progress of electrification, while electricity feeding supports surrounding industries

4 Energy Storage

Gradual improvement and cost reduction of energy storage technology, utilize energy-intensive equipment such as electric farm machinery and electric vehicles as low-cost storage devices to reduce the difficulty of peak shaving and valley filling

5 Grid Regulation and Empowerment Trading

Intelligent regulation of electricity and participation in peak and frequency regulation; successful operation of trading system models: Users can engage in electricity transactions with the grid or other users

6 Supporting System

Improvement of supporting systems, including grid upgrades, adequate energy storage subsidies, increased accessibility of green finance, and a sound electricity market system

4.1 Decreasing PV station construction costs

Despite a temporary increase in module costs attributed to escalating silicon prices in 2021, the reduction in PV generation costs has outpaced the predictions in the 2014 Technology Roadmap for Solar Photovoltaic Energy of the International Energy Agency (IEA) by more than three decades[1]. According to Wood Mackenzie's forecasts, by 2030, the cost of renewable energy generation, especially from large ground-mounted solar power plants, is expected to be 28% cheaper than coal-fired electricity for the entire region. By 2035, the cost of PV electricity is projected to further decrease by approximately 35% to 40% from the existing level[2]. In addition to falling costs, manufacturing processes are continually advancing with improvements such as simplified and more durable mounting installations and easier maintenance. For instance, the PV manufacturer LONGi, has developed a new BIPV rooftop engineered to withstand pressure and eliminated the need for dedicated inspection pathways during construction, resulting in higher space utilization efficiency[3]. The substantial decrease in construction expenses and the growing sophistication of manufacturing technologies will continue to enhance PV station ROI. This will generate greater enthusiasm for investment from a diverse range of stakeholders, including entities involved in electricity investment, PV enterprises, and individual investors.

In addition to the continued decrease in technical costs, innovative business models are expected to further reduce the construction costs of distributed PV stations. The customer acquisition process accounts for a significant portion of the costs in PV station construction. Innovative initiatives utilizing the internet to reduce customer acquisition costs can be seen in the international market. For example, the overseas PV one-stop consumer platform EnergySage[4] allows consumers to simply go to the PV platform website and enter their home address to automatically calculate and display quotes from different EPC installers in their local area. After receiving the quotes, customers can talk with PV consultants online, inquire about different options, and select their preferred PV installation and financing solutions. Once the installer completes installation, the PV station can start generating revenue. Such overseas one-stop internet platform models can typically reduce customer acquisition costs by 20% to 30% compared to traditional offline models. China boasts one of the world's most advanced internet ecosystems, and some PV developers have already used various social media platforms for PV education and promotion. We expect customer expansion models for rural residential PV to undergo sustained transformation by leveraging China's mature internet business environment, with the internet propelling PV stations to reach more households.

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[1] Qingdao Institute of Bioenergy and Bioprocess Technology, Chinese Academy of Sciences, Trends: The Future Cost of Photovoltaic Power Will Drop to About One Cent RMB, http://www.qibebt.cas.cn/xwzx/kydt/202006/t20200618_5608846.html

[2] Wood Mackenzie, A Deep Dive into China's Renewables Landscape, https://www.woodmac.com/our-expertise/focus/Power--Renewables/a-deep-dive-into-chinas-renewables-landscape/

[3] LONGi, Super Rooftop That Can Generate Electricity, https://www.longi.com/cn/products/bipv/roof/

[4] Energysage.com, https://www.energysage.com/solar/

4.2 Gradual improvement in ownership and generation structures

Currently, the promotion of residential PV in rural areas of China primarily relies on rooftop leasing and full grid feeding. This model makes it easier to control risks, and the calculation of investment returns is straightforward and accurate, making it widely favored by investors. However, as rural users become more informed about aspects such as the ROI and safety of PV power plants, more individual users with strong energy consumption need can participate in the "self-financing and self-ownership, self-generation and self-consumption" model of PV station construction.

On one hand, this approach can bring more economic benefits to households that demand high ROI and have the ability to cover construction costs themselves. While further reducing the proportion of traditional fossil energy used and decreasing carbon emissions in rural areas, the profits from PV power generation will be reinvested into rural development, effectively improving the economic status and living conditions of rural users. On the other hand, PV power plants will gain better publicity due to users seeing more tangible benefits. This broader participation in the implementation of the Dual Carbon goals diversifies the stakeholders, mitigating the risks associated with large-scale asset holdings by state-owned investment companies and other participants.

4.3 Enhanced electricity consumption capacity

With the extensive grid-integration of distributed new energy sources, including PV, rural distribution systems are evolving from radial passive networks into active networks with numerous distributed power sources. This shift poses new challenges to local grids in areas with limited electricity demand. Future solutions involve nurturing local electricity markets and integrating industrial economic development with energy planning. While enhancing local consumption and reducing the pressure on rural grids, these strategies will also significantly improve the living standards of households and stimulate economic development in rural areas.

Promoting rural electrification is a crucial step in fostering rural markets. In China's rural areas, overall electricity consumption is low, with cooking and heating being the most energy-intensive activities. Driven by large-scale coal-to-electricity and coal-to-gas initiatives, a household survey of rural residents' energy consumption structures conducted by Peking University revealed a remarkable trend. Rural electrification rates (average usage percentage) for cooking surged from below 10% to nearly 80% between 1992 and 2020, while electrification rates for heating increased from below 5% to nearly 70%. In six provinces, these rates even exceed 80%[5]. While the level of electrification in rural residents' activities has significantly improved, there is still some way to go to achieve the clean energy usage goals required as part of the Dual Carbon goals. The development of PV power generation complements the increasing level of rural electrification, creating a mutually beneficial relationship: clean, affordable energy significantly alleviates households' financial burden from consuming large amounts of electricity (such as for heating). This not only promotes electricity consumption but also reduces the challenge of integrating distributed PV into the grid. Take Chaohu Village in Shizuishan City, Ningxia Province, as an example. There, the "PV + Clean Heating" initiative has significantly improved local residents' heating conditions and living environment. Before the coal-to-electricity initiative, heating using traditional stoves required midnight refueling, causing air pollution and inconvenience. Starting from December 2021, with robust support from the local district and village governments and local new energy companies, residents began installing distributed PV power stations. Simultaneously, they replaced traditional stoves with heat pumps that captured heat from the air. These PV power stations not only support heating by air-source heat pumps but also allow residents to sell excess electricity to the state grid, generating additional income. This initiative received widespread acclaim from the villagers. As activities such as cooking and heating transition from coal to electricity to a certain extent, there is substantial potential to further electrify production activities, such as agricultural machinery and transportation tools, taking rural electrification to new heights. Utilizing electric vehicles and tools to consume rural new energy while selling surplus electricity to the grid can become a new source of economic income for rural areas.

For regions with limited consumption capacity due to their low production activities, developers of PV stations can consider local industrial attributes when selecting sites for building distributed PV power stations. In the future, this can also provide an incentive to guide the development of electricity-consuming industries in villages and towns. For instance, Chongho Bridge, as a rural distributed PV investor, chose Dashiqiao City in Liaoning due to its extensive local network and the presence of magnesite mines when entering into the PV sector. With an annual regional electricity consumption exceeding 6 billion kWh, Dashiqiao City has the ideal conditions to allow PV projects to interact favorably with the local integrated source-grid-load-storage system. This initiative reduces Dashiqiao City's annual standard coal consumption by nearly 50,000 tons[6].

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[5] China Dialogue, What's Next for Clean Heating in Rural China?, https://chinadialogue.net/en/energy/what-next-for-clean-heating-in-rural-china/

[6] Chongho Bridge, Sunshine on the Road to Common Prosperity, https://www.chongho.net/dynamic-newsDetail.html?id=644

Areas lacking minerals or production-based industries can introduce supporting industries such as automated farming, processing, agrotourism, and rural tourism under the general directive of Rural Revitalization, synchronizing rural industries with rural living conditions and facilitating modernization.

4.4 Gradual advancements in energy storage technologies and their economic viability

Energy storage, as a crucial tool for flexible control, goes hand in hand with the development of PV energy and offers an important solution to the current grid integration challenges facing the PV sector. With renewable energy, especially PV, continuing its rapid growth, the power system faces challenges such as energy supply-demand imbalances, changing traditional models, and reduced system inertia. Energy storage allows generated electricity to be stored and used when needed, allowing the system to smooth out day-to-day variations (such as generation during the day and usage at night), multi-day variations (such as generating solar power on sunny days and using stored power on rainy days), and even multi-month variations (such as generating solar power in summer and using stored power in winter). This reduces instances when solar energy generation is curtailed, enhances self-sufficiency, and ensures the reliability and continuity of the power supply. When renewable energy generation exceeds 50%, the demand for electricity flexibility significantly rises, making energy storage an indispensable part of the PV industry's development.

Currently, energy storage applications in residential PV have been piloted in some regions. For example, in Xiangyun Town, Nan'an City, Fujian Province, more than 90% of the area's electricity comes from green energy sources. To address issues arising from high proportions of distributed PV users connecting to the grid, such as bidirectional voltage limits, voltage fluctuations, flickers, harmonics that exceed standards, and three-phase imbalances, the power supply bureau of Nan'an City selected four substations in Xiangyun Town as pilot locations. They equipped these substations with energy storage sub-systems to achieve 100% local consumption of generated electricity and solve short-term supply issues for crucial loads[7].

However, economic viability remains one of the bottlenecks hindering the widespread adoption of residential energy storage. Globally, the payback period for residential PV station is delayed by energy storage system by 2-6 years. In China, due to low residential electricity prices, the economic advantage of residential PV energy storage is particularly limited. In the current U.S. market, where the adoption of PV energy storage is relatively high, the overall payback period for solar and storage projects is approximately 5 to 10 years. Such economic viability is attributed to the U.S. Federal Investment Tax Credit (ITC) policy, the mature electricity market trading system, and high electricity prices. According to estimates, 70% of the investment costs for energy storage systems in the U.S. is equipment expenses[8], and the ITC policy subsidies cover 22% to 26% of the equipment costs[9]. Moreover, users can save on electricity

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[7] China County Times, The First Microgrid New Power System Demonstration Project in Fujian Has Been Completed and Put into Operation, https://www.xyshjj.cn/detail-1482-72905.html

[8] International Energy Agency, World Energy Investment 2022, https://www.iea.org/reports/world-energy-investment-2022/overview-and-key-findings

[9] The United States Department of Energy, Solar Investment Tax Credit: What Changed?, https://www.energy.gov/eere/solar/articles/solar-investment-tax-credit-what-changed

costs through peak shaving as well as self-generation and self-consumption methods. In comparison, the payback period for residential PV energy storage in the current Chinese market can be delayed by 6 years, dissuading many investors in the residential PV industry. Consequently, energy storage technology applications in this phase are more common in the commercial and industrial PV sectors, especially where electricity prices are higher, peak-valley price differences are substantial, and self-consumption rates are high. If things work out well, the continuous reduction in the costs of PV and energy storage equipment will further enhance the economic viability of installing PV and storage systems. If we take the U.S. as an example, the current cost of a residential energy storage system is $684 per kWh, while the hardware and installation costs for residential PV systems are $2,930 per kWh. If the cost of energy storage decreases by 30% or the cost of the PV system drops by 20%, or if both costs decrease by 10%, the IRR for home PV and storage systems would increase from around 5% to 10%, a significant improvement in economic incentives[10].

The evolution of energy storage systems has propelled the development of novel business models abroad. The renowned German energy company Sonnen pioneered the concept of "community energy storage" with successful pilot projects in Germany[11]. In this model, a community central energy bank is established within a specific area, where bank members can store and purchase energy as needed. Each household in the community is equipped with residential PV systems and energy storage devices, connected to the central energy system. This setup allows surplus electricity generated from individual PV stations to be transmitted to the central energy storage system. Conversely, when electricity is required or prices are low, power can be drawn from the central energy storage system. Thus, community members act as both consumers and producers of electricity within the grid system. This approach ensures a stable and affordable electricity supply while enabling the community to internally consume the majority of the power it generates, with excess electricity sold back to the grid. Participants in the grid receive discounted electricity rates, while Sonnen generates revenue within the community through three streams: management fees for the "central battery bank", selling residential energy storage battery equipment to households, and revenue from surplus electricity sold to the grid.

In China, residential electricity is an integral part of people's livelihoods, priced comparatively lower than international markets and commercial-industrial electricity rates. The likelihood of short-term price hikes is minimal, and the grid has strong resilience, experiencing fewer large-scale power outages during extreme weather conditions. However, in economically developed regions with substantial peak-to-valley price electricity demand differentials, peak-to-valley pricing and tiered electricity rates are gradually being introduced. When the absolute value of these price differentials can cover the cost of one battery charge and discharge cycle

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[10] Orient Securities, The U.S. Energy Storage Market: Policy-Driven, Mature Business Models, https://pdf.dfcfw.com/pdf/H3_AP202109101515424831_1.pdf?1631305102000.pdf

[11] NEWCOMERS, Summary Case Study Report – The sonnenCommunity, https://www.newcomersh2020.eu/upload/files/NEWCOMERS_Summary-Case-study-report_sonnenCommunity.pdf

(currently around RMB 0.6 to 0.9/kWh[12]), residents are more inclined to invest in energy storage devices. There is also room for further reduction in energy storage equipment costs. Over the past decade, the average annual decline in energy storage costs in the Chinese market has been 10% to 15%. During this period, energy storage technology costs decreased by approximately 80%, and battery lifespans have steadily increased[13]. It is anticipated that, by 2025, prices could decrease by another 50% from their 2020 levels. Moreover, innovative and cost-effective energy storage solutions are emerging, such as bi-directional charge-discharge electric agricultural machinery. As energy storage technology continues to advance and mechanisms to steer energy storage costs are established at various levels, energy storage will continue to drive the PV industry's growth in the future. The period between 2030 and 2050 may represent the era of lowest "PV + energy storage" costs. This trend bodes well for rural residential PV installations, as the "PV + energy storage" model enables self-sufficiency, self-ownership, self-generation, and self-consumption. As energy storage technology advances and the economic viability of the Chinese energy storage market significantly improves, it will inevitably spawn new business models, benefiting a broader range of stakeholders.

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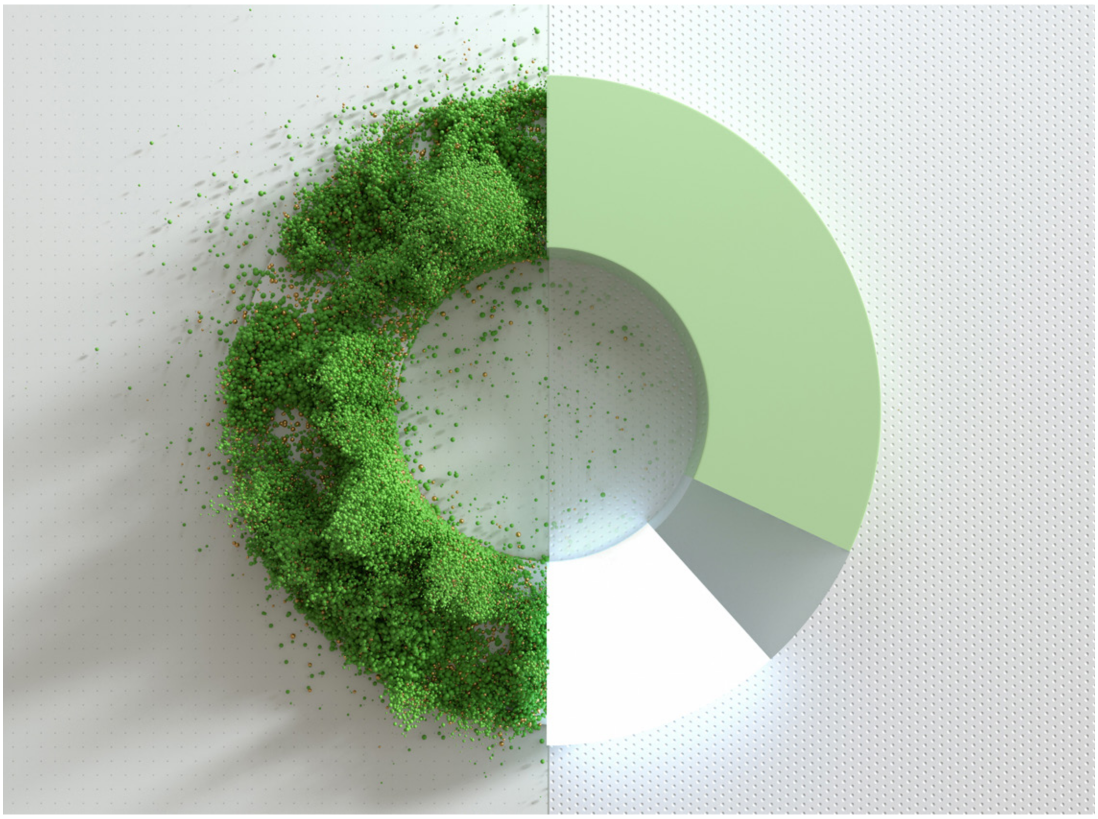
[12] Advanced Technology of Electrical Engineering and Energy (Special Issue on Energy Storage Applications), Analysis of the Cost of Energy Storage and Mileage Cost, http://www.360doc.com/content/19/1018/23/39233137_867716613.shtml

[13] New Energy Network, At What Level Does the Cost of Energy Storage Become Economical?, http://www.china-nengyuan.com/baike/6287.html



4.5 The grid: Assuming more roles and responsibilities

Under the current grid integration model, rural PV users can sell all the electricity generated by their PV stations or only the surplus to the grid, generating a certain income. However, the increase in the proportion of grid-integrated PV power poses new challenges for grid consumption and power dispatching. To address this, some local grids have adopted emerging technologies, including virtual power plants, which aggregate generation and storage resources, and optimize and coordinate electricity through unified dispatch. This approach not only assists power generation companies in reducing unnecessary generation costs and earning service fees on the supply side but also allows participation in spot electricity trading and auxiliary services on the demand side, so they can optimize bilateral transactions and earn a share from the transactions[14].

In a future of diversified renewable energy sources, the grid can optimize electricity costs, enhance power stability, assist in peak shaving and valley filling, and achieve local energy consumption by intelligently coordinating various on-site distributed generation assets. In March 2023, the National Development and Reform Commission and the National Energy Administration issued guiding opinions to promote “source-grid-load-storage” integration. The document emphasized the grid’s role in control and encouraged the grid to further enhance multi-directional interactions among source, grid, load, and storage by leveraging technologies such as the IoT. Through integrated aggregation models like virtual power plants, the grid can provide controlling support for the power system. Specifically, this involves reducing the intensity of thermal power generation during the peak period of PV power generation and directing surplus electricity to storage systems when supply exceeds demand.

Currently, most of China’s pilot virtual power plants are associated with industrial and commercial projects. For instance, Shenzhen’s virtual power plant, officially launched in August 2022, had over 40 entities engaged by December 2022. It established the first Chinese cloud platform integrating grid and land resources, enabling rapid load reduction in response to grid control demands and participating in Guangdong’s electricity spot market for peak and off-peak arbitrage[15]. In contrast, rural areas in China have limited electricity demand, with scattered and small-scale power stations that are yet to reach grid-scale operations, making them unsuitable test sites for grid control technologies. However, the U.S. has pioneered breakthroughs in commercial electricity control models. Tesla, for example, is actively transforming its network of energy storage users in California into a vast distributed virtual power plant[16]. Tesla’s residential battery storage product, Powerwall, is sold as an accessory to home solar systems. To enhance California’s energy cleanliness and reliability, Powerwall users voluntarily join Tesla and the grid in their virtual power plant project. During periods of increased grid demand and insufficient power supply resulting from situations such as extreme heat in California, Tesla’s

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[14] Power.IN-EN, Understanding What a Virtual Power Plant Is From Nine Cases, https://power.in-en.com/html/power-2399696.shtml

[15] Sinolink Securities, Research on Power Equipment and New Energy Industries, https://pdf.dfcfw.com/pdf/H301_AP202306301591917219_1.pdf

[16] Wallstreet CN, Tesla’s Ambitions for a Virtual Power Plant, https://wallstreetcn.com/articles/3668547

virtual power plant leverages the energy stored in Powerwall units to support grid operations. For each dispatch, users receive a reward of $2 per kWh, giving them a financial incentive. Additionally, Powerwall users can set a “minimum reserve power level” to retain a backup power supply, with Tesla ensuring that the battery level does not fall below this designated level. For users, selling excess electricity during peak demand periods yields additional income. For the grid, this approach potentially saves on generating costs during peak demand periods, as the cost of generating electricity during peak times is often higher than purchasing power from users. Simultaneously, Tesla’s active participation significantly boosts Powerwall sales. All stakeholders’ profitability is ensured by this innovative business model.

In addition to grid management, another crucial aspect of the future rural PV ecosystem is electricity trading. As we move from the current style of grid transactions to a future of market-oriented peer-to-peer trading, the further refinement of market mechanisms will guide users to significantly enhance the local and nearby consumption of PV power, which will reduce power losses and enhance the efficiency of both generation and consumption.

A more intuitive form of electricity trading could occur directly between users. For example, there are likely to be disparities in electricity usage within the same village as some rural households might have additional demands for activities such as livestock farming, cold chain logistics, or automated irrigation. These users can directly purchase surplus PV electricity from fellow villagers, rather than sourcing it from the grid. This localized, direct exchange of surplus electricity, often referred to as neighborhood electricity trading, typically involves electricity prices situated between grid prices and residential rates, benefiting both buyers and sellers. However, due to the involvement of multiple parties and the lack of a mature trading model, the applications of neighborhood electricity trading remain limited to specific pilot projects. The widespread adoption of this approach would not only require policy guidance but also the establishment of a fair and rational profit-sharing system. Grid enterprises, for instance, will bear additional costs from upgrading the grid, electricity metering, and operating trading platforms on top of the basic grid use fees. Finding a way to compensate the enterprises for these costs is crucial to encouraging the active participation of grid companies. A significant milestone in this direction was the successful grid integration of the 5 MW distributed generation market trading pilot project in Zhenglu Industrial Park, Changzhou, Jiangsu Province, in early 2022. This success gave a powerful boost to the promotion of neighborhood electricity trading[17]. In the future, as trading mechanisms continue to evolve, neighborhood electricity trading will undoubtedly propel the development of the PV industry, ushering it into a new era of growth.

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[17] China Development, The First National Market-Oriented Trading Pilot Project for Distributed Power Generation Has Been Completed and Put into Operation, https://m.bjx.com.cn/mnews/20210105/1127318.shtml

4.6 Increasingly sophisticated supporting systems

The establishment of a rural new-energy PV ecosystem relies heavily on robust supporting frameworks. In both 2021 and 2022, the Central Document No. 1 emphasized the need to intensify efforts in rural electricity grid construction. In February 2022, the National Development and Reform Commission (NDRC) outlined the two priorities for rural PV development, explicitly prioritizing support for integrating residential PV into the grid and paving the way for the upgrade and transformation of rural grids. Regarding energy storage development, various local governments, including Wenzhou, Suzhou, and Shaanxi, introduced subsidies for PV energy storage, buying time for the reduction of energy storage technology costs. Participants such as PV enterprises and local banks engaged in green low-carbon financial products. Exemplary products like LONGi Sunflower and the Bank of Huzhou's PV Loan have set benchmarks for the market, optimizing market conditions and bringing order to chaos. Meanwhile, with the establishment of the national-level electricity trading market, the roll-out of electricity reforms has come more clearly into focus. These initiatives have laid a crucial foundation for the sustainable development of rural PV businesses, so that the establishment of a rural new-energy PV ecosystem is no longer a distant prospect.

In summary, factors such as the efficiency of PV power plants, advancements in energy storage technologies, improvements in rural electrification and consumption levels, residential PV integration through grid upgrades, and the development of electricity trading platforms are all pivotal factors that can potentially influence the future costs and income potential associated with rural residential PV power generation (see Figure 4.2). These elements are critically important for constructing a new energy system.

Figure 4.2 Key Factors Affecting Costs and Revenue of Rural Residential PV Power Generation

EXAMPLES, NOT EXHAUSTIVE

Factors Affecting Rural Residential PV Power Generation Costs/Revenue

Factors leading to cost increases/revenue decreases	Factors promoting cost reductions/revenue increases
① **Rise in raw material prices**, primarily silicon, causing an increase in component costs	① **Technological innovation**, continuous improvement in the power generation efficiency of PV modules, advancements in station construction technology, breakthroughs in energy storage technology, and improved grid technology
② **Increase in labor costs,** potential future increases in labor costs related to installation and O&M	② **Increased digitization and intelligence**, driving process improvements, helping enhance efficiency, and reducing some costs
③ **Additional investment in storage and transformation,** additional costs generated by investment in storage equipment	③ **Government subsidies**, such as subsidies for PV station construction and energy storage
④ **Additional AC-DC transformation investment,** additional costs of transforming AC electricity to DC	④ **Income from green equity**, additional revenue from the trading of green energy equity
⑤ **Additional distribution network investment and transformation,** more investment needed for ongoing upgrades as electrification progresses	⑤ **Rural grid upgrades**, prioritizing support for Residential PV grid connection, increasing PV power generation and consumption
⑥ **Decrease in feed-in tariffs/sales prices,** gradual reduction in grid electricity prices or sales prices leading to reduced power generation revenue	⑥ **Development of green finance**, including the widespread adoption of PV loans and the improvement of product access standards and risk control systems, reducing investment and construction costs

05

PEDF Technology: A Potential Solution for Building a New Power System

In order to establish a new rural PV ecosystem, the six pillars mentioned above have gradually entered the stage of practical implementation. During this transition, various regions are experimenting with promising approaches involving comprehensive solutions. Among them, PEDF technology, as a new zero-carbon electricity solution, actively explores the "self-owned power station + electrification consumption + energy storage" model. This model effectively promotes the integration of electricity production, consumption, and storage, and is expected to become a brand-new technological path for addressing the difficulties in electricity generation, grid integration, and consumption in rural areas.

PEDF technology has four main features: PV power generation, distributed energy storage, direct current distribution, and flexible electricity usage. Through the overlapping and integrated use of multiple technologies, the traditional "source following the load" model that requires a high degree of coordination on the part of the grid is transforming into a grid-friendly "load following the source" approach. This change effectively consumes PV energy, achieving energy-efficient and low-carbon power system operations. Currently, PEDF technology is primarily applied in building scenarios, with initial estimates indicating a potential carbon reduction of approximately 25% in building operations[1].

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[1] Shenzhen Securities Times, The Ministry of Housing and Urban-Rural Development Has Approved Project Establishment and Will Provide a Representative Sample by the End of 2023; Companies Respond to the Layout, https://news.stcn.com/sd/202208/t20220821_4810894.html

PEDF technology demonstrates enormous potential in increasing the on-site consumption ratio of PV electricity, effectively alleviating the pressure to expand capacity on urban and rural power grids, enhancing the reliability of power supply, improving rural electrification levels, and reducing pollution and carbon emissions. Additionally, the technology offers solutions to issues such as insufficient electricity generation resources, unfair distribution of electricity generation profits, and imbalanced electricity usage in rural areas in China. It will play a crucial role in achieving comprehensive rural electrification. With economic development and the improvement of living standards, electricity loads from electricity demands of buildings and electric vehicles continue to grow, leading to continuous pressure for grid integration. According to calculations by the Shenzhen Power Grid, assuming the recent growth rate continues, Shenzhen's peak electricity demand from buildings will reach 25 million kW by the end of the 14th Five-Year Plan period[2]. New building power systems based on PEDF technology can reduce the peak electricity demand of buildings by 50%, lowering grid investment costs by RMB 5-6 billion[3]. Additionally, by increasing distributed power sources on the user-end and utilizing the advantages of simple direct current microgrid access and flexible bidirectional converter technology, such systems can effectively enhance electricity reliability by allowing users to sell more and buy less from the grid. Moreover, PEDF systems can help reduce the investment required for upgrading rural power grids and projects such as coal-to-electricity and coal-to-gas heating. When combined with incentive policies such as peak-valley electricity pricing, demand response, and green electricity certification, it can effectively reduce users' usage costs of energy.

As a part of new building power system, PEDF projects have been mentioned in various policy documents. In October 2021, the State Council issued a Notice on the Action Plan for Peak Carbon Emissions by 2030, which clearly stated that urban and rural buildings should "increase the level of building electrification and construct integrated PEDF buildings incorporating PV power generation, energy storage, direct current distribution, and flexible electricity usage". In March 2022, the Ministry of Housing and Urban-Rural Development issued the *14th Five-Year Plan for Housing and Urban-Rural Technological Development*, which proposed "the development of efficient and intelligent integration of PV buildings, the construction of PEDF new building power systems, and research and application of building-city-grid energy interaction technology". In August 2022, nine government departments, including the Ministry of Science and Technology, jointly issued the *Implementation Plan for Technological Support for Carbon Emissions Peaking and Carbon Neutrality (2022-2030)*, which called for research on key equipment and flexible technologies for power supply and distribution in the PEDF model, BIPV technology systems, and source-grid-load-storage technologies and equipment for region–building energy systems.

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[2] Carbon Neutrality Public Welfare, Carbon Neutrality Popular Science: What Is Photovoltaic-Energy Storage-Direct Current-Flexibility in the Carbon Neutrality Action Plan?, http://www.sepf.org.cn/article/hezuo/24288.html

[3] Carbon Neutrality Public Welfare, Carbon Neutrality Popular Science: What Is Photovoltaic-Energy Storage-Direct Current-Flexibility in the Carbon Neutrality Action Plan?, http://www.sepf.org.cn/article/hezuo/24288.html

5.1 Pilot case: Zhuangshang Village, Ruicheng County, Shanxi Province

Since the implementation of the PEDF technology in rural areas of China, pilot projects have been initiated. On December 31, 2021, the 2 MW rural PEDF system in Zhuangshang Village, funded by State Power Investment Corporation (SPIC), was officially integrated to the grid[4], marking the first commercialized rural PEDF system in the world. This is the largest county-level PEDF pilot project in China and serves as a valuable experiment for implementing the integrated PEDF model across entire rural counties.

In the first phase of the project in Zhuangshang Village, plans were made to transform the direct current power distribution system for 70 households, and then expand to cover 200 households in the third phase. Utilizing rural building facilities and rooftops, Zhuangshang Village deployed distributed PV systems and optimized its energy storage configurations. For households, the project enabled the safe, efficient, and flexible integration of residential PV, energy storage, direct current home appliances, electric vehicles, and other devices through independently developed technologies such as leakage protection, active arc extinguishing, and communication-free adaptive control. This initiative also facilitated the operation of subsidiary equipment such as building lighting, production equipment, and heating systems, achieving localized distributed PV consumption and providing a clean energy solution for rural areas. Within the confined area, the local power grid was transformed into a direct current microgrid, with each rural household connected to the microgrid through energy routers. The interconnected rural households, streetlights, centralized energy storage, centralized wind and PV power plants, and higher-level power grids are able to interact seamlessly, promoting the full utilization of renewable energy and implementing peak shaving and valley filling strategies for electrical loads. This approach addresses issues related to rural grid capacity expansion and load balancing.

An assessment of the PEDF project in Zhuangshang Village has shown it to be economically viable (see Figure 5.1). In the first phase, 71 households participated, and a total of 5,000 PV panels were installed, each with a power rating of 400 W. Calculated based on an annual sunlight exposure of 1,200 hours in Shanxi, Zhuangshang Village's annual electricity generation can reach 2.4 million kWh. Of this total, 8% is both generated and consumed by residents, totaling 190,000 kWh. The total project construction cost is RMB 9 million, with an additional one-time local administrative expenditure of RMB 150,000. Currently, the project provides 1,200 kWh of free electricity per household annually, totaling 85,200 kWh. The remaining on-site consumption is supplied to households at a discounted electricity price of RMB 0.45 per kWh, lower than the local residential electricity rate of RMB 0.477 per kWh. Over the 25-year lifespan of the power station, the PEDF project generates economic benefits for both investors and residents. Investors receive 92% of the total electricity generation income from grid sales, exceeding RMB 650,000 annually after accounting for attenuation. Simultaneously, residents' income from electricity sales can reach approximately RMB 48,100 annually. Additionally, reductions in carbon emissions from PV

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[4] CHUNENG.BJX.COM.CN, 2MW Rural Photovoltaic-Energy Storage-Direct Current-Flexibility System in Zhuangshang Village, Ruicheng County Officially Connected to the Grid, https://news.bjx.com.cn/html/20220110/1198314.shtml

Figure 5.1 Basic Information from the Zhuangshang Village PEDF Project

Basic Information from the Zhuangshang Village PEDF Project

Number of PV panels	5,000	Self-generation and self-consumption ratio	8%	Feed-in price (RMB/kWh)	0.332
PV module power (W)	400	Residential consumption of electricity	192,000	Gifted electricity per household (kWh)	1,200
Annual generation hours	1,200	Number of household	71	Total gifted electricity amount (kWh)	85,200
Annual electricity generation (kWh)	2,400,000	Project lifecycle (year)	25	Electricity bought by household (kWh)	106,800
Carbon emissions coefficient (kg/kWh)	0.977	First-year degradation rate (%/year)	2	Household preferential electricity price (RMB/kWh)	0.45
Carbon trading price (RMB/ton)	50	Second-year degradation rate (%/year)	0.7	Local residential electricity price (RMB/kWh)	0.477

Cost Items

One-time project costs	**Total project costs (in RMB 10,000)**	**899.85**
	Village-wide customer acquisition cost (in RMB 10,000)	5
	Village-wide service fee cost (in RMB 10,000)	5
	Comprehensive government service fee (in RMB 10,000)	5
Annual fixed expenses	Insurance (in RMB 10,000)	1.4
	Rooftop rent (RMB/panel)	20
	Total Rooftop Rent Expenses (in RMB 10,000)	10
	O&M fees (RMB)	20
	Total O&M costs (in RMB 10,000)	10
	Total (in RMB 10,000)	**21.4**

Revenue Items

Average annual revenue for developers	Revenue from residential electricity sales (RMB 10,000/year)	4.81
	Revenue from surplus grid feeding (RMB 10,000/year)	65.02
	Carbon trading revenue (RMB 10,000/year)	10.02
	Revenue from grid regulation (RMB 10,000/year)	0
	Total (RMB 10,000/year)	**79.85**
Residents	Rent revenue (RMB/household/year)	1,408.45
	Electricity cost savings (RMB/year)	613.01
	25-year total revenue	**50,536**
Village collectives/ governments	**One-time revenue (in RMB 10,000)**	**15**

Key Data

Per-watt construction cost (RMB/W)	4.6 (Mainly includes PV hardware costs, installation costs, energy storage costs, grid and direct current costs)	**Total revenue during the project period (in RMB 10,000)**	1,996.2	**Net present value of the project (in RMB 10,000)**	18.4

power generation can be traded at a rate of 0.977 kg/kWh, with a price of RMB 50 per ton. Developers can earn an annual income of RMB 100,000 from carbon trading, averaging around RMB 800,000 per year. Each household will receive around RMB 1,400 in income per household and benefit from over RMB 600 in reduced electricity costs annually, so their total annual benefit will exceed RMB 2,000. Without the need for additional investment, this represents a significant additional income for local rural households.

Due to the initial investments in hardware facilities and renovations for the PEDF project, including energy storage, direct current microgrids, direct current household appliances, and other investments, the construction cost per watt was RMB 4.6 approximately 30% higher than typical residential PV station construction costs of about RMB 3.2 per watt. Consequently, the overall project payback period is longer, currently nearing 15 years, twice as long as regular projects. Nevertheless, the implementation of the rural PEDF system reduces the investment in rural grid upgrade and transformation expenses associated with heating projects such as coal-to-electricity or coal-to-gas. With ongoing technological advancements, construction costs are expected to further decrease, so the economic viability of PEDF is likely to improve once again. After a pilot phase involving71 households in Zhuangshang Village, the next step involves implementing this project across the entire village. Upon its completion, the project is expected to reduce carbon dioxide emissions by approximately 2,500 tons per year, equivalent to planting 3.08 million acres of trees[5].

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[5] Nanjing Golden Cooperate DC Power Distribution Technology. Co., Ltd., Technical Scheme and Business Model Research for Rural Photovoltaic-Energy Storage-Direct Current-Flexibility System Demonstration Project.

5.2 The PEDF business model is still immature, and the promotion of rural applications will take time

Despite preliminary explorations of PEDF in various regions across the country, this technology is still in the experimental stage. Its business model has yet to mature, and challenges must be overcome to expand its applications.

First, given the current policy incentive environment and business model, the ROI for PEDF technology is relatively low. Compared to traditional residential PV systems, the PEDF technology requires equipment such as flexible bidirectional converters and energy coordinators, increasing costs by approximately 30%. Considering the impact of cross-subsidy policies on electricity prices, household electricity prices are relatively low. Therefore, investors' payback period is currently twice as long as traditional residential PV systems. Second, the end-use electrical equipment does not align with the direct current used in PEDF. At present, end-use electrical equipment, such as household appliances, is primarily designed for alternating currents. End-use devices compatible with the direct current usage in PEDF technology must be custom made. A large-scale production and sales market for these devices has not yet formed, affecting end-user usability.

Furthermore, based on the current status of pilot projects, the PEDF technology exhibits some distinct characteristics: it is relatively easy to apply in commercial buildings and industrial parks, but its commercial application in rural areas is comparatively complex. Commercial buildings and industrial parks can accommodate the construction of larger-scale microgrid systems, benefiting from economies of scale. In these settings, energy consumption primarily revolves around street lighting, electric vehicle charging stations, and building electricity, resulting in a high level of consumption. Given that commercial electricity prices are higher than residential electricity prices, there is substantial commercial potential in commercial buildings and industrial parks. In addition, the widespread implementation of PEDF technology in rural areas requires considering factors such as the level of rural electrification, the acceptance of new technologies among residents, power supply quality requirements, and the impact of economic benefits.

5.3 Three key drivers for the large-scale development of PEDF

While challenges continue to hold back the widespread adoption of PEDF technology, driven by advancements in technology, mature business models, and policy support, its widespread application might not be as far off as it seems.

Technological progress will play a pivotal role in the broader adoption and enhanced economic viability of PEDF systems across various applications. At the technical level, the successful application of PEDF systems in rural areas depends on improved safety, enhanced power supply reliability, simplified "AC to DC" technology, increased flexibility in system adjustment, and continued improvements in effective coordination with the grid. Simultaneously, ongoing optimization of complementary technologies, including microgrid construction and energy storage, is expected to significantly reduce costs. Building a theoretical framework for PEDF systems adaptable to diverse application scenarios and establishing unified standards for engineering, technology, and product specifications will enhance product versatility. Consequently, this will reduce the barriers to project construction, serving as an effective means to optimize the cost of establishing PEDF systems and enhance ROI.

Business models are pivotal for expanding the PEDF system and fostering spontaneous ecosystem. Currently, this technology is primarily initiated and resourced by researchers, but broader applications across society will flourish when all participants stand to benefit. At present, constructing PEDF systems in rural areas involves three main types of development costs. First, there are direct incremental costs, such as deploying residential PV systems, purchasing solid-state storage-type direct current heating equipment, and implementing structural modifications for enclosures. Second, there are improvement-oriented expenditures to meet the electrification needs of rural households, including acquiring direct current home appliances and electric agricultural machinery. Third, there are investments in rural grid construction, including the installation of direct current microgrids, procurement of energy storage equipment, and establishment of distributed power trading platforms. The corresponding revenues include transmission and distribution fees, electric vehicle charging service fees, and emergency power supply charges. Currently, a potential solution for the commercialization of rural PEDF systems is the “outflows with no inflows, and all benefits go to the villager” business model. (In this model, the entire village achieves self-generation and self-consumption with surplus grid feeding. All the village’s electricity needs are met by internal PV power generation, with excess electricity being sold back to the grid. This model also made villages the major beneficiaries, with villagers acting as asset holders of the power station. Rural households are encouraged to invest in and construct their own PV plants through green financial loans and similar tools. Meanwhile, communal parts are funded by the village collective enterprises. These enterprises function as comprehensive clean energy operators, responsible for key aspects including the investment, construction, and operation of local rural PV projects. This model combines government purchases with user fees, ensuring the ROI of relevant projects. The government also assists these projects in obtaining policy-based green loans.)

In terms of the policy landscape, driving the widespread adoption of PEDF systems requires robust macro-policy design, fiscal support, and specific national certification and evaluation frameworks. First, rural areas must be encouraged to make PV resource plans at the village level. The construction should be unified in stages and batches, with consideration given to the specific needs of individual households. Second, the country shall expedite the construction of distributed power trading platforms and refine market mechanisms for friendly integration with the grid. By enhancing the economic viability of PEDF systems, this approach boosts the enthusiasm of various investors. Additionally, it is necessary to explore the establishment of industry standards related to PEDF technology and construct a standardized system to regulate the market environment.

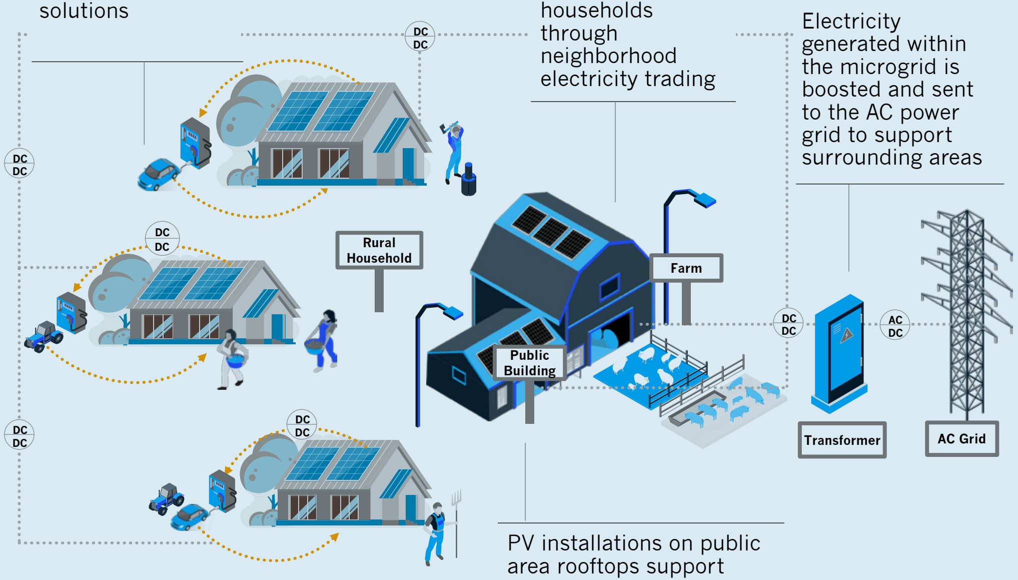
The synergy among technological advancements, innovative business models, and supportive policy environments will create a mutually reinforcing cycle. Driven by the combined impetus of these three factors, the future looks promising for the widespread application of PEDF technology.

PEDF Applications: A New Type of Direct Current Microgrid PV Ecosystem

The further expansion of PEDF technology in rural areas demands the development of a novel direct current microgrid centered around residential PV. This approach will enhance on-site consumption while improving the economic viability of residential PV. It will not only reduce the consumption of traditional fossil fuels but also lower electricity costs for rural residents, augmenting their income (see Figure 5.2).

In the context of PEDF, new direct current grids will consist of two types of units:

Figure 5.2 Schematic of the New Rural PV Direct Current Microgrid



Electrical vehicles, tractors, and other agricultural machinery with bidirectional charging and discharging functions can serve as cost-effective energy storage solutions

In case of insufficient power supply on a farm, the farm can sign a power purchase agreement with households through neighborhood electricity trading

Electricity generated within the microgrid is boosted and sent to the AC power grid to support surrounding areas

PV installations on public area rooftops support village lighting, solar storage and charging stations, and other equipments, achieving green energy use at the village level

First, there are household units. These units comprise residential PV, direct current end-use appliances, and energy storage facilities. Due to increasing electrification levels and the promotion of direct current appliances, the electricity generated by residential PV can fully cover domestic electricity needs. Additionally, the bi-directional charging and discharging functionality of electric farm machinery allows it to serve as cost-effective energy storage devices. For example, during the day, the PV charging system charges agricultural equipment, and the surplus electricity can power the household during the night or on cloudy days. Excess power is sent to the microgrid for trading, generating income from electricity sales. In this scenario, due to the considerable profits brought by the "self-financing & self-ownership + self-generation & self-consumption" model, and with household electricity needs increasing with electrification, rural households that have or can borrow the necessary funds and are willing to assume certain investment risks can actively participate in the construction of power stations and microgrids.

Second, there are village-level public units. These units are constructed on public buildings such as village government offices or village-operated schools, or they can be distributed PV stations scattered across open spaces. These public units not only support the electricity needs of the buildings themselves but also facilitate public area lighting and solar power storage and charging stations. Such units provide a green energy supply at the village level. Within the same direct current microgrid, users can freely trade electricity. If the village has poultry farms, agricultural processing plants, or other community-run industries with significant daily electricity demands, the industry owners can enter power purchase agreements with local PV rural households within the microgrid to compensate for any electricity shortfalls. They pay a grid integration fee to the grid and conduct electricity transactions at intermediary prices, increasing the proportion of locally consumed electricity. Furthermore, by utilizing energy storage facilities, a continuous power supply can be ensured day and night for village-run industries.

In rural areas where electricity consumption for daily life and production accounts for 20% to 40% of total PV generation, surplus electricity from rural residential PV systems can still be supplied to the grid. This surplus electricity not only supports the energy needs of surrounding industries but also generates revenue from electricity sales. With the help of the direct current microgrid, all PV stations in the village use a single export channel. The electricity is converged through transformers, converted to alternating current, and connected to the main grid. On the grid side, flexible control methods such as virtual power plants can be used for peak shaving at the village level.

The electricity generated by these direct current microgrids can meet the village's electricity needs for production and daily life. Furthermore, they can interact harmoniously with the main grid, facilitating integration and making residential PV an indispensable part of the rural energy landscape.

Taking Mrs. Zhong's household as an example again, under the innovative direct current microgrid PV system, if energy storage systems are properly implemented, government financial support is provided, electricity trading is facilitated among users, and carbon trading directly generates income, Mrs. Zhong's investment in PV equipment would yield significantly higher returns compared to the current scenario. Although the construction costs for PEDF systems and microgrids would increase to RMB 4.6/W, if the local government offers a subsidy of RMB 0.2/W, the total construction cost for a 10 kWh system could still be maintained at RMB 44,000, an increase of only RMB 9,000 compared to traditional PV construction costs. Simultaneously, as rural electrification levels continue to increase, the energy storage system will allow energy generated during the day to be used during the night and on rainy days, so Mrs. Zhong's self-consumption rate would increase to 40%. If "self-generation and self-consumption" is prioritized, Mrs. Zhong's household would save an additional RMB 3,248 on their annual electricity bill. The remaining 30% of surplus electricity would not be sold back to the grid but transferred to village-operated enterprises or individuals with significant electricity needs within the village at a rate of RMB 0.45/kWh. This approach reduces the impact on the grid and generates an annual income of RMB 1,890. For the remaining 30% of electricity, Mrs. Zhong's station could participate in peak shaving. Through transactions on the electricity spot market at a rate of RMB 0.30/kWh, Mrs. Zhong can generate an annual peak shaving income of RMB 1,260. Accounting for power generation attenuation, Mrs. Zhong's station could earn RMB 159,950 in electricity revenue over a 25-year lifespan. In addition, after the carbon trading platform opens to individuals, Mrs. Zhong's station could reduce carbon emissions by 320 tons over 25 years. Calculated at a trading price of RMB 50 per ton, this would bring an additional income of RMB 16,049. When combined with existing earnings, her total income would reach RMB 175,999 (see Figure 5.3). Although the high construction costs extend the payback period, further developments in PEDF systems and microgrid technology are expected to reduce costs, potentially shortening the payback period. While reducing the impact on the grid and easing pressure on central state-owned enterprises to invest and take over the projects, an innovative direct current microgrid PV ecosystem for PEDF applications could also bring economic benefits to rural users.

Figure 5.3 Analysis of Rural Income in the New Power System

Analysis of Rural Income in the New Power System

Changes to Assumptions in the PEDF Scenario

End-to-end development cost	4.6	RMB /W
O&M fees	0.05	RMB /W
Self-consumption ratio	40%	
Residential trading ratio	30%	
Peak control participation ratio	30%	
Government subsidy	0.2	RMB /W
Residential electricity trading price	0.45	RMB/kWh
Revenue from participating in auxiliary peak regulation service markets	0.30	RMB/kWh
Carbon emissions coefficient	50	RMB/ton

Cost Items			Revenue Items			Profit
One-time project costs	Power station construction costs (RMB)	46,000	**Owner revenue**	Savings from electricity usage (RMB)	81,200	**RMB 119,499**
	National subsidy (RMB/W)	0.2		Revenue from inter-user electricity trading (RMB)	47,250	
	Actual construction expenses for the power station (RMB)	**44,000**		Revenue from participating in auxiliary peak regulation service markets (RMB)	31,500	
Annual fixed expenses (entire lifecycle)	O&M fees (RMB/W)	0.05		Carbon trading revenue (RMB)	16,049	
	Total O&M costs (RMB)	**12,500**		**Total (RMB)**	**175,999**	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06

Rural Residential PV: Vision for the New Rural PV Ecosystem

The emerging rural PV system, which combines construction, electricity generation, consumption, storage, and trading, serves as an ecosystem paradigm. It not only meets the electricity needs of rural households on a self-supporting basis but also supports surrounding industries. This system lays a crucial foundation for energy integration, offering an improved electricity structure, balanced distribution of benefits, and comprehensive utilization of rural PV electricity.

We anticipate that the new rural PV system will mature over the next 10 to 30 years. The economic viability of residential PV stations is expected to increase further, and ownership models will diversify. More households will choose to build stations based on their electricity needs under the self-financing and self-ownership mode. Stable, low-cost electricity will alleviate concerns, significantly reducing cases such as the curtailment or inability to consume solar power. As living standards rise, electricity utilization rates will increase markedly, further reducing the proportion of energy from fossil fuels. Excess electricity that cannot be immediately utilized can be stored in centralized or distributed energy storage devices for use at night and on cloudy days. Even in remote areas where residential PV stations are not integrated to the grid, villages can achieve energy self-sufficiency. Electricity from major producers can be sold to the grid as well as directly to local major consumers at preferential rates, benefiting both sides economically and significantly reducing electricity costs. In addition to meeting the electricity needs of rural residents, surplus electricity transmitted through the grid will support nearby complementary industries, contributing to the strategic goal of rural revitalization.

Thousands of PV villages are set to incorporate various “PV+” scenarios, including agriculture-solar complementary, fishery-solar complementary, and distributed commercial PV, working together to build China’s distributed energy network. Each micro-energy network forms a node in this energy network. Leveraging advanced energy storage and transmission technologies, these networks achieve on-site energy collection, storage, and utilization. In cases where individual nodes cannot achieve self-sufficiency, multilateral energy exchanges balance energy supply and demand. As information technology continues to advance and the IoT becomes increasingly intelligent, the operation of micro-energy networks will be fully visible on the grid side. It will be possible to trace, monitor, and manage the generation, transmission, conversion, and utilization of electricity, ensuring the stability and compliance of energy usage and exchanges.

6.1 Key participants and roles in the new rural power systems of the future

Upon analyzing and exploring China’s new rural power systems of the future more deeply, it becomes evident that the focus will be on themes such as neighborhood electricity trading, decentralized energy systems, and microgrids. Examining the details, we can see that several key participants will be involved.

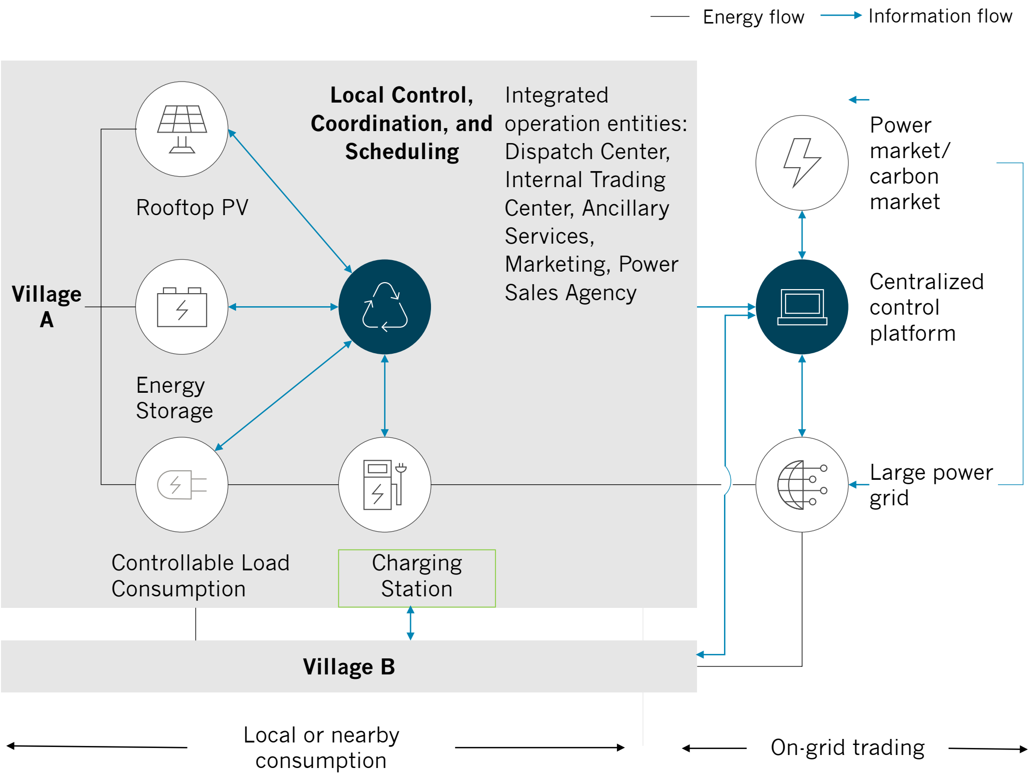
First, residential PV stands as the core element of the overall new rural power system, playing a crucial role. Rural households can choose to have their own power stations or invest in collective rural power stations. Each approach involves different electricity sales activities. Generally, after generating electricity during the day, the surplus PV power not used for personal consumption can be coordinated for nearby consumption by rural households through local scheduling. This includes supplying other rural households or industrial and commercial users within the village, storing energy for nighttime household use, or selling it to the main power grid. Currently, residential electricity follows a “tiered pricing + levels” mechanism, requiring the calculation of minimum electricity expenses and maximum sales income based on the electricity load. Since household consumption accounts for a small percentage, diversifying electricity usage and sales channels is the focus for the development of new rural power systems of the future.

Second, energy storage is indispensable in the power system. In the future, given the further reduction in energy storage costs and considering the uncertainties surrounding energy storage promotion, village collectives might use distributed shared energy storage or cloud energy storage within confined areas. Users can pay fees based on their usage needs, avoiding wasted energy storage capacity. This approach can effectively reduce costs, facilitate convenient access, and provide efficient auxiliary services within the village. From a safety perspective, village collectives can enhance the reliability of energy storage. Another key area of focus is controllable electricity loads in rural areas. With the advancement of rural electrification, the loads to meet the electricity demands for households, various industrial and commercial uses within the village, and collective economic electricity consumption can be promptly adjusted in the new rural power system. Similarly, with the increasing popularity of electric vehicles in rural areas and the electrification of agricultural machineries such as farming and livestock equipment, charging stations can also act as small-scale energy storage devices in the new power system. They can be used during the day and charged at night, and vice versa.

In addition to the aforementioned participants, optimizing power utilization in new rural power systems also relies on entities that can perform local power control and coordinated scheduling. In the future application scenarios described above, smart meters may play a significant role. Installing smart meters or IoT devices on various electrified equipment in rural areas can enhance real-time monitoring and usage of electricity transmission. Furthermore, electricity transfers between villages need to be conducted through local (additional) distribution networks for trading, bypassing the main power grid. Hence, the local control and coordination scheduling center becomes an integral part of new rural power systems. As an integrated operator for local control and regulation, its primary functions include electricity dispatch and transactions within the region, providing electricity sales agency and auxiliary services to the main power grid and electricity trading systems, as well as marketing and promotion for various businesses. In new rural power systems, this role may be assumed by three different types of organizations: emerging comprehensive energy management companies, companies financed by local governments with advanced Internet and energy management technologies, and local secondary companies of power generation companies or state-owned enterprises related to the power grid.

In addition, the government plays a crucial role in this new power system. The most recent Opinions on the Implementation of Key Tasks for Advancing Rural Revitalization in 2023 by the State Council and Party Central Committee issued by the National Rural Revitalization Administration emphasizes “strengthening the operation and management of operational poverty alleviation projects confirmed at the village level, enhancing management and maintenance of PV poverty alleviation stations in villages... and nurturing and expanding new rural collective economies”. From the perspective of grassroots governments, township-level governments can act as coordinators. For instance, they can help village collectives to participate in the construction of distributed energy systems, help mobilize funds and resources, and serve as asset management companies by effectively consolidating dispersed power generation assets in villages to increase income for local residents. County-level governments, on the other hand, play a service-oriented role by increasing the participation of local grassroots governments and residents, facilitating administrative procedures, and helping establish microgrid systems. Given the significant policy-driven impetus for revitalizing rural collective economies and its integration with market-oriented approaches, villagers, as asset owners, can actively participate in the construction of new rural power systems. The industry also needs to fully explore future participation methods and clearly define the roles and responsibilities of various parties. The government can provide subsidies or participate in the work of local control and coordination centers through investments, making use of local distributed power systems and controlling the transmission of electricity between village networks and the main power grid (see Figure 6.1).

Figure 6.1 Schematic of Future Electricity Transmission in Rural New Power Systems at the Village and Main Power Grid Levels

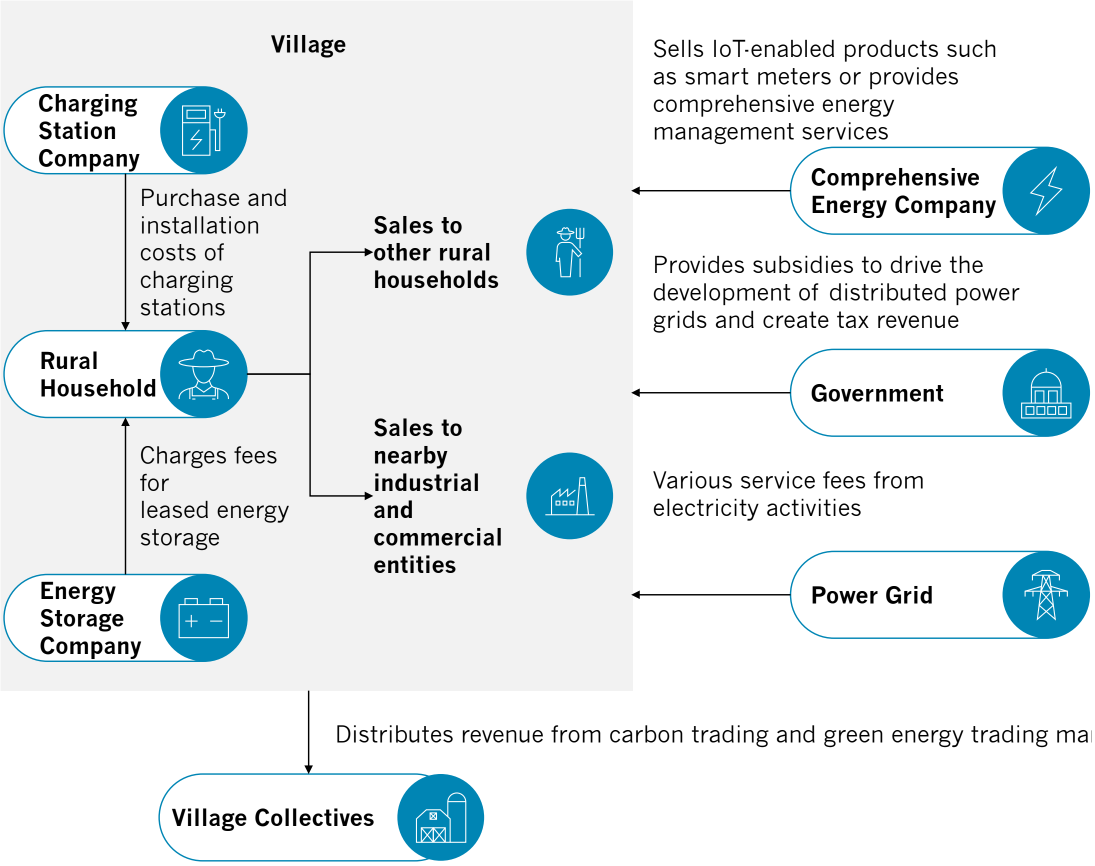


6.2 Potential benefits and influencing factors for key participants in new rural power systems of the future

Based on the business models described above, we can gain a basic understanding of the potential benefits for each party involved (see Figure 6.2). Rural households primarily benefit from income generated by selling electricity. The electricity price charged by the main power grid is higher than their PV generation costs and grid integration price. Rural households prioritize using PV electricity for personal consumption, selling the surplus to other users. For industrial and commercial users, the local consumption price falls between the direct grid price for rural households and the industrial and commercial grid electricity price. This arrangement reduces their electricity expenses while also benefiting the rural households selling electricity. Charging station companies can generate revenue by offering hardware and software services and charging for the purchase, installation, and ongoing maintenance of charging stations. Similarly, energy storage companies not only earn fees during installation and maintenance but also collect rent based on the village collective's shared storage model.

Comprehensive energy management companies, leveraging their robust software and hardware development capabilities, earn revenue by selling IoT-enabled products such as smart meters. Additionally, they undertake the role of local control centers, providing comprehensive energy management and auxiliary services in return for service fees. Looking further ahead, the profit model of coordination centers depends on the entity managing this function. Regardless of whether it's a comprehensive energy management company, local government, or power grid company, they can capitalize on their inherent advantages by participating in coordination and scheduling, collecting service fees proportionate to their involvement. Finally, village collectives earn income by distributing surplus PV electricity and engaging in carbon trading, green energy transactions, and other activities.

Figure 6.2 Potential Gains for Various Parties in New Rural Power Systems of the Future



In this future business model, several variable factors will impact the earnings of key stakeholders.

1. Advances in technology and product updates leading to improved equipment efficiency and reduced costs will benefit PV plant owners. This, in turn, will encourage equipment manufacturers to continually enhance their production and research efforts. Approximately 45% of the construction cost of a PV plant comes from module equipment, with solar cells accounting for about 60% of the total module cost. Therefore, module costs are greatly influenced by technological advancements in solar cells and the prices of raw materials. Currently, the market's primary products are monocrystalline silicon P-type PERC modules and N-type TOPCon and HJT, all using silicon as the main raw material. Following the establishment of China's Dual Carbon goals in 2020, the demand for constructing PV plants remained strong nationwide. However, due to constraints in silicon material production capacity and the lengthy expansion cycle, silicon raw material prices soared by as much as 350% between 2020 and 2021, taking a significant portion of the industry's profits. With the expansion of silicon production capacity, the silicon raw material supply has gradually recovered from the end of 2022 to the present, leading to continuous reductions in module prices. Furthermore, there have been continuous improvements in cell conversion efficiency, with new N-type technologies gradually replacing P-type technologies and larger units replacing smaller units. This reduces amortization cost per watt of non-silicon modules, ensuring that PV costs per kilowatt-hour will continue to decline in the future. For PV plant asset holders, the decrease in costs, coupled with the increase in PV efficiency, will result in higher electricity generation earnings. PV equipment manufacturers need to continuously enhance their technological R&D efforts and lean production processes. They must also develop differentiated products and downstream services to meet consumer demands, ensuring that profit margins remain at relatively high levels. Similarly, the decrease in energy storage costs will make residential PV storage systems more economical, a critical factor for the widespread adoption of energy storage.
2. The rise in electrification levels and the increasing share of renewable energy will demand reforms in the power grid, leading to additional investment costs. The growing installation and power generation share of new energy sources such as PV will gradually establish a power production structure where conventional fossil fuels guarantee electricity supply, and new energy is used for electricity usage control. Consequently, the power grid will evolve into a pattern where large grids dominate while various forms of other grids coexist. Flexible power sources, system adjustment, grid facility renovations, and network integration & distribution will all require new investments. In May 2023, the National Development and Reform Commission officially released the *Notice on Provincial Power Grid Transmission and Distribution Tariffs for the Third Regulatory Period and Related Matters*. For the first time, it explicitly included system operation costs in electricity prices, separately listing expenses essential for maintaining stable power system operation,

ensuring energy quality, and facilitating new energy integration. Although currently applicable only to industrial and commercial users, clarifying system operation costs in electricity prices aligns with the requirements for developing new power systems as the proportion of new energy rises and system operation costs significantly increase. This move is conducive to further promoting the transformation of the power system.

3. Related costs such as labor expenses are expected to increase in the future, particularly in aspects such as the installation and ongoing maintenance of PV power stations. However, the improvements brought about by digitization and automation will streamline processes, significantly reducing some costs. For instance, activities like rooftop assessment and design, as well as intelligent maintenance, will effectively cut down associated labor costs.
4. Ongoing reforms in the electricity market are bringing about changes in electricity prices. To facilitate the integration of new energy sources and enhance operational efficiency, the construction of a nationwide unified electricity market has been initiated and electricity prices will be more market-oriented. In January 2022, the *Guiding Opinions on Accelerating the Construction of the National Unified Electricity Market System* were issued, outlining the goal to establish a basic national unified electricity market system by 2030. This system will aim to optimize the allocation of electricity resources nationwide. Currently, the PV feed-in tariffs in China are set with reference to coal-fired electricity benchmark prices, even though the cost per kilowatt-hour of PV electricity is not related to coal-fired electricity costs. In the future, feed-in tariffs may gradually transit to a pricing model based on "costs + reasonable profit". Prices will be approved periodically based on generation costs. Additionally, a market-oriented pricing mechanism is expected to form after gradually promoting the participation of distributed PV energy in the electricity market. Consequently, all stakeholders in rural electricity systems will see an impact on their costs and profits.
5. Proactively driving green power and green certificate trading will boost revenue for power plant owners. If green certificate trading can cover distributed new energy sources in the future, it will accelerate the use of distributed PV at the household level, generating additional income for station owners. In the initial stages, the value design of green certificate markets primarily reflected the value of government subsidies for new energy sources. However, in the future, we expect to see a transition to market-oriented prices, influenced by factors such as market transaction electricity prices, green electricity generation costs, and system integration costs. This shift will occur due to the increasing emphasis on the environmental value of green electricity.

Achieving the vision of a distributed energy network requires collective efforts from all stakeholders within the energy ecosystem. In this regard, the government must actively engage public institutions, businesses, the grid, and rural residents to collaboratively participate and advance the development of distributed PV and energy storage technologies. It should also issue industry standards on a timely basis and provide guidance and support in terms of policy and finance. The grid also plays a crucial role within the energy network. It should continue to promote the transformation of rural distribution networks and expedite the construction of energy distribution systems, including neighborhood electricity trading, while resolving the interests of all parties involved. Enterprises and research institutions must continuously explore the possibilities of technological breakthroughs in practice. This includes reducing the construction costs of distributed PV and energy storage technologies and enhancing the economic viability of building large-scale storage station. These efforts will boost the enthusiasm of various stakeholders, including private and institutional investors. Simultaneously, the PV industry needs to foster healthy cooperation among different stakeholders. Through industry associations, forums, and other channels, it should enhance communication, promote best practices within the industry, and work towards achieving the common objectives of the Dual Carbon goals and rural revitalization, facilitating progress across the entire sector. At the grassroots level, there is a need to nurture a cadre of rural PV professionals who possess technical expertise, sales acumen, and management skills. Only with such individuals will local sustainable development be possible. This approach will pave the way for comprehensive solutions in rural areas, giving comprehensive assistance for the green and low-carbon development of villages.

The construction of the new rural power system cannot be achieved overnight, but with the passage of time, we hope to see new progress in each stage. In the next 5 to 10 years, PV installations in rural areas will become more widespread, allowing more households to enjoy clean, affordable electricity. In 10 to 15 years, energy storage technology costs will decrease, ensuring safety and meeting the needs of both household and community for energy storage. In 15 to 25 years, as technologies like direct current appliances, virtual power plants, and smart microgrids further develop, flexible control technologies will become more refined, making PV power generation more adaptable. Taking a long-term perspective, as these technologies mature, it will become easier to align with related management mechanisms and business models, bringing tangible benefits to every participant in the new rural power system.

Ultimately, as China achieves carbon neutrality, we expect the following scene to be commonplace in rural areas: A rural household with electric farm equipment charges his electric vehicle and tractor parked in the courtyard of his house from his self-owned PV power station while he is away from home during the day. The surplus energy is stored in distributed energy storage devices, ready for use in heating, lighting, and cooking activities when the sun sets. Another rural household, opting to sell all generated electricity, receives a fixed monthly roof rental income while effortlessly supporting the electricity needs of a village factory and contributing to cleaner air in the village. Not only are the electricity needs within the village guaranteed, but power can be freely exchanged between villages, ensuring ample and stable electricity supply across the whole region. Villages also play the role of distributed power plants, supplying clean energy to nearby energy-intensive industries. With collective efforts up and down the value chain, the construction of the new rural PV ecosystem will progress at a steady pace.

Conclusion:

Walking Alongside the Sun, Driving Continuous Progress in Rural Rooftop Solar PV

The decision on the Dual Carbon strategy is a significant move by our country, showing our proactive stance in taking on global responsibilities and striving to build a community with a shared future for humanity. Utilizing new energy resources not only involves technological and economic development but is also intricately linked with the well-being of the nation and its people. The importance of these efforts is tangibly reflected in the development of the rural rooftop solar PV industry. In recent years, the installed capacity of rooftop solar PV systems in rural areas of China has rapidly increased and these projects have seen a sustained increase in their economic viability. Policies and the social environment have provided fertile ground for their development. Rooftop solar PV has become a key lever for energy conservation and emission reduction, which contributes to achieving the Dual Carbon goals. However, it still faces challenges such as grid integration difficulties, subsidy reductions, policy changes, and asset upgrades. Various stakeholders in the value chain need to be prepared to address these challenges in effective ways.

Looking at the present situation, industry leaders have already created some best practices worth promoting. These include widening customer acquisition channels through user segmentation models, diversifying the ownership of large-scale power stations beyond state-owned enterprises, controlling green financial risks through innovative mortgage methods, promoting novel grid integration models like village-wide aggregation, and enhancing the enthusiasm of rural households for the self-financing & self-ownership model and subsequent operation & maintenance through promotional and educational initiatives. If these best practices can be widely applied, they will help raise the overall industry standard and drive the realization of the development goals for rural rooftop solar PV.

Looking ahead, we anticipate the establishment of a rural solar PV power system that improves the electricity structure, balances the distribution of benefits, and maximizes power utilization. As station construction costs further decrease, the proportion of self-financing & self-owned systems increases, rural electrification raises electricity consumption capacity, energy storage technologies become more sophisticated, and power trading system models become established, distributed solar PV in rural areas will substantially enhance the living standards of rural communities. With the collective efforts of all stakeholders, sustained and abundant sunshine will create ever-greater value for rural China, transforming clear water and lush mountains into wealth more valuable than gold. The realization of the grand strategic goals of Dual Carbon and rural revitalization is on the horizon.

Note

Unless otherwise explicitly stated, the currency “RMB” in this document refers to the Chinese Renminbi (CNY).

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