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Business Models for Rural Energy Renovations and Clean Heating: Case Studies from China and Europe

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1. The Importance of Rural Energy Renovations and Clean Heating in China

The building sector stands as a major contributor to China's total final energy consumption, accounting for roughly 45.5% in 2020. This encompasses energy usage during building materials production (22.3%), construction (1.9%), and building operation (21.3%). Consequently, the sector significantly impacts national carbon emissions, contributing approximately 50.9% to the total, including emissions from building materials production (28.2%), construction (1%), and building operation (21.7%).

Notably, rural houses in China constituted a substantial portion of the overall building landscape, boasting a total building area of 23.3 billion m^2, which accounts for 34% of civilian buildings in the country. The energy consumption in rural houses reached 230 million tonnes of coal equivalent, representing 22% of the total energy consumption in civilian buildings. It resulted in 427 million tons of CO_2, contributing to 20% of the total emissions from civilian buildings. Thus, reducing energy consumption and carbon emissions of buildings, including rural housing, is of paramount importance.

In September 2020, China announced its commitment to peak carbon dioxide emissions by 2030 and achieve carbon neutrality before 2060. Subsequently, the government released a series of pivotal policy documents, emphasizing the importance of rural areas within the broader context of urban and rural construction. In October 2021, the State Council took a decisive step by unveiling an action plan dedicated to advancing low-carbon energy transformation in rural regions. This comprehensive plan encompassed several key initiatives, including promotion of green rural houses, acceleration of energy renovations, adopt clean heating tailored to local conditions, acceleration of renewable energy deployment such as biomass and solar energy in agricultural production and rural life, enhancement of rural grid construction, and increase of electrification. In March 2022, the Ministry of Housing and Urban-Rural Development (MoHURD) released the '14th Five-Year Plan for Building Energy Efficiency and Green Building Development,' which further solidified these efforts with the release of the '14th Five-Year Plan for Building Energy Efficiency and Green Building Development.' This strategic plan outlined a commitment to enforce relevant standards for rural buildings, promote energy-efficient technologies, and implement ultra-low energy rural house pilots characterized by both high energy efficiency and superior indoor thermal comfort.

The increasing living standards of rural households has led to an increased energy consumption and carbon emissions in rural areas. However, promoting energy efficiency of rural houses face significant challenges. Firstly, the absence of policies for the planning and design of rural houses hampers effective initiatives. Given that these houses are predominantly constructed by households or communities themselves, a lack of standardized guidelines impedes the integration of energy-efficient features. Additionally, a deficiency exists in policies related to energy efficiency and the deployment of renewable technologies in rural settings. Moreover, the absence of a robust feasibility analysis for green and low-carbon technologies applicable to rural buildings further exacerbates the challenges. The need for a comprehensive understanding of the practicality and adaptability of such technologies is paramount to overcoming resistance to change. Lastly, the escalating electrification and overall energy consumption in rural areas underscore the necessity to actively promote the development of renewable energy sources.

The Switch Asia RurEnergy project aims to promote energy renovation and clean heating in Henan Province and Gansu Province, with replicable business models being one of the key enablers.

2. Status-quo of Energy Efficiency and Clean Heating in Chinese Rural Houses

2.1 The Economic Challenges of Promoting Rural Building Energy Efficiency and Clean Heating

Energy renovations in rural housing and clean heating represent the cornerstones of sustainable energy consumption in rural areas. Notably, commendable strides have been made since the commencement of clean heating initiatives in northern China regions in 2017. To date, 88 cities and their rural surroundings have been designated as pilots, resulting in substantial achievements. As of 2021, clean heating has been extended to cover an impressive 15.8 billion m^2 in the northern regions, attaining an impressive clean heating rate of 70%.[1] Despite these advancements, challenges persist, particularly in rural areas, with economic factors emerging as a primary obstacle.

On the one hand, the issue of high operational costs is particularly prominent. Illustrated by the 'coal-to-gas' project in Zhengzhou, Henan, residential gas prices pose a notable financial challenge. For instance, the cost for residential gas usage of 50 m^3 or less per month is 2.58 yuan/m^3 (0.26 USD/m^3), while usage exceeding this threshold incurs a higher rate of 3.35 yuan/ m^3 (0.47 USD/ m^3). Considering a typical rural house of 100 m^2, the monthly gas bill would be approximately 2,474 yuan (347 USD). Extrapolating for a 3-month heating period, the annual heating cost for such a household could reach 7,422 yuan (1,142 USD). In comparison, the average disposable income per capita for rural residents in 2021, according to National Bureau of Statistics data, was 18,931 yuan (2,656 USD).[2] This underscores the significant financial strain that clean heating operational costs can impose on rural households.

On the other hand, the upfront cost associated with energy renovation is high, with notable regional variations. Even at the lower end of the spectrum, costs fall within the range of 2000-4000 yuan (280-560 USD), with the upper limit escalating to 10000-20000 yuan (1,401-2,801 USD). Surveys conducted in Henan and Gansu provinces, the targeted regions of the RurEnergy project, indicate that 85% and 68% of rural residents, respectively, are willing to invest in energy renovation ranging from 1,000 to 5,000 yuan (140 to 700 USD). Thus, in the absence of ample government subsidies, rural households lack sufficient incentives to engage in energy renovations.

At present, the driving force behind rural house energy renovations and clean heating predominantly stems from subsidies, with national governmental support playing a pivotal role. In the period from 2017 to 2021, the national government had committed a cumulative investment of 62.08 billion yuan (approx. 8.7 billion USD) to bolster energy renovations and clean heating initiatives.[3] Following central government's

[1] Zhou Hongchun. (2022). Zhongguo qingjie gongre chanye fazhan baogao 2022 (China Clean Heating Industry Development Report 2022). Beijing: Zhongguo jingji chubanshe.

[2] Guojia tongji ju. (2021). Zhongguo tongji nianjian [J] (China Statistical Yearbook [J]). Beijing: Zhongguo tongji chubanshe

[3] Shengtai Huanjing Bu Huanjing Guihua Yuan. (2022). Qingjie Qunuan Duoyuanhua Tourongzi Qudao Jili Zhengce ji Shiji Yingyong Anli Yanjiu Baogao (Report on Policies and Practical Applications of Diversified Investment and Financing Channels for Clean Heating)

support, local governments also contribute matching subsidies. Nevertheless, a 2020 statistical report highlights the substantial annual subsidy burden on provincial, municipal, and county-level governments. In certain regions, municipal and county-level governments have already exceeded their financial capacities, posing challenges for sustaining subsidies in the future. As of now, the national government extends subsidies to pilot cities for a three-year duration, but the future landscape of subsidies remains uncertain. Some northern cities have begun a gradual reduction of subsidies, easing the burden on local government finances. [4] The subsidies have predominantly supported the switch to clean heating sources, with only 12.4% of the total cumulative subsidies allocated for energy renovations.[5] The diverse nature of self-built rural houses presents a challenge in establishing standardized cost benchmarks for energy renovations. In contrast to switching heating sources (e.g., specifying numbers of heating equipment purchases for each household), defining clear parameters for governmental subsidies and the proportion borne by rural households for energy renovations is complex. Moreover, as national and local subsidies are anticipated to decrease in the future, the willingness of economically disadvantaged rural households to invest in energy renovations is likely to diminish further.

In some regions, households have started reverting to using coal for heating, often due to rising operational costs for heating. This situation is particularly prevalent in rural areas with low income and easy access to coal. Data shows that the average reverting rate in northern regions reached 14%, with some cities reporting rates as high as 36%.[6] This suggests that aside from the habit of keeping coal stoves for lifestyle reasons, the ability of households to bear operating costs directly determines the sustainability of clean heating. The gradual reduction of operating subsidies in various regions becomes a potential reason for households reverting to coal. On the other hand, in some regions where government finances are limited, low-cost bidding strategies are often adopted to achieve task goals. Some enterprises that win contracts with low bids may have to cut costs in raw material procurement and production to make a profit, leading to low product quality. This results in a large number of inferior products entering the market as manufacturers reduce their investments in projects and the products themselves. Ultimately, this poses risks in terms of investment and safety for rural consumers.

[4] Hebei Sheng Qi Dai Mei Dian Dai Mei Gongzuo Lingdao Xiaozu Bangongshi. (2018). Hebei Sheng 2018 Nian Dongji Qingjie Qunuan Gongzuo Fang'an (Hebei Province 2018 Winter Clean Heating Work Plan)

[5] Quanguo Nengyuan Xinxī Pingtai. (2021). Nongfang Jieneng Gaizao Burong Hushi, Huoqu Zi (Energy-saving Transformation of Rural Houses Cannot Be Ignored, Obtaining Self). https://baijiahao.baidu.com/s?id=1695734070636429645&wfr=spider&for=pc

[6] Beijing Daxue Nengyuan Yanjiu Yuan. (2021). Zhongguo Sanmei Zonghe Zhili Yanjiu Baogao 2021 (Research Report on Comprehensive Governance of China's Scattered Coal in 2021), Beijing: Beijing Daxue Nengyuan Yanjiu Yuan

2.2 Promoting Rural Building Energy Efficiency and Clean Heating in Henan and Gansu

2.2.1 Policies in Henan Province

Between 2017 and 2022, a total of 13 cities in Henan were officially designated as national pilot cities for clean heating. These cities have been granted substantial financial support from the government to facilitate the implementation and advancement of sustainable heating solutions.[7]

Taking Hebi City as a case study, the implementation of clean heating is considered an important project for enhancing the well-being of its residents. Hebi City has introduced clean heating measures, considering the economic capabilities and lifestyle preferences of rural households. Adhering to the guiding principles of 'enterprise leading, government promotion, affordability, and sustainable operation,' the city has only subsidised initial installation without operational subsidies.

The expenses for energy renovations and clean heating are capped at 10,000 yuan (1,401 USD) each, with households contributing less than 1/4 of the total cost, ensuring affordability for both the government and residents. Two clean heating technologies have been adopted: low-temperature air source heat pumps and biomass heating. These approaches feature one-click equipment operation, a design that takes into account the presence of elderly individuals and children in rural households, ensuring ease of use and an integrated management platform. The heat pumps are managed digitally, simplifying operations and maintenance.[8]

As of now, notable accomplishments have been made, including the transition from coal to electricity among 23,000 rural households, the widespread adoption of low-temperature air source heat pumps across entire villages, the installation of 1,849 units serving 3,035 households, and the installation of 100 units of digitally intelligent biomass heating stoves. Energy renovations covering approximately 230,000 m^2 and benefiting 1,666 households have been successfully completed in rural areas. Significant improvements have been made to power grids in 60 villages, impacting a total of 13,207 households, with a substantial investment of 103 million yuan (14.4 million USD). This has considerably augmented the power supply capacity of rural grids.

While energy renovations and clean heating initiatives have achieved success, their sustainability remains heavily contingent on financial support, and mature business models are currently lacking. In December 2021, the Finance Bureau of Henan Province disclosed that the total investment in pilot projects in Zhengzhou, Kaifeng, Hebi, and Xinxiang amounted to 46.14 billion yuan (6.46 billion USD), of which 14.23 billion yuan (1.99 billion USD) was sourced from government funds.[9]

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[7] The Ministry of Finance PR. China (2022). Caizhengbu, Zhufang he Chengxiang Jianshebu, Shengtai Huanjing Bu, Guojia Nengyuan Ju Zhaokai Caizheng Zhichi Beifang Diqu Dongji Qingjie Qunuan Gongzuo Tuijin Hui (The Ministry of Finance, Ministry of Housing and Urban-Rural Development, Ministry of Ecology and Environment, and the National Energy Administration held a meeting to promote the winter clean heating work in northern China with financial support). http://yn.mof.gov.cn/tongzhitonggao/202212/t20221216_3858566.htm

[8] Henan sheng Hebi shi quanmian shixian re yuan duan qingjie hua (Comprehensive Implementation of Clean Heating in Hebi City, Henan Province. (2018). gong re zhileng, (04):20.

[9] Caizhengbu Henan Jianguan Ju. (2021). Yin di zhi yi, jiji chuangxin, Henan sheng qingjie qunuan gongzuo qude shixiao (Adapting to local conditions, actively innovating, Henan Province has achieved practical results in clean heating work.)

2.2.2 Gansu Province

In Gansu Province, only Lanzhou City has been included in the national clean heating pilot program. However, work related to rural housing energy renovations and clean heating is still being carried out.

Energy renovations for rural housing is relatively lagging and is still at the early stages. Newly built rural houses mostly incorporate exterior wall insulation to enhance energy performance. However, large-scale energy renovations of existing rural houses have not yet been widely implemented.

In contrast, renewable energy in rural areas is relatively extensive and includes technologies such as solar cookers, solar water heaters, biogas, straw gasification stoves (new generation), solar energy combined with air source heating systems, and solar energy + air source heating systems.

These technologies exhibit distinct regional preferences in Gansu. For instance, biogas finds widespread use in the central and western regions of Gansu, while straw gasification stoves (new generation) are prevalent in Lanzhou, Zhangye, and Wuwei areas and solar energy combined with air source heating systems is primarily found in the Gannan area. This regional variation is closely tied to local support policies.[10]

The ongoing promotion of clean heating in rural areas of Gansu predominantly depends on government subsidies, as market-driven forces remain insufficient, and innovative business models are lacking. Given the comparatively weaker economy in the Gansu region compared to other provinces and cities, heating costs have often surpassed the consumption capacity of farmers. Consequently, subsidies continue to play a crucial role in facilitating the adoption of clean heating technologies.

In summary, policy support has expedited rural energy transition. Nevertheless, there is a crucial need for sustainable business models that reduce dependence on subsidies, considering the growing financial burden on the government. The RurEnergy project has identified a spectrum of sustainable business models tailored to different technologies.

Table 1 provides a summary of the building energy efficiency and clean heating technologies implemented in RurEnergy's pilot projects in the two provinces. Subsequent chapters will elaborate on the business models associated with these technologies.

Table 1 Building Energy Efficiency and Clean Heating Technologies applied in the RurEnergy pilots

Technologies	Technical Advantages
Energy renovations	Enhancing the thermal insulation performance of the building envelope can significantly diminish heat loss in winter, partially mitigate indoor temperature fluctuations in summer, and result in reduced overall building energy consumption.
Biomass utilisation	Achieving complete combustion, extended heating duration, rapid heating rates, high automation levels, convenient ash removal, energy efficiency, environmental friendliness, and simple installation and operation.
Air source heat pump	Versatile applicability (operating in temperatures ranging from -7 to 40°C), suitable for year-round, day-and-night use, ensuring continuous heating. It is clean and environmentally friendly, producing no pollution or combustion emissions. The system boasts

[10] Li Jicheng. (2017). Gansu Zhongbu Nongcun Taiyangneng Liyong Ji Fazhan Tansuo: Yi Dingxi Shi Anding Qu Nongcun Wei Li,《Taiyangneng》(Exploration of Solar Energy Utilization and Development in Central Rural Gansu: A Case Study of Rural Areas in Anding District, Dingxi City,《Solar Energy》), 2017.01, 75-78

	low operating costs, high efficiency, and a short investment payback period. Additionally, it provides a comfortable, safe, and user-friendly experience, featuring a compact outdoor unit that requires minimal space.
Photovoltaics (PV)	Solar energy resources abound in certain villages, offering an environmentally friendly solution with a short construction period and low maintenance costs.
PV, energy storage, direct current, flexibility	In contrast to traditional PV buildings, those utilizing direct current (DC) present numerous advantages. Notably, they exhibit higher electricity utilization, experiencing an increase of 6% to 8%, and lower equipment investment costs. The elimination of inverters and transformers leads to approximately 10% savings on initial equipment expenses. Employing DC distribution in buildings can substantially enhance system performance, bolster safety measures, and elevate power quality.
Combined solar energy and heat pump	The coupling system is both simple and efficient. The waterless heat collection system ensures safety and boasts a long lifespan with minimal maintenance requirements. It is suitable for use in extremely cold areas, demonstrating efficient operation even in environmental temperatures below -35°C, and provides water at temperatures exceeding 65°C. Installation and commissioning are straightforward, requiring no indoor modifications, and can be accomplished in as little as one day.

3. Overview of Domestic Rural Energy Efficiency and Clean Heating Business Models

3.1 "One Village, One Factory" model for biomass feedstock

In this business model, the government invests in establishing a biomass fuel processing factory within the village. The plant's operation and management are leased to a contractor. Local farmers contribute collected biomass to the processing plant, receiving processed biomass at a reduced fee in return. Additionally, the government provides subsidies to households for the acquisition of biomass heating stoves.

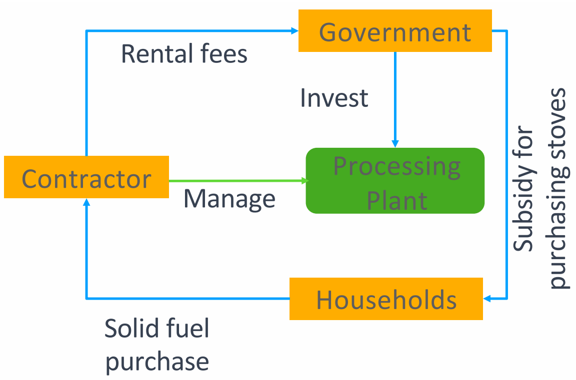

Figure 1 "One Village, One Factory" Model

Case study: Biomass plant in Sichuan

Shiyi Village, located in North Sichuan County's Beichuan County, stands as an early adopter of the described business model, benefiting 200 households.

The government's investment in a processing plant covering an area of approximately 300 m^2 within the village addresses the energy needs of rural households. An investment of approximately 200,000 RMB was allocated for the procurement of biomass pellet fuel processing equipment. Following the plant's completion, it achieves a daily production capacity of 3 to 4 tonnes, contributing to a monthly total output of about 100 tonnes. The village committee has engaged a company to manage the plant, with the processing fee set at around 300 RMB per ton. Worker wages constitute approximately 50%, equipment electricity costs about 30%, and maintenance and repair costs approximately 20% of the expenses.

In addition, the government provides subsidies that fully cover the costs for rural households to acquire and install biomass pellet fuel cookstoves. These cookstoves can be used in conjunction with traditional wood stoves or as stand-alone cooking appliances, ensuring that the cooking habits of rural households remain unchanged. Simultaneously, the cooking thermal efficiency is over 40% higher. The waste heat recovery efficiency of smoke gas exceeds 10%, supplying hot water for handwashing and vegetable washing, significantly enhancing convenience.

Households consume no more than 1 kg of biomass pellet fuel for preparing three meals a day, and the annual cooking consumption per household does not exceed 0.5 tonnes. This translates to over 80% savings in fuel consumption compared to traditional wood stoves, resulting in a substantial reduction in the time spent by rural households on collecting firewood.[11]

[11] Dan Ming, Zhang Shuangqi, Deng Mengsi, Yang Xudong. (2018). Shengwuzhi chengxing ranliao yongyu beifang cunzhen qingjie qunuan de jishu yu moshi, Quyu Gongre (Technology and Mode of Biomass Formed Fuels for Clean Heating in Northern Villages, Regional Heating, 192, 01, 9-13

Consequently, households spend no more than 200 RMB per year on biomass pellet fuel for cooking, leading to significant fuel cost savings and various benefits. Moreover, the new cooking stove has significantly mitigated indoor pollution emissions. When comparing emissions of CO and PM2.5 per unit of fuel burned to traditional wood stoves, this stove exhibits a distinct advantage. In households using traditional wood stoves, the average pollution level in the kitchen over 48 hours is 31 μg/m³ (with peak concentrations approaching 200 μg/m³). In contrast, the utilization of the new cooking stove results in an average concentration of only 7.5 μg/m³ (with peak concentrations not exceeding 80 μg/m³).

3.2 Build-Operate-Transfer (BOT) model

The Build-Operate-Transfer (BOT) model has been applied in energy renovations for public buildings in China. This model is based on an agreement between the government and private enterprises, wherein the government awards a concession for operation to the private enterprise. Throughout the concession period, the private enterprise is responsible for collecting all revenues associated with the relevant products and services. Upon the conclusion of the concession period, the enterprise transfers the equipment assets to the owner.

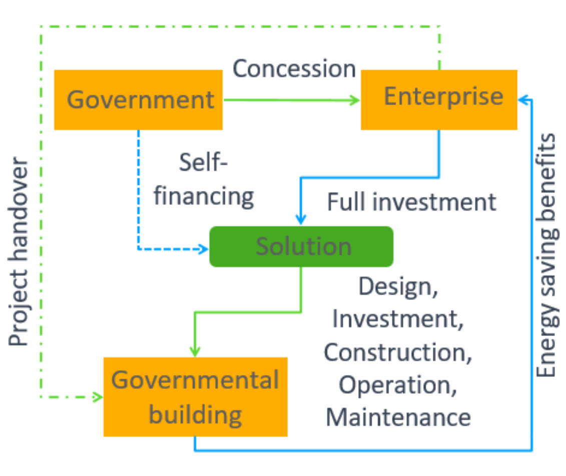

Figure 2 Midea BOT Business Model

Case study: Midea BOT

In the case of Midea Heating and Building, a comprehensive clean heating solution has been implemented in western Xining utilizing the BOT model. Midea takes charge of the entire process, including design, investment, construction, operation, maintenance, and user services for the renovation project. Throughout the contract period, Midea collects service fees based on mutually agreed-upon standards. Upon the expiration of the contract, the project assets are subsequently transferred to the government.

Midea's BOT business model is beneficial for both users and Midea. Firstly, Midea assumes responsibility for initial research and needs analysis, optimizing project planning, and executing and overseeing the construction or renovation, thus mitigating investment risks for users. Subsequently, Midea assumes the operation and maintenance, ensuring ongoing efficient operation. Finally, upon the expiration of the contract period, users gain ownership of the assets at no cost, delivering peace of mind and security.

Under Midea's BOT model, two different cooperation approaches with the government have emerged: the Self-Funded Model and the Zero Investment Model.

In the Self-Funded Model, the government and Midea agree on the investment ratio. Midea provides the preliminary energy renovation design, project construction, and building commissioning. During the construction period, when energy-saving benefits are generated, Midea and the government split the benefits according to the agreed-upon ratio. After reaching the agreed-upon baseline of energy-saving benefits created by Midea, the project is transferred to the user.

In the Zero Investment Model, Midea is responsible for full investment. When energy-savings are achieved, Midea receives 100% of the benefits. Once Midea reaches the agreed-upon baseline of energy-saving benefits, the project is transferred back to the user.

Currently, this business model has primarily been applied in northern Chinese regions and has not yet been expanded to include heating projects in rural areas. Nevertheless, it is worthwhile to explore and promote the BOT model for public buildings in rural areas, such as schools and hospitals.[12]

3.3 Solar roof leasing

In this model, the solar leasing company takes on the primary responsibility for investing, designing, and installing rooftop PV systems. Throughout the contract period, the company pays an annual rooftop leasing fee to the farmers. Upon the completion of the contract, ownership of the equipment will be transferred to the property owner.

Case study: Shandong Province, Dezhou Qihe County in Dezhou City, Shandong Province, stands as a key national and provincial pilot for the extensive deployment of distributed PV at the county level. Notably, PV installations have been completed on the rooftops of 2,410 households across 54 villages in 15 towns. The project received investments totalling 1.4 billion yuan (196 million USD) from a national state-owned enterprise and a county-owned enterprise, contributing to the venture through jointly established companies with an 8:2 capital ratio.

Before initiating the project, the government proactively engages rural households, encouraging their participation and collaborating with developers to survey farmers interested in joining. Those households expressing willingness to collaborate sign agreements with the company. As per the agreement, the company compensates households with an annual leasing fee of 35 yuan (4.9 USD) per PV on their rooftop.

Figure 3 Landscape Map of Qihe County

Prior to the commencement of the large-scale project, the company enters into contracts with the village committee. These contracts specify that the company provides the village committee with an annual assistance payment of 3 yuan (0.4 USD) per PV panel for maintenance and repair. Some basic maintenance and repair tasks are then managed by the village during the contract period.

[12] Mei di gongsi Rurenergy 2022 nian hui fayan (The spokesperson for Midea Corporation at the Rurenergy 2022 Annual Conference.)

In various regions, different models are employed. Concerning rental revenue, property owners can opt for either of the following methods:

- Rent + Dividends: Throughout the contract period, an annual rent of 35 yuan (4.9 USD) per panel is paid, and the company also distributes dividends to property owners based on profitability. (Dividend distribution may vary for different rural houses in different regions, and profitability is subject to significant uncertainty.)
- Gradual Rental Prices: The rental prices follow a tiered structure, with the first five years at 60 yuan (8.4 USD) per panel per year, the next five years at 40 yuan (5.6 USD) per panel per year, and the subsequent 15 years at 25 yuan (3.5 USD) per panel per year. Upon the expiration of the contract period, the company may choose to give the PV facilities to the property owners.[13]

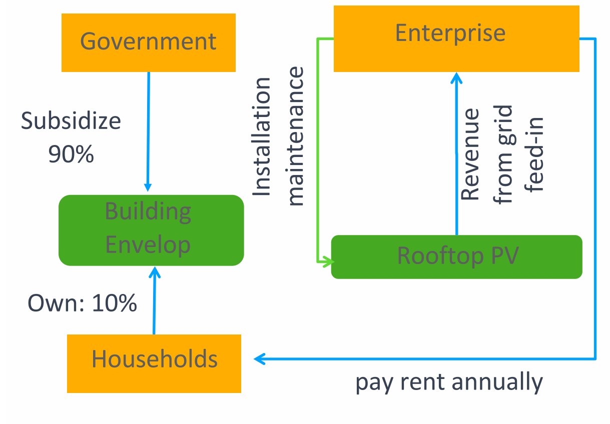

Figure 4 Solar Roof Leasing Model

Although the leasing model has developed rapidly in China, there is currently a notable absence of self-consumption of the generated electricity. Rural households could gain greater resilience against subsidy reductions or variations if they can actively benefit from self-consumption.

3.4 Self consumption: PV + Air Source Heat Pump

Companies choose idle land within the courtyards of rural households, constructing 1-2 sets of PV systems, with each set generating 25 kW and occupying an area of approximately 250-500 m^2. In areas with favourable sunlight conditions, the annual radiation can exceed 1800 hours. A 25-kW system yields an annual electricity generation of over 45,000 kWh. Considering the local grid electricity prices, ranging from 0.25 to 0.35 yuan/kWh (0.035 to 0.049 USD/kWh), the full annual income for one set of PV is approximately between 11,250 yuan (1,579 USD) and 15,750 yuan (2,209 USD). The construction and installation costs are about 80,000 yuan (11,219 USD). Consequently, the payback period ranges from 5.1 to 8.1 years, with an equipment lifetime of around 30 years.

[13] Quanguo nengyuan xinxi pingtai. (2022). Cunzhuang wuding guangfu zujin 35 yuan/nian/kuai! Shandong pingyuan xiafa zhengxian wuding guangfu kaifa mingbai zhi (Rent for village rooftop solar is 35 yuan/year/piece! Shandong issues a clear paper on county-wide rooftop solar development). https://baijiahao.baidu.com/s?id=1730797314037808439&wfr=spider&for=pc

Figure 12: PV + Air Source Heat Pump

Case Study

The PV installation company enters into an agreement with rural households, investing in and installing 1-2 sets of PV units on idle land within their courtyards. The company receives the entire revenue from the feed-in electricity generated by the PVs, and the contract duration is 20 years. Upon contract signing, the company selects appropriate air source heat pump units based on the house structure and area, and covers all expenses related to equipment procurement and installation. Throughout the contract period, the company bears the operation and maintenance expenses of the PVs. Households incur an annual heating cost not surpassing 3000 yuan (420.74 USD), determined by the actual usage data from the heating equipment metering in each household. After the contract period, the households will have the complete annual income from the PV electricity generation and will be responsible for the equipment's operation and maintenance expenses themselves.

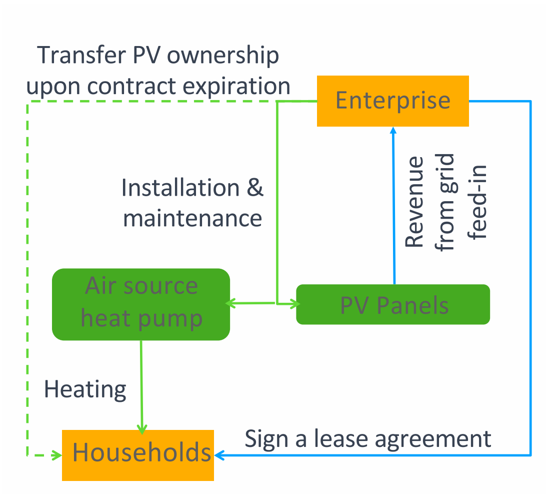

Figure 5 PV + Air Source Heat Pump Business Model

3.5 Energy Management Contract

The Energy Management Contract (EMC) is a business model in which the achieved energy cost savings cover the entire expense of energy efficiency projects. Energy service companies offer services to customers with a guarantee of energy savings.

Case Study: Hualong Hui Autonomous County, Qinghai Province

Hualong County is situated in Qinghai Province. The county experiences a high-altitude continental climate characterized by an average annual temperature of 2.2℃, a frost-free period lasting 89 days, and an average annual precipitation of 470 mm.

Shanghai Zhuneng Environmental Technology Co., Ltd. (referred to as the 'Company') has successfully implemented clean heating through EMC, encompassing a heating building area of 76,185.77 m^2 (comprising all public buildings in the rural areas). The system utilizes 74 sets of heating pumps, employing an efficient dual-energy approach with 'solar energy-assisted heat pumps' and 'heat pumps cascading the utilization of solar energy.' These systems are designed to operate in environments as low as -35°C, providing heating temperatures exceeding 65°C. The product features a simple structure, reliable operation, low cost, low expenses, and minimal electricity capacity requirements.

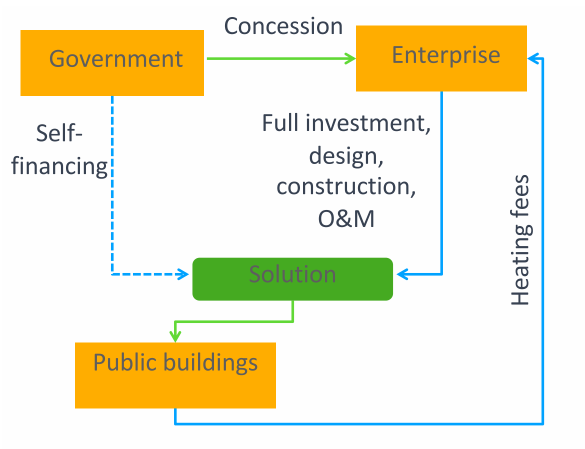

Figure 6 Energy Management Contract Model

In this business model, the company made the initial investment, installed the equipment in phases, and was responsible for monitoring, operating, and maintaining the equipment throughout the contract period. Users are not required to invest any capital; instead, they need to pay heating fees during the heating season, which are lower than the costs incurred prior to the project.

3.6 PV, energy storage, direct current, flexibility (PEDF)

PEDF is regarded as one of the key technical pathways for rural energy transition and has already undergone technical demonstration projects.

In December 2021, buildings with 2MW PEDF in Zhuangshang Village, invested by the State Power Investment Corporation (SPIC) (China Power International), was officially connected to the grid. This project stands as the world's first commercially deployed rural PEDF, serving as a model in China. The project utilizes the rooftops of over a hundred rural houses, with the company investing approximately 12.5 million yuan (1.75 million USD). [14]

In the initial phase, the project successfully implemented PEDF systems for 71 households. The project's distribution networks were designed to facilitate the safe, efficient, and flexible integration of rooftop PV, household energy storage, DC home appliances, electric vehicles, and other equipment. Microgrids were established within the neighbourhood, connecting each rural house. The microgrid enables seamless interaction among rural houses, street lights, centralized energy storage, centralized wind and solar fields, and the higher-level power grid. This integration allows for the optimal utilization of renewable energy and effective peak shaving in electricity loads, addressing challenges, such as rural grid capacity expansion and peak load regulation.

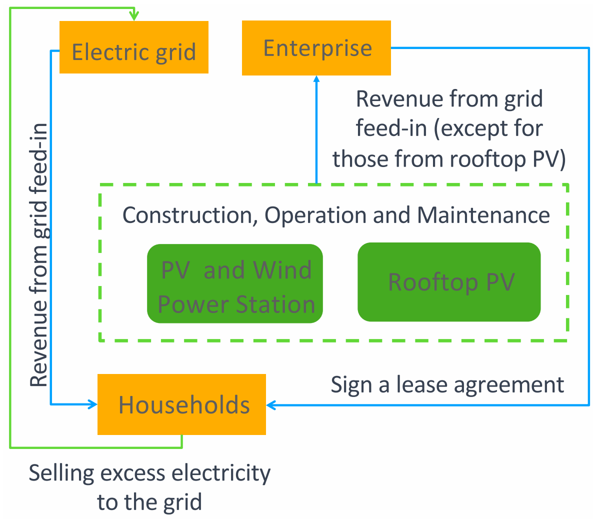

Figure 7 PV and Energy Storage Integrated Flexible Building Model

In the first half of 2022, Zhuangshang Village achieved a total electricity generation of 1,178,430.75 kWh, with a grid electricity

[14] Beijixing Chuneng Wang. (2022). Ruicheng xian Zhuangshang cun 2MW nongcun guang chu zhi rou xitong zhengshi wancheng bingwang (The 2MW rural solar energy storage and direct flexible system in Zhuangshang Village, Ruicheng County, has been officially completed and connected to the grid). https://news.bjx.com.cn/html/20220110/1198314.shtml

price of 0.332 yuan (0.046 USD) per kWh, resulting in revenue of 390,000 yuan (54,730 USD). This initiative led to a reduction of 1,175 tonnes of carbon dioxide emissions, 35 tonnes of sulfur dioxide emissions, and 17.7 tonnes of nitrogen oxide emissions. Each household in the village experienced a 600-yuan (84 USD) increase in income through rooftop rent. The electricity generated by the PV panels on the roofs can be utilized for self-consumption or storage, with any surplus being sold to the grid for additional income. Except for lighting, production, heating, electrification has been also realised for cooking, hot water, and production. Agricultural equipment, transportation vehicles, and household cooking and hot water equipment have all transitioned to electrical appliances.[15]

Building upon the successful demonstration in 71 households in Zhuangshang Village, the next phase involves expanding the project to cover the entire village. Upon completion, the project is anticipated to reduce annual carbon dioxide emissions by approximately 2,500 tonnes.

[15] Souhu Wang. (2022). 'Meili Shanxi Shengtai Xing (Huanghe Pian)' Di Shiliu Zhan Ruicheng (2) Huanghe yabian jian qi Zhongguo di yi ge 'ling tan cunzhen' (The 16th stop of the 'Beautiful Shanxi Ecological Journey (Yellow River Edition),' Ruicheng (2), has established the first 'zero-carbon village' at the edge of the Yellow River in China.) https://www.sohu.com/a/584696849_121106854?_trans_=000019_wzwza

4. Business Models in the EU and globally

4.1 Accelerating deep renovations: Energiesprong

Energiesprong, originating in the Netherlands in 2013, is an innovative and scalable model for deep energy retrofitting of buildings. It has been further promoted in other countries, including Germany, France, the United Kingdom, Canada, and the United States. In Germany, demonstration projects have been focused on multi-unit rental housing.

The retrofitted buildings achieve net-zero energy, maintain an indoor temperature of 21 °C, and have excellent sound insulation. The technologies employed in this model include:

- Prefabrication: Utilizing building survey data obtained through 3D laser scanning, prefabricated envelop is produced and attached to existing exterior walls to significantly enhance the thermal performance of the building envelope.
- Integrated systems: Some projects integrate heating, cooling, hot water, energy recovery ventilation, and controllers into prefabricated modules.
- Renewable energy: Rooftops with integrated solar PV panels and heat pumps are employed.

Through these technologies, the project has a shorter construction period, minimizing the impact on occupants. Additionally, economic viability is a highlight of this model. The large-scale retrofitting, prefabrication, and efficiently optimized design and construction processes significantly reduce the retrofitting costs. For homeowners, although they initially bear the retrofitting costs, they can fully recover this investment through tenant payment, such as tenants directly paying heating costs to the homeowner. For tenants, despite higher rent, the reduction in energy costs outweighs the increase in rent, at least to some extent.

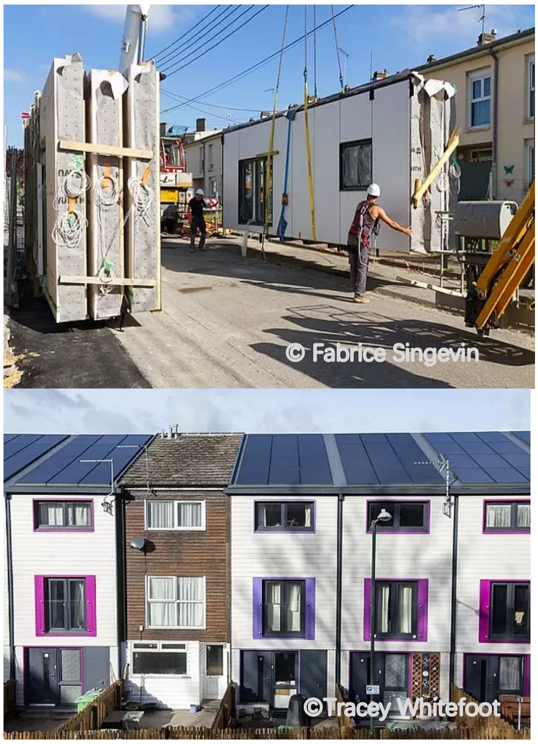

Figure 8 Energiesprong
https://www.co2online.de/

In addition to technical and quality assurance, the effectiveness of this model hinges on the presence of a reliable intermediary organization that acts as a bridge between building owners and diverse manufacturers of building envelopes and equipment systems. This organization plays a pivotal role in coordinating communication and fostering collaboration between homeowners and manufacturers, overseeing the entirety of the design and construction process. Moreover, it consolidates buildings from various owners to form a project pool, thereby achieving economies of scale. From the supplier's standpoint, the intermediary organization helps in identifying the required quantity and specifications, as well as gauging the homeowner's financial commitment. This facilitates a more precise evaluation of the necessary investments in research and production.

For the widespread adoption of this model, policies are crucial. In addition to supporting incentives for energy retrofitting, governments need to provide financial support for demonstration projects, technological innovation, and research and development of such models. For example, when initially launched in the Netherlands, the government provided €50 million for the development of this model, with €40 million allocated for subsidizing building energy retrofits. This policy provided signals to the market, and suppliers responded actively, rapidly expanding production scale. [16,17]

Advantages:

- Prefabricated module technologies significantly shorten the construction period.
- High-quality assurance of building components and systems.
- A trustworthy intermediary organisation that coordinates between suppliers and building owners.
- Government funding support for business model demonstrations, technological innovation, and research and development, which signals the market.

4.2 On-bill schemes

On-bill financing (OBF) and repayment (OBR) are financing options in which a utility or private lender supplies capital to a customer to fund energy efficiency and renewable energy projects and is repaid through regular payments on an existing utility bill. [18]

Residential buildings are a major target group of the on-bill schemes. These programmes have been implemented in the USA for more than 30 years and have recently been piloted in Europe. In the USA, two approaches are predominant: Under On-bill Financing (OBF), utilities bear the upfront costs. Conversely, in the On-bill Repayment (OBR) program, a private third party extends loans to homeowners, with the utility serving as an intermediary for repayment. [19] Rural electric cooperatives have been leaders in implementing OBF, because the schemes also help to overcome the specific challenges faced by rural communities, namely, low energy efficient buildings with low efficient appliance, low-income households, and high spending on energy. [20,21] In South Carolina, the Central Electric Power Cooperative (CEPC), a provider of wholesale power to 20 rural electric cooperatives (co-ops), embarked on

[16] US Department of Energy. (2020). Prefabricated Zero Energy Retrofit Technologies: A Market Assessment https://rmi.org/wp-content/uploads/2020/04/prefabricated-zero-energy-retrofit-technologies.pdf

[17] Energiesprong. (n.d.). Energiesprong. https://energiesprong.org

[18] U.S. Department of Energy. (n.d.). Better Buildings Financing Navigator. https://betterbuildingssolutioncenter.energy.gov/financing-navigator/option/bill-financingrepayment

[19] U.S. Department of Energy. (n.d.). Better Buildings Financing Navigator. https://betterbuildingssolutioncenter.energy.gov/financing-navigator/option/bill-financingrepayment

[20] ACEEE. (2019). On-Bill Financing Gains Ground but Faces Barriers to Wider Adoption. https://www.aceee.org/blog/2019/04/bill-financing-gains-ground-faces

[21] (n.d.). The Help My House Model. https://www.eesi.org/obf/case-study/helpmyhouse

an ambitious mission to reduce residential energy consumption in the co-ops' by 10% within a decade. This objective presented a unique challenge, especially in lower-income areas. To address this, CEPC collaborated with the Electric Cooperatives of South Carolina (ECSC), a trade organization representing the co-ops, to launch an energy efficiency program called "Help My House."

The program was initially piloted from 2011 to 2013, offering a 10-year loan with a 2.5% interest rate to homeowners, covering the entire upfront costs. Repayment of the loan was structured through charges on the monthly electric bill. Notably, about one-third of the resulting energy savings contributed to reducing the monthly electric bill, while the remaining two-thirds were allocated to repay the loan. To support this initiative, the USDA's Rural Economic Development Loan and Grant (REDLG) Program provided co-ops with a no-interest loan of $750,000 to capitalize the pilot lending pool. To maximize energy savings, the pilot program adopted a "whole-building" energy retrofits approach. Participating households underwent an energy audit, and based on the findings, co-ops facilitated the selection of qualified contractors. Furthermore, the co-ops closely supervised the implementation of the projects to ensure that the desired results were achieved before disbursing payments to the contractors.

Consequently, participants achieved an average reduction of nearly 35% in their energy consumption, resulting in approximately $25 savings on their monthly electric bills. Remarkably, these savings were realized even as participants were repaying their energy efficiency improvement loans. The pilot program would avoid approximately 6.7 million tonnes of greenhouse gases emissions over the span of 10 years. [22] Due to the success of the pilot, in 2014, USDA established the Energy Efficiency and Conservation Loan Program (EECLP), which provides loans to rural utilities for supporting energy efficiency projects, including on-bill financing. [23]

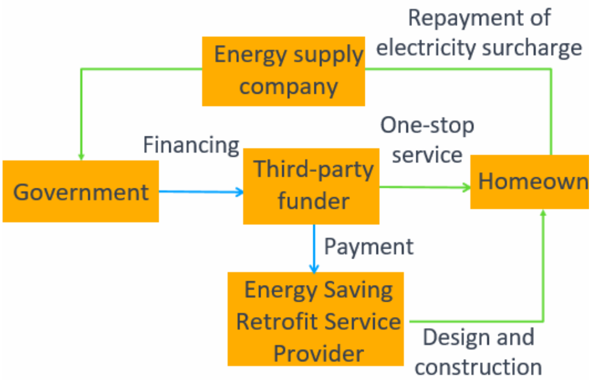

Figure 11: Picadi Energy-saving Renovation Model

This model has recently been piloted in Europe. One notable example is the Picardie Pass Renovation (PPR) pilot project initiated by the Picardy Regional Government and the Public Service for Energy Efficiency (PSEE) in France. PSEE is also the first public institution in France to establish a third-party financing mechanism.

[22] EPA. (2017). Help My House. https://www.epa.gov/sites/default/files/2017-06/documents/help_my_house_profile_6-1-16_508.pdf

[23] EESI. (n.d.). The Help My House Model. https://www.eesi.org/obf/case-study/helpmyhouse

The program is designed to accelerate energy renovations for private houses in the region. Under the PPR, the comprehensive renovation project involves:

- Offering technical support, including energy audits and project planning, to homeowners.
- Covering the upfront costs of renovation work, averaging €44,000.
- Managing the entire project, encompassing the selection of companies, tendering, site monitoring, as well as the management and payment of invoices.
- Providing individual follow-up for 5 years after the renovation, offering support in the use and maintenance of equipment, along with monitoring and analyzing energy consumption.

Owners repay the renovation costs through energy bills to municipal utility companies, at a favorable rate of 2.5%, spread over 15 years for equipment and up to 25 years for building insulation. The repayment amount is capped at or less than the energy savings. In the event of a change in ownership the new homeowner continues the repayment.

To secure the necessary upfront funds, the Picardy government earmarked €8 million from its own funds, obtained a €4 million ELENA (European Local Energy Assistance) subsidy, and secured a soft loan of €35.5 million from the European Investment Bank.[24]

Advantages:

- It addresses the challenge of high upfront investment costs for energy renovations and the installation of renewable energy sources, especially considering the difficulty low-income households face in obtaining loans from financial institutions.
- It significantly improves indoor comfort and living quality through energy renovations.
- Due to homeowners repaying the loans through their energy savings, the risk for the investing party is low.
- It helps utility companies to achieve their obligated energy efficiency goals.
- The project management agency provides one-stop services.

4.3 Solar roof leasing

This business model is similar to that in China, with the key difference being that property owners have the option to utilize self-generated solar power. Solar leasing companies invest in, design, and install rooftop solar systems. During the contract period (10-20 years), property owners make monthly payments for electricity consumption. In this model, users can choose to be self-sufficient or feed excess solar power into the grid, generating income based on grid electricity prices or through a net metering mechanism. At the end of the contract, property owners have the option to purchase the system at a discounted price. This model has gained popularity among house owners in Germany and has also been promoted in the United States, with SolarCity being a leading supplier.[25]

[24] Hauts-de-France Pass Renovation (n.d). Hauts-de-France Pass Renovation, the technical and financial instrument designed by the regional Public Service for Energy Efficiency. https://www.pass-renovation.hautsdefrance.fr/a-european-project/

[25] Roesch,A. (2016): EU-wide solar pv business models.

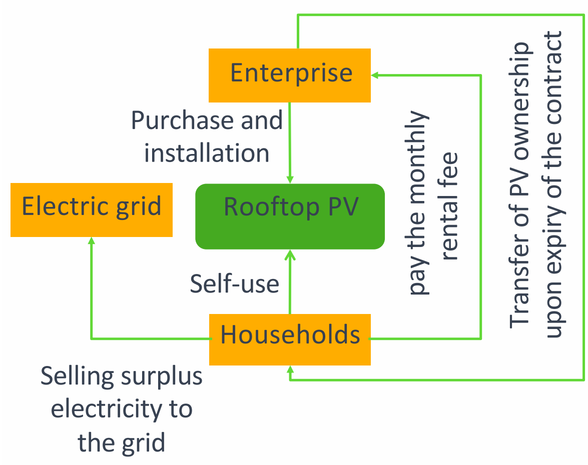

Figure 9 Solar Leasing European Model

Case: Enpal in Germany

Enpal is Germany's largest solar energy solution provider, boasting over 10,000 lease customers as of 2021. Customers have the option to lease photovoltaic panels, batteries, and charging boxes. Enpal offers comprehensive services ranging from design, installation, maintenance, insurance, to energy management and other related services. The intelligent energy management system measures PV output, battery charging capacity, and energy consumption. The initial investment for Enpal's PV systems is funded through bank loans. Enpal has strategically partnered with several banks. The scale achieved by bundling thousands of solar rooftops in projects also enables Enpal to secure more favorable loans from banks.

This business model overcomes challenges users face regarding initial investment, uncertainty about the quality of PV panels, and subsequent operational difficulties. Depending on the scale of the system installation, users pay a fixed monthly rent. During the contract period, they can choose to be self-sufficient or feed excess solar power into the grid. Typically, the contract duration is 20 years, and after its completion, users have the option to purchase the system for 1 euro. The cost-effectiveness for consumers depends on several factors, including the system's scale, grid electricity prices, the proportion of self-consumed electricity, and the development of household electricity prices.[26]

[26] https://www.enpal.de/

5. Conclusion

Energy retrofits and the adoption of clean heating technologies in rural areas play a pivotal role in realizing China's dual carbon goals, offering multifaceted benefits encompassing the environment, health, economy, and society. These initiatives not only propel high-quality rural development but also contribute significantly to rural revitalization. Despite notable progress in recent years, substantial challenges persist. In certain regions, there has been a regression to coal usage among households. Energy renovations for rural homes are falling behind, and many households face financial constraints in pursuing these essential upgrades. Government subsidies are instrumental in promoting clean heating but have imposed significant financial pressure on the government. Therefore, the development of sustainable business models is crucial in advancing rural sustainable energy transition.

This report collects diverse business models from China, Europe, and worldwide for energy renovations and clean heating in residential buildings that can be suitable for the two target provinces, Henan and Gansu. Subsequently, we engaged with stakeholders to assess the feasibility of these business models and adjusted them tailored to the specific conditions of these regions. The "One Village, One Factory" model, successfully implemented in regions abundant in agricultural wastes in the two target provinces represents a significant stride towards rural sustainable energy transition. Similarly, PV roof leasing, notably in Henan Province, has gained popularity, but the challenge arises when the generated power is solely fed into the grid, posing strain on the local grid infrastructure. To overcome this hurdle, embracing self-consumption practices, a common strategy in Europe, especially for technologies like heat pumps, emerges as a viable solution. On-bill financing business models showcase a promising approach where companies cover upfront costs of both PV and heat pumps, and households gradually repay heating expenses over the contract period. However, the success of such models relies on establishing an effective heating fee collection system, a task that can be facilitated through support from utilities or local government. Looking ahead, the exploration of PV, energy storage, direct current, and flexibility (PEDF) introduces exciting prospects for achieving self-sufficiency and unlocking substantial economic benefits for rural households and villages. Implementing this business model requires a holistic village-wide strategy, encompassing the utilization of all available rooftops and courtyard spaces, the systematic planning and construction of photovoltaic (PV) systems and equipment in batches, the upgrading of local grids, ensuring access to financing, and the establishment of policies that facilitate self-consumption within the communities.

Partner organisations:

Funded by the European Union