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PV Electrification in India and China: The NREL's Experience in International Cooperation

J. L. Stone,[1] Y. S. Tsuo,[1] H. S. Ullal,[1,*] W. L. Wallace,[1] E. V. R. Sastry[2] and Li Baoshan[3]
[1]*National Center for Photovoltaics, National Renewable Energy Laboratory, Golden, CO 80401, USA*
[2]*Ministry of Non-Conventional Energy Sources, New Delhi, India*
[3]*State Science and Technology Commission, Beijing, China*

The US Department of Energy (DOE) through its National Renewable Energy Laboratory (NREL) has initiated rural development projects in India and China to demonstrate the viability of photovoltaics in meeting the needs of the rural masses for cost-effective and reliable electricity. This paper contains details of the major projects in the two countries, along with descriptions of the implemented photovoltaic systems and lessons learned to date. The successful outcome of these projects will allow duplication of the experiences in other developing areas of the world. © 1998 John Wiley & Sons, Ltd.

INTRODUCTION

Economic development throughout the developing world has created a need for electricity in both the urban and rural areas. Some two billion people[1] are currently without any or adequate electricity to realize an improvement in their quality of life. Most of these people have little or no access to an electrical grid, therefore distributed sources of electrical power, such as photovoltaics, offer a practical and economic alternative to conventional generation. India and China, the world's most populous countries, were chosen by the US Department of Energy (DOE) to implement photovoltaic (PV) applications to demonstrate[2] the economic viability and social acceptance of PV systems for such applications as home lighting, water pumping, communications, vaccine refrigeration, battery charging, solar lanterns, small power systems and other off-grid systems. The governments of the two countries are participating on a cost-shared basis and will be responsible for sustaining the initiatives beyond what the original projects are able to deliver. Further, it is expected that the results and improvements that occur can be replicated in other areas of the world where similar needs exist. The following material is representative of the initial experiences in the two countries. In addition, the National Renewable Energy Laboratory (NREL) has international agreements in renewable energy technologies with Argentina, Brazil, Chile, Ghana, Indonesia, Mexico, Nepal, Russia and South Africa.[3]

INDIA

A cooperative program was established in 1993 by the governments of India and the US. The 50–50 cost-share project funded $500,000 of PV systems for home lighting, water pumping, battery charging and

* Correspondence to: H. S. Ullal, National Center for Photovoltaics, NREL, 1617 Cole Boulevard, Golden, CO 80401, USA. E-mail: Ullal@nrel.gov

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vaccine refrigeration systems in the Sundarbans region of West Bengal, India. The project was designed as a sustainable rural economic development initiative with the Ramakrishna Mission, a well-respected humanitarian non-government organization (NGO) in this remote area of India. Special attention was paid to building an infrastructure for financing, installing and maintaining the PV systems. A before-and-after impact study on the beneficiaries is being done. Lessons learned to date are presented, along with details of the installed systems.

Background

The Sustainable Rural Economic Development Ramakrishna Mission PV Initiative was conceived as a small-scale demonstration project that would show the economic viability of PV systems in the Sundarbans region of West Bengal.[4–6] This region comprises hundreds of villages criss-crossed by branches of the Hoogly River. There is no electricity grid in the area. Thousands of families living in the region depend on kerosene lighting systems and have no access to communications, television or health facilities that require electricity.

The viability of the project was predicated on the systems being economical without substantial subsidy, and eventually without any subsidy at all. The operation and maintenance of the systems were the responsibility of the chosen NGO, the Ramakrishna Mission. The role of the Mission personnel was to identify beneficiaries of the PV systems, to define a financing arrangement that would be acceptable and sustainable to the villagers of the region and to serve as a banker to collect revenues from the end users. The potential for expanding the project beyond the limited demonstration was also a prime consideration. The cooperative nature of the project was expected to lead to improved relationships between our two countries and lead to further trade expansion. The project was also designed so as not to distort market forces, i.e. true costs. Further, without excessive subsidies and with end-user money required for participation, it was expected that the systems would have the best of care. A more important consideration is that the benefits of electricity would be made available to those who in the past had little or no access. Improvements in educational opportunities, health care, productivity and entrepreneurship were standards for the success of the project. Finally, the project was designed to be self-sustaining. An infrastructure should remain that would support further applications, including financing, education, training, repair and maintenance. Successful PV deployment under these most difficult circumstances would pave the way to acceptance of the technologies as a way to fulfill the tremendous need for energy in the developing world.

Photovoltaic systems

The following applications and participating villages were initially identified by the Ramakrishna Mission and agreed to by the NREL and the Ministry of Non-Conventional Energy Sources. In the village of Gosaba (with 1000 families), the training center will be provided with 10 lights for 4 h of operation each night, two 30-W wall sockets, a battery charging station for 10 (100 Ah) batteries and 20 solar lanterns, and three stand-alone streetlights with 11-W compact fluorescent lamps (CFL). The village of Katakhali, with 100 families, will be provided with 100 solar home lighting systems (SHS) with one 11-W CFL and one 30-W socket per home. The youth club will have two 11-W CFLs and one 30-W wall socket. Ten systems will be distributed to other villagers in the area. The village of Pakhirala will have its weaving center provided with three 11-W CFLs, a community street light and eight 11-W CFLs with two 30-W wall sockets. These additions to the weaving center will extend the productivity hours by about four per night. The health clinic in Satyanaryanpur will get a vaccine refrigerator and eight 11-W CFLs with two 30-W electrical sockets. A second battery charging station for ten 100 Ah car batteries will be placed at the Chota Mollakhali youth center. The village of Kumirmari will have 100 SHS with a 9-W CFL and a 30-W electrical socket. One home lighting system and one battery charging station have been installed in the village of Chotomollakhali for community purposes. Figure 1 shows the installation team mounting the PV module on a home owner's roof as the villagers look on. Figure 2 shows a close up of the mounting

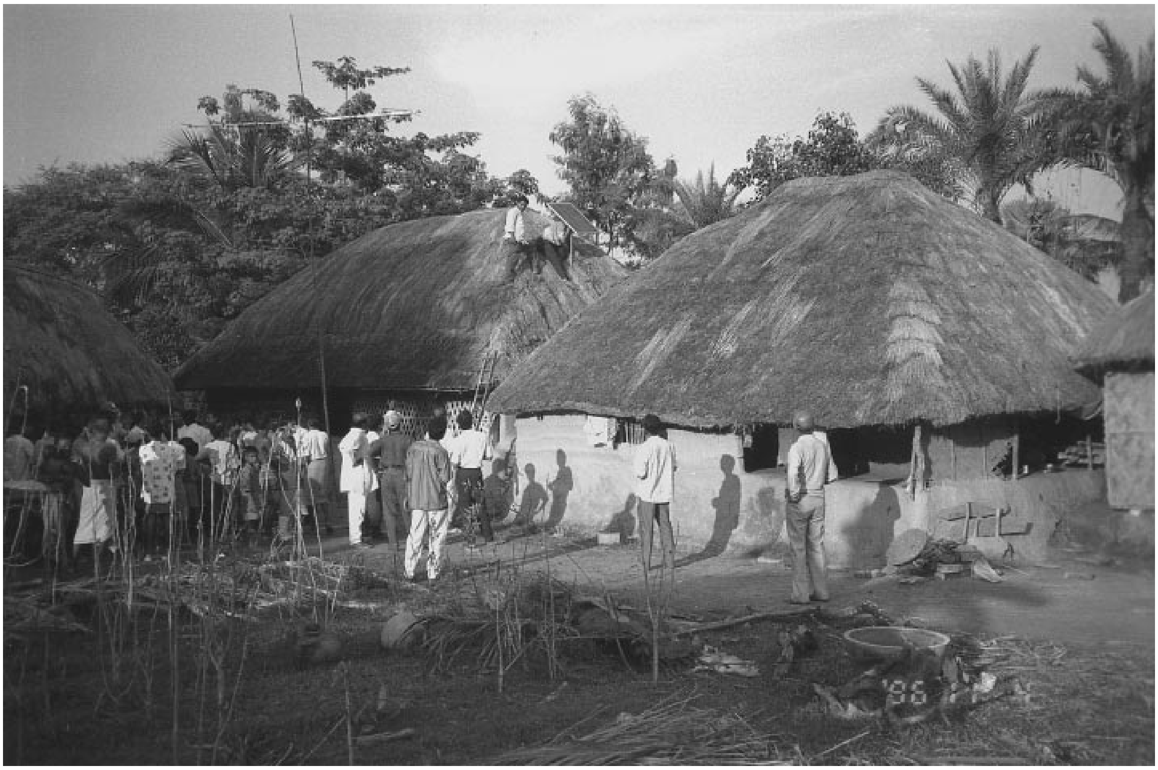


Figure 1. Installation team places a PV module on the home of a village beneficiary. Villagers gather around to witness the event. (Credit: NREL PIX 04877)

of the 50-W polycrystalline silicon PV module on a thatched roof. The solar resource in India varies from 4·6 to 6·4 kWh/m^{-2} day^{-1}, as given in Figure 3, which is very adequate for the applications installed.

A 2-week training program was available for 16 participants who were chosen by the Mission for their background in basic electrical applications (including radio and television repair). The Mission has a very good reputation for providing high-quality training in a variety of areas. Remote Power International of Fort Collins, CO prepared a detailed training manual that was left for the mission to continue training sessions after the trainers funded by the NREL leave the area. During the 2 weeks, the last week was used to do hands-on installations in the island communities. Figure 4 shows a hands-on training session at the Ramakrishna Mission headquarters in Gosaba. Applied Power Corporation of Lacey, WA, the project's systems integrator, has prepared detailed schematics for all of the systems provided. The Ramakrishna Mission trainers in turn have trained an additional 90 trainers who are capable of installing, maintaining and repairing PV systems. Table I shows a summary of the equipment to be provided.

Project structure

The agreement between the US Department of Energy and India's Ministry of Non-conventional Energy Sources (MNES) calls for 50–50 cost sharing: the USA provides the PV modules, charge controllers, a water pump and the training; India provides the batteries, CFLs, lamp fixtures, a vaccine refrigerator, mounting structures, all balance-of-systems components and solar lanterns, and pays all customs duties for the imported system components. The Ramakrishna Mission is responsible for identifying the recipients of the various systems and participants in the NREL-furnished training sessions, for providing follow-up training, maintenance and replacement and for collecting revenues from the end users. The NREL will also work with the Mission to identify potential private-sector partners with whom proposals

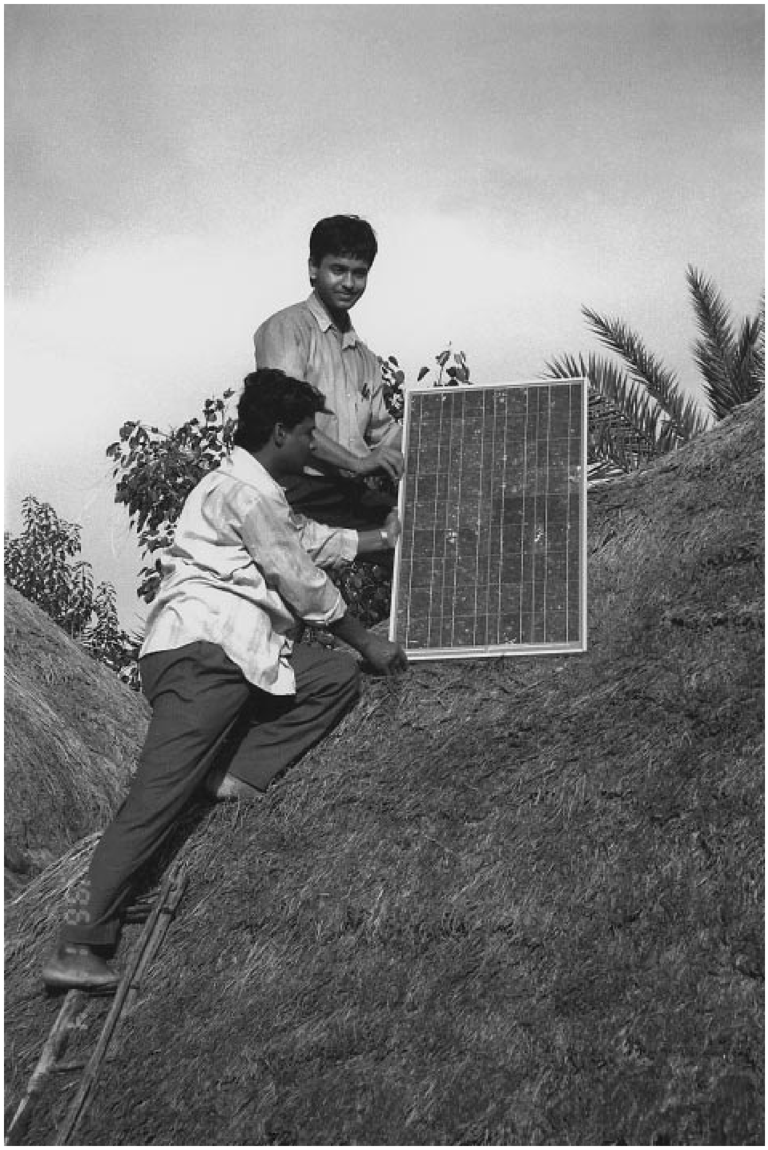


Figure 2. Ramakrishna Mission installation team mounts the PV module to the thatched roof of a village home. (Credit: NREL PIX 04875)

will be submitted to the Indian Renewable Energy Development Agency (IREDA) to move the project beyond the limited size possible from this initiative. The West Bengal Renewable Energy Development Agency is sharing part of the cost of the project and is providing technical guidance to the Ramakrishna Mission. The overall project structure is shown in Figure 5.

Revolving credit funds

In India, the domestic unit of two lights plus one wall socket along with the necessary PV panel, battery and accessories cost approximately Rs. 14 000 (1\$ $\approx$ Rs. 37). Out of this amount Rs. 6000 is available as a government subsidy. Hence, the amount to be borne by the user is Rs. 8000 per unit. The end user will be asked to provide a down-payment of Rs. 3500 at the time of installation. The rest of the amount

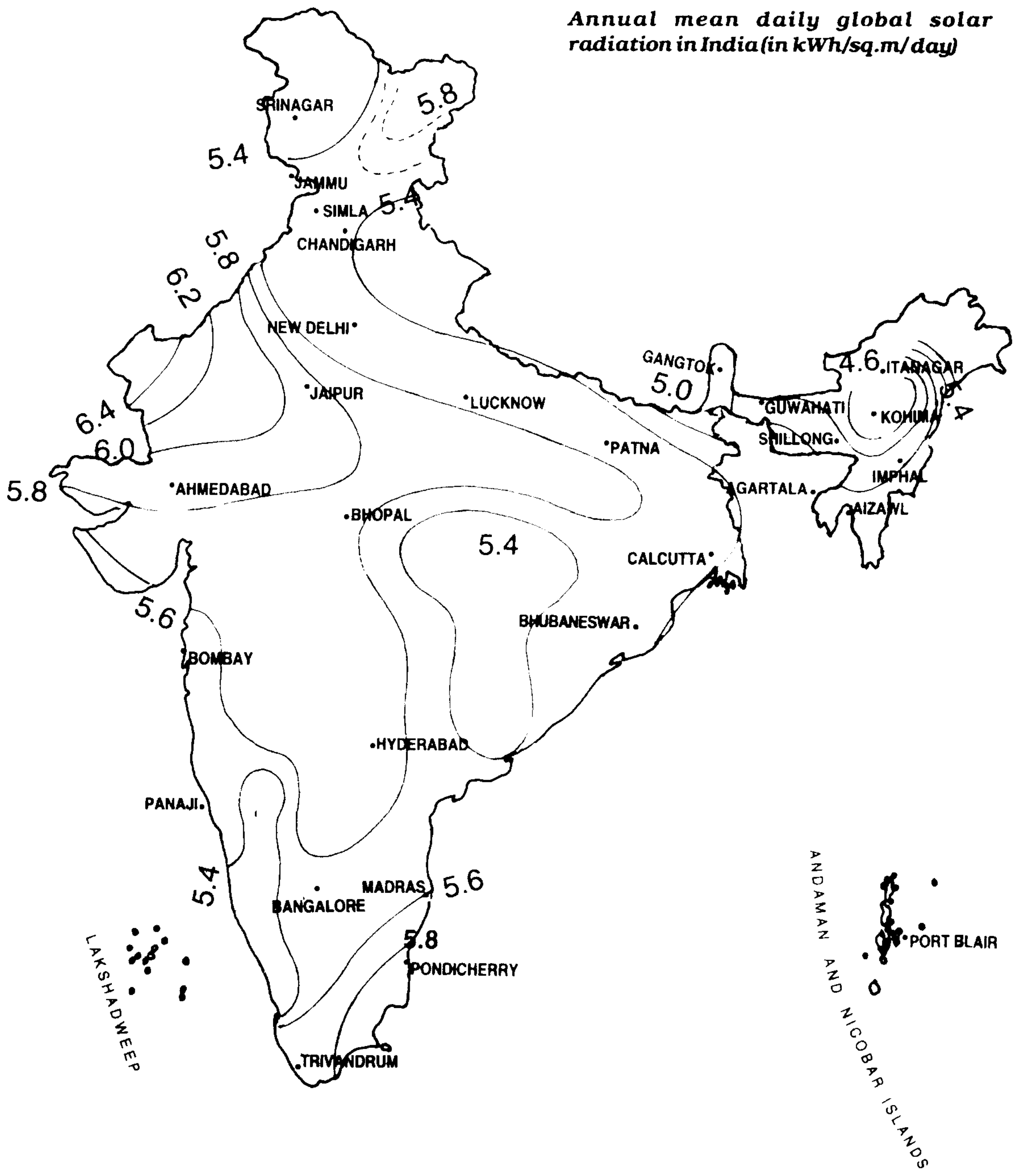


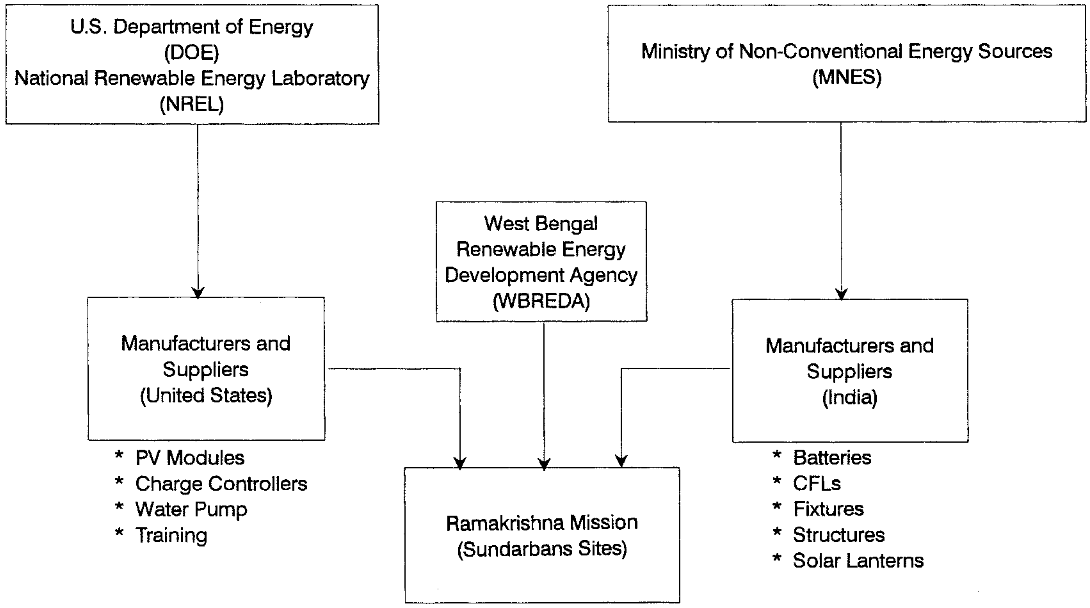
Figure 3. Solar radiation resource map for India showing the annual mean daily solar radiation in kWh m^{-2} day^{-1}. (Credit: NREL PIX 05495)

(Rs. 4500) will be treated as a low-interest loan to be repaid in monthly installments of Rs. 40 per month over 10 years. In this way, Rs. 40 x 12 months x 10 years, or Rs. 4800, will be realized — Rs. 4500 against the loan and Rs. 300 as interest. In addition, Rs. 20 per month will be charged for each unit as maintenance charges, for which the users will receive free service at their doorsteps. However, the costs for spares will be at the owners' expense. Thus, the users will pay a total of Rs. 60 per month for 10 years. They may also opt to pay Rs. 100 per month (80 + 20) for 5 years. For a few beneficiaries of special

Figure 4. The training team working with trainees at the Ramakrishna Mission center in Gosaba. (Credit: NREL PIX 04845)

Table I. Summary of systems and equipment to be provided

System type	Number of systems requested	Number of Solarex VLX-53 modules per system (50 W each)		Charge controller (one per system)
		Each	Total	
Solar Home Lighting System (SHS)	300	1	300	SunSaver-6LVD
Training Center	1	5	5	ProStar-30 Marine
Youth Club	1	2	2	ProStar-30 Marine
Weaving Center	1	5	5	ProStar-30 Marine
Clinic	1	5	5	ProStar-30 Marine
Portable lighting	1	2	2	ProStar-30 Marine
Vaccine refrigeration	1	10	10	ProStar-30 Marine
Spice grinding	1	14	14	None
Water pumping	1	16	16	SA-1500/SP5A-7 pump
Street lighting	15	1	15	Trace C-12
Solar Lantern Station	1	1	1	ProStar-30 Marine
Auto Battery Station	2	88	176	Two APT2-4X special
Total	326	150	551 (27·55 kW)	



Roles and Responsibilities

DOE/NREL:
* Purchase all necessary PV modules
* Purchase all necessary charge controllers
* Training

MNES:
* Purchase all necessary batteries (PV compatible)
* Purchase all necessary compact fluorescent lamps
* Purchase all necessary lamp fixtures (home and street lights)
* Purchase all necessary mounting structures, wiring, etc.
* Purchase a predetermined number of solar lanterns (with removable rechargeable batteries)
* Pay or waive custom duties

Ramakrishna Mission:
* Assume transfer of title of equipment from DOE
* Provide personnel for training on system installation
* Provide for maintenance and upkeep of equipment
* Responsible for revenue collection from end users

WBREDA:
* Provide technical backup to the project
* Provide PV powered vaccine refrigerator
* Receive funds from MNES for purchase of equipment bought in India
* Assist in installation where necessary
* Assist in maintenance and repair when necessary
* Perform data collection on selected systems

Figure 5. The sustainable rural economic development Ramakrishna Mission initiative project structure

category who are not in a position to make the Rs. 3500 down-payment, provision will be made to pay Rs. 500 only during installation and the rest of the amount will be treated as a loan to be repaid in 5–10 years. After the loan is liquidated, ownership will be transferred to the users. The amount recovered from the end users in the form of the down-payments and loan interest will form the 'Revolving Fund Capital' for the project, which in turn will be used to replicate the program among new users and also to finance the replacement of batteries. The sustainability of the project and its further replication is thus ensured through this arrangement. The latest information from the Mission indicates that there have been no defaults by beneficiaries in paying their monthly loan amounts.

Lessons learned

When involved in a project such as this in a remote location, you learn to be patient and expect the unexpected. In the USA, participants were determined through a public procurement process that takes typically 6–9 months to complete. After selection of Applied Power Corporation and Remote Power International as the system integrator and training provider, system components were shipped by boat to India. Upon arrival in Calcutta the shipment encountered a dock strike. After waiting patiently, the next obstacle to be overcome was payment of customs duties, the responsibility of the MNES. Unfortunately, the amount budgeted was inadequate because the components came in two shipments and the order could not be aggregated to take advantage of lower rates. Eventually all was taken care of, but then the rains came with the onset of the monsoon season and local holidays and festivals have to be respected.

Hence, the second lesson learned, and the most important, is to select a credible partner on the ground in the area. The Mission is a well-respected humanitarian NGO with excellent credentials in training, education and working with the area's poor. Just as important, the Mission was empowered to select the beneficiaries of the PV systems, become trained in installation and maintenance and serve as the banker to make loans and collect revenues from the project. The trained Mission personnel now have replicated themselves such that a full complement of trainers exist in the area, who can carry on once the government-funded project is completed. The Mission has established a solar store in the region with separate funding from the MNES where locals can purchase SHS, arrange for the subsidies on the spot and receive their systems from an inventory. This type of solar store has been proposed by the MNES for expansion this year to six stores. The NREL is working with the mission to identify a private sector partner to team together on a proposal to the IREDA to expand the project in the region. Tens of

Figure 6. Mother and son try their home lighting system for the first time. (Credit: NREL PIX 05466)

thousands of potential purchasers of PV systems have been identified in the Sundarbans region alone. The MNES has committed to an additional 2000 SHS in this fiscal year. This region can potentially have among the largest rural electrification projects in the world[7]. The RKM has sold an additional 1100 SHS in the months following the initial installations of 300 units.

Future requirements

In addition to the project being self-sustaining, it is important to identify both positive and negative impacts on the beneficiaries of the energy systems. To accomplish this, a before-and-after impact study in the region is being undertaken by the Tata Energy Research Institute (TERI), New Delhi, India. Another expectation by the governments of India and the USA is that business opportunities will be expanded as potential end users become better informed of the economics and performance of PV systems. This also extends to the financial community, who will be responsible for making the necessary loans for any significant future purchases. The NREL is working with the Solar Energy Centre of the MNES to develop test procedures for PV modules and systems. Such test standards will ensure that the various company's products will be evaluated on a fair and equitable basis as well as providing higher probability that reliable products will be fielded that meet expected performance criteria. The latest reports back from the Sundarbans indicate minimal system failures. Twelve charge controllers have failed either in service or prior to installation. These units have been returned to the manufacturer to determine the cause of the failures. The 50-W systems appear to be adequate for the users' needs. There have been no instances of hitting the low voltage disconnect (LVD), indicating that the batteries are operating at a high state of charge. Most end users do not have television and are using their lights 3–4 h each night. This contrasts with the 35-W Indian SHS, of which 700 have been sold. Of these, 20–30% are hitting their LVD.

A successful outcome of this project can have significant impact around the developing world. The experiences of the beneficiaries in the Sundarbans will be common to the two billion people who currently do not have access to the many benefits of cost effective and reliable electricity. The mother and son shown in Figure 6 switch on the light in their home for the first time, which tells a stronger story than any words.

CHINA

Rapid growth in economic development, coupled with the absence of an electric grid in large areas of the rural countryside, has created a need for new energy sources both in urban centers and rural areas in China. The most critical need for rural electrification exists in northern and western China, where 80 million people had no access to grid electricity at the end of 1995. In February 1995, the DOE signed an Energy Efficiency and Renewable Energy Protocol Agreement with the Chinese State Science and Technology Commission in Beijing. Under this agreement, NREL is providing assistance to several central government and provincial government agencies in China to develop photovoltaic and photovoltaic hybrid applications for rural electrification.

Background

The People's Republic of China is a rapidly developing and industrializing country with a population of approximately 1·2 billion people, of which about 80% live in rural areas. The use of solar, wind and biomass resources for general energy needs is already widespread in rural China, and the potential for the use of renewable energy resources for rural electrification is very large. For example, in the five northern and western provinces and autonomous regions of Qinghai, Tibet, Inner Mongolia, Xinjiang and Gansu, there are a minimum of 2·2 million unelectrified households that are located in a region of China where grid power does not exist.[8] For several hundred islands along the coast of China, the development of grid power in the near term is also not feasible. In the heavily populated regions of China where grid power does exist, there are still at least 20 million households without electricity due to severe shortages of

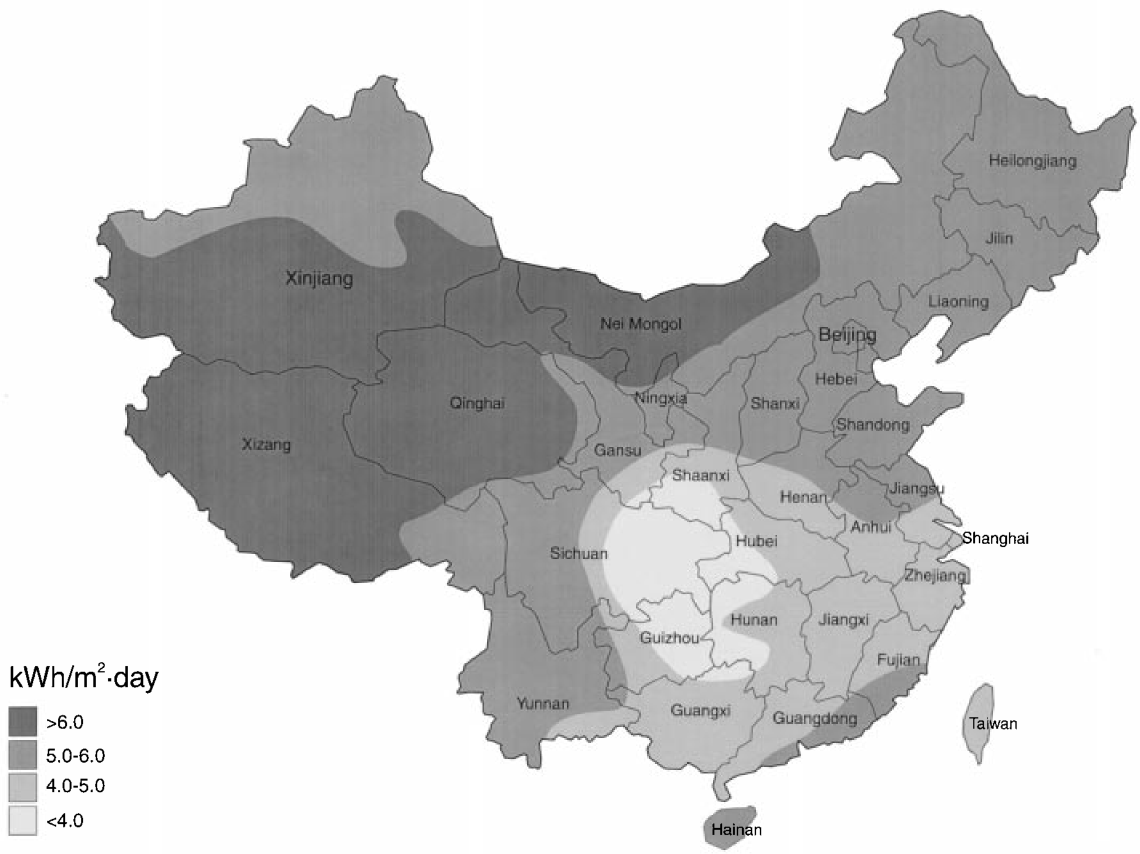


Figure 7. General distribution of solar resources in China: annual mean daily solar radiation in kWh m^{-2} day^{-1}. (Source: A. Wang and Y. Nan, 'Promoting solar markets in china for environmentally sustainable development', *Solar Energy in China*, Beijing, China, 1995, p. 120)

conventional electrical generating capacity based on coal-fired steam turbines and hydropower. There are also reliability problems and concerns over the environmental impacts of fossil power generation.

At the end of 1995, the total installed PV generating capacity in China was relatively small at about 6·6 MWp, of which 65% was used in the rapidly growing telecommunications market, 16% for household electrification, 11% for agricultural and industrial applications and 8% for consumer applications.[9] Currently, the market for telecommunications systems still represents the largest market for PV systems in China, but the fastest growing market is for remote SHS for basic lighting and power for television/radio. Photovoltaic and small wind technologies are increasingly being recognized as a cost-effective alternative to coal-based power generation and to conventional line extension for meeting rural energy needs. Figure 7 shows the general distribution of solar resources in China.

Solar home system development in western China

The US/China cooperation for rural electrification in China is focused on the development of SHS applications for western China. The cooperation started in the Province of Gansu and has now been expanded into the provinces of Qinghai and Xinjiang by the Chinese Ministry of Agriculture (MOA).[10] The Gansu project is being implemented by the Solar Electric Light Fund (SELF) in Washington, DC and the Gansu Solar Electric Light Fund (GSELF) in Lanzhou, Gansu, and builds upon work previously conducted by these organizations. The objective of the present phase of this project is to provide

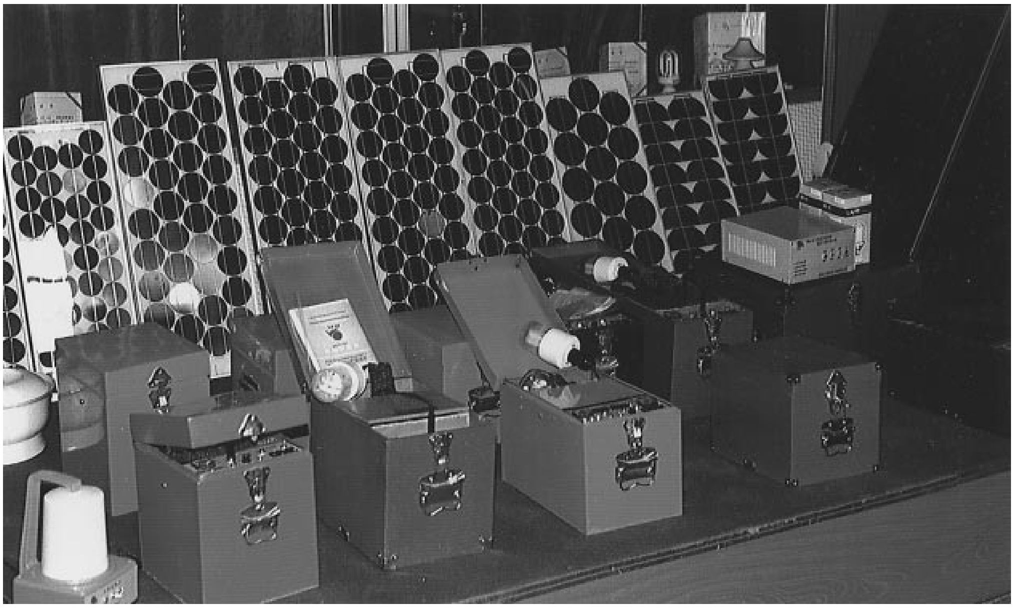


Figure 8. Examples of typical Solar Home System lighting kits that are sold in China. (Credit: NREL PIX 05400)

electricity to more than 600 remote homes and schools during the course of the project and help to construct an infrastructure for technology deployment in the form of a distribution network for sales and service, a comprehensive training program and experiments for financing systems through cash and credit sales.

A typical SHS in Gansu and for most of western China consists of a 20-Wp crystalline silicon PV panel, a charge controller, a 38-Ah sealed lead-acid battery, two 8-W compact fluorescent lamps and the necessary wiring. Examples of typical SHS kits that are sold in China are shown in Figure 8. The average retail price of such a system in Gansu is about 2400 RMB (US$290). The lack of credit experience in rural China necessitates the continued experimentation with installment credit terms to develop a functional credit system. The Gansu project is directed toward poor communities in rural Gansu, using limited subsidies that will be phased out during the course of the project. The planned overall recovery rate for the project is 80%. A revolving-fund account has been set up at the Lanzhou Branch of the China Construction Bank by SELF and GSELF to leverage the project by using customer receipts to purchase more systems.

The Gansu rural electrification project is a cost-shared project, with the DOE providing 50% of the cost (US$220 000) and the rest provided by Chinese partners, including: the Gansu Office of the Chinese State Council Office for Poverty Alleviation and Rural Development (US$110 000), the Gansu Planning Commission (US$44 000), the Gansu Economic and Trade Commission (US$44 000), and the Gansu Solar Electric Light Fund (US$22 000). Three local PV system integrators in Lanzhou are responsible for system assembly and installation, for providing product warranties and for after-sales support and training. The systems are owned by the households who purchase the systems and local technicians are trained to perform routine maintenance and simple repairs for the systems. Major system repairs or replacement is the responsibility of the company installing the system, under warranty.

The three companies represent three common types of business organizations in China. The Gansu PV Company is a privately owned company started by a local entrepreneur in Lanzhou. The Gansu Zi Neng Automation Engineering Company is a for-profit subsidiary of the Gansu Natural Energy Resources Institute (GNERI) in Lanzhou, which is a state-supported research institute. The Zhong Xing Electronic Instrument Company is a state-owned manufacturing company of electrical equipment, which has converted from being a military hardware supplier. These companies are supplying charge controllers,

Figure 9. Example of a charge controller manufacturing line in China. (Credit: NREL PIX 04304)

compact fluorescent lights, wiring, and support structures for the project. An example of a small-scale charge controller manufacturing line is shown in Figure 9.

The USA are supplying components including polycrystalline silicon modules from Solarex, complete USSC Unikit solar home lighting systems that incorporate a-Si:H modules and batteries from SEC Industrial Battery Corporation that are produced in a joint venture manufacturing plant in Shenzhen. In Phase I of the project, 180 Solarex 20-Wp VLX-20 PV modules, 180 38-Ah sealed lead-acid batteries, 10 complete 53-Wp solar lighting kits (consisting of Solarex VLX-53 PV modules, Ananda Power charge controllers and 65-Ah batteries) and 20 USSC Unikit SHS have been delivered and installed in Gansu during 1997. The 53-Wp PV systems were installed in elementary schools in Gansu in an education program associated with the project.

A major barrier to the widespread deployment of photovoltaics in China has been the variable quality of modules and balance-of-system components. Quality control is being implemented through component testing and system monitoring during the Gansu project. The NREL provided modules measured under standard test conditions as secondary testing standards to the three system integrators in Gansu. Chinese-made charge controllers have been bench tested for safety and reliability at both GSELF and NREL. As a result of charge-controller testing, recommendations were made for modifications to improve safety and reliability. A testing protocol was developed by Daystar, Inc. for testing simple shunt-type, 12-V charge controllers used for stand-alone systems.

A training program has been conducted to train users and installers and teach marketing techniques. A 2-week PV technician training seminar has been conducted in Lanzhou with 35 people attending. Most attendees were village technicians and rural energy officers. The seminar teaches basic principles of solar electricity as well as PV design, installation, and maintenance. As an outcome of the Gansu project, the MOA has establish a regional testing and training center in Lanzhou that will provide services throughout northwest China.

The current project emphasis is on capacity and infrastructure building to develop a commercial market for SHS. Partners include the rural energy office network to reduce the high cost of marketing, distribution and SHS in remote areas. The rural energy offices at county, district and township levels provide local market assistance to identify customers and help to monitor the post-installation performance of systems. Experience gained in working with the MOA and its extensive rural energy office network will help in the future expansion of the project to other parts of China. The MOA has rural energy offices in 1800 of the 2300 counties in China.

Based on the results to date in the Gansu project, the Chinese MOA plans to extend the project into five additional western provinces in China. In 1998, the MOA started development of a 10 000 SHS project to be completed by the end of the year 2000 with financial assistance from the State Council Office for Poverty Alleviation and Rural Development and local provincial agencies. The NREL is providing technical assistance to the MOA in the design phase of this expanded rural electrification project.

The MOA plans for infrastructure development include making use of an extensive network of agricultural service stations that are supported under the rural energy office network. These service stations normally provide repair services for agricultural machinery, but many service stations have now entered the business of selling and repairing SHS in remote areas. Solar home systems have become the primary business for a few of these service stations, which is conducted mainly on a private enterprise basis with minimal financial support from government sources. Some SHS distributors have also contracted with village retail outlets for electronic consumer products including radios and television sets. These village outlets sell and repair consumer electronic products and are now beginning to include SHS in their product inventory.

Hybrid systems for remote households in Inner Mongolia

The Inner Mongolia Autonomous Region (IMAR) in northern and western China has a population of about 23 million people, 14 million of whom are herdsmen. The land area of the region is 1·18 million km^2, and 75% of the land area consists of grasslands. The average population density in the IMAR is approximately 19 people per km^2, but in the remote rural areas the population density is equal to or less than 3 people per km^2. The annual solar energy density in IMAR ranges between 1280 and 1860 kWh m^2.

The IMAR government has been aggressive in developing renewable energy resources for both grid-connected utility and off-grid applications. In an aggressive rural energy development program over the past 10 years, more than 120 000 households have been electrified with small wind generators of energy in the range 100–300 W. In addition, more than 7000 small PV systems (a total of 120 kWp) had been installed in remote households at the end of 1994. An extensive infrastructure to support rural energy development in the form of a new energy service station network was also established in 56 of the 73 counties in IMAR. This infrastructure provides installation, maintenance and sales support services for rural energy systems.[11] To date there has not been a systematic investigation of the performance and status of these installations, although it is known that equipment failures and system reliability are problems.

There are still more than 300 000 remote households, 1100 villages and 198 townships that are unelectrified in remote rural regions of IMAR. By the year 2000, the New Energy Office of IMAR plans to install 25 000 remote household systems in IMAR and a total of 80 000 remote household systems using wind, PV and wind/PV hybrid systems in the longer term. In 1997, 48 township centers in IMAR were electrified using a combination of conventional grid extension and renewable energy central village hybrid systems, based on wind/diesel and PV/diesel systems with battery storage. The use of subsidies for rural systems is being phased out and commercialization based on market forces is being encouraged. The rural population of Inner Mongolia, consisting of herdsmen and farmers, has among the highest annual income levels of the rural populations in China.

The Center for Energy and Environmental Policy (CEEP) at the University of Delaware, the NREL and the Chinese Academy of Sciences in Beijing have jointly completed a case study analysis of rural electrification options in IMAR.[12] The project was conducted in cooperation with the Planning Commission and the New Energy Office of IMAR, which are the two key agencies responsible for renewable energy planning. Other participating organizations included the University of Inner Mongolia, the Inner Mongolia Polytechnic University and several local companies.

The first phase of the case study project consisted of levelized cost analyses of existing systems in four counties in central and northern regions of IMAR, including Si Zi Wang, Su Ni Te You, A Ba Ga and Dong Wu Zhu Mu Qin counties. Solar and wind resource data were collected from the four counties and

Table II. Levelized cost-of-energy (COE) values for rural electrification options in IMAR for remote households

System	Output range (kWh $year^{-1}$)	Levelized COE based on Mfr. quoted battery lifetime (\$ kWh^{-1})	Levelized COE based on battery lifetime from field analysis (\$ kWh^{-1})
Wind	200–640	0·24–0·37	0·50–0·63
PV	120–240	0·67–0·73	0·77–0·83
Small PV/wind hybrids	400–750	0·31–0·46	0·57–0·72
Large PV/wind hybrids	560–870	0·32–0·46	0·43–0·57
Gas gen-set (not serving continuous duty cycle equipment)[a]	660–730	0·76–0·80	0·76–0·80
Gas gen-set (serving continuous duty cycle equipment)	480–560	1·09–1·19	1·16–1·27

[a]Estimates based on systems without storage.

performance/load data were collected from 10 PV systems 22 wind systems, and 6 PV/wind hybrid systems, which were in the 22-W to 600-W size range. Two sizes of gasoline gen-sets, common for household and ranch use, in the size range 450–500 W were examined for comparison.

The results of the levelized cost-of-energy analyses are shown in Table II. For the types of systems currently being deployed for stand-alone electrical generation in rural areas of IMAR, wind generators are the least-cost option for household electricity in the four counties. Small wind generators in the 100-, 200- and 300-W size ranges are manufactured locally in IMAR for the household market. The levelized cost of energy for small PV/wind hybrid and PV systems is higher than the cost of electricity generated by wind systems but significantly lower than the cost of electricity from gasoline gen-sets.[12]

The use of small wind/PV hybrid systems for remote-household electricity is attractive because of the seasonal complementarity of solar and wind resources. Wind energy is relatively more available during spring and winter months than in fall and summer months. Solar insolation levels, however, peak during summer months and are at a minimum during peak winter months. Therefore, designing wind/PV/battery-storage hybrid rural household systems that are optimized based on the local wind/solar resource mix produces an annual electric power supply for a given household-load demand that is more reliable and economical than wind or PV systems alone.

The New Energy Office of IMAR and the Inner Mongolia Planning Commission are developing plans for expanding the use of wind/PV/battery hybrid systems by remote herdsmen families for household electrification. The NREL and the CEEP (at the University of Delaware) are providing technical assistance to these agencies in designing rural energy programs. Based on annual income levels, two types of systems are receiving attention. Hybrid systems in the 400–500 W range are being developed to serve household loads that include lighting, a color television set and radio, a small washing machine and a small freezer, requiring approximately 1·6 kWh per day of energy. Smaller systems in the 150–200 W range are being developed for intermediate-income-level households that provide approximately 0·6–0·7 kWh day^{-1} for household loads that do not include a freezer or washing machine. The larger systems combine a 300-W wind generator with 100–200 W of PV panels with battery storage. An example of a pilot household system under test is shown in Figure 10. A pilot project based on remote-household hybrid systems is in development for 300 households to be conducted in 1998. The results of this pilot program will be fed into the planning process for the larger 25 000- and 80 000-remote-household projects by the IMAR government.

Lessons learned

There is a large renewable energy market for rural electrification in China. The need for renewable energy for rural electrification is greatest in a large area in northern and western China and along the coastal island region of China. In these regions up to 80 million people in remote households and villages are

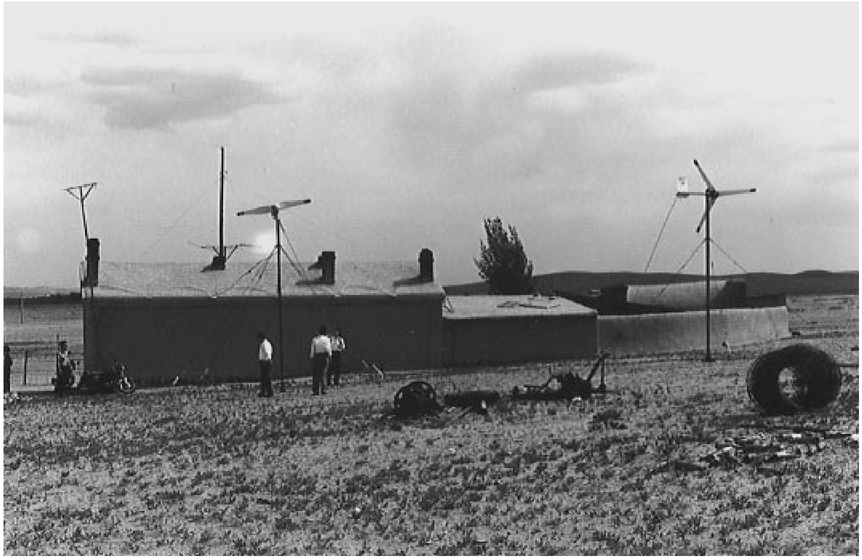


Figure 10. PV/wind hybrid pilot system for remote household use in Inner Mongolia with two types of 300-W wind turbines under test combined with 100 W of PV panels. (Credit: NREL PIX 04173)

currently without electricity and do not have near-term prospects for connection to grid power. These regions of China also correspond to the areas of highest availability of solar and wind resources.

Potential applications for renewable technologies in remote rural regions include power for remote households, telecommunications and agricultural applications, especially water pumping. Solar and wind energy are appropriate for electrifying remote households using both individual household systems and central village power systems. Photovoltaic, wind and PV/wind hybrid systems with battery storage have been found to be cost-competitive with diesel and gasoline gen-sets for rural applications. The choice of renewable energy systems should be optimized as a function of the local solar and wind resource mix in order to obtain the lowest cost energy with high reliability.

There are several challenges for the development of renewable energy markets for rural electrification in China. The infrastructure for supporting commercialization is at a very early stage of development. There is a need for the development of distribution networks that include installation, O&M and warranty services. Some provinces and autonomous regions, most notably Inner Mongolia, now have considerable experience in the development of commercialization infrastructures for renewable technologies. Potential infrastructures exist in other provinces, which can be used to promote the development of a renewable energy commercialization infrastructure, e.g. the rural energy office and agricultural service station networks in the rural regions of western China. In addition, there is a growing base of entrepreneurial Chinese companies now entering rural energy markets, creating considerable competition in some regions.

Training services are needed to train village technicians, to support marketing activities and to improve business management. There are severe problems with quality control of individual components and the integration of components into complete systems. Foreign equipment, such as PV modules, is frequently preferred in China by system suppliers because of higher quality and reliability. Testing and certification of SHS is currently an objective of several Chinese agencies. In some cases Chinese equipment is not cost competitive with international equipment; however, high tariffs and value added taxes (VAT) represent a barrier to international competition to help reduce costs.

There is a lack of experience with consumer credit in rural areas of China, which will require innovation to develop credit terms and loan mechanisms that work in practice. There is a general lack of financing available to expand rural energy markets in China, and the assistance of multilateral development banks and other financial institutions for developing loan funds and fundable projects is needed. Overlapping and dispersed responsibilities for renewable energy development in China among a number of Chinese agencies also represents a barrier to efficient coordination of government activities.

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