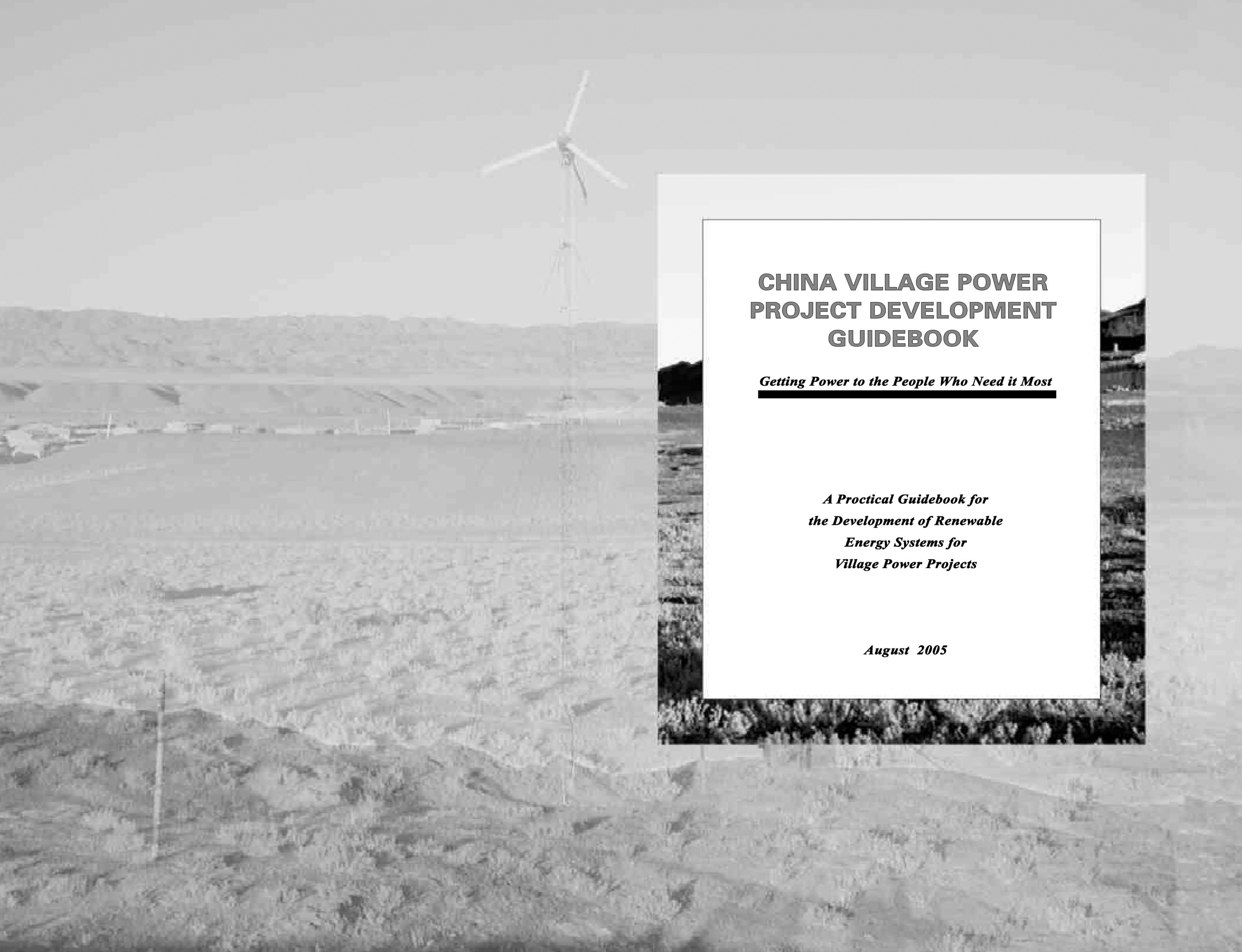
CHINA VILLAGE POWER PROJECT DEVELOPMENT GUIDEBOOK

Getting Power to the People Who Need it Most

A Practical Guidebook for the Development of Renewable Energy Systems for Village Power Projects

August 2005



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PREFACE

Access to modern energy services should not be confused as being an indicator of the level of a community's development. It is an active and integrated driving force behind this development. Through remarkable national and local efforts, China has achieved rates of electrification far exceeding those found in most developing countries. An inevitable but unfortunate consequence of this achievement is that the 7 million households who remain without electricity today are found in extremely remote locations and are made up of the countries poorest communities. For the majority of these communities, conventional approaches to widening electricity supply, principally through grid extensions, have not and will not provide the answer.

This Guidebook has been written to serve as a resource for those institutions and individuals working to increase access to energy services in remote areas in China, including government officials, rural electrification planners, and members of the communities themselves. The book introduces the common village power system solutions, from conventional solutions to renewable energy alternatives, highlights their specific features and provides some guidance for the selection of optimal solutions under given conditions. The Guidebook draws on experiences gathered from the field, in China and abroad, to provide recommendations on how such community power systems can be operated and managed on an economically sustainable basis. Finally, practical advice for the establishment of community power systems is given at the end of the book in the form of step-by-step guidelines, from resource monitoring to sustainable system operation.

This Guidebook is published in both English and Chinese.

ACKNOWLEDGEMENTS

This publication is the result of an SETC/UNDP/GEF initiative under the project CPR/97/G31 Capacity Building for Rapid Commercialization of Renewable Energy in China. The project is locally implemented by the China State Economic and Trade Commission (SETC) and the State Environmental Protection Administration (SEPA), and internationally implemented by United Nations Development Programme (UNDP) and executed by United Nations Department of Economic and Social Affairs (UNDESA). The Global Environment Facility (GEF), AusAid (Australia), and the Royal Netherlands Embassy in Beijing have contributed generous resources to complement core national support for the project.

James Graham of the PMO acted as the project manager and co-editor for the realization of this guidebook and also contributed detailed work in Chapter 1 and Chapter 4. Charlie Dou of Beijing Bergey Windpower was the project coordinator, co-editor and lead author, Vivian Cao of Beijing Bergey Windpower also made important contributions through survey work in Xinjiang and Inner Mongolia. Sicheng Wang, Luying Dong and Dongrong Ye of Beijing New Technology Company made significant contributions to the guidebook through survey work in Tibet and Inner Mongolia autonomous regions, and drafting Annex II. Zhizhang Liu and Yan Jia of Inner Mongolia Polytech University contributed to Chapter 2. Ian Baring-Gould of NREL (US DOE) made great contribution in improving and revising of Chapter 2 and Annex II; Winfried Rijssenbeek of RR Energy (the Netherlands) provided guidance in the survey work and completed the detailed economic and financial analyses used in the guidebook. Finally, the project team is extremely grateful to Dr. Vaughn Nelson of West Texas A&M University, USA, for reviewing entire drafts of the guidebook in contents and editing.

The project team also would like to give great thanks to Shaoyi Li of UNDESA, Dr. William Wallace of UNDP PMO in China, and Junfeng Li, Zhongying Wang and other staffs of CRED for their valuable suggestions and comments, which makes The Guidebook more perfect and complete.

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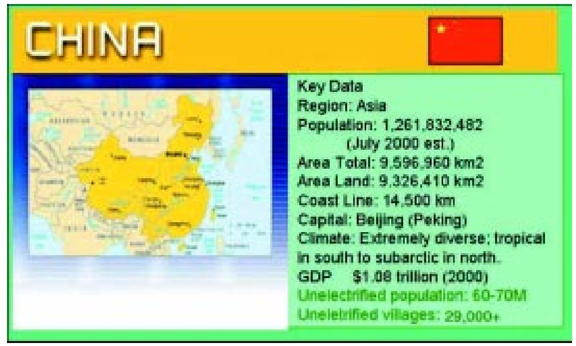
CHAPTER 1 GETTING POWER TO THE PEOPLE WHO NEED IT MOST

1.1 Developing China's Remote Rural Areas and the Role of Rural Electrification

For a community to raise itself out of subsistence and into an upward spiral of increasing prosperity, certain basic services must be available and affordable. These include potable water, health care, education, transportation, and communication. Access to electrical power is both a precondition for the provision of many of these services, and an active agent in catalyzing further advancement.



Access to electrical power improves living standards, through better health (improved health care delivery, reduced indoor pollution, access to clean water), through better education (more effective education and training facilities and improved lighting to facilitate evening study at home), and through reduced drudgery and time spent by women in unproductive tasks. Power is also a tool that can be harnessed to increase economic productivity and create new income generation opportunities. Particularly important in remote locations, electricity enables the use of modern communication systems, allowing otherwise isolated rural communities to take part in affairs beyond the confines of their own village. These information links enable crucial connections between rural communities and their markets and local and national counterparts[1], and promote national political and social cohesion.

Notwithstanding the benefits of access to services reliant on power, today over 7 million households across China still lack access to electricity. Most of these people live in rural areas of western China, leading lives far-removed from those of their prosperous urban cousins in China's eastern provinces. Children struggle to learn by the dim light of kerosene lanterns, and many women and men lack the tools that even modest energy services can provide. In recent years access to power has increased only incrementally, and its highly uneven distribution represents a significant social divide within the nation.

1.2 Historical Approaches to Rural Electrification in China

Electricity supplies have conventionally been brought to communities through the extension of centralized electricity networks, taking power generated in large installations fur-

Charlie Dou

A herdsmen village in western China

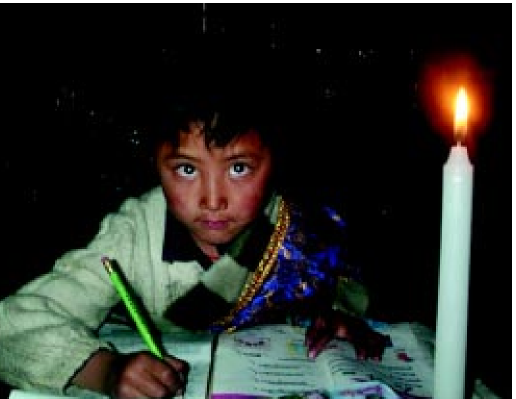
Charlie Dou

A fishmen island in eastern China

Vivian Cao

Herdsmen having dinner under candle light

[1] Ms. Nemat Shafik , Empowering People and Transforming Markets, Village Power 2000, Washington DC, Dec. 2000.



Dongrong Ye

Student studies with candle light

Shiyu Xin

Lighting by butter

Charlie Dou

A REVPS with four wind turbines located on Xiaoqingdao Island, Shandong

ther out to county towns and from there into rural areas. In parallel to the enlargement of these networks, China has also promoted the establishment of hundreds of independent grids that harness local hydro resources. Over time, many of these independent grids have been linked to provincial power grids as the latter expanded. Other renewable energy technologies, such as wind power and solar power, have also begun to play an increasing, though up to now marginal, role in rural electrification in China. The costs of these alternatives have declined rapidly over the last three decades and their relevance is heightened by the fact that the majority of those without access to electricity live in regions enjoying the country's best wind and solar resources. Table 1.1 shows the current application status of various rural alternatives to grid-extension that are used to solve the problem of rural electrification in China today.

Table 1.1 Status of Application of Various Grid-extension Alternatives

Stand-alone Alternative	Application Status
Small Hydro (10kW-25MW)	By 1998, national installed capacity of small hydropower had reached 25,200 MW with an annual output of 80 TWh, accounting for about 39 percent of the total hydropower installed in China. It is estimated that the total installed capacity of small hydropower stations will reach 35,000 MW and output will reach 112 TWh by 2010[2].
Micro Hydro (0.1-10kW)	More than 89,000 micro-hydro stations with 160 MW capacity generate 260GWh a year in China, powering 320,000 remote households. These stations supply electricity to household loads and some productive loads.
Diesel Mini-grid Systems	Diesel stand-alone systems have been installed as a first attempt by many remote villages beyond the reach of existing grids to gain access to electricity. Many diesel gensets (1-15kW) are operated informally by private individuals (microenterprises) for productive applications, as well as for powering their own domestic needs and those of their neighbors for 2 - 4 hours at night. Some larger diesel systems have been installed by local governments and are operated as part of the community infrastructure.
Wind and Solar Village Power Systems	Over the last 20 years, around 70 renewable energy village power systems (REVPS, 5kW- 200kW) have been installed across China[3]. This includes wind power systems, photovoltaic (PV) systems, wind/PV or PV/Diesel or Wind/PV/diesel hybrid systems, (Annex I lists part of REVPS s installed in China to date).
Wind Household Systems	150,000 small-scale wind power generators (100W to 10kW) have been installed in China, resulting in a total installed capacity of 20,000 kW and supplying electricity to more than 200,000 households. Most of the systems are less than 1 kW.
Solar Household Systems	More than 52,000 small-size PV systems with a capacity of 800,000 peak Watts (Wp), the majority bought on the open market, are in use in Western China[4].

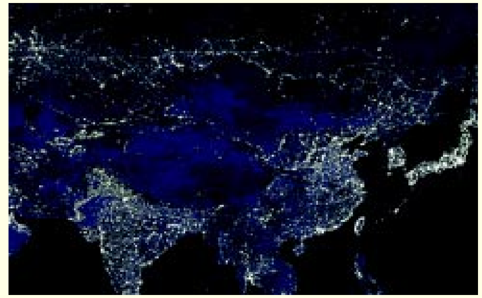
[2] "Renewable Energy Development in China: The Potential and the Challenges, report supported by the China Sustainable Energy Program, The David and Lucile Packard Foundation in partnership with The Energy Foundation, Edited and produced by the Center for Resource Solutions."
[3] China Renewable Energy Village Power Database, UNDP PMO, 2001.
[4] Hao Xianrong, "Rural renewable energy statistics", China Ministry of Agriculture, 2001

1.3 Size and Distribution of China's Unelectrified Populations

Through the expansion of provincal electricity grids, development of local hydro resources, and, more recently, promotion of other renewable energy alternatives, China has achieved remarkable rates of electrification of over 95%. This far exceeds rates found in most developing countries. However, a single percent of the population in China represents thirteen million people. Furthermore, the achievements of the past mean that those communities remaining without access to electricty in China today are often living at very large distances from existing grids and usually at low populatons densities. Furthermore, under the ongoing process of power sector reform, in which provincial utilities are scrutinizing their balance sheets more closely, the prospect of a conventional solution to deliver modern energy services to these distant, low-load (and hence low or no profitability) markets seems further away than ever.

The latest statistics show that over 7 million households and over 29,000 villages are still without access to a reliable supply of electricity (Table 1.2). These counties, townships, villages and scattered families are principally found in remote areas of China's western provinces, and some on islands off the east coast. Some communities use diesel mini grids to provide electricity for a couple of hours at night, and most others use candles and kerosene lights and batteries for small-scale applications. However, Western China and the coastal island regions enjoy some of China's best wind and solar resources. In these locations it is therefore worthwhile to consider the potential of renewable energy applications as a least cost energy supply solution.

CHINA AT NIGHT



Satellite image

China's western regions, including Tibet, Guizhou, Gansu, Inner Mongolia, Qinghai, Xinjiang and Sichuan, are home to the majority of the country's unelectrified populations. Most off-grid islands lie between 15 and 100 km from the mainland in Zhejiang, Fujian and Guangdong provinces, and to a lesser extent in Shandong, Liaoning, Hainan, Taiwan and Guangxi. Many currently use diesel for electricity generation, but they enjoy only an intermittent service (a few hours every evening) at a high cost (up to 3-4.5 Yuan/kWh)[5].

1.4 Benefits of Increasing Access to Modern Energy Services

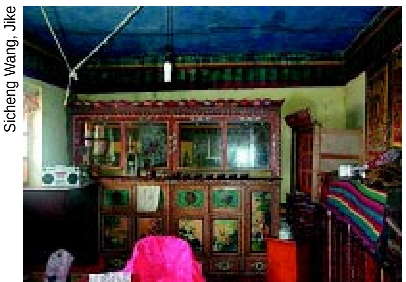
While the lack of access to electricity is only one of many causes of the slow development of rural communities, villages lacking access to electricty are invariably poorer than those which do not. This goes a long way towards explaining why rural electrification programmes have formed a central part of national development programmes around the world. Electricity brings multiple positive benefits, which can be qualified in terms of social, economic and environmental impacts.

[5] Wu Yundong, et al, The Development of China coastal island Wind/Diesel power Systems and Market Potential, Workshop of Design and Integration of Village Hybrid Systems, UNDP, Beijing, August 29-31, 2000

Keyi

Celebration when the wind power system started to provide electricity

Sicheng Wang, Jike



Ali, with light, Tibet

Charlie Dou

TV signal trasmission station

Qinghai

Radio power by SHS

Charlie Dou

Watching TV is not a dream now, Zhalute, IM

Willian Wallace

Energy saving bulb powered

TABLE 1.2 China Unelectrified Villages and Households#

Province / AR	Unelectrified Counties	Unelectrified Township	Unelectrified Villages Administrative	Unelectrified Villages Natural	Total Unelectrified Villages	Total Unelectrified Households
Tibet	6	486	5,254	-	5,740	289,300
GuiZhou	-	-	3,000	377	3,377	1,294,000
GanSu	-	9	871	2,384	3,264	360,173
InnerMongolia	-	-	960	2,100	3,060	249,590
FuJian	-	-	960	1,400	2,360	249,590
QingHai	1	94	773	1,254	2,121	101,000
SiChuan	-	126	1,459	40	1,625	648,300
XinJiang	-	28	216	1,095	1,339	316,200
NingXia	-	-	-	1,306	1,306	64,000
HuBei	-	-	75	975	1,050	121,500
HeNan	-	-	700	-	700	577,000
GuangXi	-	-	666	34	700	388,600
YunNan	-	4	528	-	532	1,003,800
HuNan	-	-	-	518	518	279,500
HeBei	-	-	357	43	400	13,800
ShaanXi	-	11	344	-	355	289,100
ShanXi	-	-	259	-	259	112,000
HaiNan	-	-	253	-	253	160,300
ChongQing	-	3	163	-	166	191,900
AnHui	-	-	17	33	50	80,500
JiangXi	-	-	17	33	50	287,000
HeiLongJiang	-	-	13	-	13	9,100
LiaoNing	-	-	4	-	4	4,800
GuangDong	-	-	-	-	-	50,800
Total	**7**	**761**	**16,889**	**11,592**	**29,242**	**7,141,853**

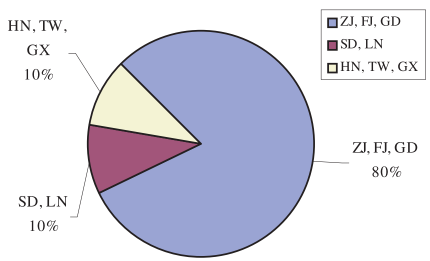
Figures (valid to end of 2000) compiled by Jikedian from Provincial Planning Bureau Statistical Records for *UNDP Village Power Market Survey* -

Delivered Price of Diesel and Price of Electricity Found in Remote Villages in China

Villages	Distance to nearest town (km)	Diesel price (Yuan/kg)	Electricity Price (Yuan/kWh)
Baiyinaobao, IMAR	200	3.2	2.00-2.50
Gaize, Tibet AR	500	4.5	2.00
Jiming Island, Shandong	2	3.2	0.80
Weijing, IMAR	100	3.0	1.80-2.50
Beiji Island, Zhejiang	67	3.00-3.60	2.00-4.00

Data from *UNDP Field Survey, July-August 2001*

Distribution of Islands



1.4.1 Social Impacts

The major social impacts of modern power services are:

In the home

- Raising standards of living (particularly for women), information acquisition, and social activities

In the community

- Improving community health services
- Improving educational facilities

Social impacts

Service Rendered	Social Impact
Street Lighting	Improved security
	Stronger sense of community
House Lighting	General quality of life improvement
	Social evening activities
	Facilitation of evening work/study
School Lighting & Power	Extended schooling hours
	Use of satellite and video educational programming
	Use of computer systems
TV & Radio	General quality of life improvement
	Informal education
	Stronger sense of regional and national identites
Refrigeration	Healthcare vaccinations
	Broader diet
Household Appliances	Labor and time saving

In the home - Improving life quality, information acquisition and social activities

Lighting

Lighting is the first priority for families when electricity becomes available. After sunset, lighting facilitates completion of household tasks and improves living conditions, particularly for reading and studying. Research[6] shows a big difference of the amount of reading time with and without electricity. Where electricity is not available, kerosene lamps may provide some opportunity for reading, but the quality of service is inferior to that of an electrical lamp and the costs are often higher.

[6] Douglas Barnes, South Asia Energy Unit, World Bank, Social Infrastructure and Poverty Studies, Village Power 2000, Washington, USA, Dec., 2000

Charlie Dou

Herdsmen can use washing machine now, IM

Charlie Dou

A solar powered microwave station

Willian Wallace

A rural clinic in Barkol, XJ

Willian Wallace

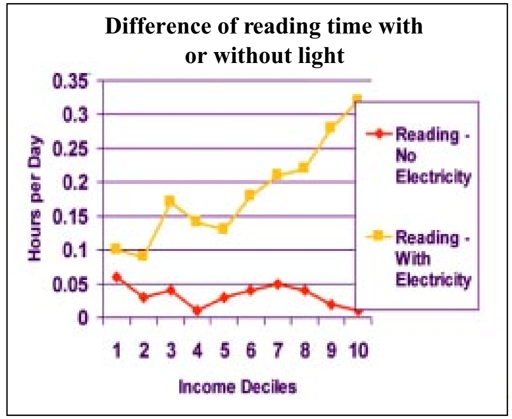
Inside of the clinic

Charlie Dou

A microscope
at a rural clinic

Qinghai Renewable Energy Institute

A clinic powered by 1kw solar panel
in Bazha, Huzhu county, QH



Example: Electronic Appliances Used by 20 Households in Siziwang Banner, Inner Mongolia, after RE Electrification

Items	# of families	%
Color TV	18	90%
B/W TV	8	40%
Tape	12	60%
VCD	4	20%
Washing Machine	5	25%
Freezer	16	80%
Iron	3	15%
Fan	6	30%

Television

Lack of information and of educational opportunity has become one of the major barriers to poverty reduction in rural areas. Due to historical, geographical and economic reasons, remote rural populations are isolated from the outside world. Electricity can help communities connect with the outside world, by allowing them to watch TV at night. For the majority of the nation, TV is an important part of normal household life, and it is also a tool for both educational and entertainment purposes. TV has been found to be the highest priority appliance for newly-electrified households. The information from TV programs give youngsters so strong affects that driving them to improve their current situations. Valuable information-such as weather forecasts-can help these communities make more informed decisions, thereby increasing agricultural productivity and incomes. VCDs are low power consumption appliances and commonly used in conjunction with TVs. Furthermore, villages often install a satellite antenna, allowing reception of more than ten channels, from CCTV to local and minority programs. Through watching TV people learn about new techniques and new products, new concepts, and new activities. This exposure directly stimulates economic and social activity.

Other household appliances

Modern domestic appliances can significantly reduce the burden of daily household work, to the particular benefit of women. As a consequence, the role of women in the family and society are empowered. Where 24-hour power is available, many households use refrigerators or deep freezers. Where before, households ate dry meat, or several families shared a slaughtered sheep over a few days, refrigeration helps to preserve vegetables and meat, resulting in a more balanced diet and better health. Washing machines are used not only for washing clothes, but are also used for separating butter from yogurt, thus saving a lot of time. After electrification, some families in Inner Mongolia have started to use fans and irons. Some even use steam irons.

Social Activities

Social activities that had been severely restricted during long, dark winter nights now become possible. Games, karaoke, story telling and other forms of entertainment brighten the lives of rural households.

Freeing-up of Time Previously Spent Collecting Biomass Fuels.

The availability of electricity frees time previously devoted to collection of conventional fuel (wood, dried dung), which can now be devoted to productive work, education, social activity, or well-deserved relaxation!

In the community

Health care

Primary healthcare facilities are essential for the improvement of child survival rates and the overall quality of human health. The relationship between health and energy is compelling. The World Health Organization (WHO) states that "Health and energy are inter-dependent factors which largely determine the progress of rural development. An energy strategy for rural areas will be critical in achieving lasting health improvements. The WHO believes solar energy can play an important role in improving health energy infrastructure if integrated with a broader array of end uses."

Example: Power and Community Development

Increased living standards affect a community's ability to retain and attract residents, directly addressing the problems of unsustainable living patterns and of urban migration1. The Xinjiang government has a program to develop new village neighborhoods to encourage nomadic herdsmen to settle down. However, the herdsmen do not remain these villages when they lack electricity services. The resident in a village located in Barkol, Hami, XJ was getting less and less due to poor living conditions. But, the people are coming back, even more families would like to move in since the village has been electrified by a REVPS. Currently any family has to submit application and get approval prior to moving in. Another telling example comes from Inner Mongolia, where village populations have been found to increase after installation of a village power system.

Some statements by members of newly electrified communities

- We feel connected to outside world
- We can see things we have never seen before in our life
- There are more people coming from outside because they like where there is light
- The winter is too long, at least we have some entertainment
- Light is just great

Source: Accelerating rural electrification in Inner Mongolia with the use of wind and solar energy, Marliene Richter, et al, GTZ, May, 1997

Distribution of energy by conventional means has failed to be reliable or affordable in meeting the modest needs of rural health clinics in many developing countries. Propane fueled refrigerators provide adequate vaccine preservation, but the more widely used kerosene fueled refrigerators do not. Furthermore, supplies of gas and kerosene are often costly and unreliable. No basic electric or electronic diagnosis and medical treatment equipment are available in many rural clinics. To receive these services, patients must travel to towns. The minimum cost for a member of a herdsman's family in Xinjiang to see a doctor in town is more than 100 Yuan.

Renewable energy power produced on site has proven capable of delivering high quality electricity for vaccine refrigeration, lighting, communication, medical appliances, clean water supplies, and sanitation. After installation of REVPSs, X-ray equipment has been purchased and used in the clinics of some villages, such as Baiyinaobao Sumu and Chaganaobao Sumu in Inner Mongolia. However, the potential for renewable energy to provide for these limited but critical power needs remains largely untapped.

Willian Wallace

Drinking water

Mike Bergey

Wind electric water pumping for dringking water.

Willian Wallace

Rural kids, Xialaoba, XJ

Charlie Dou

A PV power system for school in Weijing, IM

Charlie Dou

A rural school in XJ

Contributes of Electricity to Clinics

- Lighting
- Vaccine refrigeration and ice pack freezing
- Communications, especially for emergencies
- Medical applications
- Sterilization
- Water treatment
- Water supply
- Education
- Medical staff amenities
- Income generation

Source: Renewable Energy for Rural Health Clinics, NREL, USA, Setp, 1998

Improved Community Water Supply

Improving water supply, especially drinking water for residential uses, is another benefit of power availability. Many places in China are deficient in drinking water supply, or lack convenient access to water for livestock and irrigation. Power can be used to drive water pumps for:

- Domestic water supply
- Livestock water supply
- Irrigation

Education and schooling

A large proportion of schools in remote rural and island villages do not have access to basic services, including running water, toilets and lighting. Schools in rural communities are generally worse off than those located in urban areas, and those schools located in remote rural areas are as least favored of all. They are often last to be served from the education budget, and what they do get tends to go less far because they are on the periphery. Communication with these schools is difficult, and they rarely have the infrastructure required to keep running smoothly. Despite this, schools in remote areas often fill a larger role in the local community than schools in urban areas. The school may be the only institution in a given rural area, serving not only to provide education, but also other social and administrative community activities. Electricity will enhance the role of a school as the hub of a remote village.

A modern power supply can bring schools facilities such as lights, for longer study hours, televisions, for increased exposure to the world outside the village, and even modern communications with the Internet and its limitless learning opportunities. Distance-based learning programs can been used as a highly effective tool to reach thousands of students in rural areas. All these facilities raise teaching standards, thereby providing students with better opportunities in their lives ahead.

Contributes of Electricity to schools

- Lighting
- Powered educational equipment, such as color TVs, overhead projectors, VCDs, tape recorders
- Computers, Internet
- Communication
- Possibility of distance learning
- Enhanced role in the community

Strengthening the Community

The every process of developing and installing a community power system has a great impact on community organization and morale. And community recreational activities, such as dancing, movies, and karaoke, have been found to increase by over 50% after installation of village power systems. Other community benefits include:

- Receiving outside advanced information
- Strengthening local institutions
- Enhancing relationships between different nationalities

- Providing drinking water through electric pumping
- Changing social behaviour through community activities

1.4.2 Economic Impacts

Power systems not only provide the electricity to improve daily living standards, but also stimulate economic development. This results from opportunities to increase productivity of existing activities and to start new micro-enterprise activities. Common micro-enterprise activities include retail and hospitality services and value added businesses, such as machine shops and upstream product processing. These activities provide both direct and indirect employment opportunities and stimulate knock-on development through increased levels of prosperity.

Increasing Productivity

- Irrigation for crops and drinking water for animals
- Extendsion of working hours
- Increased production capacity through powered processing for agriculture and other industry
- Generation of value-added products e.g. milling & grinding of cereals
- Preservation of products
- Mechanisation of home industries, such as sewing
- Improving working conditions
- Attracting customers

Electricity does not guarantee an increase in income levels, but it does provide greater opportunities for individuals and collectives to pursue income generating activities. The magnitude of the impacts will depend on the available resources and initiative of the people served. In some cases the impacts will be great and in others they may be disappointing. The development of integrated rural projects, e.g. coupling new power systems with business training and start-up financing, has been found to be an effective way of maximizing economic impacts.

Common Microenterprise Activities

- Mechanical workshop
- Cereal processing
- Water supply / irrigation
- Retail stores
- Restaurants, karaoke bars
- Tourist facilities
- Product preservation/ cold storage
- Establishing community center
- Communications (Tel/fax etc.)
- Hairdresser

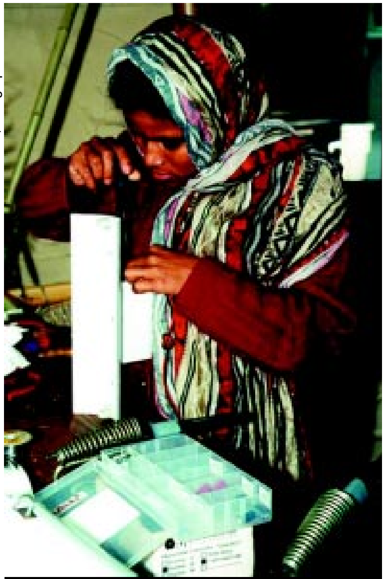
TIPs - Common Microenterprise Loads

- Lights, radios, televisions, and cell phones, most of them can be DC powered, then TVs, and VCD players
- Power tools, grain mills, or other large motors for workshops and light industries
- Water pumping, ice making, and battery charging
- Process heat, cooking and drying for food preservation

Some examples of common income geernation activities associated with a new power supply follow below.

Increasing income from agricultural activity
The use of power tools and equipment provides new services, increases the efficiency of labor and adds value to agricultural products. For example, grinding and milling machines

World Bank, Village power 2000



A woman from Bangladesh is using solder iron powered from a 12VDC battery to make DC lamp.

Winfried Rijssenbeek

Small machine shop power

Charlie Dou

A rural retail shop in Baiyingaobao, IM

Sicheng Wang, Jike

Ali, Tibet

Winfried Rijssenbeek

Bulunkou, Kirgize, XJ

allow people to process crops in quantity, adding post-harvest value to their bulk product. And preservation (through refrigeration or ice making) increases the quantity of product reaching the market.

Electricity can also be used to pump water for irrigation of crops or watering of animals. Irrigation results in greater crop yields and reduces the risk of losses in times of insufficient rainfall. This is a common way for communities to increase their incomes following installation of a power system and may result in a significant extra load. In some cases, water pumping may even be managed as a separate income generating activity.

The advent of regular and reliable market and meteorological information through radio and television is very important to farmers. A higher awareness of market demands and prices at a given time can make a significant difference to annual income levels. Meteorological forecasts reduce risks and increase productivity of cultivation and animal husbandry. The forecast is also important to rural retailers. Their orders and stores rely very much on the monthly forecast.

In conclusion, electricity raises agricultural income levels by providing new services that increase productive output.

Development of machine shops

Electric welders (usually 1kW to 3kW) are very popular in rural machine shops to repair tractors, agricultural and husbandry tools and so on. Electricity will allow the local machine shop to be equipped with welders, and sometimes other tools such as a lathe or drill press. The existence of a service network for machinery has a key role in facilitating local economic development.

Establishment of hotels, restaurants and entertainment centers

Power brings the possibility for small hotels and restaurants to offer better services and to operate as evening entertainment centers, providing light for social gatherings, showing TV programs and films and offering karaoke.

RENEWABLE ENERGY MICRO-ENTERPRISE ZONE CONCEPT

Grameen Shakti is a pioneer in the wind energy application in Bangladesh. It develops wind/PV/diesel hybrid system on micro-enterprise zone basis in coastal areas.
Micro-enterprise zone concept: One main building where micro- entrepreneurs can come and use power for their businesses is electrified. The Grameen Bank has many cyclone shelters along the coast, which turned out to be the perfect places to house the micro-enterprise zone. These buildings are two or three story concrete buildings that often house a Grameen Bank Branch office. Thus they are frequented by the Grameen micro-entrepreneurs, and enjoy the presence of trustworthy staff. The targeted options of this micro-enterprise are battery charging station, workshops, rice husker, ice making etc.

Source: Dipal Chandra Barua, Energy's Role in the Rural Income Generation: The Grameen Strategy, Village Power 98 Scaling Up Electricity Access for Sustainable Rural Development, Washington, D.C., October 6-8, 1998

Facilitating night work

Lighting extends the working hours of all economic activity, hence increasing productivity. Aside from restaurants and hotels, retail shops and local markets benefit in particular from extended evening working hours. Household industries benefit not only from the provision of light for work around the house, but also from the use of more efficient electrical appliances (e.g. sewing machines).

Lighting is also particularly helpful to grassland farmers during the lambing season, when sheep and goats must be cared for throughout the night. Again, the improvement in working conditions can have a direct impact on productivity and household income.

Providing a foundation for development of tourism

Many remote places in China have great potential as tourist attractions, such as Moztaga Peak in Bulunkou Village, Kirghiz Prefecture, Xinjiang, which is a worldwide famous glacier mountain. Power is required for tourist facilities, such as hotels and restaurants to realize this business potential and provide the community with a valuable source of outside income.

Examples of applications of PV systems for income generation in Bangladesh

- One customer is using PV system for heating soldering iron for repairing radios, TVs etc
- One carpenter extended his working hours after the sunset using a solar system, enabling him to earn more than before
- One saw mill owner has extended his working hours as well by installing a solar system
- Another buyer has installed a system in the rural market and he is selling power to the shop owners who buy power to light their shops
- By operating a solar powered computer, some institutions in the remote area have improved their working ability
- Other examples are: operating a sewing machine; pumping for irrigation; battery charging stations for batteries for household use; charging cellular phones; operating drill machines (for the carpenters), operating blending machines to make juice in market places etc

Source: Dipal Chandra Barua, Energy's Role in the Rural Income Generation: The Grameen Strategy, Village Power 98, Scaling Up Electricity Access for Sustainable Rural Development, Washington, D.C., October 6-8, 1998

1.4.3 Environmental Impacts

China, like the rest of the world, faces many environmental problems. Air pollution, water and soil contamination, and desertification have direct and measurable local impacts. Conventional rural energy supply modes, burning coal and biomass for cooking and other domestic activities, causes severe indoor and local air pollution and results in high rates of respiratory illnesses. Increasing pressure on fragile rural environments is turning more and more of the northern China grasslands into semi-desert and desert, and Inner Mongolia has encountered severe drought for the last three consecutive years. Modern energy supplies ensure a clean living environment and relieve pressure on fragile ecosystems - allowing trees to grow to consolidate the land and leaving manure on the ground where it can nourish future growth.

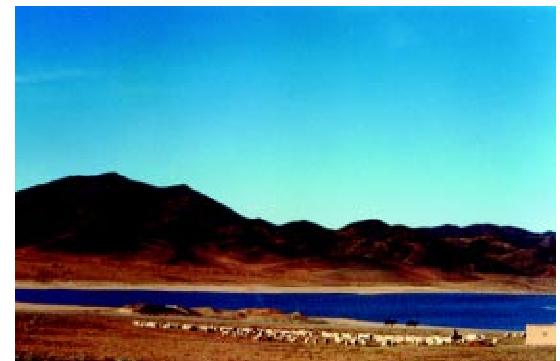
Although the global climate is a secondary environmental concern for remote populations in China, the snow lines on mountains such as Tianshan Mountain have moved higher and higher in recent years, with the result of less water in the surrounding lakes and rivers. Scientists trace acid rain and global warming to greenhouse gas emissions, many of which stem from burning fossil fuels such as coal, oil and diesel fuel. By comparison, renewable energy sources contribute no or very few emissions.

TIPS: Emissions from coal fire power plant (Per kWh)

CO_2	0.75kg
SO_2	0.0061kg
NO_2	0.0045kg
Dust	0.0052kg
Consume	Std coal 0.39kg or diesel 0.37kg
Water	3kg

Charlie Dou

Xiaoqingdao, Shandong



Charlie Dou

Barkol, XJ

Charlie Dou

Charlie Dou

Tianchi, XJ

Sicheng Wang

Grassland is turning desert, IM

QH Renewable Energy Instition

Suonandajie Wild Protection Station, QH

The Contribution of Fossil Fuel to Environment

Greenhouse gases - carbon dioxide, methane, nitrous oxide, hydrocarbons, and chlorofluorocarbons - surround the Earth's atmosphere like a clear thermal blanket, allowing the sun's warming rays in and trapping the heat close to the Earth's surface. This natural greenhouse effect keeps the Earth's average surface temperature at about 60°F (33°C). But the increased use of fossil fuels has significantly increased greenhouse gas emissions, particularly carbon dioxide, creating an enhanced greenhouse effect known as global warming.

Energy use from fossil fuels is also a primary source of air, water, and soil pollution. Pollutants - such as carbon monoxide, sulfur dioxide, nitrogen dioxide, particulate matter, and lead - take a dramatic toll on our environment. On the other hand, most renewable energy technologies produce little or no pollution.

Both pollution and global warming pose major health risks to humans.

Source: NREL Website, USA

In China, renewable energy technologies are adopted to meet rural electrification needs, rather than out of purely environmental considerations. Even so, using renewables will:

- Improve indoor air quality
- Relieve presssure on local ecosystems and biomass resources
- Prevent land desertification through lessened demand for biomass and grassland irrigation
- Reduce acid rain
- Reduce the consumption of finite fossil fuels
- Reduce the emission of CO_2

1.5 The Purpose of The Guidebook

Given the benefits of access to modern energy services and the potential in China for village power systems to deliver these to those who lack and need them most, the objectives of this guidebook are as follows:

- To raise the level of awareness and understanding of the potential for village power projects to serve as integrated rural development tools amongst policy makers, rural electrification planners, system developers, and rural communities.
- To introduce various common village power system alternatives and highlight their distinguishing features.
- To summarise the economic performance of various village power systems and provide some rough rules of thumb for the determination of the least-cost power supply solution in a given case.
- Based on experiences gathered in the field, both in China and abroad, to highlight both common difficulties and best-practice examples of village power projects, and to make recommendations for the improvement of future projects.
- To provide practical guidance for best practices in the implementation of village power projects.

CHAPTER 2 : VILLAGE POWER ALTERNATIVES : System Features and Requirements

2.1 Alternative System Solutions

For those communities living beyond the reach of existing power grids, the various alternative solutions open to them vary widely, not only in terms of technology but also in terms of the scale and the level of services provided. The way to determine the most approprate system solution for a given case, is first to consider the demand-side of the system - what is power needed for, how much, and when? For example, if there is limited demand for power for productive applications during the daytime, the most appropriate and cost-effective solution may be a system that initially only provides power during the evenings, rather than an immediate 24-hour service. The specific requirements and resources of an individual village will determine which is the most appropriate choice to provide power to that community. This Chapter introduces the principal design and service features of various common village power alternatives, and highlights their requirements in terms of renewable resource (where applicable), operation, and maintenance. Appendix II provides more information on actual system design and resource assessment, two steps that are critical to the implementation of renewable energy based systems in rural areas.

Alternative Rural Electrification Solutions

- Grid extension
- Hydro power system
- Diesel stand-alone system
- Wind power system
- Solar power system
- Hybrid system incorporating multiple technologies

Examples of Various Levels of Service and Corresponding System Solutions

Electrification level	Load Features	Load type	Time of Service	Example
Pre-electrification	Provide power to lights, radios, few B/W TVs	Provides only DC load	Service for a few hours most nights	20W Solar home system, battery charging station
Minimal electrification	Lights, color TVs, and other limited household appliances.	Poor quality AC power	No back up, sometimes the power will be unavailable, or provided for limited time periods..	100-300W wind power system with a square-wave inverter. or part time diesel power systems.
Isolated remote power system	Provide grid quality power for households and productive loads; some restrictions on peak loading and industrial loads	Near grid quality AC.	24-hour service. RE provide 60-85% of energy	Small-hydro, or wind/PV/ Diesel/battery community Systems
Grid-connected	All loads can be serviced up to heavy industry	Firm AC	24-hour	Grid-extension

2.1.1 Grid extension

Extension of the utility grid has historically been the principal rural electrification method used in China. In the last 10 years, more than 60 million people have been connected to utility lines through rural grid improvement and extension. For larger villages and villages those are not far from an existing utility grid, especially those with good productive load potentials, utility extension is often the most economic solution. Experiences with grid extension in China have been generally positive, although in the past some systems have not delivered power for productive loads and/or have had high losses and poor reliability. A large government program in the last three years has upgraded existing rural transmission lines in many provinces resulting in a reduction in line losses to less than 12%.

When considering grid extension for a village or an area, the local utility normally looks at a number of criteria, such as:

- Economic development potential to help support the cost of the grid expansion (does the area or village have the potential for the processing of agro-products, for mining or other resource exploitation, or is it in an important area for government special planning)

William Wallace

Rural grid

Sicheng Wang

Mini Hydro in Linzi, Tibet

- The existing affordability of people to pay for electricity and for appliances
- Political reasons (e.g. minority area with a high poverty incidence)

However, as has been described in Chapter 1, those communities remaining without access to electricity in China today live in extremely remote areas, often more than 20km from the nearest transmission line. Furthermore, the unattractive economics of grid extensions are a challenge to a power sector undergoing major reform towards a more economically efficient model. Investing in improved performance of the existing grids is more rewarding than extending new lines. Where payback periods of 15 years were once acceptable for grid-extension projects, 3 to 5 years are now desired to improve profitability. As a result, stand-alone systems have come to the forefront as the most appropriate solution for many communities still without electricity. The features of various alternative stand-alone systems are presented below.

2.1.2 Small and Mini Hydro Power Systems (HPS)

Status

Small hydropower

In China, small hydropower refers to stations with an installed capacity of less than 25MW. Today small hydropower provides power to 300 million people in around 782 counties - or to around one-quarter of China's population. By 1998, national installed capacity of small hydropower had reached 25,200 MW, with an output of 80 TWh, accounting for about 39 percent of the total hydropower installed in China. By 2010 the total installed capacity of small hydropower stations could reach 35,000 MW with an output of 112 TWh. In terms of commercialization, small hydropower generation is the largest and fastest growing renewable application in the country. At the end of 1997, there were 22,000 enterprises with nearly 1 million employees offering small hydropower products and services.

The Government believes that the development of small hydropower is an important way for China to promote rural electrification. A series of incentive policies for developing small hydro have been adopted, such as the granting of preferential loans and the reduction of VAT on electricity sales from 17% to 6%. These systems are thus able to offer consumers a grid-quality power supply service, at what often amounts to a cheaper price than that of fossil fuel derived power.

Mini-hydropower

Mini-Hydropower refers to facilities with an installed capacity of 0.1-10kW. Mini-hydropower plants use small rivers with a drop of 1.5-30 meters and a flow of 15-500m3/h. These facilities normally supply power to rural households or small villages for lighting, home appliances, and small farm processing machines. By 1998 national total installed capacity had reached 163.6 MW. Output had reached 271.8 GWh, and the number of connected households totaled 566,000. According to the Ministry of Agriculture, total installed capacity of mini-hydropower is likely to reach 6,400 MW by 2010.[1] The installed systems with capacity of 10 to 100 kW (for 30 to hundreds of households) have, in general, performed technically without difficulty, but there are still some concerns with respect to their long-term sustainability. To date, most of these mini-hydro facilities have required substantial civil works. New technology now allows for more streamlined,

[1] "Renewable Energy Development in China: The Potential and the Challenges", a report supported by the China Sustainable Energy Program, The David and Lucile Packard Foundation in partnership with The Energy Foundation, Edit and prepared by the Center for Resource Solutions.

run-of-river power generation, although this technology has not yet been widely implemented in China.

Resource requirement and availability

Flow rate (liters/s) and net head (m) of water determine the energy output potential of a hydropower system. The required supply of water, with a fall of some meters to ten's of meters, can be found in many southern and western provinces. Table 2.1 shows the relationship between gross water head and water flow in terms of the minimum water resource requirement for a 62kW mini-hydro generator. It can be observed that a lower head requires higher water flow rates for a specific power output. Further tips on system sizing and a chart to help identify power availaibilty from various water flowrates and heads are given in Annex II.

Table 2.1 Mini-hydro Head and Flow Requirement for a 62kW Generator

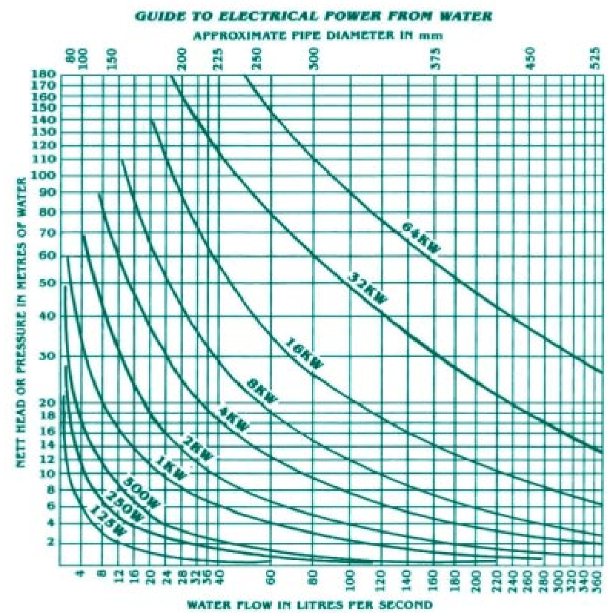
Gross Head	Flow
In m	In l/s
10	1469
15	980
20	735
25	588
30	490
40	367

The annual flow rate is important, but the monthly distribution of the resource will determine the minimum output of the system. If the minimum output is much more than the system peak energy demand, then the design process is almost trivial. If not, storage capacity or optimizing power use (by determining priorities amongst productive, consumptive and social loads) may be considered to increase the reliability of the system. The distribution of hydro resources across China is described opposite. In most provinces, the local utilities are familiar with the potential sites, of which quite a few not have been exploited for number of reasons. Careful data collection of the flow rate, at least monthly for as many years as possible, will provide a good picture of the power available at a given site. In most provinces in China there are good potential mini-hydro sites, but mountainous and humid climates in the South and Southwest enjoy the highest potential.

System Features

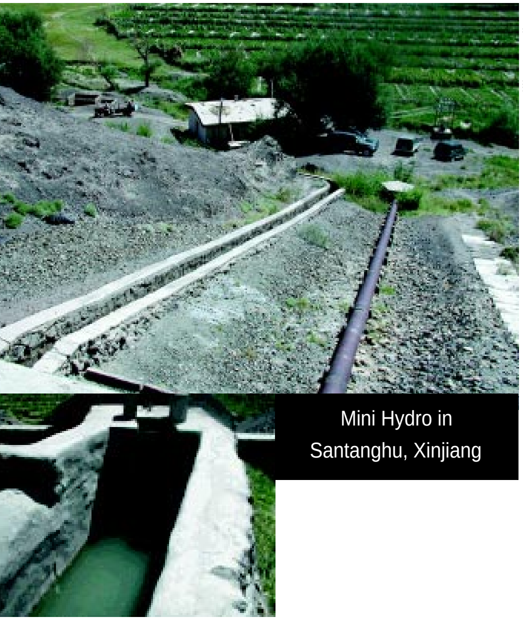
Mini hydro systems (MHS) range from a few hundreds watts (suitable for several households) to 100 kW (suitable for a community of several hundred households) and will provide rated power as long as the water flow-rate required flows through the system. The basic features of these systems are a dam (usually), water channel or pipe with an inlet control, electromechanical power generator(s), basic power control system and an associated electrical mini-grid for power distribution. System installation normally requires significant civil works (dam construction and generator foundations) but this is largely dependent on the local conditions and the size of the power plant. In China, micro hydropower generators of all sizes can be found, facilitating system sizing according to the demand for power. Furthermore, different types of machines are available for matching virtually all heads and flow rates. In general, systems are low cost (Chinese mini-hydro is lowest cost in the world), and are of good quality.

The peak energy demand available from these systems is more limited than that of grid extension, and an important consideration is whether the system is to supply productive power

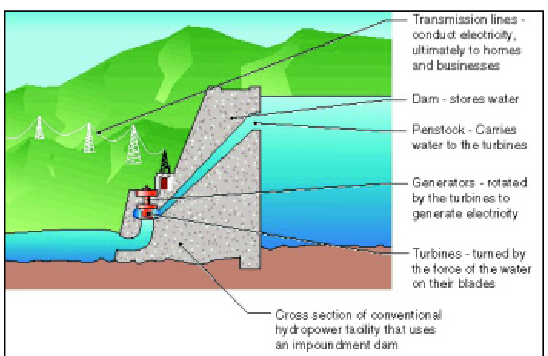


Sicheng Wang

Mini Hydro in Linzi, Tibet


William Wallace

Mini Hydro in Santanghu, Xinjiang



NREL

Hydro power station

uses during working hours. If excess power is available during the daytime and there is good productive load potential, system costs can be better sustained with the additional income from this demand. In the system design and planning stage, prospective productive power users will need to make informed choices, and once made, be enticed to contract a minimum consumption and minimum (and maximum) capacity so as to ensure revenues are generated from the full installed capacity[2]. Energy efficiency measures on the demand-side (e.g. use of high efficiency bulbs) can be a useful way of keeping system size down and making maximum use of system power output where resources are scarce (or intermittently scarce).

In case of water shortage, or periods of reduced water availability, larger reservoir storage capacity or demand-side management, such as limiting power generation to evening hours only, are ways of effectively managing the system. Where water resources are sufficient to meet demand, 24-hour power is common. This is normally the case for larger HPS systems.

In the case of HPS, the initial investment costs are the single major system cost component (see Chapter 3), so system sizing is important. Even so, since the lifetime of electromechanical generators is relatively long and investment costs of the equipment are relatively low, some excess capacity can normally be installed to cover future load growth. A common practice is to layout the civil works for the maximum long-term future system capacity, but to limit the electromechanical equipment size to that of the medium-term. Thus, as demand grows, new equipment can be added. This way the flexibility of the system in terms of expansion is ensured without the need to expand costly civil works.

2.1.3 Stand-alone Combustion Power Systems (diesel/gasoline fuelled)

Status

Stand-alone, combustion power systems (CPS) are a conventional and widely adopted power solution in remote villages where electric grid extension is unfeasible due to technology limitations or expense, and where other alternatives were considered unfeasible or not considered at all. Often the local village administration sets up such systems, starting with the aim of electrifying the village administrative center. In addition, the relatively low investment costs of combustion power plants mean that this is also an affordable power solution for a private operator. It is often the case that an entrepreneur requiring power for his or her own productive use during the daytime will use their generator to provide residential lighting for neighbors during the evening and generate some extra income. Since the technology is widely known and available, and has an understood technical basis, it is the technology of choice for organizations without the technical expertise to look at other electrification options. The two main fuel choices are gasoline and diesel, although kerosene is used in many areas and natural gas generators are becoming more common as the availability of this fuel in rural areas increases. Generally, gasoline generators are prevalent amongst small power generator units of below 10 kW, while diesel engines are widely used from about 7 kW up to 10 MW. Diesel engines are heavier in construction and can be operated for up to 24hours a day for long periods of time. Gasoline engines are lighter weight and primarily designed to operate for only a few hours at a time.

It should also be noted that other alternative fuels might also be applicable in the Chinese market. Locally produced fuels,

[2] This also is true for every energy that can be used for productive uses.

such as natural gas, biofuels (e.g. ethanol, vegetable oil) and biogas, may be used in combination with other traditional fuels to allow system operation without a dependency on unpredictable imported fuel sources.

Resource availability

Diesel, gasoline and kerosene are widely available throughout most of rural China, though costs increase with distance away from local towns. In some very remote regions, such as Western Tibet, fuels may not be available at all, and in other areas fuel supply by road transportation may be interrupted for several weeks due to rain or snow.

System features

Autonomous CPS can be sized to meet the service level required, but power supply will be more limited than in the case of grid extension. The systems often provide service to government offices as well as to residents, using a diesel generator and low-voltage distribution system or mini-grid. Generally, systems of less than 25 kW provide only single-phase power for all connections. Hence, for smaller systems, the supply is normally for household and social uses only. In such cases the systems run only a few hours per day, primarily during the evening. However, demands for daytime productive power and evening residential power can complement each other within a single system. System costs can be better sustained with the additional income from productive loads. However, some productive loads may merit their own dedicated generation system.

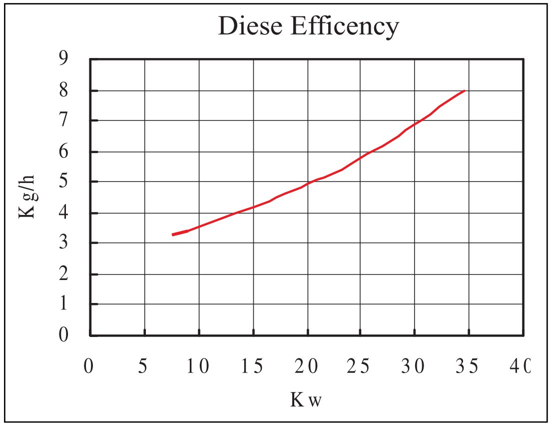
Although initial investment costs are relatively low, the short lifetime of gasoline generators (3-4 years), small diesel engines (5 to 7 years) and fuel costs make this a system with high operation and maintenance (O&M) costs. Diligent O&M can extend the lifetime of gensets and hence reduce overall costs, but since fuel purchase makes up the majority of operating costs, the systems remain expensive in areas where the delivered cost of fuel is high. These systems are most successful if they employ a local technician for O&M and if fee collection is carried-out by the local authorities, based on cost recovery or an acceptable maximum tariff.

Optimal management of combustion power systems should always seek to reduce the specific fuel consumption (kg/kWh or l/kWh). Fuel consumption of a combustion engine is based on two parameters, the first being the fixed consumption when the generator is operating, the no load fuel consumption, which is a function of the size of the unit, and a parameter that changes as the generator is loaded. Every engine has a point of maximum efficiency, usually around 80% of its rated capacity at a specified power factor, usually 0.8. The engine operating away from its peak efficiency rating will cause consuming more fuel, the lower the load, the more per kW fuel consumption. Also, due to the basically fixed idle fuel consumption, the lower the power output, the lower the total unit efficiency. One aspect of combustion engine generation is that the marginal cost of increased power production is usually quite small if the engine is already operating. Because of this, energy efficiency measures are not commonly used in diesel power systems and in many cases light switches are not even incorporated into household lighting. Since diesel engines require heat and pressure to operate, if units are operated at low loading for long periods of time, damage may result. For this reason diesel manufacturers specify a minimum recommended operating level, usually around 40% of their rated power. Engine fuel consumption will also vary with age and is greatly dependent on the level and quality of system maintenance.

Generally, the total capacity of a CPS is based on the peak

William Wallace

Diesel genset, Qinghai



Wind power System, Huaerci, Xinjiang

load expected for the community. However, in many cases this is assumed to be much larger than is normally the case. For example, short system peaks (spikes) may result from the use of welders and other power tools. As a result, it is not uncommon to find diesel systems running at very low power loadings. Since the initial, no load fuel consumption can be close to 50% of the full load consumption, as is seen in the figure above, oversizing a diesel system can result in needless consumption of large quantities of fuel.

To optimize the performance of a CPS, the power system should have some means of adjusting its power output according to the changing load without a significant loss in efficiency. A good practice is for a CPS to consist of several differently sized gensets, instead of a single large generator unit, even if the single large unit is available at a lower cost than multiple units. The number of units and capacity of each unit will be determined by the system load and load profile. When the size and combination patterns of a multiple diesel genset system have been determined, the conditions for switching between operating patterns need to be determined. Some suggestions for configurations of multiple generator systems and combination patterns of CPSs are given in Annex II.

2.1.4 Wind Power Village System with Battery Bank (WPS)

Status

In China's wind-rich coastal island regions and northwestern areas, a number of autonomous wind generator systems have been installed over the last 10 years. Over 150,000 household wind systems (up to 1kW) operate across the country. There are currently at least 6 wind battery power village systems working in China, and experience with these has been encouraging. A further 28 village power systems using wind turbines in conjunction with diesel generators have also been installed (See section 2.1.6 Hybrid Systems).

Resource Requirement

Wind resources are extremely site specific. And aside from the influences of variations in local topography and micro-siting, available wind power varies from hour to hour and from year to year. Because of these fluctuations, the wind resource must always be confirmed through on-site measurement prior to finalization of the system design. Larger system sites will warrant a more prolonged period of wind monitoring to get a full understanding of the local wind regime. The power in the wind is directly related to the cube of the wind speed and to the air density. As a rough guide, wind resources become exploitable where average annual wind speeds exceed 4 - 5 m/s. However, since the power that can be extracted from the wind is proportional to the cube of its speed, a site with a 10m/s wind regime half of the time can

Essential Factors in Wind Resource Evaluation

- Monthly average wind speed (historical meteorological data)
- Height at which wind speeds were measured
- Site altitude
- Any daily variation in wind speed, called the diurnal wind pattern
- Frequency distribution of wind speed if available
- Indication of primary seasonal wind directions, wind rose
- Topography of the site
- Forestry cover at site, height of the tallest growth

generate more power (albeit intermittently) than a site with a constant 5 m/s wind resource, although the annual average will be the same in both cases. Because of the importance of air density, thinner air at higher altitudes reduces the power availability. The essential factors to be considered in assessing wind power application are shown in the box below. A more detailed discussion of measuring and evaluating wind resources is provided in Annex II, Section 4.1.

System Features

Power is generated from the wind using a tower-mounted wind turbine. Since, due to wind speed variations, wind systems do not provide a constant level of power supply, a common practice is to add a battery bank to the system to store surplus power for use in times of calm or low wind. Power is stored in the battery bank in DC form, which can either be directly used in DC appliances or, if to be used in standard AC appliances, must be converted to AC power using an inverter. The energy that can be produced by such a system is more limited than in the case of grid extension; hence demand should be more strictly controlled. Wind-battery systems are therefore most applicable for small loads, such as dedicated uses (water pumping for instance), individual rural homes, schools, remote health posts or any other small loading situation in an area with a good wind resource.

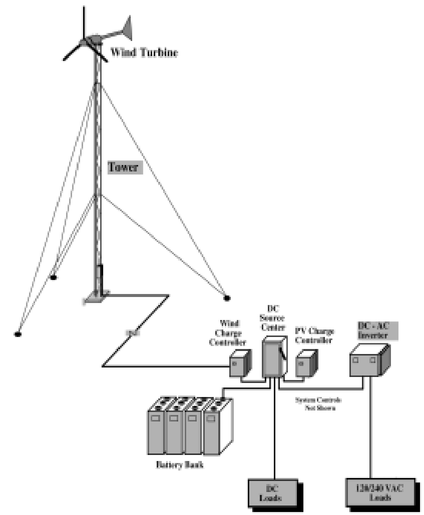
A typical WPS consists of the following components:

- One or multiple wind turbines with towers.
- Charge controllers (for battery bank)
- Battery bank
- Inverter
- Low voltage distribution grid

Wind turbine: The wind turbine is a machine that converts the energy in the wind into electric energy, dependent on variations in the wind resource. To provide stable electricity to users, WPS have to include some method to stabilize the power output of the power system. Furthermore, the wind turbine must also have the capability to limit the turbine speed, and to provide a method for stopping it in high wind conditions or for maintenance. Wind turbines generally fit into two basic categories, smaller DC based permanent magnet turbines, generally used for rural electrification, and large induction turbines, normally used in conjunction with an existing grid. There is some overlap between these technologies for potential applications in rural China (e.g. on islands), but this work focuses on the smaller systems, as these will be more prevalent for rural electrification activities. Generally, small wind turbines use permanent magnet alternators to produce wild AC power that is in turn rectified to DC and used in conjunction with a battery bank. Small turbines are usually made with few moving parts and are designed for rural applications where frequent maintenance is difficult. Large AC turbines are designed for incorporation into an established power grid, either conventional or supplied by a diesel genset. They are usually incorporated into wind farms and require more general maintenance.

Wind generators of all sorts and sizes can be found in China. There are low cost systems designed for household applications of 100W costing 1000 RMB, and bigger units of 5 kW (70,000 RMB) and 10 kW (100,000RMB). However the operational life of these low cost turbines is often limited. Better quality systems partially produced in China come with 600-1000 kW capacity at 5000-6000 RMB/unit to 10 kW at 120,000-150,000 RMB[3].

Figure 2.1, A typical WPS layout, consisting of wind turbine, charge controller, battery bank and inverter.



[3] These prices quoted only cover the turbine itself (not including tower, inverter, battery storage and foundation).

Michael Bergey

Single Pole Tower

Michael Bergey

Guyed-wire Tower

Tower: Because wind speeds increase with height off the ground, the taller the tower, the more the power. On the other hand, a higher tower costs more, so this trade-off must be balanced. Such a comparison is provided in the following example box. The height of the tower should be at least 2 meters higher than any obstacles around the turbine. For small home systems, smaller towers around 4 to 6 meters can be used to assist in maintenance and transportability. For larger power systems, such as for schools or rural communities, the minimum tower height should be 18 meters. Although some towers can be produced out of locally available materials, it is recommended that the design is checked by a professional engineer and that the tower hardware, which is used to connect the turbine to the tower, be purchased from the turbine manufacturer. Also, the construction of the tower concrete foundations should follow the instructions from the turbine manufacturer. Any failure to observe the foundation contraction may cause fatal consequence.

Example: Cost Effectiveness of Increasing Tower Height

The cost of increasing tower height by 6m can be estimated as 5000 Yuan. The increment of power output is 4.3 kWh/day. or 1570 kWh/year. If the tariff is 1.5 Yuan/kWh, annual income difference is 2,355 Yuan/year. About two years will pay the extra investment back.

Charge controller: The charge controller controls the charging of the battery by the wind turbine. Improper battery charging will lead to low charge efficiency and short battery lifetime. The charge controller usually has the following basic features:

- Battery over-charge control to prevent the wind turbine from charging the battery too heavily
- Malfunction protection from inverter and other system components
- Lightning protection
- Protection from inverse direction current flow, where the battery may discharge through the wind turbine
- An easy disconnection point to separate the wind turbine from the power system

Battery bank: When the electricity produced by the wind turbine exceeds the system load, the extra power can be stored in a battery bank. Power system battery banks are made-up of multiple units of stationary deep-cycle batteries linked together in series. The size of the battery bank (number of units) is determined by the load capacity, local wind pattern, and desired storage time, typically in days. In determining the appropriate battery bank size, the investor must carefully

Guidelines for Battery Bank Sizing

Battery bank capacity (kWh) = (Avg. daily load (kWh) / battery discharge rate) x required backup days /(Inverter conversion efficiency × power transfer effieciency)
Example:
Avg. daily load = 30kWh
Battery discharge rate = 50% - (though depends on the battery).
Expected backup days = 2
Inverter conversion efficiency = 0.9
Power transfer efficiency = 0.98
Battery bank capacity (kWh) = (30 / 0.5) × 2 /(0.9 × 0.98) = 136 kWh
A battery bank of this size might typically be made up of:
2 strings of 60 batteries, each battery of 2V × 600Ah capacity
(cost approx. 130,000 RMB)
or
6 strings of 10 batteries, each battery of 12V × 200 Ah capacity
(cost approx. 114,000 RMB)

Battery Selection and Maintenance

- Use a deep-cycle, marine or industrial batteries instead of a vehicle ignition batteries
- Keep the room where battery bank is installed warm in winter to maintain the battery efficiency but not at the expense of heaters
- If not housed in a separate room, batteries should be housed in an explosive resistant watertight box made of wood or steel
- Battery rooms or housings should have venting to reduce the build-up of explosive gasses
- The level of the water in flooded batteries should be checked at least once a month and filled with distilled water
- Battery terminals should be coated with sealant or grease to prevent oxidation
- Equalize the batteries following the manufacturer's instructions, typically every two months

weigh-up the need for a reliable power supply against the costs of power storage capacity. The battery is an expensive component of the system and will need to be replaced within 6-8 years[4], depending on its quality and application. Appropriate battery sizing, careful management (no over charging or over discharging) and good battery maintenance are therefore critical to the cost-effectiveness of the entire system. Prevailing community wind system design philosophy in China is to install enough storage capacity for 2-days power demand.

Inverter and load controllers: In a DC-Bus WPS, electricity is transmitted by direct current (DC). The DC power can be used directly for any DC loads, such as light bulbs, radios, TVs, and many industrial appliances. If DC loads are used, a DC load controller must be implemented between the DC bus bar and the loads. The DC load controller should have the following features:

- Low voltage disconnect to disconnect the battery when it reaches a low state of charge
- Fast acting fuses to protect the user and battery bank from short circuiting in the DC loads
- Polarity protection so that devices cannot be connected improperly
- Manual disconnection to allow the user to disconnect all of the DC loads safely

However, most household appliances use alternating current (AC). Inverters are commonly added to the system to convert DC power into AC power for these appliances. Inverters are available in many sizes and capacities but reliability of the electronics is a big concern for some locally produced inverters. In most cases the failure of the inverter will render the power system useless and this has been a weak link of REVPS in China in the past. A quality inverter should at least have the following features:

- A wide DC input range and stable AC output;
- High conversion efficiency and very low idle power consumption;
- Able to sustain the surge power when starting large loads;
- Over-current and over voltage protection;
- Low voltage protection to keep battery from being heavily discharged;
- Wire shortage, fast acting fuses and wrong connection (polarity) protection.

Michael Bergey

Tilt-up Tower

Bergey Windpower

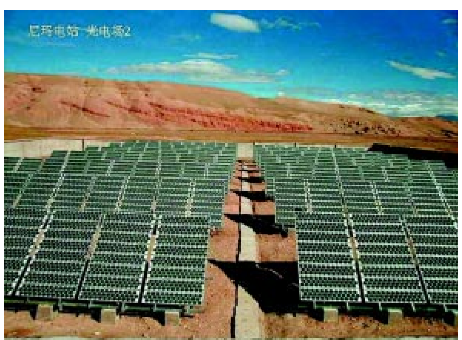
Controller with DC source center

Sicheng Wang

Battery bank, Nima, Tibet

[4] Most batteries on the market are vehicle starting batteries, and are not designed for energy storage purposes. These batteries will have a very short life time if they are used for village power (0.5-1 year). For renewable energy systems, we have to use energy storage batteries (deep cycling batteries). See Annex II.


SPS in kekel:,QH


SPS in Nima, Tibet

In the case of wind systems, the initial investment cost is the single major cost component, while O&M costs are minimal. Battery replacement costs are the second major cost component as battery lifetime can range from as little as two to up to eight years, depending on their use. Appropriate system sizing (investment cost related) is thus a first requirement. Smaller systems supply power for household and social uses, and sometimes only run during evening hours. As for alternative power solutions, the inclusion of productive loads will increase the initial investment, but will help to sustain system costs through increased power sales and increased income from productive applications.

For flexibility of the system in terms of expansion, a modular system (e.g. 5 wind generators of 10 kW instead of a single 50 kW unit) is usually better, but this would have to be balanced against the cost advantage of a larger single unit. Experience has shown that proper demand assessment is essential and that modularity for wind generators (and battery bank storage) is a cost-effective method to cope with uncertain demand growth.

Further design tips and requirements for WPS are provided in Annex II.

2.1.5 Community Solar Power System (SPS)

Status

More than 18 community solar PV-battery village power systems (some with diesel back-up) have been installed over the last 10 years in China's sunshine-rich western provinces. Installed systems vary widely in capacity, from a few kW to 100 kW, providing electricity to as many as 250 households. In general, these systems have performed well technically and operated without difficulty. Examples are shown of a 10kW PV power system operating in Kekeli, Qinghai, and a 55kW PV power system in Nima, Tibet AR.

Resource Requirement

Solar power resources vary seasonally, monthly, daily, hourly and from place to place. The solar resource is directly related to solar irradiation, latitude, altitude, cloud cover and the content of water vapor and dust in the air. The higher the latitude, the lower the solar power due to the tilt of the earth and the amount of atmosphere through which the sun's rays must pass before reaching the earth. China's best solar resources are found in the western provinces, such as Tibet, Qinghai, Gansu and Ningxia (see solar maps). Most locations in these provinces will have at least fair solar resources (1200 - 1500 hours peak sunshine hours equivalent per year), which are exploitable. A more detailed discussion of solar resource evaluation is given in Annex II, Section 5.1.

Essential factors in solar energy application

- Monthly average of daily sunshine hours
- Site latitude
- Local average cloudy days, foggy days, rainfall days, etc.

System Features

SPS are generally simple, built-up arrays of photovoltaic (PV) modules, which feed power through a charge controller to a battery bank, from where the system load is fed (see Figure 2.2). Use of battery storage is required due to the intermittent nature of the energy resource (in the case of a PV system, daytime only). In larger systems, energy is converted to 220V AC to feed a mini-grid for domestic, social or productive uses.

Larger PV systems might consist of multiple substations with separate control systems and battery banks. In the larger systems, power is conducted to the residences by a three-phase mini-grid. SPS are modular and can be easily be adapted to meet increases in demand.

Energy supply from a SPS is far more limited than in the case of grid extension. Consumers thus must restrict the use of high power consuming equipment, and use energy efficient appliances wherever possible. However, since the electricity supply of these systems is standard in character (220 V, AC, 50 Hz), individuals will be tempted to purchase such equipment. For smaller systems, the load is more focused to serve household and social needs, bringing quality of life improvements and enabling relatively small and limited productive uses. In such cases, the systems may only run during evening hours. For larger systems, power supply can also be extended to working hours but, even so, only minor productive loads (ventilators, cool storage and refrigerators, hand machine tools) might be supplied. High power consuming motors or heat generating appliances such as air conditioning and electric water heating are too energy intensive and will usually be beyond the capabilities of these systems. High power consumption productive loads, such as milling, grinding, and saw milling, are also not recommended. In short, productive loads should not be precluded but prospective productive users will need to make informed choices in the system design and planning stage and be encouraged to contract a minimum (and maximum) consumption, so as to ensure the revenues required to off-set the high-cost of extra installed capacity.

SPS investment costs are extremely high and are in fact the single major component; battery replacement costs are the second component, while other O&M costs are minor (see Chapter 3). Appropriate system sizing based on the costs of various alternatives is thus the first requirement.

PV array: PV arrays should connect modules of same specs in series or parallel. The installation should be fixed at a certain pre-determined angle so as to collect the maximum solar irradiation over a year or collect the maximum during the season of highest demand, and may be adjusted seasonally. The structure design should assure an excellent connection between modules and frames, and be able to sustain wind speeds of 28m/s.

Battery: The principles of battery design and sizing are as in WPS (see above). However, the sunshine is only available in daytime but the most loads are at night, an SPS has to store the energy got from daytime and for evening application, while wind may available any time. So the prevailing SPS design philosophy in China is to install more power storage capacity than WPS. This is a contributing factor to the excessive costs of SPS for community applications as compared with other alternatives.

Tips - Special Care with SPS

SPS design must satisfy the climatic conditions of the project site. As for applications in higher altitude areas, the system developer has to be very careful about the air pressure of the gas-valve of gel cell batteries and the heat sink of all electronic components.

Inverter: Same as in WPS (see above).

Further design tips and requirements for SPS are provided in Annex II.

Figure 2.2. A typical SPS, consisting of PV array, battery bank charge controller and inverter.

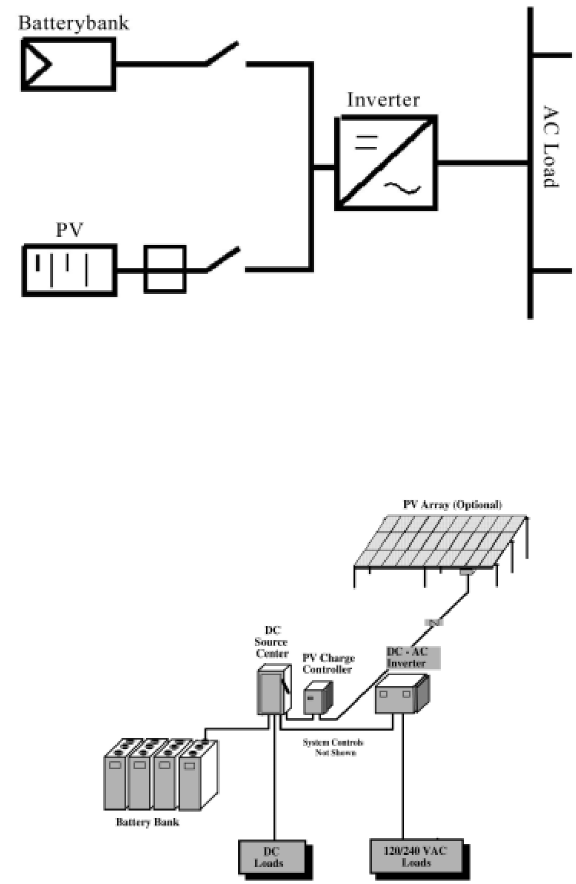


Figure 2.3 Example: Monthly Annual Windspeed Variation

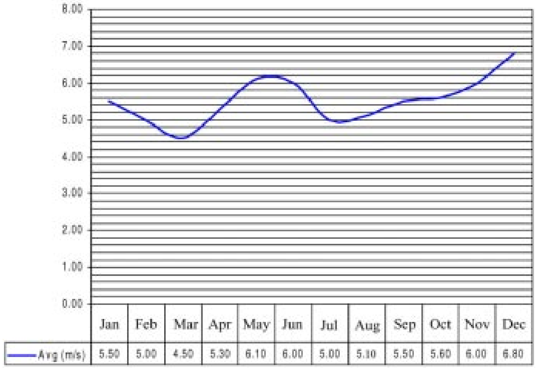
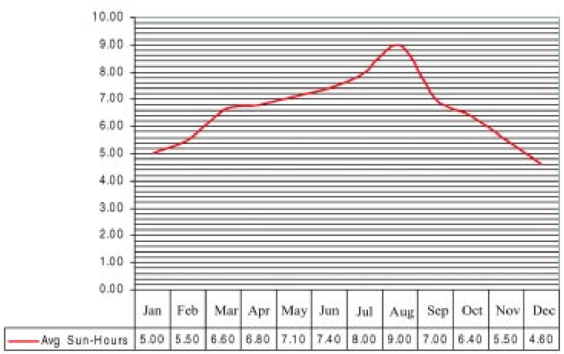


Figure 2.4 Example: Monthly Annual Sunshine Variation



2.1.6 Hybrid Systems

Status

Since renewable energy resources are, by their nature, intermittent, in some cases it is desirable to design a system that combines a renewable energy technology with another power source, thereby improving the level of system service and reliability. These "hybrid" combinations may involve the addition of a second renewable energy technology (say wind and solar) and/or the addition of a conventional fossil fueled generator. The commonest practice is to add a diesel genset to a Wind/battery or PV/battery system, but Wind/PV/battery and Wind/PV/battery/diesel systems are also standard design solutions. As mentioned in section 2.1.3 above, dispatchable generators either fueled with gasoline, natural gas, kerosene, biogas or bio-fuels, can also be used in place of diesel gensets. Around 40 hybrid village power systems (5kW- 200kW) have been installed across the country to date. These are sited in two distinct types of locations, on islands in China's coastal regions, and in remote regions of the northern and western provinces. Typically, the island systems employ a combination of wind, diesel and battery technologies, while the inland systems also make use of PV technology.

Resource Requirement

Wind and solar resource requirements are basically the same as per stand-alone wind and PV systems above. However, in a hybrid system, where one or both of these resources is insufficient to provide all of the power demanded by the system, an additional power source is harnessed to make up for the deficit. As previously noted, wind power resources vary with time, with generally seasonal and diurnal characteristics. Figure 2.3 gives an example of a typical monthly wind speed variation over one year. It can be noted that the wind speed is lower in spring and fall. Solar energy resources also vary seasonally, generally providing a much better energy resource in summer than in winter. Figure 2.4 gives an example of monthly sunshine hour variation over one year. From these graphs, it can be seen that these two resources can be combined to complement one another in a W/PV hybrid system. In this way, solar energy can be used to supplement insufficient wind energy in July, August and September, and available wind energy will match poorer solar resources in winter.

Alternatively, if there is no such complementary match between the solar and wind resources, a diesel genset can be installed to keep the battery well charged or to be available as a back-up power source when needed. Since each type of technology has different technical advantages, capital costs and operational costs, the true question that must be addressed is how, given the unit costs and natural resources, to optimize the system to determine the best mix and sizing of technologies. There are a number of computer simulation models that have been created to assist the system designer determine which system configurations should be considered.

System Features

Some examples of common hybrid arrangements are introduced below. By nature, hybrid systems are technically more complicated than wind or solar stand-alone solutions but this depends greatly on the size of the systems being considered. Hybrid systems can also be used to provide power to systems ranging from a few kWh per day up to very large remote power systems several MW in size. Since hybrid systems are often used to provide power to a whole community or larger load base in remote locations, system reliability should always be the foremost design criterion.

Wind/PV/Battery Village Hybrid System (W/PV/B)

A W/PV/B system configuration is shown as in Figure 2.5. Usually the size of the PV array is about 10-20% of the entire hybrid system capacity, although this will depend on the renewable resources available at the location. The W/PV/B system consists of:

- One or more wind turbines
- PV array
- Inverter
- Charge controller
- Battery bank

Typical Wind/PV Hybrid Systems and their Application

Wind (kW)	PV (kW)	Daily output (kWh/day[1])	Families served
2-3	1	15-20	~10
5	1	25-35	20-40
10	2	50-70	40-70

(1) Typical wind speed is of~5m/s and solar equivalent hours of ~4kWh/m²

W/PV/B REVPS provide more reliable power supply than WPS or SPS alone, especially if the W/PV/B is equipped with large battery bank to ensure power supply during low wind days. The trade-off is the high cost of PV panels and battery bank. PV modules will usually not account for more than 10-20% of the system energy production. The battery bank is the second greatest cost component and usually requires replacing every 6-8 years. These costs may restrict the application of W/PV/B systems to small and medium-sized villages (up to 300 households).

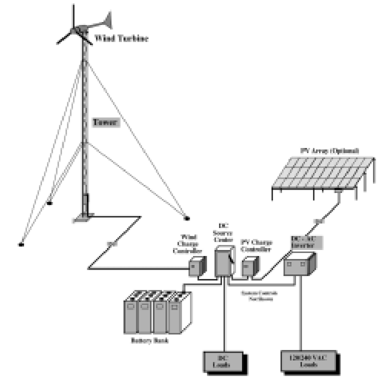
Wind/Diesel/Battery hybrid system (W/D/B)

A cheaper alternative to adding PV capacity is to use a back-up diesel generator. Another reason to develop a W/B/D system may be that solar and wind resources are not sufficiently complementary, such as in March in above example. There are two principal kinds of W/D/B systems: DC-bus and AC-bus. DC-bus systems are based on components providing power in the form of direct current and are always tied to a battery bank, which is used to store energy for use when there is no renewable energy generation. In this case almost all of the generation capacity, other than the dispatchable generator usually, is tied to the DC-bus and the battery bank. Their limitation is the cost associated with the battery bank used to store power and the fact that DC-bus devices tend to be smaller and more expensive than their AC counterparts. Hence DC-bus systems are generally smaller and suitable for communities of up to 1400 households. For large communities, an AC-bus system, in which all of the energy producing devices generate AC power and are directly connected to the grid, may be a more cost-effective solution. Several island systems employ AC-bus configurations. The principal differences between DC- and AC-bus systems are listed in following tables.[5]

DC Bus Systems

A simple W/D/B system is shown in Figure 2.6. It consists of a wind turbine, one diesel genset, a battery bank and an inverter. Electricity generated by the wind turbine(s) is either passed directly on to the inverter or used to charge the battery. The battery then supplies power to the system in response to the demand, making up any deficit in the wind power. The diesel is used as a backup for times of low wind and/or peak power demand and is started automatically when

Figure 2.5 Wind/PV/Battery System Configuration



Ian Baring-Gould

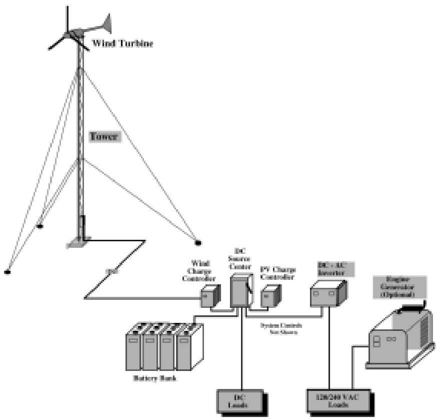
A wind/PV hybrid in Inner Mongolia

Charlie Dou

A wind/diesel hybrid in Baiyinaobao, Inner Mongolia

[5] High penetration AC bus Wind Diesel Hybrid Power System, Village Power '98, Steve Drouilhet, NREL, US DOE

Figure 2.6 Wind/Diesel/Battery DC-Bus System Configuration




Charlie Dou


Charlie Dou

A wind/PV hybrid in Zhalute, Inner Mongolia

Comparison of AC and DC Bus Wind Hybrid Systems

Issue	AC Bus	DC Bus
Scale	Best suited to systems >50 kW. Permits use of larger more cost-effective wind turbines.	Best suited to small systems. Simpler architecture more easily maintained.
Renewable Energy Path	Wind turbine power can flow directly to the load, without the losses associated with power conversion.	All power must flow through a DC/AC converter (rotary or inverter)
Siting	Existing AC distribution lines can be used to connect wind turbines to power system.	Requires dedicated lines to connect turbines to power system.
Control Complexity	Active control system required to dispatch wind turbines, modulate dump load power, dispatch storage, etc.	Relatively simple system control. However, embedded inverter controls can be complex.
Cost	Often competing with existing diesel power stations. Must be competitive with diesel only.	Often offers 24-hr/day power where none existed before. Higher costs are tolerated.

the system monitor detects the battery level is lower or high current is needed to supply the load. When operating the generator will provide the mini-grid directly and charges the battery bank simultaneously up to its rated power. When the battery is fully charged or enough power is being generated by the wind turbines the diesel will stop operating. In this way the diesel can usually be run at very high efficiency and with very few start/stop cycles. The system should make maximum use of the available wind energy, using the diesel near its rated working point. The rest of the time the diesel is shut down, and should result in a large reduction in fuel consumption as compared to a diesel only power system. At the locations where have excellent wind resource, the wind power can provide up to 80~90% off the total consumed electricity.

AC-bus Systems

In an AC bus system, the battery is normally eliminated or used to provide a buffer that enables a diesel engine to be started when there is reduced output from the renewable devices. As is shown in Figure 2.7, in AC-bus systems, the primary connection point is on the AC-bus and thus more care must be taken to ensure that power quality is not adversely affected by the inclusion of the varying renewable devices.

AC-bus system configuration can vary greatly depending on the size and amount of the renewable devices connected to the system. The amount of renewable energy connected to the grid can be described using two terms, instantaneous penetration and average penetration. Instantaneous penetration is the ratio of renewable energy production to the total load on an instantaneous basis, measured in kW. Instantaneous penetration is used in the determination of power quality issues relating to the stability and soundness of the power system and relates more to system design and operation. Average penetration is the amount of energy produced by renewable sources compared to the total produced energy over a given time period, typically a month or year, and is measured in kWh. Thus this is an economic parameter, which can be used to determine the cost saving, or penalty, resulting from the use of renewable energy. Both penetration figures depend on the capacity of renewable energy devices installed on the system and the renewable resources present. Basically, the higher the average wind power penetration, the higher the savings in diesel fuel consumption. AC-bus systems can be classified into three basic categories as described in the following table.

Since AC-bus systems have only limited power storage capacity (relative to power production capacity), more advanced control systems are required to manage the system output, e. g. in non-diesel operation modes or during periods of excess power supply. The higher the instantaneous wind penetration in an AC-bus system, the more sophisticated must be the control system that will be used to manage the system. There are a number of methods that are available to provide control to the power system when the diesels are switched off, these include:

- Active control of the wind turbine(s) to reduce power production when an excess power is being produced. This may be done by shutting down turbines or adjusting the power production through the use of ailerons, mechanical pitching mechanisms or power control. It is highly recommended that turbines with these control options be favored in remote power stations
- Installation of dispatchable loads to consume extra power, such as resistance heating or water purification
- Load shedding, a process in which non-critical loads are temporarily shut-off to quickly reduce system load
- Back driving the diesel generator, a process where power is actually put into the generator to overcome the generator losses while keeping the gen-

PENETRATION CLASS	OPERATING CHARACTERISTICS	PENETRATION	
		PEAK INSTANTANEOUS	ANNUAL AVERAGE
LOW	Diesel runs full time	< 50%	< 20%
	Wind power reduces net load on diesel		
	All wind energy goes to primary load		
	No supervisory control system		
MEDIUM	Diesel runs full time	50 - 100%	20 - 50%
	At high wind power levels, secondary loads dispatched to ensure sufficient diesel loading		
	Alternatively, wind turbines are curtailed during high winds and low loads		
	Requires relatively simple control system		
HIGH	Diesels may be shut down during high wind availability	100 - 400%	50 - 150%
	Auxiliary components required to regulate voltage and frequency		
	Requires sophisticated control system		

Charlie Dou

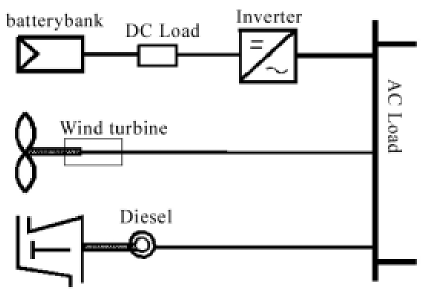
A wind/diesel hybrid in Baiyinaobao, Inner Mongolia

Lawrence Mott

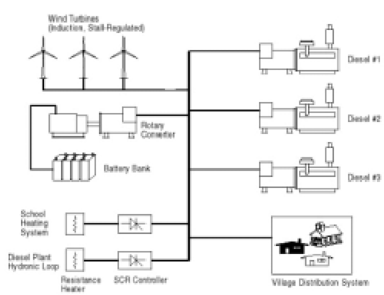
Lawrence Mott

A wind/Diesel hybrid in St. Paul, Alaska, USA

Figure 2.7 Typical AC-bus System Lay-out



AC Bus Wind-Diesel Architecture for Wales, AK



Jerry Bianchi

A wind/PV/diesel hybrid in New Mexico, USA. 17KW PV, 70kW Wind and 80kW Diesel

eration running so that it can be loaded quickly. This is analogues to using a car's engine to control speed while going down hill

- Installing systems, like block heaters, to allow quick starting of generators
- Installation of a capacitor bank to smooth out rapid system fluctuations and partially correct the systems power factor
- Installation of a synchronous condenser or rotary converter, which is used to produce reactive power and help control system voltage
- Use of fast acting dump loads to maintain a load balance and thus control system frequency

AC-bus systems typically use wind turbines of 50kW and larger and are therefore more suitable for large village applications. In low- and medium- penetration systems the diesel generator is used as the source of active power, while in high penetration systems other devices are incorporated to insure high power quality when the diesel engines are not running. The technical support required for AC-bus systems depends greatly on the level of system penetration. Low penetration systems have little need for much expert technical assistance, other than providing maintenance to the wind turbines. However, high penetration systems have greater requirements for specialist technical support infrastructure and this has been found to be a limiting factor for some island systems installed in China in the past.

Wind/PV/Diesel/Battery hybrid system (W/PV/D/B)

Further to the above arrangements, it is also possible to include wind, PV and diesel power in a single hybrid power system. This system also uses diesel back-up power to complement exploitable but insufficient renewable resources. Such systems can provide power for daily life, and also for small productive loads, such as small power agricultural or husbandry tools, or pumping drinking water for either residents or livestock.

AC-bus Example - St. Paul System Details*

System:	Stand Alone Utility: Combined Heat and Power
Configuration:	High Penetration/No Storage Wind-Diesel
Size:	500 kW
Application:	Public Power Supply, Providing Electricity and Space Heat to Industrial/Airport Facility
Location:	Pribilof Islands, Bering Sea
Peak Load:	160 kW (With Load Growth Planned)
Customer:	NPS/Tanadgusix Corporation (TDX)
Funding:	Commercial, lease based
Cost of Energy:	+ $.21/kWh (Current Diesel Grid Cost is $.34/kWh)

*Ian Baring-Gould, Commercial Status of High-Penetration Wind-Diesel Systems, National Wind Technology Center, USA

The following are two examples of W/PV/D/B configurations based upon different village sizes (load) and renewable resources.

1) Small Community System Configuration

Equipment	Qty	Notes
1kW Wind generator	3	3 kW
1kWp PV panel	1	1 kWp
6kW Charge controller and inverter	1	
12V¡ `200Ah Battery[6]	8	19.2KWh
10kW Diesel genset	1	

[6] The DC bus will be 12V. Suitable deep cycle batteries, such as 2V or 6V batteries should be selected.

With good renewable resources, this system may power 10~20 families with very little diesel consumption.

2) Medium-size Community System configuration

Equipment	Qty	Notes
10kW Wind generator	1	
2KWP PV panel	2	4 kW peak
7.5kW Charge controller and inverter	1	
77kWh Battery[7]	1	77 kWh battery bank
24kW Diesel genset	1	

With good renewable resources, this system may power 40~70 families with very little diesel consumption.

Again, optimal system configurations can only be determined by careful analysis of available renewable resources and component lifetime costs. Further technical tips on hybrid system design and sizing are provided in Annex II.

2.2 China Renewable Energy Resources

2.2.1 China Hydro Resources

Total hydro resources in China are estimated to be 676 GW and 5920 TWh, while useful electric power capacity is about 378 GW and 1920 TWh. This corresponds to 39.4kW/km^2, or 0.338kW, 1,719 kWh/capita.

The resource is concentrated in Southwest (232 GW, 61%), Mid-south (67.4 GW, 18%) and North-west (41.9 GW, 11%) regions. The Yangtze River has over 50% of total resources, the Yellow River about 6% and Zhejiang River has about 6%.[8] Technically exploitable mini-hydro resources are estimated at 80, 000 MW, mainly scattered in hilly areas around southern China.

2.2.2 China Wind Resources

China is located in a monsoon weather regime, where the wind direction is generally northerly in the winter and southerly in the summer. The wind resource is normally indicated by wind power density (W/m^2) by year and in some case by season. See wind maps in Figures 2.10 and 2.11. (These figures are based on wind speeds at 10 meters height and take into account a turbulence factor and the rotor diameter of the wind turbine).

The wind power resources in China can be classified into four levels (see table below): A (Excellent), B (Moderate), C (Marginal) and D (Poor). The wind map shows two areas

Figure 2.8 Regional distribution of China hydro resource

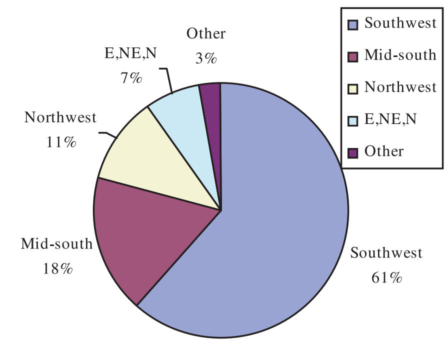
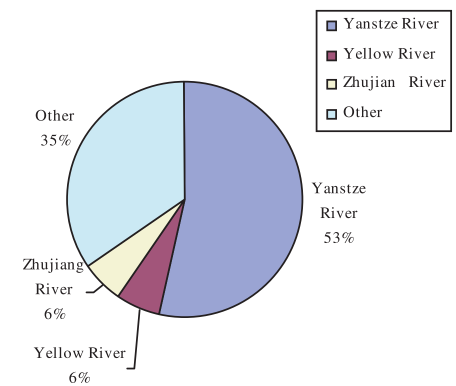


Figure 2.9 Distribution by major rivers



China Wind Resource Classification Table

Classification	A (Excellent)	B (Moderate)	C (Marginal)	D (Poor)
Annual effective wind power density (MJ/m^2)	>5850	5000-5850	4150-5000	<4150
Annual effective wind hours (>=3 m/s)	>5000	4000-5000	2000-4000	<2000

A-class regions account for about 8% of the total area of China, others are respectively: B 18%, C 50%, and D 24%.

[7] The DC bus may use 48V or 110-120V. For large DC bus system, the bus voltage may use 220-240V.
[8] Zhou Guangzhao, et al, Proceedings of the High-level Expert meeting for China, Beijing, China, 1995

with excellent wind energy resources. One is along the NE-N-NW region; another one is along the coast. Both areas have power densities of greater than 200W/m^2, and in some locations the value even reaches 500-700W/m^2. The annual effective wind duration is more than 5000 hours, and in some locations up to 7000 hours. However, wind energy is very site specific and therefore large-scale maps like these can only be used to determine if a project should consider using wind energy as an option. It is always important to understand fully the local resources before a technology is selected to provide power for a specific community.[9]

2.2.3 China Solar Resources

Solar radiation is mainly influenced by clouds, latitude and altitude. The average annual radiation in China is about 140 Kcal/cm^2, average solar power is about 1.7×10^{12} kW and the average annual hours of sunshine is 2200h[10]. In accordance with theoretical calculations, the maximum solar irradiation occurs on the high plateau of Tibet, (10,100 MJ/m^2/year or 2,807 kWh/m^2/year). See the solar resource distribution maps for details[11].

Solar resources are usually classified into four categories: Excellent, Good, Fair and Poor. These areas with “Excellent” and “Good” solar resources have good potential for solar energy applications.

SPS should be built in locations with at least fair solar resources.

Grade	Annual Value kWh/ m^2	Daily Value kWh/m^2
Excellent	> 1860	> 5.1
Good	1500 - 1860	4.1 - 5.1
Fair	1200 - 1500	3.3 - 4.1
Poor	< 1200	< 3.3

9 Plan of the first phase of Brightness Program of China, Beijing JKD Renewable Energy Development Center, July, 1999

10 Zhou Guangzhao, et al, Proceedings of the High-level Expert meeting for China, Beijing, China, 1995

11 Plan of the first phase of Brightness Program of China, Beijing JKD Renewable Energy Development Center, July, 1999

Figure 2.10 Distribution of effective wind power density in China (w/m²)

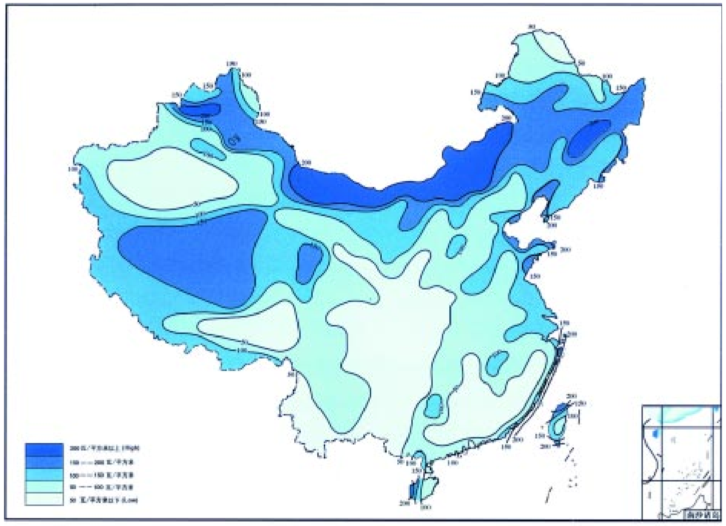


Figure 2.11 Distribution of annual duration of wind speed above 3m/s in China

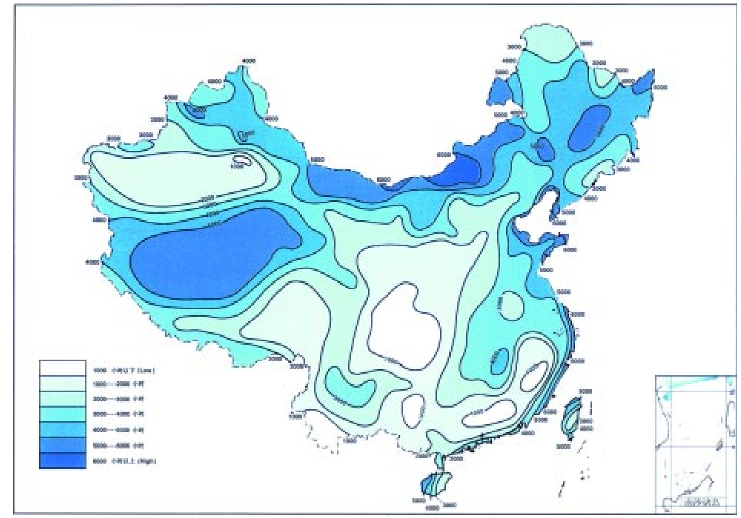


Figure 2.12 Distribution of annual sunshine duration in China

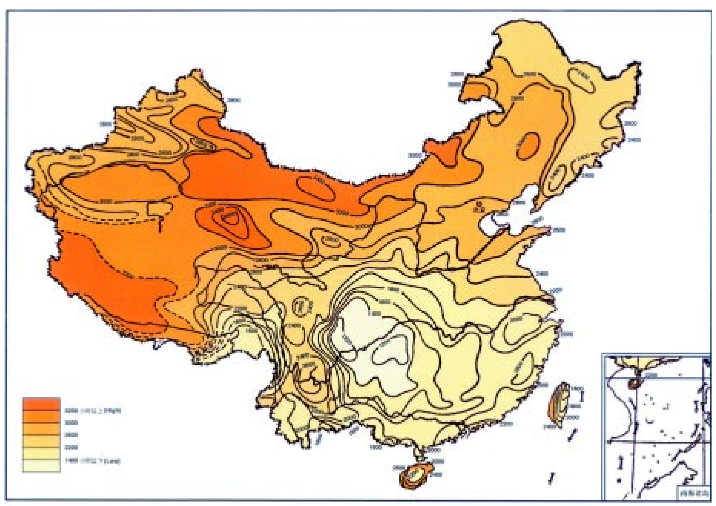
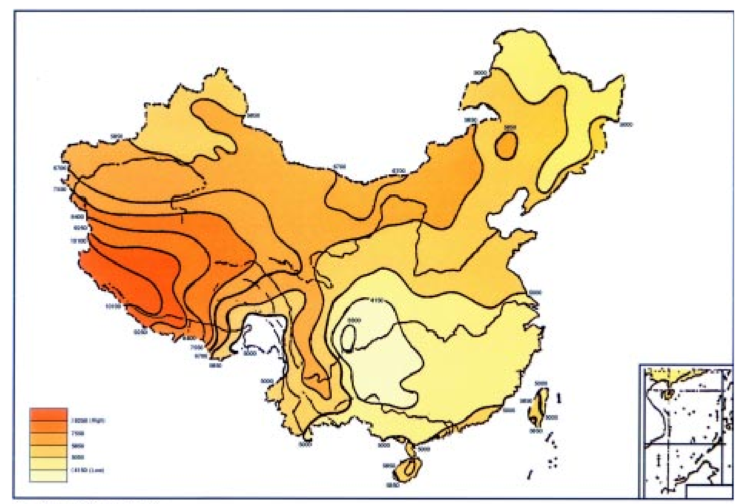


Figure 2.13 Distribution of solar energy in China (MJ/m²)



CHAPTER 3: EVALUATING THE COST-EFFECTIVENESS OF VILLAGE POWER ALTERNATIVES

3.1 Introduction

3.1.1 General

While the costs of conventional grid extension are relatively well-known to rural electrification planners, the comparative costs of renewable energy systems, which have declined significantly over the course of the last three decades, are less so. For a given community, the costs of different electricity supply alternatives will vary depending on very specific local conditions, such as load size and distribution, wind and solar resource availability, diesel price, and transportation network, to name only a few of the variable determinants. Nevertheless, this Chapter will present some basic comparisons of the relative economic and financial characteristics of village power alternatives in order to help in the identification of the most appropriate supply solutions. Needless to say, a detailed cost analysis will be merited on a case-by-case basis in determining the least-cost option for a particular village.

3.1.2 Methodology

A comparative analysis of various village power alternatives has been carried-out according to two "standard" villages, one of 300 households[1] and one of 60 households. The economic and financial costs of grid-extension, small-hydro minigrids, stand-alone diesel minigrids, wind minigrids, wind-diesel minigrids and PV minigrids have been calculated in each case. It is important to remember that the power supply services offered by each of these alternatives are not directly comparable. For example, seasonal water flow variations may mean that a mini-hydro system sees periods in which power cannot be supplied. The key assumptions used in making the calculations presented in this chapter have been derived from field data in China and are given in Annex III.

The principal investment costs associated with each of the village power systems are given in Table 3.1. Based on these costs, some economic and financial performance indicators for each of the alternatives have been calculated. Comparative economic anaylses have been performed by stipulating a required 12% return on equity (RoE)[2], and then calculating the electricity tariff necessary to generate this return in each case. Table 3.2 presents the results of these calculations according to two financing scenarios. The first, the "present case" (PC) scenario, represents current financing practices, incorporating a significant grant element (50%), with the balance of the investment coming from loan (30%) and equity (20%) contributions. The second, the "commercial case" (CC) secnario, represents a more commercial situation in which finacing comes from loan (70%) and equity (30%) sources only.

[1] Assumed that the large scale village has 300 household with 2 institutions and 5 micro-businesses (300/2/5), and a small village has 60 household with 1 institution and 2 micro-business (60/1/2).

[2] Only consider the return on equity, since most REVPSs will have a part of funding from domestic and/or international source and no return will be expected by these parties.

Table 3.1: Principal Investment Costs of Various Village Power Alternatives*
System Investment

System/ Component	Unit Cost RMB	per Unit	300 household Village		60 household Village		% of 60 HH over 300HH
			Qty	Item Cost	Qty	Item Cost	
Grid Extension (30km)							
HV Line	60,000	/km	30	1,800,000	30	1,800,000	
LV Line	36,000	/km	2	72,000	1	36,000	
Substation	3000	/Unit	1	3,000	1	3,000	
Service drop /connection	300		307	92,100	63	18,900	
Transformer	3000	/Unit	1	3,000	1	3,000	
Installation				43,200		11,700	
Spare parts (1%)				20,133		18,726	
Project development (2%)				40,000		40,000	
Total				**2,073,433**		**1,891,326**	**91%**
Micro Hydro							
Hydro-turbine	1600	/kW	2 × 31	99,200	10.3	16,480	
Civil Works				49,600		8,000	
LV Lines	36,000	/km	2	72,000	1	36,000	
Transformer				2,000		1,000	
Service drops	300	/Conn.	307	92,100	63	18,900	
Installation				23,600		11,700	
Spare parts (1%)				3,385		921	
Project development				25,000		10,000	
Total				**366,885**		**103,001**	**28%**
Diesel System (Diesel price = 3.6 Yuan/kg)							
Diesel genset	1,000	/kW	2 × 30	60,000	12	12,000	
Power House				12,000		6,000	
LV Line	36,000	/km	2	72,000	1	36,000	
Transformer				2,000		1,000	
Service drop	300	/Conn.	307	92,100	63	18,900	

System/ Component	Unit Cost RMB	per Unit	300 household Village		60 household Village		% of 60 HH over 300HH
			Qty	Item Cost	Qty	Item Cost	
Installation				23,600		11,700	
Spare parts (2%)				5,234		1,712	
Project development				10,000		2,000	
Total				**276,934**		**89,312**	**32%**
Wind Battery System (Average Annual Wind Speed =5m/s)							
Wind turbine (Tower & foundation)	16,000	/kW	41	656,000	6	96,000	
Battery*	900	/kWh	400	360,000	90	81,000	
Inverter	7,000	/kVA	35	245,000	4	28,000	
Controller & Other electronics	2,000	/kWp	41	82,000	6	12,000	
Power House				12,000		6,000	
LV Line	36,000	/km	2	72,000	1	36,000	
Service drop	300	/Conn.	307	92,100	63	18,900	
Installation				23,600		11,700	
Spare parts (1%)				15,427		2,896	
Project development				25,000		10,000	
Total				**1,583,127**		**302,496**	**19%**
Wind/diesel/Battery Hybrid System (Average Annual Wind Speed =5m/s, wind penetration = 70%, Diesel price = 3.6 Yuan/kg)							
Wind turbine & Tower	16,000	/kW	20	320,000	4	64,000	
Battery*	900	/kWh	200	180,000	45	40,500	
Inverter	7,000	/kVA	24.5	171,500	4	28,000	
Diesel genset	1,000	/kW	1	18,011	1	1,000	
Controller	2,000	/kWp	20	40,000	4	8,000	
Power House				12,000		6,000	
LV Line	36,000	/km	2	72,000	1	36,000	
Diesel charge controller				2,000		1,000	
Service drop	300	/Conn.		92,100		18,900	
Installation				23,600		11,700	

System/ Component	Unit Cost RMB	per Unit	300 household Village		60 household Village		% of 60 HH over 300HH
			Qty	Item Cost	Qty	Item Cost	
Spare parts (0.75%)				6,984		1,613	
Project development				25,000		10,000	
Total				**963,195**		**226,713**	**24%**
PV System (4.5 equivalent peak insolation hours)							
PV Modules & Frame	42,000	/kW	40.3	1,692,600	9.2	386,400	
Battery*	900	/kWh	600	540,000	135	121,500	
Inverter	7,000	/kVA	35	245,000	4	28,000	
Controller and Electronics	2,000	/kWp	40.3	80,600	9.2	18,400	
Power House				12,000		6,000	
LV Line	36,000	/km	2	72,000	1	36,000	
Service drop	300	/Conn.	307	92,100	63	18,900	
Installation				23,600		11,700	
Spare parts (0.25%)				6,895		1,567	
Project development				25,000		10,000	
Total				**2,789,795**		**638,467**	**23%**

* Note: only the principal costs are given, and the totals for each alternative may not equal the sum of the listed component costs.

* Battery size has a significant impact on the economic performance of renewable energy systems. The present study sizes community power system battery banks according to the prevailing design philosophy in China, which is for 2 days power storage for wind systems but 3 days storage for PV systems. Clearly, under a good solar regime or where reliability of supply is not paramount, storage capacity can be reduced and the economics of the PV option will improve.

From Table 3.2 we can see that for a 300 household village, solar energy has the highest initial investment, 30-km grid extension is the second, and diesel stand-alone has the lowest. Furthermore, for villages of between 60 and 300 households, the investment costs of stand-alone systems vary more or less in proportion with the size of load (or village) to be served, while investment in grid extension is independent of the size of the village (the cost of electrifying a 60 household village by grid extension is over 90% of the cost of electrifying a 300 household village by the same means). Figure 3.1 gives an indication of the relative proportions of investment and operating costs in the lifetime costs of different village power alternatives according to the assumptions in Table 3.2. This is greatest for diesel and PV systems, due to fuel and battery replacement costs respectively, while grid extension and mini-hydro systems have the lowest operating costs.

However, care should be taken not to make detailed comparisons between alternatives based on general assumptions. More detailed considerations of the economic and financial performance of various village power alternatives are discussed individually below. In each case changes in specific, cost-senstive variables have a dramatic effect on performance. These effects are described, and following this, indicative boundary conditions for determining the least cost alternative under given conditions are outlined.

Figure 3.1 System Lifetime Costs

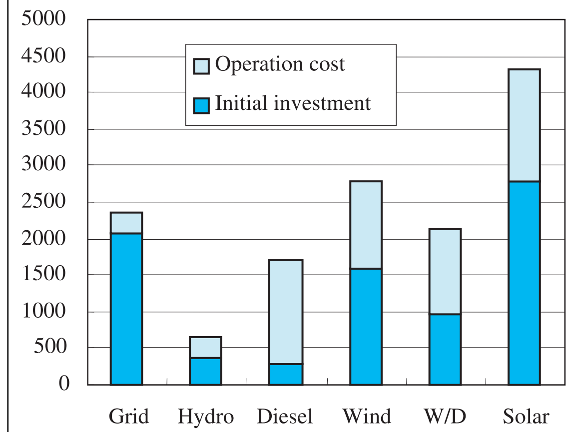


Table 3.2 Summary Financial and Economic Characteristics of Various Village Power Alternatives (For a community of 300 households)

	Initial Investment 1,000 RMB	Operating Costs over 20 years* 1,000 RMB	Present Case Tariff (RoE=12%) RMB/kWh	Commercial Case Tariff (RoI =12%) RMB/kWh
Grid extension (30km)	2,073	292	3.7	9.0
Micro hydro (1,600Yuan/kW)	367	292	0.5	1.4
Diesel stand alone (3.6Yuan/kg)	277	1,433	1.7	2.9
Wind generation (Avg. WS=5m/s)	1,583	1,191	2.6	6.3
Wind diesel generation (Diesel run 30%, 3.6Yuan/kg)	963	1,157	2.0	4.4
PV community system (45,000Yuan/kWp w. controller, 4.5 hr insolation)	2,790	1,535[3]	4.2	11.0

* Only includes O&M costs and replacements, does not include loan principal and interest payments

[3] The regular operation and maintenance cost for SPS is very low. But its battery bank is the largest one of above mensioned alternatives. The replacement of battery bank builds the 20-year O&M cost high.

Figure 3.2 Load-Disance-Tariff (PC 12%RoE)

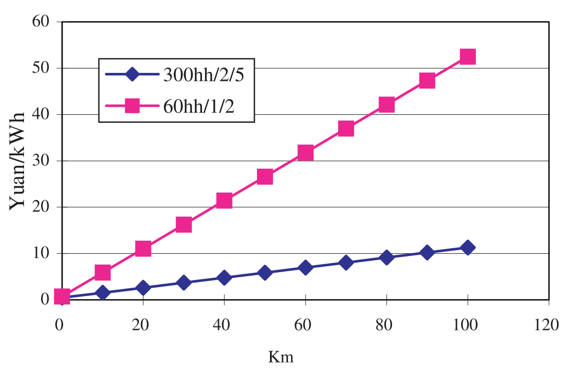
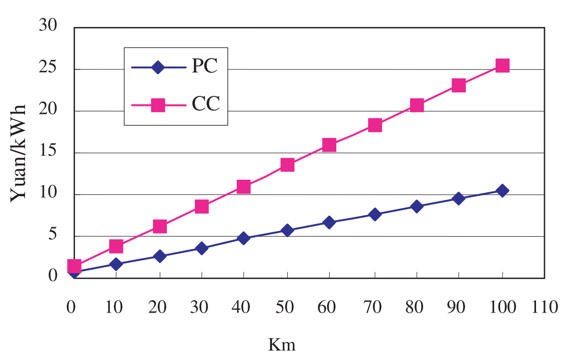


Figure 3.3 Grid Extension CC vs. PC (300/2/5, 12%RoE for PC, 12% RoI for CC)



3.2 Comparative Cost Analysis of Various Village Power Alterbatives and Sensitivity to Key Variables

3.2.1 Grid Extension

The costs of grid-extension, comprising installion of high-voltage lines, substation(s) and a low-voltage distribution network, are relatively well known in China (see Table 3.1). Grid-extension requires a significant upfront investment, but the lifetime of the system is long (over 20 years) and running costs are minimal. Since the costs of lines and poles are fixed, grid-extension requires a minimum load in order to be economically viable. Also, since grid-extension delivers an almost unlimited electricity supply, and increased consumption increases the economic performance for a given distance of extension, commercial use of electricity can be encouraged and there are few incentives for introduction of energy efficiency measures. A big advantage of grid extension is that load growth is generally unlimited.

The key variables in determining cost-effectiveness of grid extension are the size of the load to be electrified, the distance of the load from an existing transmission line and the type of terrain to be crossed. Other determining factors include the price of wholesale electricity being fed into the grid and the power distribution losses. The present study has assumed 12% losses (including both technical and administrative losses), which is consistent with the target set by a recent Government program to improve the performance of rural power grids.

Figure 3.2 illustrates the varying cost of electrifying different village sizes by grid extension at various distances from an existing tranmission line. It can be seen that even at short distances, the costs of electrifying small communities are unacceptably high (>4RMB/kWh). As the size of village increases, both the costs and the rate of cost increase over distance decline. Even so, at distances of 30km, the cost of electricity supplied by grid-extension to a village of 300 households already exceeds 3 RMB/kWh.

Residential electricity prices commonly found on rural power grids (0.65-0.80 RMB/kWh) require high levels of consumption (>37.5kWh/household/month) in order to make electricity supply economically viable. In turn, this implies that consumers have sufficient disposable income to afford appliances requiring this level of consumption i.e. a house with two or three 40W lightbulbs, refrigerator, fridge freezer, and television. Where these levels of consumption are not found, electricity supply through the grid is not economically viable.

3.2.2 Minihydro Minigrids

Since hydro resources are free and running costs are minimal, the investment costs are the single major cost component of minihydro systems. These are made up of three main elements: the civil works, the electro-mechanical equipment and the minigrid. Of these, the electro-mechanical equipment accounts for the major portion (see Table 3.1).

Mini-hydro technologies have been fully comercialized for several decades in China, bringing cost reductions through standardization and mass production on a scale not yet achieved by other renewable energy technologies. The equipment costs on average 1600 to 2000 RMB/kW. The machines are available for virtually all heads and flow rates.

Flow rate (litres/s) and net head (m), which determine the energy output, are also the major determinants of the cost-effectiveness of the system. For the purposes of the comparative calculations, the flow rate minimum has been as-

Case study: Grid extension in Xinjiang and Inner Mongolia

Village Location	Village Size	Terrain Type	Distance Covered	HV Line	LV Line	Total Cost (RMB)	Cost per km (RMB)
Banfanggou/Urumqi/XJAR	60 households	Mountainous	20km	-	-	1,400,000	70,000 (in 1998)
Wulanjilin/Otogi/IMAR	140 households	Grassland	27km	10 kV	0.4 kV	2,000,000	74,000

sumed to exceed the peak demand, and the installed cost of power generation equipment taken as 1600 Yuan/kW. Under these assumptions, the payback tariff will be 0.5 Yuan/kWh for PC and 1.4 Yuan/kWh for CC (RoE/RoI=12%). This makes mini-hydro the lowest cost of all options where an adequate flow of water is available.

Adding reservoir capacity is one way of overcoming intermitant shortfalls in water supply. A sensitivity analysis of increasing system investment costs is shown in Figure 3.4. This could reflect either the addition of a reservoir, or alternatively, higher costs for electro-magnetical equipment. By doubling the installation costs, tariffs still do not exceed 2 RMB/kWh, even in the commercial scenario. Hence, where these system can price their electricity independently of provincial grids, they offer sound opportunities for high profitablilty.

3.2.3 Diesel (/gasoline) Stand-alone Systems

Diesel minigrids have traditionally been the first electricity supply solution adopted by communities living in remote locations. One attraction is that the initial investment required by these systems is relatively small. China produces inexpensive diesel generators costing as little as 7000RMB for a 10kW unit. As a result, enterpreneurs can often afford to purchase their own generator for productive power applications. At the same time, the lifetime of cheap diesel generators is very short (as low as 3 to 4 years), demanding frequent capital injections to replace disfunctional units, and running costs are high. High running costs are principally due to the cost of fuel, but spare parts, operator salaries and lubrication costs also contribute significant further costs. Annual operation and maintenance (O&M) costs of a 300 household village system normally exceed 15,000 RMB.

TIPs Diesel Units Conversion Litre-kg

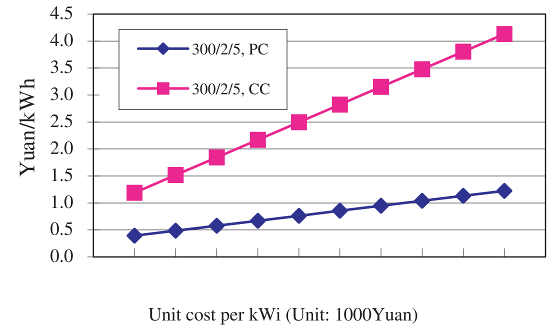
1 liter diesel = 0.8kg
2.90 Yuan/l = 3.625 Yuan/kg

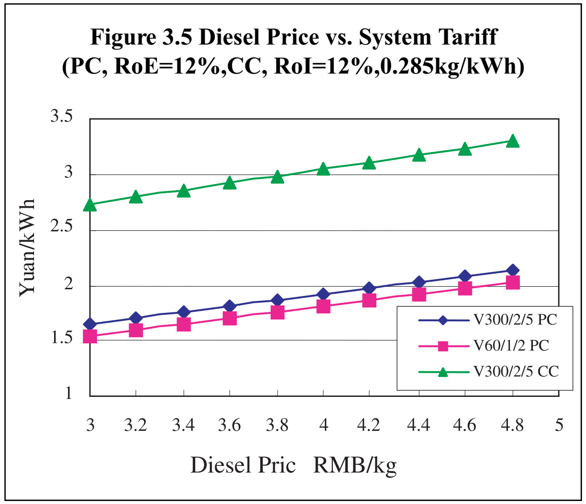
Survey of Diesel Prices Paid in Remote Villages

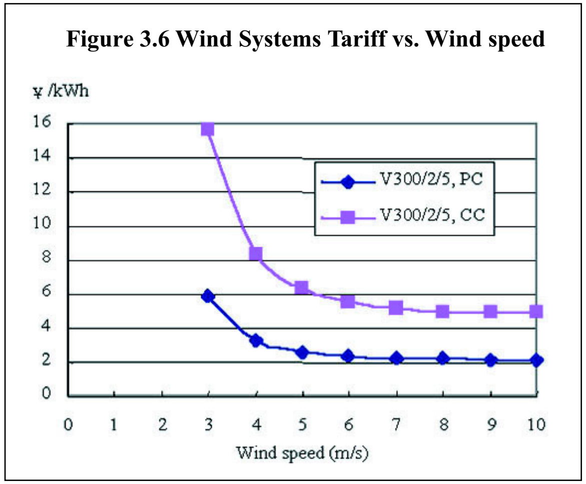
Village Name	Distance to Nearest Town (km)	Delivered Price of Diesel (Yuan/kg)
Bulitai, IM	30	4
Baiyinaobao, IM	30	4.2
Cuoqin, TB	500	4.5
Dahongliuxia, XJ	90	4

*The average diesel delivery cost is 1-1.5 Yuan/Ton.km

Figure 3.4 Minihydro-Tariff vs. Construction Cost







Diesel system electricity costs are highly dependent on diesel consumption and the price of diesel fuel[4]. Specific consumption of diesel is partially determined by the design efficency of the generator. The increased fuel consumption of a low efficiency diesel generator (3.75kg/kWh) compared to that of a high efficiency generator (2.85kg/kWh) would result in a tariff increase of about 15% if operating at high fuel efficiency, and of about 20% at low fuel efficiency.

Another factor influencing fuel efficiency is the loading of the generator. A diesel generator operating at less than maximum loading will demonstrate a sharp loss in fuel burning efficiency. It is therefore extremely important that diesel generators are optimally sized to meet the requirements of typical load demands. The utilization of multiple gensets of varying sizes can allow the operator to maximize fuel efficiency and overcome this problem.

Figure 3.5 illustrates the effect of varying diesel prices on the electricty tariff of a diesel system. The real cost of electricity from a village diesel system powering 300 households will vary from 1.7 to 2.0 RMB/kWh with fuel prices of 3.2 to 4.2 RMB/kg. Figure 3.5 also shows the different tariffs of a small scale village under the PC scenario (PC, 60/1/2, 12% RoE).

3.2.4 Wind Power Village System with Battery Bank (WPS)

The economics of wind-battery systems are characterized by high upfront investment costs, low running costs, and further capital investments (~50,000RMB for a 60 hh system) to replace the battery bank every 6 - 8 years. The wind turbine(s) and battery bank account for the major share of the investment cost (see Table 3.1). For the purposes of the analysis, high quality turbines with a long lifetime have been selected (135,000 RMB/10 kW), as the lifetime of cheaper, poorer quality turbines is extremely uncertain.. A basic battery bank capable of storing one evening's power for a 60 household system would cost around 40,000RMB. Wind systems normally size the battery to allow for 2 days power storage in order to increase the reliability of supply. The costs of adding longer-term battery storage capacity (both in terms of investment costs and replacement costs) have to be weighed up against the cost of alternative intermittant power sources (e. g. hybrid systems which combine wind and diesel power).

There is no significant difference between the cost per kWh of supplying electricity to a village of 60 households or to a village of 300 households. However, the tariff of the wind generated electricity is highly dependent on the wind regime, both in terms of wind speed and density, and of the annual, seasonal, and monthly windspeed patterns. This is because the wind power potential varies with the cube of the wind speed. Under the same local conditions (load, altitude, etc.), a higher average annual wind speed will reduce the number of turbines required. Table 3.3 shows that for a 300/2/5 village, only 3 turbines will be needed if the average annual wind speed is 6m/s, but 4 turbines will be required if the wind speed is 5m/s, and 7 turbines for 4m/s. The effect of average annual windspeed variations on the tariff of these systems is shown in Figure 3.6.

Wind systems are technically feasible when average wind speeds reach 4m/s, and become an economically interesting prospect when average windspeeds exceed 5 m/s. The chart also shows that switching from present financing practices to fully commercial financing would virtually double the cost of wind-generated power. Thus full commercialization will

[4] Diesel fuel is 3.06 Yuan/kg at the pump in Barkol and 4.00Yuan/kg in Santanghu, which is 100km away from Barkol, in Oct. , 2001

Table 3.3 Number of turbines required vs. Average annual wind speed

WS	3	4	5	6	7	8	9	10
Output Daily	9.8	25.2	44.4	62.9	77.1	86.2	90.5	91.1
# of turbines	18.6	7.2	4.1	2.9	2.4	2.1	2	2

*1 The calculation is based on a 300/2/5 village with 46,452 kWh annual load, 500 altitude, 24m tower.
2 Turbines cannot be partially purchased. The calculation is for economic analysis; and can help to approach the optimal configuration and choice of the best turbine size.

Tariff vs.WS (300/2/5, RoE=12%, 24m tower, 500 Elev)								
WS	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
V300/2/5,RC	5.24	2.81	2.15	1.895	1.788	1.725	1.703	1.703

be feasible only at sites with good to excellent wind reosurces, i.e. annual average windspeeds of 5.5 m/s and greater at a height of 10 m.

3.2.5 Community Solar Power System (SPS)

A photvoltaic (PV) community system costs 50% more than the next most expensive alternative per kW capacity installed (Table3.1). Although such systems are not interesting for financiers seeking a profit on an investment, at long distances from exisitng grids they provide power solutions where no other can be found, and hence are strong candidates for rural development projects. Under an assumed solar regime of 5 kWh/m2/day, a tariff of 4.2 RMB/kWh would be required to generate a RoE of 12 %. Compared to other stand-alone options this is high, but it is not significantly more than a 30km grid-extension project. Even so, the level of grant funding assumed (50%) is likely to be the minimum necessary for the adoption of this technology for community applications.

The largest part of the investment costs is the PV modules. Chinese PV modules are no cheaper than foreign produced modules, ranging from 36 - 48 RMB/kWp (4.5 to 6 US$/kWp) installed, depending on module size. Costs of PV modules on the international market are expected to decline dramatically in the coming years. According to Japanese sources, costs of 16000RMB/kWpa[5] can be attained over the next 10 to 20 years, based on high volume sales of PV and new mass fabrication technologies Realizing this, PV systems can come close to the other technologies (see Chart 3.7). The battery bank also constitutes a major cost component, both in terms of investment costs and of operating (replacement) costs. Prevailing PV community system design philosophy in China allows for a minimum of 3 days' storage capacity, which in some cases may be excessive. Again, the need for a relilable supply must be weighed-up against the additional costs of power storage.

The other critical cost-sensitive factor is the local solar resource, or average insolation time (hours/day). Good insolation (solar radiation/area) will reduce both the required upfront investment in PV module capacity and the battery storage capacity, with signifcant impacts on system economic performance. Figure 3.8 shows that a site enjoying 5 hours/day insolation can reduce the required tariff by almost 11% compared to a site receiving 4 hours/day (4.0 RMB/kWh cf 4.51 RMB/kWh).

Figure 3.7 PV Systems Tariff vs. Cost of PV Panel (4.5 hr.equ. insolation,300/2/5)

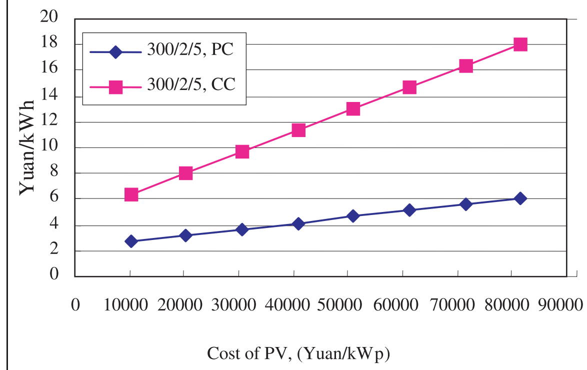
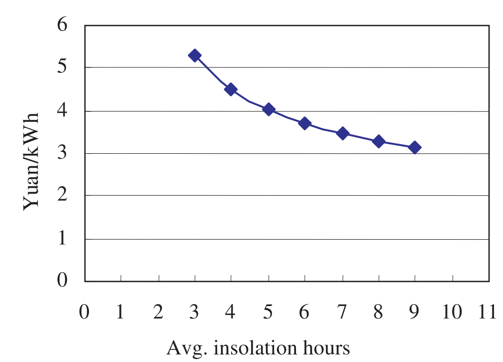
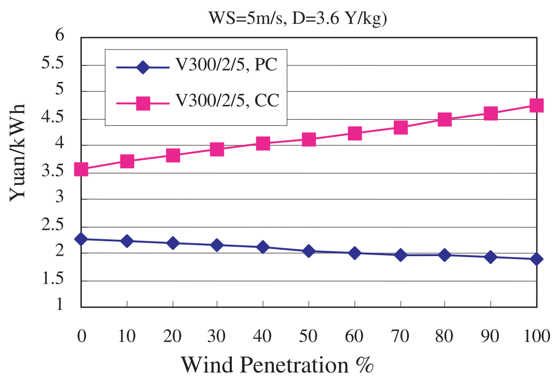


Figure 3.8 PV Systems Tariff vs. Insolation Hours (300/2/5 PC, PV panel price=42,000 yuan/kWp)



[5] Where the "P" stands peak capacity and "a" for included except the mini-grid.

Figure 3.9 Hyrid Systems Tariff vs. Wind Penetration



3.2.6 Wind-Diesel Hybrid Systems

As discussed in Chapter 2, wind-diesel hybrid systems are developed for:

- complementing insufficient wind energy during calm wind periods, and
- improving system reliability by using a diesel generator as a back-up power source

Addition of a back-up diesel genset will slightly reduce the system up-front investment of a hybrid system relative to a wind only system due to the replacement of some wind and battery capacity. Some of this saving is balanced out by increased operating costs due to the cost of diesel fuel, increased maintenance and spare parts costs, and more sophisticated technology for controlling the system. Even so, when operated optimally, a wind diesel system can offer better system performance then WPSs or DSSs.

Under a good wind regime[6], where the wind turbines provide 70% of the power consumed, a return on RoE of 12 % would require a tariff of 1.98 Yuan/kWh (Figure 3.9). This tariff is only slightly higher than that of a diesel system (assuming same diesel price for both of 3.6 RMB/kg delivered). Of course, where diesel prices are higher than those assumed, or the average wind speed is higher, or the penatration of power generated from the wind turbines is increased, the cost-competitiveness of the hybrid system will improve further. The chart also shows clearly the large savings that result from the use of diesel power under the commercial financing scenario.

3.3 Indicative Boundary Conditions

Boundary conditions can be defined as the conditions under which one village power solution becomes more cost effective than another given alternative. For example, one can imagine the boundary condition between a diesel-based power system and a wind-based power system being defined in terms of the wind resource compared to the delivered price of diesel. Based on the comparative calculations introduced in the previous section, a further study has been made to determine the indicative boundary conditions for various village power alternatives in China (see. Figure 3.10). As previously stressed, every village merits its own individual comprehensive analysis and the following graph can only be used as a general rule.

The figure shows that:

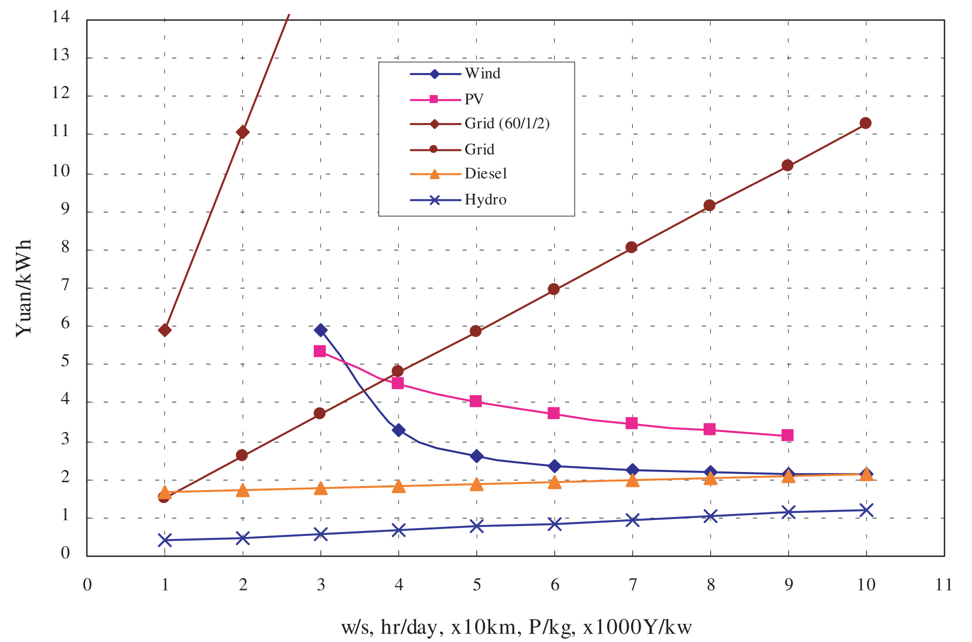
- At distances of over 40km from the grid, and where exploitable renewable resources exist, grid-extensions for villages of up to 300 households are less cost effective than all other alternatives
- Where small-hydro resources meet minimum criteria in terms of head and flow, this is always the least cost option. Seasonal availability can be a limiting factor for small hydro systems, but pumped storage, diesel generators and wind power can all provide supplementary power supply in periods when shortfalls occur
- Diesel Stand-alone Systems are less expensive than utility extension if the distance from the village to the existing grid is greater than 10km (for villages of 300 households or less)
- Even ignoring diesel supply uncertainties and the environmental benefits of renewable energy power, WPSs are competitive with Diesel Stand-alone Systems where average wind speeds exceed 5.5 m/s and diesel prices reach 3.8 RMB/kg or more[7]

[6] Suppose village = 300/2/5, wind speed =5m/s, tower height = 24, elevation = 500m, diesel price = 3.6Yuan/kg, diesel genset efficiency = 0285kg/kWh.
[7] The diesel price was 3.6Yuan/kg (2.9 Yuan/liter) at the pump in Dec., 2001, Adding transport costs to remote areas or islands, delivered prices can be close to 4Yuan/kg.

- Under good wind resource conditions (avg. wind speed >5.5 m/s) WPSs can compete with grid extension for a 300 household village at distances of greater than 20km from an existing transmission line
- Finally, SPSs are always more expensive than WPSs where both resources are available

Further indicative boundary conditions can be derived from this chart[8].

Figure 3.10 Boundary Condition Analysis
(RoE 12%, PC)



Data Series	**Most sensitive variable**	**Value of X axis**
Wind	Avg. wind speed	m/s
PV	Avg. insolation hours/day	hours/day
Grid extension	Distance for line extension	x 10km
Mini hydro	Cost of construction	x 1000 Yuan/kW capacity
Diesel	Price (at least transportation and efficiency)	2.8 + 0.2x Yuan/kg

[8] The chart 3.10 gives relative cost and tariff comparison, the exact price per kWh for each option can only be determined on a case by case basis according to the specific local conditions.

CHAPTER 4: THE PROJECT DEVELOPMENT PROCESS- STAKEHOLDER ROLES, PROJECT DEVELOPMENT MODELS, AND FINANCING ASPECTS

4.1 Introduction

For a village power system to be sustainable on a long-term basis, the services it provides must match both the needs and the affordability of the community that it serves. This Chapter identifies the key stakeholders in a village power project and highlights their respective roles in the project development process. Whether village power projects are financed commercially or through government supported programmes, commercial involvement in the project development process (and in system operation, which will be discussed separately in the next Chapter) has proven highly effective. The private sector can be engaged in this work through various project development models. Several options are presented below.

Finally, the various existing channels for financing village power projects in China are summarized and some innovative financing mechanisms that have been successfully applied in other types of projects in China and in village power projects around the world are introduced.

4.2 Project Stakeholders and their Roles

The importance of a participatory stakeholder approach to village power project development, from the outset, at the conception phase, cannot be over-emphasized. This includes all stakeholders, from project financiers to intended beneficiaries. The key stakeholders and their typical roles in the development of a village power project are given in Table 4.1. Although several of these groups often share many common objectives, each group will have its own unique set of expectations and priorities. These expectations and priorities must be resolved at the outset of the project developement process if the system is to be founded on a sustainable basis. Experience has found participatory stakeholder approaches to project development to be the most effective and efficient way to integrate the priorities of the different groups.

Table 4.1 Key Stakeholders and their Roles in a Village Power Project

Key stakeholders	Typical Role
Village Community	◆ Determine appropriate quantity and quality of service ◆ Determine customers ability and willingness to pay for power ◆ May contribute cash and labor to establish system
Local Microenterprizes	◆ Key load determinant ◆ Contribute to initial investment ◆ A final user to target income generation applications
Local Government (Village and County)	◆ Initiate the project ◆ Contribute to initial investment ◆ Solicit and assemble outside financing, especially upper-level government funding ◆ Regulate private sector participation in project development process and in management of the system e.g. draw up lease agreement
Provincial and State Government	◆ Co-finance the project through all kinds of grant or subsidized loan ◆ Usually provincial government must approve the project if some financing are from state or province
Project Developer*	◆ Identify project opportunities ◆ Bring together all stakeholders ◆ Source and procure equipment ◆ Ensure the priorities and expectations of all parties are met
System Designer*	◆ Design the most cost-effective technical solution to meet requirements of the community ◆ Install and commission the system ◆ Provide training on system operation ◆ Provide service and maintenance support
Third party Financier(s)	◆ Provide co-financing for initial investment

* Often the same entity

	◆ Grant financiers must ensure the project will be economically sustainable after the initial investment ◆ Equity investors and loan financiers must ensure other (more demanding) economic and financial performance criteria will be met
Plus, in some cases	
Provincial Power Utility	◆ Provide broader rural electrification context of the project ◆ May be directly involved in project implementation through local utility ◆ Provide technical and managerial assistance
International Agency	◆ Provide grant or other financing ◆ Must ensure the project is in-line with local planning and will be sustainable after the withdrawal of foreign assistance; this includes evaluating the benefits of using foreign equipment against using less-advanced but more easily repaired / replaced local equipment

Participatory approaches to project development are based on the principles of widespread consultation and open discussion. The benefits of this approach are manifold. If the power system fulfils the needs and desires of the community, then the villagers will have a vested interest in ensuring its sustained operation.

Community Participation in System Design: Mali Multi-functional Platforms

Multi-functional diesel platforms, delivering residential power through a mini-grid and capable of running such applications as mills, pumps, grinders, and battery chargers, have filled a niche for power-hungry rural communities in Mali. One of the innovative elements in these projects is the participatory feasibility study. Before the acquisition of a platform by the requesting Village Women's Association, the project needs to be sure that the system is affordable for the village. The study process starts with information about the platform, its application benefits and constraints, and the terms and conditions attached to its acquisition. In the following step the demand for the different applications (grinding, oil pressing, etc.) is divulged, using participatory techniques. With this information the market for the platform services is indicated. The feasibility study also looks into the issue of financing. The mobilization of social and institutional capital and the prospective owners own sources are examined. All the costs of the platform as defined and adapted to the local conditions are also mapped, so that all elements of financial viability can be assessed.

Such participatory assessment takes on average 5 to 6 days for a village of 1000 to 2000 inhabitants. The participation of the village in the feasibility study using PRA techniques is attractive because it provides the villagers effective tools to acquire insight and aids them to decide on future applications. Additionally it gives raw data, which supports the preparation of proposals to institutions comparable to banks. And, perhaps most importantly of all, it generates responsibility, commitment and a strong interest in the operation of the platform.

4.3 Project Development Business Models

4.3.1 Current Practice

In the ongoing process of power sector reform, provincial utilities appear to be less inclined to extend services to communities beyond the present reach of the grid. Utilities typically concentrate on serving their existing grid-connected customers and improving the performance of existing grids. Other government departments, such as the Poverty Alleviation Programme and the Brightness Programme, and the private sector are stepping in to fill the gap for those communities left in the dark. This situation has come about in recognition of the high investment costs in establishing energy infrastructure in remote areas and private sector's ability to bring specialist knowledge and more effective management, and to reduce costs.

To date most of the village power systems developed in China have been one-off government (national and/or international) supported projects[1]. In essence the projects are government projects, but the private sector already plays a key role in many parts of the project cycle (see Table 4.2), and is often the proactive agent in the identification and initial development of new projects. In fact, there are already more than ten domestic project development/system design groups who effectively compete for Government-supported projects. And although the financial performance of village power project investments is likely to continue to place limits on the participation of the private sector in all elements of the project cycle, China could take more steps towards the commercialization of the project development process in order to draw on the inherent benefits of private sector involvement. A number of alternative business models, tried elsewhere in the world, are outlined below.

[1] With the exception of Inner Mongolia, where provincial funding and a sustained bilateral programme have helped to install over 35 systems.

Table 4.2 Current Practice in China

	Sector roles	
	Public	**Private**
Project development	×	×
System design and installation		×
System Management	×	×
Investment	×	

Table 4.3 Summary of Various Project Development Models

	Project Development	Investment	System Management (see Chapter 5)
Utility	Utility	Utility investment, possibly with Govt. Support	Utility
Govt Projects for Single Villages	Experienced outside contracted system designer	Mixed, Government, Endorser contributions	Local government, community or private leaseholder
Individual Entrepreneur	Entrepreneurial initiative	Wholly private sector	Private entrepreneur
Multiple Villages	System developer private/public develops several village projects simultaneously. If private, could be selected through competitive bid.	Mixed, Government, Endorser contributions	As a cluster by a single company / Government agency
Concessions	Developed by private concessionaires	The holder of the concession will make the investment, but some Govt subsidy may be provided	The holder of the concession

4.3.2 Commercializing the Village Power Project Development Process

Multiple Village Projects

Bundling several villages located in the same vicinity together in a single project has manifold advantages. This will result in cost savings in almost all elements of project development, from resource characterization to system design and equipment procurement costs. Standard, modular systems can be designed for these applications. It will also offer an opportunity for creating a sustainable business out of the joint management of the systems. The Brightness Programme and some planned internationally supported large-scale village power initiatives have the potential to benefit from these sorts of economies of scale. The resultant savings and experience should benefit all future village power projects.

Ideally, cluster projects should include villages harnessing the same technical solution (hydro/wind/solar etc.) and have approximately the same size. For such a group of villages, using a multiple project development strategy will significantly reduce the project development costs, and greatly simplifies spare parts supply and servicing requirements for individual systems. The example shows that overall costs can be cut by 15% and costs of items such as system design, training and O&M can be cut by over 50%. Furthermore, the organization of a competitive bid for design and installation of multiple system projects would generate significant interest from the community of system developers in China and result in further cost savings for such projects.

Case study: Potential Cost Saving through Cluster Project Development for Five Villages

Items[2]	Unit Cost per Single System(Yuan)	Unit Cost per System in 5 Village Cluster Project (Yuan)	% Saving in Cluster Project of 5 Villages
Site investigation and resource assessment	5,000	3,000	40%
Load estimation and system design	10,000	5,000	50%
Equipment	250,000	225,000	10%
Transportation	2,000	1,600	20%
Installation and commissioning	20,000	16,000	20%
Training	5,000	1,200	76%
O&M[3]	10,000	4,000	60%
Total	**302,000**	**255,800**	**15%**

Concessions Model

Though not as yet used in China, rural service concessions have been applied in other countries around the world. Concessions, granted by the state to Community Power Service Companies (CPSC), may be exclusive or overlapping. In any case, the holder of a concession will enjoy some beneficial terms (such as preferential market access or a direct subsidy) for providing power services to rural communities living within a defined geographical area. This model is often applied in conjunction with a fee-for-service business model, which will be discussed separately under system management options in the following Chapter.

RURAL CONCESSIONS CASE STUDY: EXPERIENCE IN ARGENTINA

BACKGROUND

- Although 92% of Argentinians have access to electricity services, around 2, 5 to 3 million remain without, mainly due geographic dispersion problems
- Relatively high numbers of public services have no electricity supply (schools, first aid medical centers, water services, etc.)
- Electricity supply by grid extension is not feasible due to high extension costs. A study for Argentina shows mean values of US$8000/user with minimums of US$5000/user and maximum of US$ 25,000/user
- The main problem of past off-grid supply strategies has been sustainability due to programs having a strong emphasis on social welfare and not addressing medium/long term issues such as maintenance and parts replacement

ELECTRICITY SUPPLY PROGRAM: GOAL AND GUIDELINES (PAEPRA)

- Provide minimum electricity services to dispersed rural inhabitants and rural services (lights, social communications)
- Electricity services provided by private concessionaires whose income is enough to run the business under prevailing economic conditions in the private sector
- Concessionaire has the freedom to select least cost technical solution under life cycle criteria
- Shared responsibility
  -Endusers-pay a tariff in all cases
  -State (provincial) governments-use an electricity promotion fund for the program
  -Federal government-assist those states in which the local available funds are not sufficient

GOOD NEWS FOR WIND AND SOLAR ENERGY

- Law for wind and solar
  -VAT financing for people using wind or solar systems for electricity production for public service purposes
  -Subsidy rate of US$5/ MWh

EXAMPLE

A wind generator with a current market price of US$25/ MWh can receive additional payment of around US$15/ MWh because of these stimuli.

Source: Lic. Aldo Fabric, Rural Concessions: The Argentina Experience, Village power '98, WB/NREL, Oct. 6-8, Washington DC

[2] Local civil works not included

[3] Labor only, cost of spare parts not included.

Integrated Business Projects led by Individual Entrepreneurs

Multi-service provision by an entrepreneur who needs power for his own business and extends this service to residential end-users (or to other productive users) is an energy generation model seen thrughout the world. These services result from the direct response to a local demand and have proved to be highly effective. However, allowing these entrepreneurs to operate within a legal framework, which protects the consumer through clear codes of practice and standards, would require the revision of rural electrification regulations.

Entrepreneur Establishes Diesel System for Local Marketplace in Bangladesh

- Motivation - The motivation of the owner to build and run the diesel generator system is purely commercial. He is an entrepreneur who has responded to the local need for electricity, a need that the government has not met. He offers lighting to the market people that helps them to prolong their business hours and make more money. In turn, they pay him a tariff per lamp per night
- System - The diesel generator set has a capacity of 8 HP, or roughly 6 kW, and generates 4 to 4.5 kW of electricity. A heavy bundle of ordinary 220-volt cables leads from the power shed to both sides of the market. Power from this diesel generator lights the 60-Watt incandescent lamps that are in about 70 market stalls. The system runs during the twice-weekly market days. It begins in the evening, between 5:30 and 6:30, and runs until around 9pm
- Tariff - Users pay per lamp and not per kWh. This gives the system operator a net profit, and although users may pay a very high rate per kWh, the actual payments are affordable
- Techncial Support- Because diesel systems are used for irrigation throughout Bangladesh, there is an extensive maintenance network
- Policy/legislation: The Bangladeshi Government has a far-reaching rural electrification program plan but as the pace of expansion and the supply of electricity is inadequate, people have taken initiatives outside the formal power sector structure and hundreds of such systems exist

Diesel Power Services, China

- A 8kW diesel genset is run by an entrepreneur to power his restaurant in Santanghu, Xinjiang. The power is also used by his two neighbors, who are running other businesses. This electricity is not paid for but traded for other productive services, such as free use the neighbor's truck
- A public security administration (PSA) in Jiang'an, IM, owns a 10kW diesel genset to generate power for its office. Meanwhile, the electricity is supplied to 10 more surrounding families who pay a monthly charge per lamp

4.4 Financing Arrangements

4.4.1 A Historical Perspective

Historically, all over the world, rural electricity supply has been a service provided by the state, usually through state-owned utilities. As such, the state bore the investment costs of establishing rural grids, with varying emphasis on cost recovery. In this regard, China has been particularly conscious of the need for achieving cost-recovery on provincial and on independent (often mini-hydro) grids. However, in the current process of power sector reform, where power corporations are examining their balance sheets more closely, the prospect of investment in grid extensions for small, and hence low or no profitability, loads is more uncertain than ever.

Diesel minigrid systems have often evolved from an initial demand for productive power for comercial uses, which has then been harnessed during the evening to provide a residential power supply. Low investment costs mean that these systems can be wholly financed by the entrepreneur themselves. As for the renewable energy power systems installed in China to date, the high up-front costs associated with investing in a village power system and the low income levels of remote

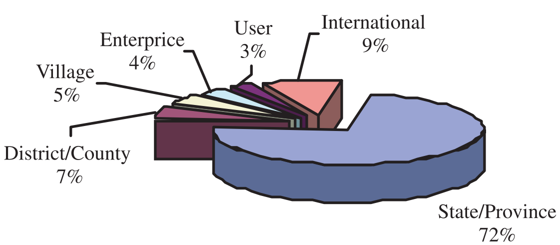
Charlie Dou

A diesel genset is used to power a restaurant

Charlie Dou

The backyard of the restaurant


Charlie Dou




Qinghai, REI

7 kWp solar power system in Shengge, Tianjun, QH

communities[4] has meant that such projects have relied on a significant element of grant support from national and international programmes, often combined with contributions from local government and the beneficiary community.

It is standard practice for new customers to pay a grid-connection fee. But as the direct beneficiaries of a dedicated electricity supply, remote communities are normally willing to make a further contribution to the establishment of a new system. However, since income levels in these areas are low, this contribution cannot normally account for more than 25% of the investment cost for a renewable energy system. A survey of 16 existing village systems found that more than 90% of their funding had come from Government sources-from state and provincial government, international donors, district and county contributions. Some systems have been 100% funded by central or provincial governments. Figure 4.1 shows the distribution of investment contributions of the sixteen surveyed village power systems.

With non-commercial investors and limited incentives for cost-recovery, tariffs charged for the electricity generated by these systems are not normally even adequate to provide for the replacement of the battery bank (after around eight years). This has served to encourage a reliance on the provision of subsidised services from the state, which has been a fundamental constraint on the more widespread deployment of these systems.

The financial and economic analyses given in Chapter 3 demonstrate that the high up front costs of renewable-energy-based power systems mean that returns generated from village power systems are unlikely to be sufficient to interest commercial investors. Hence, for the foreseeable future, combinations of private equity, community equity, and favorable financing, will be required to make such systems financially viable on a widespread basis. Nevertheless, there are still opportunities for local entrepreneurs to turn a profitable business from operating one (or several) community power systems, and with Government support the potential scale of this business could be dramatically increased.

Case Study: Government Support to Establish a PV Power System in Tibet

Gaize county lies in Ngali District, the most remote district of Tibet. Gaize is 500km from Shiquanhe, the County Government town of Ngali, and 1600Km from Lhasa. There are 500 households in the town with 2500 people in total. A PV power plant of 20KWp was first built at Gaize in 1992. In 1998 the plant was expanded to 80KWp. The total initial investment of the plant was 12,800,000 Yuan. Central government provided 11,000,000Yuan (91.5%) and the rest (1,080,000Yuan) was invested by the local government. The battery was replaced in 2000 and financed by Utility Bureau of Tibet. Daily operation and maintenance are self funded by the local government and the money comes from the system revenue which is 200,000 Yuan per year.
Source: Beijing JIKE

Table 4.1 Investment Distribution of 16 surveyed REVPSs (Unit: 10K Yuan)

Distribution	Total funding	State/Province	District/County	Village	Enterprise	User	International
Investment (10K Yuan)	3347	2433	220	157.82	121	88.28	327
%	100%	73%	7%	5%	4%	3%	10%

[4] In China, most un-electrified villages are located in the western regions, where the economy is significantly less developed. Many villages' average income per capita is still under national poverty standard (NPS). The NPS for 2000 is RMB 1,013 Yuan (National GDP/capita is RMB 7,074 (US$ 856)), in some villages in Western China the average income in 2000 was around RMB 500 Yuan .

4.4.2 Financing Prospects

Project development is now proceeding steadily but slowly, with financing usually being assembled on a project-by-project basis. However, if the problem of rural electrification is to be addressed in earnest, a more comprehensive approach to financing village power projects through the allocation and application of new financing resources and mechanisms is required.

There are opportunities to harness the resources of nationally supported initiatives. The Brightness Programme represents the first initiative to attempt to provide an open channel through which provinces can apply for central government financial support on an annual basis. Furthermore, The Western Regions Development Initiative and the Poverty Alleviation Programme, both recognize the role that power supplies can play as an integrated development tool for driving sustainable economic and social development in China's remote regions. There are already examples of some communities that have pooled the poverty alleviation office (PAO) loan entitlements of individuals for a community power project.

Case study: Loan Pooling for REVPS Development

In Huaerci village, Barkol, Xinjiang AR: a 3,000 Yuan Poverty Alleviation Loan, (3% annual interest rate with 5 year loan-term), has been organized by consolidating individual loan entitlements. The County PAO organized the loan project and used the loan as one integrated fund to develop a wind REVPS for the village. The loan payback will also be organized by the PAO.

Provincial power utilities have historically played a major role in rural electrification, and they continue to do so today

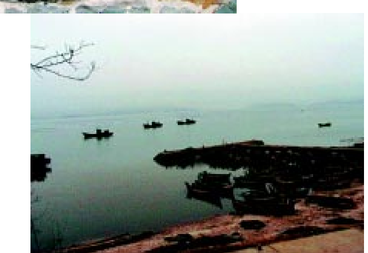
Postulation of a Levy for Rural Electrification in China

Historically, power plants and power infrastructure have been developed by the state as national infrastructure development projects. The development cost, including the initial investment, has been shared by the entire grid. If the initial investment costs of decentralized REVPSs could likewise be shared by entire grid, this could provide the complete solution for remote and isolated area electrification. In 2000, China consumed 1,346.62161TkWh of electricity. If 0.0001 Yuan were withdrawn or added to the price of each kWh consumed in China (roughly equivalent to 0.025% of the cost to the consumer of electricity in 2000), this would yield an annual fund of 135 Million Yuan. Used as a foundation for rural electrification, this could allow development of over 135 decentralized REVPSs every year[1].

Potential financing sources

- Central government
- Provincial government
- District government
- County government
- Village government/community
- Final end-users
- Local microenterprises
- Utility
- Project developer
- Other social org
- International financer or donor

Charlie Dou



A wind diesel hybrid system on Xiaoqingdao, Shandong where circumstances allow. It is extremely important to raise awareness amongst utilities of the potential for using distributed power systems for rural electrification in remote areas. In some cases, the investment required to extend the grid to one village could be used to power several villages using decentralized solutions.

Even so, the most effective means of having a significant impact on the rate of rural electrification amongst China's rural communities would be through the establishment of a dedicated financing facility for community power projects. This could be created by allocation of new resources from government budgets, or through a small incremental levy on all electricity consumers (see box).

Other innovative financing mechanisms have been tried in China and around the world. Examples of two approaches taken by the IABD in Peru and the World Bank in China are provided in separate text boxes.

Whatever the financing source, the most important thing to remember is that unlesss systems are managed and operated efficiently they will require continuous financial injections for continuous long term operation. Experience has found that most efficient system mangement is achieved by commercializing this aspect of the project. This approach can free the original financier from follow-up funding obligations, thereby releasing additional resources for the electrification of further villages. Approaches to commercialization of system operation and maintenance (O&M) are discussed in the following chapter.

Recommended Features of Rural Electrification Fund

- Specify eligible applicants - villages or utilities or project developers
- Financing term: low interest; long term loan (some grant if necessary)
- Co-financing conditions for support e.g. up to 50% only
- Standardization of practices for project development
- Revolving
- Technical advice provided to fund administrators in project selection/approval

Revolving Credit Fund for Small Power Projects in Peru

The IADB has set up a rotating fund to provide loans for micro-hydro power plants in rural Peru. The fund is managed by Intermediate Technology Peru (IT Peru) and to date has funded 15 systems. The credit amount varies from $10, 000 to $50,000. The loans are repaid in five years at 8% interest. The fund is capitalized with $400,000 at a 1% interest rate over 25 years, plus a technical assistance grant.

WATER USER ASSOCIATIONS - AN INNOVATIVE MECHANISM FOR FINANCING COMMUNITY PROJECTS IN CHINA

In a program providing finance for community water supply projects, the World Bank has developed a financing model whose principles can easily be extended to community power systems. At the bottom level, the mechanism makes use of specially established Water User Associations (WUAs). The WUAs are self-financing, community-based, legal entities managing local water supply systems. When granted the right by local government, the WUA can collect water fees (normally done according to the area of land irrigated). This revenue should allow the WUA to cover loan interest and system operation and maintenance costs. Guarantees against loan repayment can be provided in the form of the fixed assets (e.g. a pumping station) and/or through a separate guarantee provided by the county government. Such mechanisms have been successfully operated in self-financing irrigation districts of Hubei and Hunan Provinces.

CHAPTER 5: OWNERSHIP AND MANAGEMENT OPTIONS

Over the last fifteen years, a large number of pilot projects, in China and around the world, have proven the technical maturity of renewable energy-based power systems for remote village power applications. Commercially produced equipment is available and can be supplied with manufacturer's warranties. Where technical problems occur, these are often caused by improper use or abuse of equipment, which in turn is only a symptom of the real challenge facing the sustainbale operation of such systems -clear ownership and management arrangements.

5.1 Ownership

System ownership is conventionally determined by the source (s) of investment. As has been shown in Chapter 4, most REVPSs installed in China to date have relied heavily on government and outside financing (such as international donors). An unintended but unfortunate consquence of this has been an unclear ownership situation for many systems. Not surprsingly, institutional grant financiers have not watched their investments as carefully as private sector investors might have. Similarly, ownership rights have not been sufficently transferred to local parties, such as the communities themselves, to allow them to take over the responsibilties of ownership of the systems. Confused ownership arrangements can swiftly lead to short-cuts on operating practices and long-term maintenance. The resulting situation has posed serious challenges to the sustainable operation of many existing village power systems.

Although experience has shown that having financiers who lack a direct interest in the economic performance of a project can compromise the sustainability of a system, it is likely that a mixture of investors, including government departments, communities and other less profit-driven financiers, will continue to be the principle financiers of village power projects in the coming years. The key to solving this problem therefore lies in a clear separation of ownership and management responsibilities, as is happening in the more widespread economic reforms currently underway in the national economy. The challenge is therefore to employ mechanisms which clearly assign responsibilites and recourses. This can be done through authorization, contracting or leasing arrangements. Under each of these models, community and outside funds are combined to cover the initial system investment costs. Effective management of the system is then carried-out under a formal arrangement by an individual or group. While not yet widespread, contracting and leasing models have been tested in China and could be used to launch a new paradigm in public/private partnerships for rural service provision.

5.2 Management and Operation Options

There are four basic options for management of community power systems:

- Authorization arrangement
- Contracted Operation
- Leasing
- Ownership transfer

Chart 5.1 shows the management mechanisms employed by 16 surveyed wind, solar and hybrid systems operating in China. A village community or village power management committee is the commonest way to manage REVPSs. Only a few of the systems have contracted to private individuals for management.

Chart 5.1 Management Mechanisms in Surveyed Villages

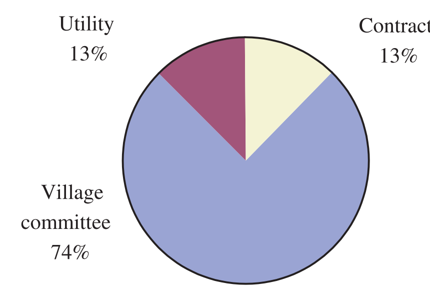


Table 5.1 Summary Assessment of Management Mechanisms

Management Mechanism	Advantages	Disadvantages
Authorization Arrangment	◆ Simpliest O&M pattern	◆ Non-commercial operation pattern ◆ The acting owner (usually village committee (VC)) takes all responsibilities for system long-term perfomance, such as the fund for battery replacement or system maintenance. If the system has multiple investors, the ownership is unclear and undefined. This usually results in poor system technical and economic management ◆ The VC may use the system revenue for other purposes, resulting in no or not enough funds for future battery replacement
Contracted Operation	◆ Contractor has more responsibility for system operation, which is better than an employee ◆ The contractor has no risk (not own investment) and can concentrate on how to optimize system operation ◆ Operator may try to run system more effeciently to maximize the revenue and minimize expenses	◆ This is an incomplete commercial operation pattern ◆ Based on current practice in China, a contract, especially a contract to an individual(s), is a weak arrangement. Usually operators are guaranteed to make profits, without being exposed to the risk of losses ◆ Often the contract between owner(s) and operator(s) is incomplete, which results in a blurred situation. Contracts must specify in detail the quantity and quality of service to be provided ◆ In most cases, the operator(s) will keep all remaining income (after payment of direct costs) as their profit. The system will not have any reserves for future needs. The local government will receive pressure to fund long term operation costs, weakening its enthusiasm and capacity to develop more REVPSs
Lease Arrangement	◆ Completely separate the ownership and management functions ◆ Completely commercialized relationship ◆ The owner does not have any responsibility for operation. This is left to leasor, who can operate the system in a more efficient and business-like way ◆ The business has less risk (not private investment) and can concentrate on how to optimize system operation ◆ The Government can get some stable payback for its investment, which can be rolled-up for development of future projects	◆ It may be difficult to determine the monetary amount for the lease arrangement. The business won't be interested if the threshold is too high, but the owner(s) will seek to maximise revenues. First-hand information from experience will provide the best guide ◆ It may be difficult to determine what kind of service will be provided by the leasor to final users. Some negotiation processes may have to be defined, such as determining the charge for kWh at regular intervals
Ownership Transfer	◆ Investor does not worry about the future operation/funding of the system ◆ System may be operated at high efficiency ◆ Investor may use the tranfer fee to do other projects	◆ Some legal issues must be solved if public investment or property is inelved ◆ A mixed investment may make the negotiation process more complicated ◆ The transfer-fee is hard to determine and the negotiation process may be tough ◆ System operation must be more profitable than above models to ensure service provision is sustained

5.2.1 Authorization Arrangement

This is the most basic arrangement and most existing systems fall into this catagory. Under the "Authorization Arrangement", the village power system is managed by the village government (VG), or a village committee (VC), or village power management committee (VPMC). The VPMC usually consists of village officials, a community representative, and a representative from the Public Security Administration (PSA) or other local authority.

The VG/VC/VPMC usually has the following roles:

- Determine the price of eletricity
- Determine the hiring of operator
- Determine the operator's salary
- Determine the distribution of revenues
- Determine which families can be connected to the mini grid if the capacity is insufficient to match all household demands

The major investors (usually government) or legal owner (such as village committee and VPMC) appoints one (or maybe two) individual(s) to manage and operate the system. The individual operator(s) (in most places of Inner Mongolia, called "Ji Shou") is paid a salary by the owner and becomes a direct employee. For some reliable and highly automated systems, management and operation could be on a part-time basis, which saves on salary expenses. Salaries are usually several hundred RMB per month, varying from place to place and also depending on the work-load involved.

Responsibilities of the Authorized Operator

- Operating the system
- Monitoring the system situation
- Providing regular maintenance, such as adding distilled water into batteries
- Recording the system performance
- May provide consulting to residents for some electric equipment applications
- Contacting the system developer in case of system problems

Legal Relationship between Owner and Operator

- Full-time or part-time employee

Financial Relationship Owner and Operator

- Pay/receive salary
- Owner(s) keeps any remaining revenues and contributes funds to keep system in running if required

Case Study: VPMC Practice in Xinjiang

Location: Dahongliuxia, Barkol, XJ
Number of household: 80
Number of population: 320
System configuration: 10kW WPS
Management:
The system is managed by a VPMC consisting of village officer, representative of villagers, officer from Border Control Station.
The responsibilities of VPMC:
Assigning operators
Determining tariff/kWh
Making regulations for REVPS operation
Assist in fee collection
Discussing and determining all other issues related the REVPS.

Articles of Village Power Management Committee (VPMC)
(An example)

As the principle financier of several stand-alone village power systems, the Barkol Poverty Alleviation Office (PAO) in Xinjiang has developed the following regulations to improve the management of their systems:

1. The formation of VPMC

- The administration village power management committee (AVPMC) is formed under the supervision of the village government
- The AVPMC consists of representatives from the village government office, border control station (BCS), and village community. The officer from government is the director of AVPMC, and the representative from BCS the vice-director
- The natural village power management committee (NVPMC) is formed by the director of natural village (NV) and representatives of village community. The director of NV will be the director of NVPMC, and the village public security officer will be vice-director

2. Rights and responsibilities of VPMC

Rights:

- Determine the power distribution scenario of the WPS, and supervise its operation
- Determine the tariff schedule, and supervise the collection of the tariff. Determine to cut the power supply to final users who don't pay the tariff on time
- Issue penalties based on China "Electricity Law" in case of damage caused to the system, until due legal process can occur

Responsibilities:

- Employ or assign dedicated person to manage the WPS
- Employ or assign dedicated people to collect the tariff, and establish a power station managerial fund
- Make the management regulations of the power station fund, and supervise its execution
- Supervise the system operator to operate the system, keep the system in good condition, and distribute the power on time.
- Provide training on safe use of electricity. Eliminate unsafe action and problems

3. Management and Use of WPS fund

- Establish the WPS fund based on collected tariff
- The fund will be used for the following
  - Purchasing the spare parts of WPS and for regular maintenance
  - Replacement of system components; such as battery every 8-10 years
  - The WPS will be depreciated over 15 years. The depreciation money will be used to establish a renewal account to renew the system equipment in future
  - Pay the salary or fee of system operator
  - Other VPMC permitted payment

The WPS fund will be managed by an authorized person. The fund will be used for WPS only. Detailed account records should be kept and supervised by government departments. Audit once a year.

Source: Barkol County Poverty Alleviation Office

5.2.2 Contracted Operation

The "Contracted Operation" arrangement is based on the Authorization Arrangement pattern. The system owner(s) contract the operation of the system to individual(s) or an enterprise, mostly is individual(s) in current China. Usually the major content of the contract stipulates the "service" to be provided. The operator takes full responsibility for the system operation. The owner (VC) determines the price of electricity (Yuan/kWh), while the operator provides the service, collects the tariff (may not), and pays for the diesel fuel, and minor repairs. Any remaining funds are kept as the operator's profit.

Some village systems in Inner Mongolia are operated in this manner. In some cases incomplete or unclear contract terms have resulted in a less than ideal system management situation. Great care is required to draw up complete contracts, clearly defining the rights and responsiblities of both owner and contractor. Very few existing systems are using detailed contract arrangements.

Basic Contents of a Village Power System Management Contract

- System management principles
- Service time and level
- System maintenance requirements
- Tariff schedule and fee collection arrangements
- Distribution of revenues and accounting practices
- Salary arrangement for all related individuals
- Any other responsibilities
- Recourses in cases of breach of contract

Case study: A Wind/diesel hybrid system in Weijing, Siziwangqi, Inner Mongoia.

Case Study: Contracted REVPS Operation

Location: Weijing Sumu, Siziwangqi, IM
Number of households: 45
Village population: 160
Distance from nearest grid: 100km
System configuration: 10kW wind turbine, 67.2 kWh battery bank, 20kW diesel backup
Management: The system is contracted to a private operator. The operator collects the tariff. He has the responsibility to pay for diesel and other minor maintenance expenses, including the 1,800 Yuan annual maintenance fee of the system installer, and keeps any remainder. Not responsible for later battery replacement.
Estimated annual revenue: 10,000 Yuan
Current system situation:

- System performs satisfactorily under normal conditions
- Not enough funds for later battery replacement

Responsibilities of the Operator under Leasing Arrangement

- Operate and maintain assets leased
- Provide the service according to terms of the lease
- Pay lease fees based on the leasing contract

Legal Relationship between Owner and Operator

- Clear legal relationship as defined in the lease contract

Financial Relationship Owner and Operator

- Leasor has the full right to operate the system in their own way to provide the service and generate profit
- Owner oversees honoring of the terms of the lease contract and receives lease fees

5.2.3 Lease Arrangement

The third system management option is a "Lease Arragement". This arragement is a more complete arrangement than a contracted operator arrangement and results in deep legal engagement of the system operator. The contractor or leasor can be an individual or a legal entity (a business organization). The tangible assets, such as a power production system, are leased to the operator, who in turn takes on a greater degree of responsibility for medium-term system maintenance. A detailed lease arrangement specifies the distribution of revenues including the amount of funds which must be set aside for long-term maintenance. While the system owners will usually set up some basic guidelines, the service offered by the system will normally be determined between the operator and their customers, the end-users. A high level of success has been achieved by number of mini-hydro systems in Tibet using this arrangement.

Case study:

Private Leaseholders Operate Mini-hydro Systems in Tibet

A GtZ project in Tibet has developed a standard private leaseholder contract for operation of rehabilitated of mini-hydro systems. Many of these systems had fallen into disrepair as a result of remote management indifferent to their operational status. The private leaseholder approach encourages decentralized management by vesting management responsibility in an individual living in the beneficiary community. Typically, the water rights are transferred to the leaseholder who pays a rent of 30% of revenues for operating the system. These funds are used to build up a fund for major replacement and repair costs (>10,000RMB), which are the responsibility of the system owner (community/local government/Ministry of Water

Resources). In addition, the leaseholder must open a bank account and deposit a further 10% of monthly revenues to ensure funds are available for short-term maintenance. The remaining balance reverts to the leaseholder to cover labor, daily repair costs, and some profit. Revenues can be collected either by the system owner or by the leaseholder. The critical terms of the lease are negotiated between the system owner and the leaseholder on a case-by-case basis. By November 2001, 21 mini-hydro systems were being run along these lines by private leaseholders in Tibet.

Key points for wider application of this arrangement:

- This arrangement may be most applicable in well developed areas, such as off-shore projects, where the load demand will be high.
- The economic viability of system management would be increased by managment of multiple systems. Where 5-10 villages exist within a geographical area in which all villages can be reached within one day's travel, these could be managed by a single operator. This situation exists in many parts of Western China. For example, Barkol County in Xinjiang AR has already developed four village power systems, and is planning to develop another eight. (The situation in Barkol County is discussed in more detail in the next section).

The Difference Between Contracting and Leasing

	Contracting	Leasing
Contractor	Individual/ Business org.	Individual/ Business org.
Contract target	Service	Tangible asset
Legal relationship	Weak	More formal
Financial relationship	Flexible	Premium only

Responsibilities of the Operator in Leaseholder Arrangement

- Operating and monitoring the system
- Buying diesel and any other minor parts, such as distilled water
- Provide regular maintenance
- Provide consulting to residents for some electrical equipment applications
- Negotiate with end-users and system owner for principles and charges of system operation.
- Collect revenues
- Set aside funds for long term system refurbishment/replacement

5.2.4 Ownership transfer

Under the above three management models, the owner makes some arrangement for the power system to be operated by another party. Another quite different arrangement is to have the ownership of the system transferred. Under this arrangement, the system developer may transfer the system ownership to a specialized enterprise (even a private individual) for a certain fee, leaving the managment and sustainable operation of the system in the hands of the business sector. A detailed transfer agreement should cover the minimum levels of service to be maintained by the new owner, and usually specify some upper limit for the tariff that can be charged for this service. In addition, the transfer fee and its payment terms are included in the agreement. Complicated negotiations and legal professionals may be involved since public property is often involved. However, once a model transfer agreement has been developed it could become widely used.

Key points for this arrangement:

- Proper candidate(s)
- Reasonable monetary arrangement for the transfer.

No existing systems are using this model. However, many state-owned small and medium-sized enterprises in other fields have been reformed in this way. Under China's transition from a centrally-planned economy to a more market-driven economy, some poorly operated state-owned enterprises have been sold to other interested organizations or individuals. For village power systems, the transition is from a social welfare project to a well run business operation. The aim is to relieve the government of a long-term burden and free it to make more effective use of public capital in other places and new projects.

China State Council Commented and Transmitted Notice of State Economy and Trade Commission on the Views of Reformation and Development of State owned Enterprises in 1997

2 (2) Further adopt flexible measures with regard to small state owned enterprises. From the reality of each individual place and acting according to local circumstances, adopting multiple formations, such as restructure, union, annexation, joint-stock cooperation, leasing, contracting, sell and bankruptcy so as to further adopt flexible measures with regard to small state owned enterprises and speed up the progress of the reformation and development of state owned enterprises.

China State Council 1997 #19
Issued date: 19970523 Effective date: 19970523
Issuing Organization: China State Council

5.2.5 Other Innovative Management Arrangements

Community Power Service Companies (CPSC)

CPSC. provides a flexible business framework for rural elec-

Responsibilities of the Operator (Transferee)

- The transferee will take full responsibility to operate the system as required by the transfer agreement

Legal Relationship between Owner and Operator
- Clear legal relationship between Transferor and a transferee
- The transferee will usually own the property forever
- Transferee may forfeit ownership if the terms of the transfer agreement are not respected

Financial Relationship Owner and Operator
- One time payment or installments

trification service provision in an off-grid scenario. CPSCs manage multiple stand-alone power systems (community and household systems), taking over operation and maintenance duties, for which they usually collect a fee for service from their customers. Although CPSC is new to China, they can be found elsewhere around the world. The first private sector rural energy service companies or CPSCs, were established in Indonesia and the Philippines by Community Power Corporation (CPC), a company from Colorado, USA[1].

CPSCs sign a management contract with the system owners (government, if the government is the sole owner, or mixed owners), which will describe the rights and responsibilities for each side (refer to box). Since a CPSC is specialized in energy project management, they can bring their experience to bear in running systems more effectively. CPSCs may or may not have been involved in system development and installation, but where market demand is strong and other economic conditions allow, there can be incentives for their full participation in contributing towards the capital investments.

This management model normally uses a "fee-for-service" payment mechanism, which is discussed in detail in the following section.

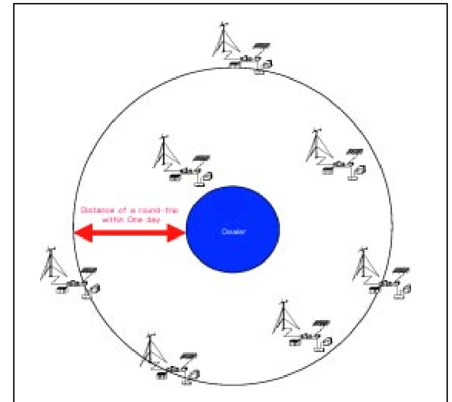
Although the management arrangement is a completely market-driven, some government or other outside financing will probably be required to cover initial investment costs and, where demand and ability to pay are low, to ensure at least a basic service reaches all households.

The following are the key lessons learned from the CPSC experience:

The CPSC model developed by CPC

- Serve all customers in a geographic area-build a service territory, build business density, build loyalty
- Use mix of most appropriate renewable energy technologies (AC, DC, Solar, Biomass, Wind)
- Meet each customer's priority energy requirements with reliable, hassle-free, clean and efficient electricity services
- Charge customers less than what they now pay for inferior energy services from kerosene, batteries, small gensets, candles
- Sell energy services-fees, not kWh rates
- Provide customers service, without technology risk
- Use modular/transportable RE power systems
- Establish local service infrastructure
- Share capital costs with local/national government, development organization

Source: Robb R. Walt, A New Model for. Sustainable Energy Service and Economic Development in Off-grid Communities, Village Power 2000, World Bank December 2000



The service zone for a CPSC


A community served by a CPSC

[1] Robb R. Walt, A New Model for: Sustainable Energy Service and Economic Development in Off-grid Communities, Village Power 2000, World Bank December 2000

Responsibilities of the Operator (CPSC)

- ◆ Provide energy services to end-users according to contract terms
- ◆ Operate the system effectively
- ◆ Monitor the system situation
- ◆ Provide regular maintenance, such as adding distilled water to batteries
- ◆ May provide consulting to residents for some electric equipment application
- ◆ Connect with system developer for possible system problems
- ◆ Buy diesel and any other minor parts, such as distilled water

Legal Relationship between Owner and Operator

- ◆ Official legal contract

Financial Relationship Owner and Operator

- ◆ Based upon the contract

- ◆ Requires business of a sufficiently large scale
  The load, or electricity, sold by one village power system is usually limited due to system capacity and local income levels. To maximise its business activity and make its operations profitable, a CPSC should manage at least 10-15 villages to reduce operating costs.
- ◆ Reliability of the village power systems
  Any system or component failure will result in a loss of revenue and increase operating costs. The more reliable the system, the lower the operating costs.
- ◆ Appropriate selection of CPSC candidate
  Based on current China practices, the most likely candidate for a CPSC would be the enterprise who developed and installed the system, often this is an enterprise located in the same province. It is not suggested that an outside enterprise take this role because it requires a strong local presence.

5.3 Tariff Regimes, Determining Appropriate Tariff Levels, and Payment Mechanisms

The economic viability of a village power system is, to a large extent, determined by its ability to generate income through tariff collection. However, we have seen that the communities benefitting from these systems are often poor and have a limited ability to pay. Careful tariffing arrnagements must therefore be made in order to ensure that villagers enjoy the benefits of access to electricity without compromising the economic viability of their system.

5.3.1 Alternative Tariff Regimes

Fee per kWh

Flat Rates and Differential Customer Group Rates

The clients of a village power system can usually be classified into three catagories:

- ◆ Residents
- ◆ Institutions (government offices, school, clinic, public safety administration etc.)
- ◆ Businesses (restaurants, stores, hotels, machine shop, etc.)

Currently most village power systems charge the same tariff rate to all three types of client. This is not an optimal situation and a graded tariff regime can exploit the fact that the second and third groups have a higher disposable income. Table 5.2 shows how extra revenue can be generated by adopting a system of differential or varying tariff rates.

Based on the VR regime, the greater the productive client load, the more the revenue. In the above case, the VR regime generates over 10% more revenue than a FR regime. It should be noted that charging varying rates is justifiable, especially when the state has contributerd to the system investment as a social development project. And this will greatly help the break even and cash flow of the system.

Developing the varying tariff model, a stepped tariff regime within the residential customer group can also be employed. A “life-line” is a tariff applied to a limited consumption which is enough for households to meet their basic electricity needs (e.g. 1RMB/kWh for the first 5kWh of consumption every month, and therefater 2.5 RMB/kWh for any additinal

Table 5.2 Flat Rate (FR) vs. Varying Rate (VR) Tariff Regimes

Client catagory	Qty.	Consum- ption kWh/Yr	Charge rate(Yuan/kWh)		Total kWh	Revenue(Yuan/year)	
			FR	VR		FR	VR
Residents	300	100	2.00	2.00	30,000	60,000	60,000
Non-profit institutions	1	730	2.00	2.00	730	1,460	1,460
Public Business	1	730	2.00	2.50	730	1,460	1,825
Private Business	5	1,500	2.00	3.00	7,500	15,000	22,500
Total					**38,960**	**77,920**	**85,785**

consumption). As consumption increases, further price increases can be applied. In this way, wealthy households that can afford more appliances will pay more for their electricity.

5.3.2 Determining Appropriate Tariff Level(s)

Tariff levels can be split into four bands - free of charge, subsidised tariff, break-even tariff and profitable tariff. A recent survey sample of REVPSs in China found kWh charge rates as listed in Table 5.3. More than 90% of the surveyed villages charged rates of less than or equal to 2.00 Yuan/kWh, which represents a tariff with some degree of subsidy.

Table 5.3 The Distribution of kWh Rates in Surveyed Villages

kWh rate	No
0	1
0-1	2
>1 - 2	10
>2- 3	0
>3-4	1
>4	0
Total	**14**

Free of charge

People often consider village power systems as a welfare project more than as a substainable business operation. As such, it is sometimes argued that the services they provide should be free of charge. However, where the system collects no revenue, it will be obliged to request continued financial support from the government to cover operation and maintenace and component replacement costs. This is clearly an unsustainable model and sooner or later the system will collapse due to having no funds available for system maintenance and repair. Moreover, this is no basis for widespread system deployment. Public budgets are limited and the establishment of further systems will be severly restricted by the ongoing obligations of public funds and an understandable reluctance of these financiers to take on additional open-ended obligations.

Case Study: Free of Charge REVPS Service

A wind turbine and PV REVPS was installed in China in 1999. To date the system has not generated any cash reserves due to severe drought and other reasons . There are no clear plans for how to fund the replacement of the battery in future.

Subsdized Tariff

Most village power systems currently charge subsidised kWh rates, in the range of RMB 1.00 -2.00 Yuan/kWh. Field experience shows that governments have to contribute extra funds on top of this to replace the battary bank after several years. Otherwise, the system will not continue to operate.

Furthermore, based on such a tariff, the government may even need to subsdize somewhat the operators' salary to keep the system running, as happens in Weijing Sumu, in Inner Mongolia.

Low tariffs are partly the result of government subsdized projects. Other reasons for low kWh rates are due to some prevailing attitudes and misconceptions:

- Wind and sun are free
- The tariff of village power systems should not be

An improper comparison

My uncle is living in town, and he just pay 0.50 Yuan/kWh, why do I have to pay 2.00 Yuan/kWh or even more?

Charlie Dou

Charlie Dou

Deteriorated batteries

Luying Dong

A broken blade

Table 5.4 Summary Assessment of Various Tariff Rates

Catagory	Indicative RMB/kWh	Advantages	Disadvantages
Free of charge	0	◆ No financial burden on end-users receiving electricity service ◆ Encourages the application of electricity	◆ No fund for long-term operation ◆ System cannot run sustainably ◆ Application limited to availability of already overstretched government resources ◆ Encourages a culture of reliance on the state ◆ May completely lose control of load demand increment
Subsidized tariff	1.00-2.00 (Except mini-hydro)	◆ Low financial burden on end-users ◆ Encourages culture of paying for services ◆ Promoting the application of electricity	◆ No fund for long-term operation ◆ System cannot be run sustainably as a business unit ◆ May lose control of load demand increment ◆ Government does not have sufficient funds to power all un-electrified villages on this basis
Break even tariff (or close break even)	>2.00 (Varying depends on the type of system)	◆ Usually affordable, at least for minium service provision ◆ System can operate sustainably	◆ No profit, so not able to attract outside financers
Profitable tariff applied as per kWh charge	>2.00	◆ System can operate sustainabaly, with profit	◆ Charge may be unacceptable/unaffordable to end users
Profitable tariif applied through Fee-for-Service Model	Equivalent to > 2.00	◆ Break even operation for small load REVPSs ◆ Avoids unnecessary kWh rates comparison ◆ Avoids installation of kWh meter so as to reduce the user connection expense ◆ Easy calculation for each individual household payment according to appliances	◆ How to verify the real load of each household ◆ Less stimulation of load increment and resulting economic development

more than diesel electricity

- The tariff of village power systems should equal the urban utility gird price

Break even (or close to break even) Regime

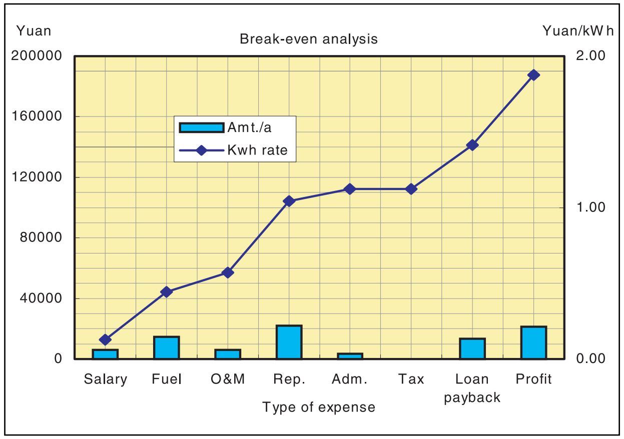
Table 5.5 Minimum Breakeven Requirements for Various Systems

System	Minimum cost recovery requirements
Diesel	Fuel, salary, maintenance, diesel genset replacement
Wind	Salary, system maintenance, battery replacement
PV	Salary, system maintenance, battery replacement
Hydro	Salary, system maintenance

As the term implies, this tariff regime is designed to generate enough revenue for the system to break even. The key is which costs are included in the calculation of the break even tariff ? In order of increasing expendability, these are:

- Management (salary)
- Fuel and lubrication costs
- Operation and maintenance (O&M)
- Replacement of diesel gensets and battery bank
- Administrative costs
- Any applied tax
- Repayment of the investment and interest
- Profits (where required)

Recall the wind/diesel hybrid system for a present case of 300 household village in Chapter 3. Table 5.5 gives an example of a calculation to determine the break-even kWh tariff. The first two costs are essential for daily system operation. That is to say, the operator salary of 6,000 Yuan per year and the fuel cost of 14,557 Yuan. To cover these two fundamental costs, a tariff of 0.44 Yuan/kWh must be charged. To break-even for battery and diesel replacement, the users have to pay at least 1.04 Yuan/kWh. If the users pay 1.41 Yuan/kWh, and the system components last according to the expected life time, and the system will be paid back in 20 years. Therefore, without any profit, the break-even is 1.41 Yuan/kWh. Above this, a further 0.20 Yuan/kWh is needed for every 1% profit



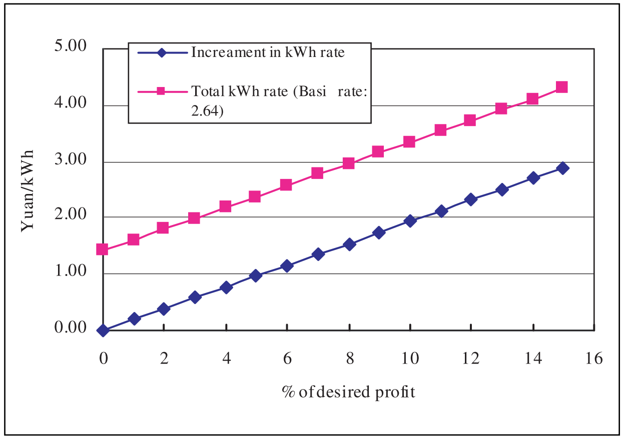


Table 5.5 Tariff Composition Analysis

Items	Cost per Year	kWh Charge Equivalent	Accumulated Cost	Accumulated kWh rate	Notes
Salary	6,000	0.13	6,000	0.13	
Fuel	14,557	0.31	20,557	0.44	
O&M	6,000	0.13	26,557	0.57	
Replacements	21,939	0.47	48,496	1.04	Diesel: 2251, battery: 19688
Administration	3,645	0.08	52,141	1.12	
Tax	0	0.00	52,141	1.12	
Loan payback	13,438	0.29	65,579	1.41	20 years
Profit	21,497	0.46	87,076	1.87	2.5%


William Wallace

Ag business

of total investment value. Table 5.5 shows that in order to generate a 2.5% return on total investment, the system would have to charge consumers 1.87 Yuan/kWh. According to this calculation, a 12% return on investment would require a tariff rate of 3.7 RMB/kWh[2].

Table 5.6 The Profit/Tariff Relationship for an Example Hybrid System

Profit = % of TI	Increment in kWh rate	Total kWh rate (Basic rate: 1.41)
0	0.00	1.41
1	0.19	1.60
2	0.39	1.80
3	0.58	1.99
4	0.77	2.18
5	0.97	2.38
6	1.16	2.57
7	1.35	2.76
8	1.54	2.95
9	1.74	3.15
10	1.93	3.34
11	.12	3.53
12	2.32	3.73
13	2.51	3.92
14	2.70	4.11
15	2.90	4.31

Fee-for-Service (Market based)

All three tariff regimes discussed above are based on charges for the amount of electricity comsumed (measured by individual household kWh metering). Charging users based on metered kWh can have several problems. The first problem is that in some places, a meter may not be available. Where available, consumers may be unfamiliar with the principles of how to manage household power consumption and meter reading is laborious. Another limitation is the incorrect, direct comparison which is often made between electricity supplied to an urban household connected to the national grid and that supplied to a household served by an independent village power system.

To avoid this awkward situation, many diesel village systems use a fee-for-service charge instead of kWh-based charges. Operators, mostly village governments or committees, have operated systems economically for years based on such charges. For example, in one case in Inner Mongolia where power is available for 2 hours every evening, consumers pay 12 Yuan per month per 40W light. When converted to kWh rate, this represents 5.00 Yuan/kWh, which the consumers would almost certainly refuse to pay.

Where households use the same appliances for the same applications, it may be possible to adopt a “flat” monthly charge for access to an electricity supply. However, as the gap between households in terms of prosperity grows, it will soon become essential to adopt a pricing regime according to the use of different appliances, e.g. as in Mauritania (see box).

The fee-for-service model strongly favours the adoption of energy efficient appliances, since for the same amount of power production, the operator will be able to offer a service to more customers. The CPSC model discussed in the previuos section normally charges customers according to this fee-for-service model instead of per kWh. In practice, additional benefits of this system have been found in consulting services, trouble shooting and safety education given for household appliance applications by operators. This is particularly beneficial for those who are unfamiliar with electricity use.


Winfried Rijssenbeek

Herds business

[2]Note this calculation is simplified version of the calculations presented in Chapter 3, hence the costs per kWh are slightly reduced.

Case study: Package service vs. kWh rate in Inner Mongolia and Xinjiang

Case 1: 40W, 4hours/day, 9.6 Yuan/month
kWh consumed: 40W x 4h x 30 = 4800Wh = 4.8kWh
Equivalent kWh rate: 9.6 Yuan/4,8kWh = 2.00 Yuan/kWh

Case 2: 40W, 2hours/day, 12 Yuan/month
kWh consumed: 40W x 2h x 30 = 2400Wh = 2.4kWh
Equivalent kWh rate: 12 Yuan/2.4kWh = 5.00 Yuan/kWh

Case 3: 40W light and 40W TV, 4hours/day, 15 Yuan/month
kWh consumed: (40W+40W) x 4h x 30 = 9600Wh = 9.6kWh
Equivalent kWh rate: 15 Yuan/9.6kWh = 1.56 Yuan/kWh

Advantages and disadvantages of Fee for Service

Advantages

- Break even operation for small load REVPSs
- Avoids inapropriate kWh rates comparison
- Avoids need for installtion of kWh meter so as to reduce the cost of connections (for users)
- Easy calculation of each individual household payment (All families will be charged same)
- Encourages promotion of energy efficiency by system operator

Disadvantages

- How to verify the real load of each household ?
- Less incentive to stimulate load increment and encourage new economic development
- Less control over load growth

Case Study: Fee for Service, Mauritanian Wind System

A wind power system operating in Mauritania uses a "Points" regime to charge customers for electricity use. The terms of the regime are specified in client contracts. Each point costs 450UM/month. Each lamp counts one point and each power plug outlet counts two points. Few people have problems paying for the service, even though the costs on a kWh basis seem very high compared to urban electricity costs. Average monthly expenditure per household is lower than it was before the village had electricity (US$6 now vs. US$8.46 before).

If we assume full cost recovery with a 7 % interest rate, and depreciation over 8 years, annual costs would be about US$10,000 per year, requiring a monthly tariff of US$8.33 (100 customers). The villagers thus reap substantial benefits at lower costs.

Features:

- Energy saving equipment for lighting should be used to the advantage of the system operators and would be part of the conditions of the client contract
- The systems are run by cooperatives, who employ a system technical manager
- Professional management, client, and servicing contracts
- Service contract requires that outages are fixed within 48 hours

Table 5.7 Example of Possible Tariff Packages

Package #	Service contents					Service	Rate(Yuan/mth)
	# of ESL	Radio	14" B/W TV	17" Color TV	VCD Player		
1	2	×				×	9.6
2	2	×	×			×	12
3	3	×		×		×	14
4	3	×		×	×	×	15

*ESL=Energy saving light

William Wallace

Fruits for sale

Pre-payment meter

Pre-payment card

TIPS Typical Power consumption of common household appliances

Items	Capacity W	Power consumed kWh/day
Energy saving bulb	11-14	0.05
14" color TV	70	0.2-0.3
Radio	20	0.01
Karaoke	20	0.01
Refrigerator	130	1

5.4 Fee Collection Mechanisms

Monthly Payment

Charging clients once a month for the electricity they use is the most common practice in urban areas, but has proved difficult to execute in rural areas where incomes vary seasonally with agricultural sales. This fee-collection schedule is not very common for village power systems and in a survey sample no system was found to use this approach .

Once or Twice a Year

Most rural househlds are engaged in agricultural or husbandary production. They usually harvest once or twice a year. Even those residents who live in townships, working for local government or public agencies, such as school teachers, post office staff, doctors and nurses, are usually paid only once or twice a year. Only small commercial business (restaurants and hotels) have more regular incomes. Therefore, a more feasible fee collection schedule in remote areas is to collect electricity fees once or twice a year, after harvests or after salary payments. Weijing Sumu in Siziwangqi, Inner Monglia, Dahongliuxia village and Huaerci in Barkol, Xinjiang, charge households once a year, while Halabulake, in Akqi, Xinjiang charges twice a year.

In-kind payment

Charging cash is sometimes not convenient for farmers and herdsmen. An alternative way to collect fees is to collect payments in-kind. This makes life easier for final users. Farmers may lack cash, but they almost always have some livestock or other agricultural assets. Of course, the fee-collecting will have extra work to handle these kind of payments, and will also need to have (or have access to) some expertise in the products they receive. The in-kind payments can then be converted into cash by trading with other agencies, such as the local livestock administration, purchasing centers or outside buyers. If the in-kind payment is made in livestock, the system manager may choose to keep feeding the animals for a while, to be traded later at greater profit.

Prepayment cards

Charging electricity tariffs through a pre-payment card metering system instead of a conventional meter is becoming more and more popular in cities, and espcially in newly devloped communities. The meter automatically cuts off when the card value is used up and supply is resumed only after more credit is purchased. Using a pre-payment card reduces the labor required to collect the tariff payments and also avoids the situation of non-payment of electricity. The disadvantage is that using such a system will increase the initial project investment, though costs are expected to decline as these systems becomes more widely adopted.

CHAPTER 6: OTHER CRITICAL ISSUES

6.1 Resource Evaluation

Thorough evaluation of available renewable resources is a precondition for a successful project. Although the outcome may result in the abandonment of a potential project, this is preferential to the wasted investment and bad feelings that would result from the establishment of a power system incapable of meeting the expectations of the stakeholders. In any cases, detailed evaluation of available renewable resources is fundamental to the design of an optimal power solution.

Resource evaluation includes the collection of data (existing data and new, on-site data) and interpretation of this data. Resources must be evaluated both in terms of the quality of the resource available and its seasonal and diurnal fluctuations. In cases where there is no existing data, it is necessary to monitor on-site resources for one to two years before a true picture of the situation can be compiled. Experience has shown that a thorough resource evaluation always pays-off in terms of optimal system design.

It should be recognized that renewable resources are, by nature, variable, so resource evaluation is a question of establishing best estimates based on the best available data. In general, average annual RE data can be used for preliminary system design. If the preliminary design gives a positive result, then reliable monthly data should be used to do the final design. Short-term on-site resource monitoring (3-6 months) is a useful tool in this regard. For large wind projects, one year of resource assessment is generally a minimum requirement, unless there is other regional data available.

On-site resource measurement should use a reliable data logger. These can be used to monitor wind, solar and other weather information. The logger memory can store several months' data, depending on the number of channels and averaging time. Hourly averages will suffice for both wind and solar data.

Careful calibration of historical data sets through on-site measurements can generate an invaluable historical database of renewable resources. Remote data acquisition, in which data can be accessed by cell phone or satellite, is also possible.

Particular attention should be paid to critical month(s), such as months or seasons of low winds, cloudy or rainy seasons, lower insolation seasons (winters), dry seasons, and highest load months. Practical guidelines for the assessment of hydro, wind and solar resources are provided in the relevant sections of Annex II.

Assessing resource availability for diesel-based generating systems is more straightforward. In this case, conditions of diesel price, diesel transportation, and sources of spare parts must be considered.

6.2 Load Analysis and Estimation of Load Growth

A fundamental question in project development is the determination of the scale of the system in terms of the load to be

Michael Bergey

Missed wind

Principles for Renewable Resource Evaluation

Existing data

- Use updated maps: wind maps, solar maps. Some renewable resource assessment have adopted the latest technologies, such as satellite data and GIS (Graphic Information Systems)
- Obtain available meteorological / historical data from nearby sites (weather stations / telecommunications stations/ other village power systems)
- Ship data can be helpful in coastal and island locations
- Get on-site information from local residents and look for the deformation of plants around the project site (see Annex II)
- Careful calibration of historical data sets through on-site measurements can generate an invaluable historical database of the renewable resource.

Acquisition of additional data

Existing solar data may be adequate. For wind (and sometimes hydro) data, these will always have to be confirmed by on-site measurement because:

- Wind resources are extremely site-specific and project sites are normally far away from weather stations
- Historical data sets may be distorted, for example due to interference at the measuring site, sensor problems, such as worn out bearings, or improper or lack of necessary calibrations, etc

See Annex 2 for practical guidelines for assessment and evaluation of individual renewable resources.

Source: Paul Gipe, Wind Power for Home & Business, Renewable Energy for the 1990s and beyond

served. This is especially critical for renewable energy based systems, which have high investment costs per kW installed. Underestimation of the load demand and growth will cause a power shortage within a short time period after the system is installed, but overestimation will result in a wasted investment, at least initially.

A further complicating factor is that after installation of a village power system, households inevitably purchase new electrical appliances, dramatically increasing the community load. Estimating the rate of this load growth requires careful work. One system in Inner Mongolia experienced drastic load growth as households quickly purchased 600W electric rice cookers with a daily power consumption of 0.3kWh, or 10kWh per month. The village was forced to take special measures to limit the load in this case.

Common practice is to design systems according to the load anticipated for 5 years after installation. Annex II provides some practical guidelines for initial load analysis and for estimation of future load growth.

One way to reduce the risks associated with an uncertain load growth-rate is to design a system that can easily be expanded in future. PV modules and wind turbines can easily be added to an existing power system, but electronic devices cannot. Therefore, these components may be over-sized for initial loads in order to ensure system flexibility in future. For wind and solar systems, the capacity of the electronic devices and transmission line can be doubled at the design stage. For mini-hydro systems, extra civil works can be prepared for future addition of an additional generator(s). Since diesel generators have a relatively short lifetime (3-4 years), these can be upsized as and when required.

Adopting standardized "package systems", which can easily be expanded in the future is a common way to overcome such design dilemmas. Another approach to expanding a village power system is implement larger projects through a staged installation approach, basing expansion on actual load growth experience.

6.3 Component Selection and Procurement

6.3.1 Principles of Component Selection

For most technologies, a range of product types and qualities are available. There will always be a cost-quality trade-off, but given that these systems operate in remote locations, reliability must be the primary consideration. Many system investors, system developers, and end-users have suffered from component quality and reliabililty problems in the past. The cost (and time) required for a trained engineer to repair a malfunctioning component means that poor quality products often turn out to be an expensive choice over the system life time. Forthermore, poor quality equipment requires more frequent servicing, bringing added problems and costs in remote sites. Quality manufacturers can provide reassurance in the form of technical guarantees and warranties. Wherever possible, these should be secured. An additional warranty for the overall system from the installer is also highly desirable. While some of the most advanced technologies are manufactured abroad, their advantages should be carefully weighed up against those of more easily repaired or replaced domestic equipment.

In summary, selection of the most suitable system components is critical and an overall evalutation should consider:

- Operational Reliability
- Quality
- Efficiency
- Regular maintenance requirements
- After-sales service availability
- Cost of servicing
- Warranty
- Spare parts availability
- Price
- Project lifetime cost

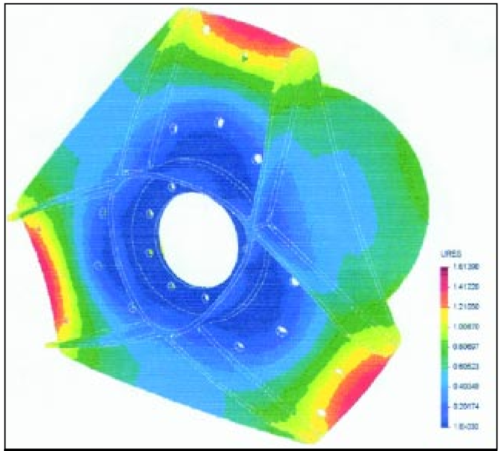
Recommendations for selection criteria for individual components are provided in Annex II.

6.3.2 Standardized System Components

Adopting a standardized system can have multiple benefits. A standard system design will save cost in many areas of project development, from system design and component selection to installation and maintenance. Sometimes the capacity of an available standard package may initially exceed the current load. In such a case, selecting a standard design represents shifting an investment from the cost of a detailed custom design to an investment in greater capacity for future load growth. Moreover, standard packages will be more reliable due to experiences gained from many projects and use lower-cost standard system components (such as inverter and battery with stable suppliers) due to mass production. Warranty terms of standard packages should also be more favorable for the purchaser. Several examples of standard renewable energy village power packages are introduced below.

Advantages of Standardized Packages

- Low system package cost due to less custom system design work involved
- Low production cost benefits from standardization
- Technically mature
- Improved reliability
- Easy to expand to system



Advanced computer-aided design

Packages	Capacity (kW)	Households served	Wind (kW)	PV (kW)	Back up diesel (kW)	Battery Bank(kW)	Inverter (kW)[1]
Std. Wind	5	20+	5			25	3
Std. Wind	10	40-50	10			50	5
Std. PV	5	20+		5		25	3
Std. PV	10	40-50		10		50	5
Std. Wind/PV	6	20+	5	1		25	5
Std. Wind/PV	12	40-50	10	2		50	5
Std. W/PV/D	12	40-50	10	2	10	50	5

[1] The capacity of inverter should be larger if significant inductive loads existing.

Example of a Standard 12kW Hybrid Package

- 10kW wind turbine
- Wind charge controller with DC source center
- 2kW PV with charge controller
- 5kW Sine-wave inverter
- 18m tower
- 50kWh battery bank
- 12kW diesel generator
- Average daily output 56 kWh at 5.5m/s windspeed and 4.5 hours insolation
- System cost: ~500,000 Yuan

6.3.3 Procurement Principles

In order to obtain high quality products at a reasonable price, procurement should be through a competitive bidding mechanism. Often the project developer will issue a call for tender to manufacturers who may bid to supply individual or multiple components. And of course, bundling procurement of hardware equipment for multiple village projects into one procurement action can provide opportunites for manufacturers to offer products at reduced prices.

Less often in China, but commonly throughout the world, system integrators are invited by the project developer to provide complete systems on a "turn-key" basis. The advantage of this process is that a complete solution will be purchased (no risk of component incompatibility) and a single system integrator can be asked to provide a whole system warranty. Whichever process is used, manufacturers must be asked to provide information supporting the reliability of the equipment to be supplied, citing existing village power applications which have been operating in the field for a specified period (preferably at least 3 years).

6.4 Key Activities During System Installation and Commissioning

6.4.1 Training

In addition to detailed operating manuals, the system designer/installer must provide local operators with at least basic training on how to operate and maintain the power system. This training normally consists of two parts, factory training and field training.

a) Factory Training

The purpose of this training is to ensure that the local service engineers are capable of repairing the system components in case of malfunctions and that system operators are familiar with the basic operation of the system. The training may take 3-4 weeks and should cover:

- Detailed principles of the power system and its components
- Main layouts description and the connection between components
- Detailed trouble-shooting procedures
- Documents: Operational manuals, technical manuals and main layouts

b) Field Training for Local Operators

The purpose of this training is to teach the system operators to run the system and perform routine maintenance. The training may take 2-3 weeks and should cover:

- Brief principles of the power system and its components
- Operational process of the system and each individual component
- Standard operating procedures
- Outage and emergency procedures
- Maintenance program of the system and all components
- System monitoring activities and record keeping
- Documents: Operational manuals of the system and all components

6.4.2 System Testing and Checking

Thorough system testing and checking must take place during the commissioning of the system and should be detailed as a requirement in the contract of the system installer. These checks should include all standard operating modes, outage and emergency procedures.. Annex II lists the standard checks required for major individual village power system components.

In addition, all systems must complete the following checks:

- Check spare parts
- Check all manuals
- Check all system rules
- Complete necessary documentation and signatures

6.5 Warranty and After-Sales-service

If this issue is not properly addressed in the original system planning, after-sales service costs can become a crippling liability for a remote village power system. The quality of a manufacturer's after-sales service can normally best be determined by consulting with their previous customers.

An after-sales service package consists of the following aspects:

6.5.1 Warranty

It is the right of customers to ask for a "Warranty" document from the manufacturer or authorized dealer. The warranty term is an important indicator of manufacturer's confidence in their products. Usually, the longer the warranty term, the higher the quality of a product. Warranty terms should be included in the purchasing contract or a separate "Warranty" document, which states the contents of the warranty. Most manufacturers offer "Limited warranty", which means the warranty will be provided under certain conditions for a given period of time. For an initial period, manufacturers will normally replace components at no cost. For a longer period thereafter they will charge transport, parts and labor. Manufacturers will not replace the parts and/or whole unit if the unit has been used improperly, or damaged by an event of force majeure, such as a typhoon, tornado, lightning, flooding etc.

Experience has shown that in instances of system failure, it may not always be clear which component is at fault, and therefore which manufacturer is responsible for fixing the problem. Where a single system integrator has installed the system on a "turn-key" basis, the system owner should negotiate a system warranty that avoids this situation. Under this arrangement, it may be desirable for the system installer to hold the component guarantees in their own name. In this way the system owner can refer all faults or outages to one party.

6.5.2 Failure of parts and product replacement

It is the manufactures' responsibility to replace any failed parts and products if they have been used in a proper way and are still under warranty.

6.5.3 Provision of spare parts

Some parts, especially moving parts such as diesel pistons, belts, and bearings; some wood blades for wind turbines; etc., will need to be replaced several times within the system lifetime. Without a prompt supply of parts, the energy system will not be able to keep operating. Manufacturer should provide a spare parts kit for remote locations as part of the initial cost and indicate delivery times for additional spare parts in future.

6.5.4 Technical assistance

Technical assistance provided by manufacturers is a very important component of after-sales service. Whenever possible, manufacturers should be encouraged to visit their products operating in site. Due to modern technology development, in addition to on site help, technical assistance can be provided in many other ways:

- Telephone
- Fax
- Email
- Internet, on site evaluation
- Manufacturer's website
  Websites are very common for many commercial product manufacturers in China, but not as yet for renewable energy product manufacturers. Putting technical information on a website is an economic way of advertising products, and of providing customer training and technical assistance
- Updates and product news

It is desirable for customers to receive prompt notification of any developments related to existing products or newly available products.

6.6 Maintenance and Servicing

The importance of diligent maintenance and servicing of a village power system cannot be over-emphasized. The first requirement is that responsibility for O&M tasks is clearly appointed to a specific individual(s). The operation and maintenance of the system should strictly follow the O&M procedures as stated in the relevant manuals provided by the system designer/installer and component manufacturers. Deviations from these procedures will result in a shortening of system lifetime and, in the end, higher costs. Particular care must be taken to look after diesel gensets, wind turbines and batteries (see Annex II for details).

The operator must record system performance parameters on a daily basis. If problems occur, the operator should follow procedures as specified in the operating manuals. If the problem cannot be solved by basic troubleshooting procedures, the operator should record the situation and inform and request technical assistance from the responsible party (system designer/component manufacturer).

6.7 Project Budgeting and Planning

Comprehensive project planning and budgeting are standard management tools to ensure projects are completed efficiently and according to the expectations of all parties. These principles are especially important for the implementation of multiple-stakeholder community power system projects.

The level of service required and the ability the local community to pay for this service must be fully understood in order to determine the economic viability of the system in the long-term. If the results are positive, then the appropriate management mechanism can be defined.

As a basic approach to budgeting for the initial investment in a village power project, this should include the following items.

- Local survey and preliminary system design
- Final system design
- Power station house and civil works
- Transmission lines, input line and metering box
- Hardware equipment and the spare parts
- Connection cable and tools
- Equipment transportation
- Equipment installation
- Commissioning
- Personnel training
- Project commissioning
- Project management
- One Year Monitoring

Drawing-up a realistic work-plan or schedule and informing all stakeholder of this is also very important. Often the completion of a task by one stakeholder (e.g. civil works by the community) is linked to the next stage of system installation. The following table shows an example schedule for the implementation of a village power project. Of course, the time duration for different systems will be different, but the process is similar. Mini-hydro projects may require more time for civil works and wind projects may require more time for resource monitoring.

Table 6.1 Example Work Schedule for a Village Power Project
Example Work Plan and Time Schedule

Activities	Month																				Remarks
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1. Site Selection & Data Collection					X																
Site Selection & Local Survey	■																				
On-site Resource Monitoring	■	■	■	■																	1 month installation + 3 months monitoring minimum for wind system, may not be necessary for PV system
2. System Design							X														
Preliminary design		■																			
Detailed Design					■	■															
3. Determination of Management Mechanism							X														
4. Procurement																X					
Bidding Document Preparation							■														
Bidding process for equipment								■	■												
Issue Contracts and Sub-contracts										■											
Manufacturing											■	■	■								Wind turbines manufactured abroad may take 8 months to manufacture and deliver
Factory training														■							
Delivery															■						
5. Installation and Commissioning																		X			
Local civil construction							■	■													Usually it is possible to start civil works after the system design has been finalized
System Installation																■					
Local Training																	■				
Debugging and Putting the system into operation																	■				
Commissioning and Acceptance Testing																	■				
6. One-year Operation Evaluation																					Complete one year after commissioning date

CHAPTER 7: CASE STUDIES

Barkol County

Barkol

7.1 Domestic Cases

7.1.1 HUAERCI, BARKOL, XINJIANG AR: A Wind Power Village System Project Developed by Harnessing a Poverty Alleviation Loan

General

Huaerci is a herdsmen's village located in Barkol County, in the mountainous regions of eastern Xinjiang. The village, sited at an altitude of 1600m, has 90 households with 360 Kazak inhabitants. Animal husbandry is the major economic activity. Average annual income was only 400 Yuan per capita in 2000, well below the national poverty line. The distance to the nearest electricity grid is 110km and local roads are very poor. The village has no electricity and the most common way for providing lighting at night is by candles. In order for children to do their homework, most families use 2 candles every night. People are eager to have access to electricity but the distance from the main grid and the local geographic conditions make it impossible to extend the utility line.

Renewbable resource

The average annual wind speed is 8.3 m/s, and average annual insolation is 3100 hrs.

System configuration

In October 2000, a single 10kW wind power system with 55kWh battery bank and 7.5kW DC-AC inverter was installed in the village.

Economics and financing

The county Poverty Alleviation Office (PAO) made the arrangements for a loan for the project. This was a government-subsdized loan for the people, with a 3% interest rate and 5 year loan term.

Load and performance

The system provides power 24 hours a day to 90 households. All lights connected to the system use energy saving bulbs (ESBs). Ten color TVs, more than 30 black/white TVs, and 1 CD player have been purchased. Furthermore, two villiage offices, a school, and a TV transmitting station are powered by the system. The total residential load is about 5kW, and the monthly power consumption is about 300kWh, with an additional 45kWh consumed by the institutional loads.

Management

A Village Power Management Committee (VPMC) has been formed and is made-up of village government officials, representatives of villagers, and the deputy director of the border control station. A tariff of 1.2Yuan/kWh is charged to all consumers. The operator operates the system as a part-time job. Most of the revenue is used for maintenance costs. Run in this way, the cash flow will be enough to replace the battery bank but the operation is not yet fully commercialized.

Impacts

Up to now, the system has run very well, and to the complete satisfaction of the residents and government. The system has greatly improved the quality of life of residents and allows


XJ Keyi
Erecting the wind turbine


William Wallace
The operating WPS at Huaerci, XJ


William Wallace
Huaerci village

children to study in the evenings. No productive loads are served to date due to limited system capacity. Residents need be educated in how to make full use of their system, especially for productive uses.

Policy and legal context
Huaerci is a remote Kazak neighborhood of Barkol County. The Barkol government is interested in using renewable energy to develop stand-alone systems for other remote communities. RE systems are seen as a way to combine poverty alleviation actions with rural electrification programmes. Six villages have been powered by renewable energy since 1999. Each one is powered by a WPS. The plans are to power another two large villages, each with a 30kW WPS, in the near future.

Lessons leant

- Load analysis and prediction is important. Proper system configuration to match the system load is a critical factor for system cost recovery.
- Six village-level REVPSs have been developed in Barkol. This provides a great opportunity to develop a multiple-project management entity and to introduce a commercialized management model so as to ensure system sustainability.
- Having productive load potential would help to place the system on a more commercial footing.

Sustainability and replicability
The high initial investment costs of a WPS system are beyond the affordability of local residents and local government. If such a system could be considered as a part of utility extension program, or financing is available from upper-level government or outside donors, then sustainable operation is possible. The system can be replicated elsewhere if:

- A good wind resource is available
- The village is of a reasonable size, preferably with opportunities for harnessing productive loads (The smaller the village size, the higher the unit cost per installed capacity)
- Carefully considered tariff structure to maximize system revenue
- A skillful technical operator does not just run the system, but also provides some services to end-users and encourages wise electricity use

Reference and contact information
Geng Liu, PAO, Barkol, Xinjiang, (902) 6822322

7.1.2 KEKELI, QINGHAI, CHINA: Solar stand-alone PV Village power System

General
Kekeli village is located in the most western part of Qilian County, Haibei District, Qinghai Province (close to Ali District in Tibet). The village is a herdsmen's community with 120 households and 385 inhabitants. In 2000, the average annual income was 2,104 Yuan per capita.

Renewable resource
The average annual solar radiation is 7.3 MJ/m2, average insolation time is equivalent 2,030 hours of peak capacity, and average sunshine time is 5.56 hours per day (slightly less than Ali). As a part of Qinghai-Tibet Plateau, Kekeli has very open terrain. The wind resource needs to be explored.

System configuration
The system, which includes solar panels of 10kW capacity, two (2) 15kW inverters, battery bank and controller, was installed in August 2000.

Load information and performance

The current load is 8.9kW, which includes 3.18kW of residential lighting, and 0.68kW of institutional load. The household appliance load is 5.72kW, including 30 color TV sets, 70 tape recorder sets, 11 washing machines, 2 refrigerators, and 1 TV transmission station. The system provides electricity 4 hours a day. Average daily power consumption is 35.3kWh. The local government and residents are satisfied by the system performance.

Economics and financing

The total system investment was 3,200,000 Yuan. The solar panels, inverters and controller were donated by a German Government programme, which is equivalent to 1,700,000 Yuan (or 53% of the investment). The rest, 1,500,000 Yuan was funded through domestic contributions form the Qinghai provincial government (300,000 Yuan) and county and village governments, as well as local residents.

Management

The operator is appointed by the village government (Authorization arrangement). His salary is paid by village government. The average annual power generated is about 10,000 kWh, which is charged at 4.00 Yuan/kWh. This should generate 40,000 Yuan revenue every year, but the relatively high tariff means full fee-collection from poor families cannot be guaranteed.

Impacts

The SPS provides power for families, village government offices, clinic, veterinary station, retail shop, bank branch, school, and post office etc. Electricity has greatly improved the local people's quality of life. The rate of children registered in school has increased since the power system was installed.

References and additional information

Sicheng Wang, Beijing JIKE Energy and New Tech Development Co., Beijing, China, (10) 6234 4485

7.2 International Cases

7.2.1 BOLIVIA: Chapisirka Micro Hydro-Electric Scheme

General

Chapisirka is a community of some 140 households (1162 people) living at 3500m altitude in rural Bolivia. The community is classified as having a medium poverty level. The average income in the community is between US $1,000 and US $1,500 per household per year. The main crop is potatoes, while wheat and onions are produced in small quantities. Oxen are used for land preparation and other livestock, such as sheep and cattle, are also kept.

System Technical Configuration and Performance

The community power system is composed of a 60 kW microhydro generator with an associated minigrid for 90 households. For design purposes, the electricity consumption per household was estimated at 25 kWh per month, based on data relating to the rural areas of the Altiplano and Andean valleys. At present the average household use is somewhat lower, at 20 kWh per month. The peak demand of the system is 38 kW, which is reached in the evening.

The system started to operate with only 20 users connected, but in less than 3 months this number increased to 80. Last year two extensions of the minigrid were made, each of 0.8 km length, so as to connect new customers. The extensions were realized using the funds generated by the tariffs and the fixed charge fee. Solidarity and a fair distribution of benefits were the main motivation for the line extensions. The net is

William Wallace

The regulations of a WPS

William Wallace

A herdsman's family with TV

QH REI

10kW PV power system
in Kekeli, Qilian County, QH

now able to connect an isolated hamlet of families which had worked in the project but were not considered in the first service provision.

Characteristics of the Chapisirka Mini hydro System

Design Discharge: 200l/s
Net Head: 43.9 m
Net Capacity: 60 kW

Pipe diameter: 15"
Wall thickness: 4 mm
Turbine: Pelton 60 kW 300 rpm
Synchronous 3 phase generator: 50 Hz, 380/220 V self regulating, 1500 rpm 80 kVA
Regulator: Discharge control
Step-up 3-phase transformer: 80 kVA 380/3000 V
Transmission line: 3 kV, 3.35 km, Conductor 6 AWG
Step down transformers: 25 kVA, 3000/380 V
Distribution network: 380/220 V, 1868 m; 220 V, 1815 m

Cost per kW installed (including line and minigrid): 2908 $US/kW
Yearly costs: 7758 $US/yr (O&M, depreciation)
Electricity Tariff: Lifeline tariff of $1.00 for first 10kWh per month, thereafter 0.11 $US/kWh (c.0.85 RMB/kWh)

The system operates all day. However, people primarily use electricity early in the morning, evening and night. Last year the system produced 21,000 kWh, of which an estimated 60% was for household use. Since the installation of the plant, two workshops have opened. One is a mechanical repair workshop and the other repairs electric appliances. The capacities of the workshop machines are 4 and 6 kW, and these require a three-phase supply. The extra load associated with the workshop machines can be sustained by the system because they function during daytime only (the low usage period). There are some limitations on power use during the dry period when the discharge is diminished. This year a moderate drought presented a critical condition, requiring the end-users to save energy.

Development Approach

In this case, the Municipality promoted the development of a hydropower plant by the villagers. Energetica, an NGO with energy expertise, provided technical assistance at a later stage, while Italian volunteers came even later and supported the project with their skilled work and donation of key equipment.

Demand and affordability

A study revealed that in 1997 people in Bolivia spent US $4. 78 per household per month to purchase candles, kerosene, LPG, and dry cell batteries for their lighting needs. The electricity demand per household in Chapsirka is between 8 and 21 kWh per month, which is an average of 10 to 12 kWh per family. The average would rise from 12 to 20 kWh per month when social users, for example: the school, community building, health clinic and street lighting (which enjoy electricity free of charge) are included in the figures. The tariff for the households has a base of US $1.00 for the first 10 kWh per month and US $0.11 per kWh for each additional kWh consumption. The tariff is reviewed once a year at the annual general meeting of the stakeholders. A result of this is that costs have declined, and the rates have become lower than the urban electricity rates. A recent evaluation revealed that local residents are quite happy about their system, and that they can easily afford to pay for their electricity use. The villagers presently pay US$1.00 to US$1.20 per household per month, instead of their previous expenditure of US$4.76 per month for much lower quality services. Two households that did not pay were disconnected, and later reconnected once they had paid their arrears.

Financing and Ownership

The total investment costs were US $174,480, or US $2,908 per kW installed.
The total investment costs were approximately distributed as follows:

- Equipment costs (hardware) US$84,000
- Civil works US$72,480
- Costs of technical assistance US$18,000

Ownership of the system is divided on shareholder basis according to the contributions of each party. The Dutch Government supported the final system design of the project with a grant amounting to 7% of the total investment. The Italians donated the power plant equipment, amounting to 50% of the investment. The Municipality provided a further 25% of the aggregate investment. The villagers contributed their labor to the construction of the system, and made a cash contribution averaging US $50.00 per family. The villagers' contribution was quantified, giving them a 15% stake in the project. Finally, Energetica contributed technical assistance and holds 10% of the company shares.

Management

Management of the system is undertaken by the village company, Empresa de Servicios Chapisirka. This organization has as maximum authority a 'Shareholders Assembly' in which the municipality, Energetica, the village, and the Italian Volunteers are represented. The assembly meets once a year to discuss tariffs, investments, and allocations.

Under the supervision of the assembly, a directorate takes charge of the management of the system. The directorate has three members, including one representative from the community, one from the municipality, and one representative from the Italian volunteers. This group meets at least 3 times a year. The directorate steers the operational unit that is headed by an executive from the community with a technician who is involved in the electrical maintenance and operation.

Operation & Maintenance

The system O&M is performed by the operations unit trained by Energetica. It checks the system regularly and does minor repair jobs. In the case of serious problems, they seek technical assistance from Energetica. The operations unit also collects the fees on a monthly basis.

A technician, educated in the city, is nominated by the households. He repairs the in-house systems and derives a small income from this activity. Energetica further contributes technical assistance to ensure the smooth running of the system.

Financial Aspects

Monthly revenues amount to, on average, US$66.50; the maximum being US$76.00[1]. US$600 is spent on the operational management and administration of the plant every year. Since the yearly revenues amount to US $798, the project can cover its operational costs. The remainder of the revenues are set aside in a reserve fund for covering major repairs. The revenues do not cover the investment costs, which were donated. However, in September 2001 the shareholders assembly decided to restructure the tariffs so as to increase the financial sustainability of the company.

Policy and Legal Context

The policy of the Bolivian Government aims to develop rural areas and combat poverty. They have taken on a serious decentralization effort, backed-up with financial flows. Municipalities have some financial independence, derived from local tax revenues. This allows municipalities to set their own priorities and make their own investments. Thanks to this decentralization, a positive atmosphere has been created, allowing municipal investments in areas such as drinking water, agriculture and electricity supply. However, the technical level of local officials is often low and a substantial capacity building effort is required.

According to new electricity laws, all rural installations of less than 300 kW are liberated from the requirements imposed on utilities. This facilitates the establishment of small hydroelectric schemes. However, the law does provide some minimum requirements concerning the functioning of these systems, for example quality control, tariffs, and coverage.

With respect to the tax legislation, some problems should be mentioned. The present tax requirements and procedures do not match rural realities. To comply with the all the tax regulations would cost Chapisirka more than US$600.00 per year. Declarations should be completed in tax offices of major cities, which require the work of accountants and other professionals. This cost is too high, and outside the scope of such a minor operation. In fact the Empresa de Servicios of Chapisirka would like to comply with the tax law but due to this financial constraint, in practice cannot.

Lessons Learned

- The shareholder ownership model has been successful, but it took one and a half years to agree on the complete management structure
- Hardware and other costs in Bolivia are relatively high. Where high investment costs are encountered (more than US $3000 per kW capacity installed), micro hydro-electric systems need financial support to cover initial investment costs. However, costs in China are typically much lower (and can be less than $1000 per kW)
- The system can cover productive loads because of its capacity, but to do this requires modification of the grid. Before designing a system with such a possibility, it must first be established that this would be the least cost energy provider i.e. direct diesel systems are not cheaper
- Households have extremely low incomes and therefore low expenditures for lighting and audio-visual equipment

Replicability

The system would be replicable in other villages under the following conditions:

- The village enjoys good hydro resources
- Hardware costs (in Bolivia) must be overcome, either by increasing availability of more affordable equipment or by provision of up-front Government financial support
- The village contributes to the system with a substantial labor input thus reducing the civil works costs
- The village is active in organizational capacity and decision making capability
- Major attention is given to dissemination and training of villagers and local organizations in the technical limitations and benefits of the system in terms of technical, demand, management, organizational, and financial aspects
- Energetica and/or other NGOs actively support the municipalities in setting out their priorities in the rural electrification area using renewable energy
- There are no legal impediments for small power systems. The new electricity law is not excessive in demands for systems with a capacity of less than 300 kW

[1] Reduced US$ equivalent revenues have resulted from devaluation of the local currency and from both technical and administrative losses.

Judy Siegal

An onion farmer displays his crop

Judy Siegal

Children of onion family now attend school

Judy Siegal

The onion field and wind turbine

7.2.2 INDONESIA: Community-Based Power for Microentre-preneurs

General

The purpose of the project is to strengthen the local capability to adapt wind-based energy technologies to numerous applications. The project endeavors to build a sustained interest in renewable energy and the potential for economic development that this can bring to a rural area. As the microenterprises build their capability to utilize renewable energy, they create a market for future renewable energy development. By demonstrating that the cost of the systems can be recovered through end-user fees, project managers hope to attract private sector investments in energy enterprises. Private sector development of renewable energy would create a sustainable means of providing power to fuel long-term rural economic development.

System Configuration

The systems use 10kW and 1.5kW wind turbines. Each system includes a wind turbine, at least one inverter, a diesel backup, and a battery bank.

Economics and Financing

USAID provided funding to Winrock International to develop 10 wind power sites in Indonesia as part of its contribution to the Global Environment Facility (GEF). Winrock was the ideal candidate based on its long experience working in the region and the existence of nearby Winrock programs that also support and develop microenterprise.

Management

By February 1999, nine community-operated wind energy systems had been installed. Each system has a working group, made up of local technicians who carry out the routine maintenance and customer service tasks. Wherever possible, an NGO is involved in the project to conduct the revenue collection and arrange the funding of the working group. The end-users are responsible for a service fee, which is metered according to energy usage or volume of water supplied. The NGO assumes responsibility for revenue collection and receives 15% of the fees as operating costs. The remainder of the fees is put into a maintenance account. Once the account reaches a certain amount, the funds are used to expand the system in a manner that the community decides. In a few situations, an NGO could not be identified to assume responsibility for the systems. In those cases, a community committee is formed to assume the responsibility. In general, it is easier for an NGO or a committee to collect payments rather than an individual because in these villages, it tends to be culturally inappropriate for an individual to press friends or family for payment, whereas an NGO is sufficiently impersonal to complete the task.

Impacts

Income generation--An onion grower in Indonesia was accustomed to working 1,040 hours per season, hauling water to irrigate his crop. These efforts produced a crop valued at \$550. Using a wind-powered community water pump, this farmer was able to increase his crop and his income four-fold and to reduce his labor to 100 hours per season. In return for the water service, the farmer pays a fee of \$0.10 per cubic meter of water used to the community committee that manages the water-pumping system. This amounts to about \$40 per month in expenditures during the six-month dry season. His profit of more than \$1,400 per season makes the cost worth it, particularly for his children, who can now attend school rather than work in the fields.

Irrigation--Six of the sites use wind energy for irrigation. In these cases, entrepreneurs use the water to diversify their agricultural activities to include high-priced vegetables, citrus, or lumber or to merely increase their present activities. The citrus growers had access to a microenterprise assistance program, which taught them to select products for size and consistency, establish efficient transportation links to the urban market, improve the freight packaging, and develop a brand name for the produce. One vegetable grower increased her production and profit five-fold.

Ice-making--Several entrepreneurs used the electricity to make ice for sale to local fishermen. The availability of ice enabled the fishermen to store their catch until the market demanded it. Fishermen are now able to avoid the middlemen who took advantage of their lack of options, and now sell to trawlers that take their products to markets as far away as South Africa.

Other Applications--One of the priorities of the wind project was to develop a wide range of capabilities when applying renewable energy. Entrepreneurs use the systems for a wide variety of applications from power tools to corn grinding to chick incubation. As these local communities develop technical capacity in these enterprises, they also increase their ability to reap economic growth from renewable energy resources.

References and additional information

Judy Siegal, Winrock International

7.2.3 MUARITANIA Wind Systems for Villages

General Information

The Alizes program began in 1990 in Mauritania and aimed to install wind pumps for water in 100 villages. In addition to the wind pumps, three 1 kW wind generators were installed as pilot projects. The wind generator portion of the program was so successful that both the Mauritanian Government and the Groupe de Recherche & Exchanges Technologiques (GRET) proposed a new program for the electrification of villages with small wind chargers. This came to be known as the Alizes Electric Program (AEP).

Tiguent is one of the villages in which a community system has been installed under this program. Tiguent has 180 households and approximately 2700 inhabitants, 14 shops and 2 restaurants. Tiguent is relatively large village for Mauritania, where a few hundred inhabitants per village are common. Tiguent was once an important trading center for Arabic Gum, which was collected from the Acacia arabica by the Brakna and Trarza Moors[2]. The village is surrounded by sand dunes and its population consists of herdsmen, businessmen and government people.

Technical configuration

The Tiguent village configuration is a hybrid, wind diesel mini-grid. The wind turbine has a rated capacity of 2.5 kW that feeds through a controller, a 950Ah battery bank. From there a 3kVA sine wave inverter feeds the power in a single phase (220 VAC) to end-users. In addition, a 7 kW diesel backup genset has been installed. The system serves 167 families, who each use one or two light bulbs and perhaps a black and white television, two restaurants, and fourteen shops.

In 1997, 2700kWh were produced during 2600 wind hours. There were 101 customers at that time and 20 street lights. The system worked continuously through the night. The diesel genset only operated 8 % of the time. In the low wind period, the genset is started in the early evening, and after eleven o'clock the charged battery takes over. This system allows the highest loads to be absorbed by the genset and leaves the battery well stocked as the mini-grid shuts down at midnight.

Tariff Payment and Affordability

The project uses an energy service concept and not a kWh tariff. This clearly increases the viability of the system. If the power tariffs (as kWh) were compared with urban rates, there would have been large political risks and the local people would have complained heavily.

Payment is determined by a points system specified in customer contracts. Each point costs US$3.46/month. One lamp counts one point. So, one lamp costs US$3.46, two cost US$ 6.92 and two with an outlet cost US$13.85 (One outlet counts for two lamps). Analysis shows that the costs of power consumed vary according to the number of points used by the households, from US$5.10 /kWh for one lamp, to US$10.60/kWh for three lamps. Although the kWh costs are very high, the monthly costs per household are still within reach for consumers.

The cost for the average consumer comes to US$6/month, or, with 15 members per family, this comes to US$4.80/capita/annum. With a per capita income of an average of US$410 (World Bank 1997) and a lower boundary of US$100, this amounts to 1% to 5 % of a villager's income.

As the expenditure on electricity with this system (US$6) is somewhat lower than the average spent with the previous power sources (a survey found families without electricity typically spent US$8.46 per month on batteries and kerosene), the project has succeeded in providing higher quality electricity at a lower cost.

[2] Chasing the Lizard's Tail by Jens Finke, 1996

The tariff will cover the costs of the sustained operation of the system (including operator's salary), but it cannot recover the costs of the initial investment. The majority of these costs must be covered by grants, though users contribute 10% of the initial investment up front.

Approximately 90% of the customers pay on time, though some are in arrears for several months. The problem here is that the monthly payments are not timed with the seasonal income of the Mauritanians.

Financing

The Mauritanian government and private donors funded 90% of the original investment. The beneficiaries contributed the remaining 10%. Donors also paid for the technical assistance. There are no bank loans in the financing. A similar financial arrangement is envisaged for the expansion of the project.

Ownership and Management

The systems are run by cooperatives that have been given the system. The cooperatives are required to raise a minimum amount of money to cover the running costs of the system. The electrification committee of the cooperative meets approximately two times per month to discuss the following issues:

- Handling the problem of non-payments
- Requests of new clients
- Tariff levels
- Operations and management, information of technical manager
- Relations between the manager and the clients

The committee has members representing the clients' interests, and at the same time maximizes the efficiency of the system management. In the Tiguent village, the clients enter into a contract with the cooperative, a feature considered highly professional. More generally, the program learned that professional management and O&M (through skilled and responsible technicians and caretaker contracts with clients) are prerequisites for system sustainability. To reduce the fee collection problems, the program is looking at pre-payment systems, but has not yet made a definitive choice.

Operation and Maintenance

An important feature of the project approach has been the training of operators and village cooperatives in all aspects of the system. The day-to-day operation is a part time job left entirely to the technical manager. The revenues from the system pay for his salary as well as the part of the maintenance work that is contracted out to the local installers. Three levels of maintenance can be distinguished:

- Village maintenance: Most caretakers in the villages manage to repair minor problems in household connections and appliances. In some cases, however, it is difficult for village managers to replace their stock because of travel costs and lack of funds to pay the supplier

- Preventative maintenance: There are two elements to preventative maintenance: the wear on the rotor blades (which can generate vibrations and machine breakdown) and the painting of the tower and changing of the corroded parts. These tasks are normally done once a year by the installer/supplier

- Curative maintenance: The contract with the installer/supplier stipulates that they must repair the system within 48 hours after having received notice of a fault. The present difficulty with this is that two companies are involved. To whom the responsibility for repairs falls is often unclear; and their tasks need to be defined more precisely. In future, the project aims to have only one service contract. The Dutch hardware supplier is also engaged by contract to supply spare parts within a certain period. The contract also contains a penalty of US$23/day.for each day of non compliance

An evaluation of the project concluded that those villages that succeeded in recruiting good managers who were capable of assuring a rigorous implementation of management and operation procedures had the best functioning systems. Although early servicing contracts have been found to have limitations, it is interesting to note the professional approach taken to this issue in order to heighten system sustainability.

Financial Aspects

The cost of the wind diesel power system in Tiguent is estimated to be approximately US$15,700 for the wind generator and 1000Ah battery bank. The diesel set of 7 kW is about US$8000 and the mini-grid in the village US$30,000. These are the costs for high quality equipment with long lifetimes (batteries 8 years, Japanese diesel). The investment costs of the wind, diesel, and grid systems are quite high (they total US$5,800/kW installed). With a total investment cost of about US$53,719, simple depreciation (no interest) over 10 years would mean US$5,372 per annum. If we assume that 100 households pay for electricity, this would mean a monthly payment of US$4.48. With 167 customers this comes down to US$2.68.

The financial aspects also concern revenues and costs. The revenues of the system are generated by the points system and it is estimated that US$7,200 is collected per year, excluding the costs paid by businesses and for the street lighting. This shows that revenues could likely cover the operating costs as well as part of the investment.

Policy and Legal Context

Presently, Mauritania has 150,000 unelectrified households in 3,000 villages. The Mauritanian Government is interested to find institutional solutions for rural electrification. Its Ministry of Energy has discussed the establishment of a Decentralized Electrification Unit (CELED) and of an Investment Fund for Electrification (FERD). The second phase of the program aims to install systems for 8,000 households. The Ministry would like to continue to expand the program with the villagers paying for 10% of the costs of the original investment as well as covering all running and maintenance costs.

Lessons Learned

The Tiguent experience has several important lessons for other village power projects:

- Professional management (e.g. contracts with customers, proper administration) and competent operation and maintenance (e.g. technical operator and service contracts) are key to sustainable systems. They are an essential element for any business operation and a requirement for any bank loan. The village must be well organized to take the responsibility of the ownership of the system; if not payment problems might arise
- When energy is sold as a service (by the light points and outlet), there is a better chance of raising tariffs to a sufficient level for economic viability, without leading to political conflicts
- People seem to be prepared to pay a relatively high price for electricity services, and they seem to be able to afford it. Most likely this is because the electricity service is still cheaper or equivalent to their previous expenditures, while offering a better service. Electric light is cleaner, brighter, and more dependable than kerosene lamps and batteries for flashlights. Poor remote areas can indeed be a market, if the systems are designed properly (matching the low load) and investment hurdles are overcome. Unfortunately, banks have not shown much willingness to make loans to the villagers for such projects, and possibly not even to the local system suppliers. Dedicated funds may be necessary
- If government uses projects like the AEP to create the correct conditions, a strong stimulus can be provided for entrepreneurial operation, e.g. open tariffs, no utility monopoly, no taxation, and no official standards enforced

Sustainability and Replicability

The initial investment costs of this system are very high, which inhibits replication on a commercial basis. For this to happen costs still must be reduced. Otherwise, only national and international grant support to the investment can make them viable.

Once the hurdle of reducing up front costs is surmounted, other factors that may impact replicability are:

- The village must be well organized to take the responsibility of the ownership of the system; if not payment problems might arise
- Such a system should be legally classified as an energy service rather than grid electricity to avoid problems with the government utilities monopoly, government legislation on rural electrification tariffs, unnecessarily high standards for equipment and service, other taxation, etc
- Household energy requirements should be kept low using high efficiency lighting and audiovisual appliances
- Productive use loads must be factored into system design
- Thorough assessment of demand and affordability
- Good wind resources
- A skillful technical manager: his or her skills, motivation and personality are essential for sustainable operation of the system
- A good supply network and professional service contracts with the installers/suppliers are a must

CHAPTER 8: LESSONS LEARNED

8.1 For Rural Electrification Policy-makers and Planners

- Most of China's remaining un-electrified populations live far from existing power grids.
- Grid extension for electrification of small and remote communities is neither technically not economically viable. In these cases stand-alone systems will often be found to offer a more appropriate solution.
- The most cost-effective power solution for these communities must be selected on a case-by-case basis, and evaluation of system costs should be done on a lifetime (and not only investment) basis.
- Costs of power to customers of remote stand-alone systems cannot be directly compared with grid-connected electricity prices.
- Renewable energy solutions (hydro, wind and solar) have been tried and tested and are technically proven in China. Beyond the social and economic benefits of all power supply systems, renewable energy based systems have additional environmental benefits. Furthermore, there is a strong correlation between the distribution of China's un-electrified populations and areas of high renewable resource availability.
- Perceptions of renewale energy are often inaccurate or over simplified. Common misconceptions are that since renewable resources are free, so should be the electricity that they generate, or that such systems require no maintenance.
- Community electrification should be carried-out in co-ordination with the provision of other services, such as: public health, agricultural support, safe water supply, economic development and communications. These links are in need of development.
- A conventional, utility managed supply model is unsuitable for small, dispersed systems. At the same time, rural entrepreneurs and the private sector can play an effective role in service provision. At the very least, commercialized arrangements have proven to be much more effective than the public sector for the management and operation of community power systems. In addition, rural businessmen who own power generation equipment for their own use often generate extra income by supplying electricity to members of the communities in which they live. More widespread and more formalized participation of the private sector in rural electrification could be achieved through mechanisms such as Community Power Service Companies and Rural Concessions.
- New power sector regulations should reflect full consideration of the significant potential role of the private sector in rural electrification. Regulations are required to reassure the private sector of the extent of its legal legitimacy to operate in this field, and to ensure the safety and protect the rights of customers.
- Community energy supply must be supported by an economically viable service infrastructure. Existing local service infrastructures may be adapted to provide routine maintenance and timely repair services.
- A policy framework to integrate all village power alternatives into rural electrification planning must be supported with political will and commitment. Significant public resources will continue to be required for investments in the electrification of remote communities, especially for the initial costs. New, dedicated funds would be the most effective way to ensure this support achieves its objective.

8.2 For National and International Funding Agencies

- Government funded projects (national and international) often concentrate on social welfare objectives, but without commercialized O&M, sooner or later the system will fail. The most critical question is, in the long term, how will the system be maintained and operated on a sustainable basis? Amongst other things, this requires sufficient system income to cover O&M costs (and preferably major component replacements), a reliable service network, and the availability of spare parts
- Village selection and project development should be co-ordinated with ongoing national and provincial rural electrification efforts.
- The benefits of selecting the most advanced international equipment must be carefully weighed up against those of less costly and more easily repaired/replaced domestic components.
- Pilot projects must be replicable, of a manageable scale for those implementing them and use proven technologies. Since the central barrier to replication lies

in achieving economically sustainable system operation, pilot projects of a purely technical nature do not address the fundamental challenges for extending power to remote communities. Pilot projects must be monitored and evaluated prior to implementation of full-scale projects.

8.3 For Project Developers

- Multiple stakeholder participation in the project development process is the most effective means of ensuring the establishment of an appropriate and sustainable system. The system solution should be the least cost solution to meet the current and anticipated needs of the community.
- Development of packaged, multiple village projects results in cost savings in all parts of the project cycle and in opportunities for shared system management arrangements. Benefits of custom design should be evaluated against lower costs, proven reliability and flexibility of standardized system designs.
- Lack of procurement standards leads to confusion on the part of suppliers and often results in higher costs; system procurement on a "turn-key" basis can give the opportunity for the supply of a system warranty.

8.4 For System Designers

- For remote locations, reliability is the single most important system design criterion. Technical designs should be simple, robust, and easy to maintain.
- Product quality is a considerable factor for system technical and economic performance; Poor quality results in a short lifetime or high lifetime operating costs. Although higher efficiency results in lower costs, simplicity in system maintenance should also be taken into account. Manufacturers of quality equipment can provide warranties and these should be sought wherever possible. Electronic components have been a weak point of community systems in the past. These should be of high reliability and well protected from improper operation and outside damage (such as corrosion and lightning).
- Systems must be designed to produce appropriate and affordable power. Key points are the level of service provision (hours per day) and the inclusion of commercial loads. System designers must consult extensively with the communities themselves to determine the appropriate level of service of the system to be installed.
- System design must take into account future load growth. Common practice is to design systems for the load anticipated 5 years after installation. Adopting flexible system designs that can be expanded as load demand increases can mitigate risks associated with unpredictable load growth rates.
- Thorough evaluation of local renewable resources is essential in achieving an optimal system design. Wind resources are extremely dependent on micro-siting and on-site resource measurement for several months will normally be a minimum requirement.
- Lack of system installation standards leads to system failure.
- Adequate technical and user manuals must accompany systems and equipment. These should include complete O&M procedures. Training must be thorough and ongoing.

8.5 For System Owners and Managers

- In the past, it has been common practice for local governments to assign staff to manage and operate systems. Results have been poor, thus restricting the replication of pilot projects. Commercialized system management arrangements, such as contracting and leasing, have been tried and found to offer more effective approaches. More market-driven O&M models for sustainable system operation need to be explored and experimented.
- Management arrangements must clearly assign responsibilities and ensure that the system operator makes sufficient provision for long-term maintenance costs.
- Tariff regimes need be carefully designed and practised. At a minimum, tariffs should cover O&M costs. Using fee-for-service tariffs avoids direct comparison of kWh costs and can result in better system economics. System revenue and expenditure accounts should be carefully managed to ensure that future system maintenance needs can be paid.

8.6 For System Operators

- Operators must attend factory and field training provided by the system designer and/or manufacturer.
- Operators must follow O&M procedures as described in the manuals provided by the syste installer and component manufacturers. The battery bank is the core element of a renewable energy power system and particular care is needed to ensure it is properly managed and maintained. Lack of even routine maintenance is common and leads to system failure and shortening of component lifetimes.
- End-users are often unaware of the proper operation, care, or limitations of electrical equipment. It is the responsibility of system operators to educate them.

ANNEX I : Renewable Energy Community Power Systems Installed in China[1]

Rated Capacity of REVPSs Installed in China

No.	Location	Wind kW	Solar kW	Diesel kW	Total kW
1	Wumang Island, Changhai, LN	130		174	130
2	Jimin Island, Weihai, SD	30		70	30
3	Xiao Qingdao, Weihai, SD	40		30	40
4	Kongdong Island, SD	60		60	60
5	Dachen, ZJ	165	40	780	205
6	Beilu, ZJ	132		275	132
7	Xiaosanmen, GD	10		12	10
8	Baiyinaobao, Wulancabu, IM	10		12	10
9	Caganaobao, Wulancabu, IM	10		12	10
10	Jiegelangtu, IM	10		8	10
11	Yingen, IM	10		12	10
12	Wentugaole, IM	10		8	10
13	Baiyingebi, IM	10	12	12	22
14	Weijing, Wulancabu, IM	20		12	20
15	Naomugeng, IM	10	24	24	34
16	Saihantala, IM	33		30	33
17	Hesiewula, IM	66		?	66
18	Gasongshan, IM		2.5	0	2.5
19	Hanwula, IM		12	12	12
20	Menggen, IM		10	12	10
21	Songbuer, IM		7	8	7

[1] This is an incomplete list. The data of some installed REVPSs are not available by the time of compiling this book.

Rated Capacity of REVPSs Installed in China

No.	Location	Wind kW	Solar kW	Diesel kW	Total kW
22	Tamusu, IM		6	8	6
23	Shugui, IM		4	12	4
24	Gurinai, IM		5	8	5
25	Huhenor, IM		5	8	5
26	Wuliji, Alashanzuo, IM	10	4	12	26
27	Yantaishancun, Zhalute, IM	10	2	0	12
28	Cuoqin, Ali, TB		40	75	40
29	Geji, Ali, TB		50	75	50
30	Gaize, Ali, TB		80	195	80
31	Jielong, Yushu, QH	1.5	3	0	4.5
32	Hongshuicun, Xiangjia, Dulan, Haixi, QH	1.2	0.4	0	1.6
33	Suonanda, Kekexili, TB	1.6	0.6	0	2.2
34	Dahongliuxiaxiang, Balikun, Hami, XJ	10		0	10
35	Damazhacun, Takelamagan, Hetian, XJ		10	0	10
36	Yingpancun, Barkol, Hami, XJ	10		0	10
37	Garila, Gonghe, QH		4	0	4
38	Haxiu, Yushu, QH		3	0	3
39	Shuanghu, Naqu, TB		25	100	25
40	Anduo, Naqu, TB		25	160	25
41	Bange, Naqu, TB		70	120	70
42	Nima, Naqu, TB		55	120	55
43	Halabulakexing, Kirghiz, XJ	10		0	10
44	Dahongliuxiacun, Barkol, Hami, XJ	10		0	10
45	Huaerci, Barkol, Hami, XJ	10		0	10
46	Hongyancun, Dashitouxiang, Mulei, XJ	10		0	10

Annex II: Practical Guidelines for Village Power Project Implementation

Step-by-Step from Resource Evaluation to Sustainable System Operation

This Annex aims to provide project developers and system designers with some concrete guidelines for the successful implementation of village power projects. However, it should not be forgotten that technical aspects of power system design and operation are only one facet of the project development process. Other critical aspects, such as financing and management, have been covered elsewhere in the Guidebook.

The first section of the Annex describes how to analyze the load requirements of a community and how to estimate future load growth in order to appropriately select the system capacity. This process is required for all types of power systems. Thereafter, the Annex is divided into five separate sections, each giving guidelines and tips on how to develop alternative village power systems (mini-hydro, diesel, wind power, PV and hybrid systems). The guidelines include resource assessment, system design, component selection, installation, commissioning, training and O&M. At the end of the Annex a separate section introduces some tips on the balance of system components which are part of most renewable energy systems.

1 Load Analysis and Estimating Load Growth

A detailed load analysis is a fundamental information input for power system design. The information should cover: load type, efficiency, quantity and daily distribution.

1.1 Load Type

The first question is: what kind of load(s) will be served? These may include domestic loads (such as lighting, TVs, refrigerators, irons etc.), community loads (schools and government lighting and appliances, water pumping) and commercial loads (electric power tools etc.). Some loads can be powered only by electricity, like radio broadcasting, televisions, electrical motors or refrigerators. Other loads-such as cooking, space heating and drying-can also be powered by solar energy, animal dung, wood, or biogas. Sometimes large individual loads are best served by a dedicated power source and therefore may not need to be allowed for in the community system design. Equally, when considering water pumping, grain processing or lifting, mechanical power, waterpower or manpower should be considered prior to electricity. Determination of which loads are to be included in the system design must be carried-out through close consultations with the beneficiary community.

1.2 Load Calculation

The second question is: how much power is required? The following data need to be identified:

1) Efficiency and specifications
2) Quantity of the load
3) Daily working hours
4) Concurrence rate (the proportion of the time all the loads are used together and the total working time)
5) Daily power consumption kWh

Load calculation (calculate for each type of load and then sum together)

$P = \sum Pi \times Ni$

where

P: Peak Load (Usually to be used for determine the inverter capacity)

Pi = rated power for one load type

Ni = Quantity of the i-type load (the number of one appliance with identical rated power capacity)

$i = 1 \cdots n$

$Pa = \sum Pi \times Ni \times Ci$

where

Pa: Adjusted Peak Load (based on load concurrency)

Pi = rated power for one load type

Ni = Quantity of the i-type load (the number of one appliance with identical rated power capacity)

$i = 1 \cdots n$

Ci = concurrence rate

$L = \sum Pi \times Ni \times Hi$

where

L: Maximum daily power consumption

Pi = rated power for one load type

Ni = Quantity of the i-type load (the number of one appliance with identical rated power capacity)

Hi: Daily working hours of the i-type load

i = 1…n

The load and power consumption of a typical village of 20 households is shown in the following Table A2.1.

Load	Quantity	Power (W)	Daily Hours	Concurrency	Adjusted Peak Load (W)	Daily Consumption(kWh)
Energy Saving Lights	60	11	5	0.8	528	3.30
TVs	20	70	5	0.8	1,120	7.00
Recorders/VCDs	20	40	3	0.6	480	2.40
Washing Machines	3	150	1	0.5	225	0.45
Refrigerators	5	120	8	0.7	420	4.80
Water Pumps	1	1000	2	1	1,000	2.00
Others	1	300	2	1	300	0.60
Total					4,073	20.55

Table A2.2 Rated Power and Average Daily Working Hours for Typical Loads:

Load	Rated Power (W)	Average Daily Working Hours (h)	Load	Rated Power (W)	Average Daily Working Hours (h)
Energy Saving Lights	9 - 30	5	Dust Cleaner	750	1
21" Color TV	70	5	2P Air Conditioner	2000	5 (Jun. - Sep.)
B/W TV	20	5	Electric Fan	50	2 (Jun. - Sep.)
Cassette Recorder	40	2	Moveable Electric Heater	1000	3
Washing Machine	150	2	Bubble Jet Printer	20	1
120L Refrigerator	120	10	Desk Computer	400	5
1/5 HP Water Pump	165	0.5	Monitor	200	5
Radio Set	10	1	Fax Machine	100	30 min
VCD/DVD	40	3	Microwave Stove	1000	10 min

1.3 Load Growth Estimation

It is very common that the power system load will grow sharply during the first year after installation. Further load growth will continue as households purchase new electrical appliances and more loads are connected to the system. The system must be designed to accommodate such load growth, and usually systems are designed according to the anticipated load of the 5th year after installation.

One way to reduce the risks associated with an uncertain load growth rate is to design a system that can be easily expanded in future. PV modules and wind turbines can be added to an existing power system relatively easily, electronic devices usually cannot. However, there are different ways to expand the system capacity. The first is to oversize the capacity of electronic devices and transmission lines at the design stage, and then to add further PV modules or wind turbines when needed. Of course, over-sizing of the system will compromise the economics of the system in the first years. The second is by inter-connection of new capacity. For this the inverters used should have a grid-tied feature. As an alternative approach, a village can be divided into several areas, with new areas served by independently functioning systems.

2 Design and Implementation of Mini-hydro Systems

Hydro output depends on the pressure (head) and amount of water passing through the turbine (flow).

2.1 Head

Head is the vertical height, usually measured in meters, from intake water level down to the turbine. Gross head can be measured fairly accurately. For sites in forest areas with rough

Table A2.3 Actual Load Growth at Gaize PV Power Plant, Tibet.

Year	1993	1994	1995	1996	1997	1998	1999	2000	2001
Load kW	15	23	32	38	42	60	70	75	80
Daily Consumption kWh	60	92	140	180	220	300	350	375	400
Load Growth Rate (%)		53	39	19	11	43	17	7	6.7
Consumption Growth Rate (%)		53	52	29	22	36	17	7	6.7

Note:The original capacity of the power plant in 1993 was 20 kWp and this was expanded to 80 kWp in 1998.

terrain, where the water head is more than 40 meters and not easily measurable, the head can be measured by a barometric altimeter. However, several sets of data should be taken to allow for inaccuracies due to air pressure changes. Where there is an existing pipe already in place, the head can be measured by a pressure gauge. The net head is determined based on the gross head and on the friction losses as estimated according to the selected pipe diameter and type.

2.2 Flow

Flow is the amount of water, usually measured in liters per second, flowing past the point where the turbine will be sited. If water flow is less during the dry season, then the power output will be reduced. A micro-hydro scheme must therefore take into account normal and minimum flows available to the turbine. Water flow can be measured in several ways, from the simple method of measuring the time taken to fill a container of known volume, to sophisticated electronic equipment.

2.3 System Sizing and Budget

Figure A2.5 may be used as a guide to judge how much power can be expected from a generator under specific condition. Clearly less water is required for the same power if the net head is higher. The curves may be used for selecting sites, but are most suitable for choosing a turbine after the best site has been selected. If the water resources are known, an appropriate hydro turbine can be selected from above graph. For example: for a water flow of 120 liters per second and a water head of 40 meters, a 32kW hydro power station is most suitable.

Besides the water resources, the pipeline, water intake design, pipe materials, and other aspects must also be considered during micro-hydro system design.

Pipe Size and Material

Pipe design is critical. Many systems do not perform as expected because of high head losses in the piping. The pipe diameter should be as large as possible to keep frictional losses to a minimum, though cost will be a limiting factor. In terms of pipe material, the choice is among black polyethylene, PVC, steel and concrete. For small units, polyethylene and PVC are popular, with PVC generally cheaper for pipes with diameter above 50mm. In cases with a gross head of less than 40 meters, 90 or 100mm piping can be used. PVC must be either buried or painted (due to degradation from UV radiation). Joints in pipes should be kept to a minimum and be as smooth as possible.

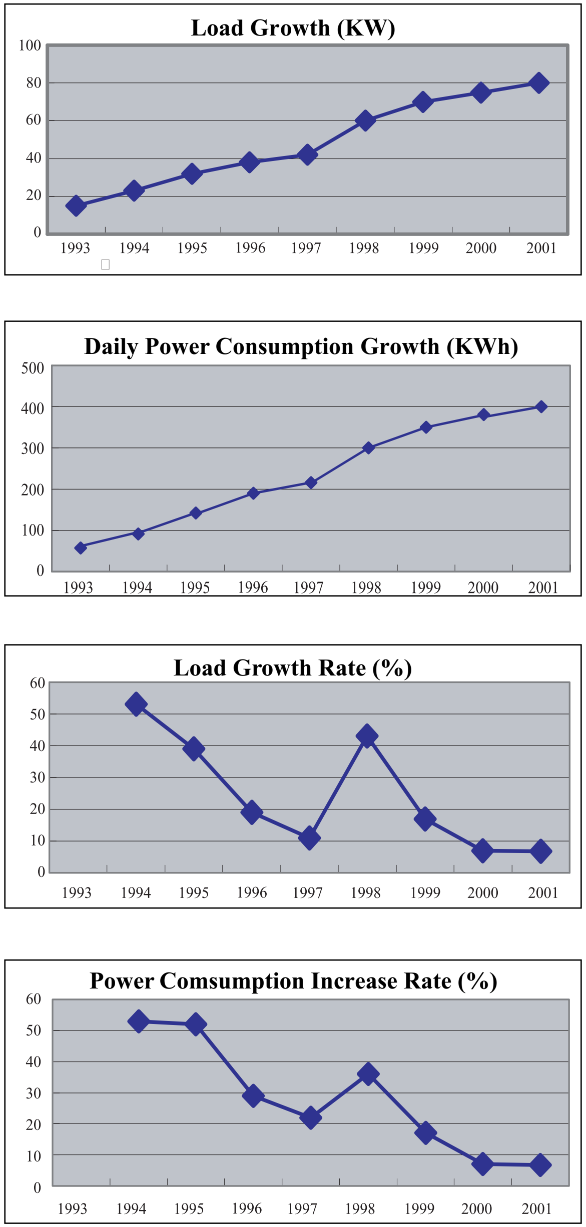
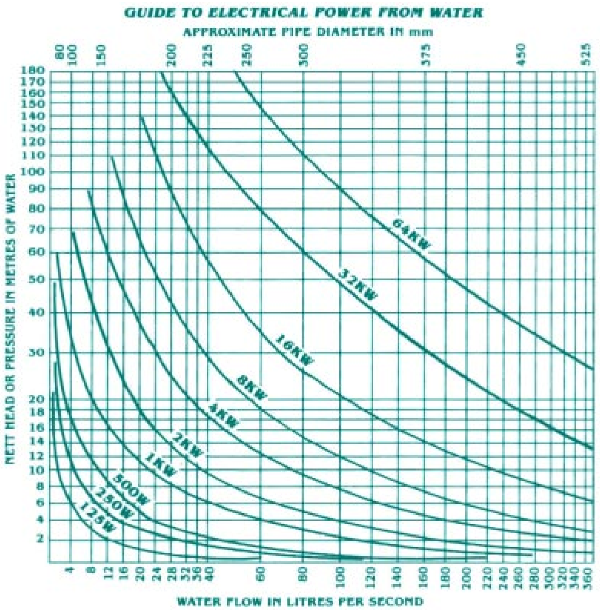


Figure A2.1~A2.4 Load growth at Gaize

Figure A2.5 Hydropower System Sizing Guide



Intake Design

The intake strainers must be capable of filtering debris from the water entering the hydro system, especially during river spates following heavy rain. The entrance must be large enough so as not to be choked easily and must also include a vent system to prevent the pipeline from collapsing in the case of a blocked intake.

Isolating and Washout Valves

A valve should be fitted at the turbine inlet to isolate the water intake from the turbine. It should not be opened or closed quickly, avoiding the possibility of bursting the pipe, and should not block the flow or introduce turbulence into the flow. The designed valve should allow the turbine to be fixed or removed without the need to drain the pipeline, thus making maintenance easier.

2.4 Component Selection

There are two types of hydro turbines: impulse turbines and reaction turbines. The best type of hydro turbine for a given application is determined by net head, the flow and required output.

Impulse Turbine:

One or more jets of water impinge on the turbine wheel, making it rotate in the air, with used water falling freely to the tailrace. The turbine case must not be flooded with water and therefore must be mounted above flood level. Flow can be controlled by fixed nozzles, spear valves and/or jet deflectors. The Turgo impulse turbine is more popular than the Pelton, due to its smaller size and ability to run at a higher speed for the same jet diameter.

Reaction Turbine:

The runners in a reaction turbine rotate in the sealed turbine case that is fully immersed in water. Water is discharged by a draft tube to the tail water, creating a negative pressure at the discharge side of the runner. Thus the head below the turbine will not be lost when the turbine is mounted above the flood water level. Usually the pressure from the water below the flood level is more than that above the flood level. Flow control is normally achieved by inlet guide vanes and/or variable pitch blades. A reaction turbine is generally more suitable than an equivalent impulse turbine for conditions with low head and high flows.

Generators

AC generators generally supply 220V/single phase electricity directly to the load. DC generators supply output of 12V, 24V or 48V.

Where power generation is about 500 watts or less, battery-charging units are generally found. The advantage of mini-hydro is that it may be used continuously for charging due to the constant flow of water. This means, for example, even a small set generating only 100 watts can produce 2.4 kWh per day. The unit cost is generally far less than that of the equivalent stand-alone solar or wind systems.

Governors and Control Equipment

An AC unit requires a governor to control the generator speed and output frequency (nominally 50Hz), especially when the load is changing. The governor can be either mechanical or electrical. Electric governors can divert excess electricity for use to heat air or water. Governors can also govern turbine power output, by controlling the water flow and thereby saving water. (A DC unit does not require a governor.)

2.5 Location and Installation

Location

Selection of a suitable site will usually be a trade-off between the highest head, the shortest pipe route, and the least friction for the required output. To keep the pipe cost and frictional losses to a minimum, a site with the largest fall and the shortest distance should be chosen. However, the topography should also be consistent with the required load. Impulse turbines must be located above flood level.

Installation Checklist

- Civil engineering
- Power generating equipment
- Distribution grid
- Inlet water pressure measurement
- Start operation
- Metering
- Measurement of the output power at a certain water pressure
- Protection functions.

2.6 Operation and Maintenance

Operation:

- Rotating speed of the water turbine should be increased gradually and not rise or drop sharply
- Add lubricating oil regularly
- Monitor and record the equipment temperature and noise during operation and inspect closely for problems if there is any abnormality
- Stopping the system should also be gradual and follow the operating rules
- If the system is not operated during winter, drain the water to avoid freezing

Maintenance

Maintenance of mini-hydro installations:

- Regular inspection and maintenance of the civil works to ensure their good and safe condition and repairs as required
- Regular inspection of the turbine (main bearings, regulators, coupling or transmission, valves, inlet trash cleaning, flushing, penstock, etc.); lubrication of all moving parts according to manufacturer's specifications
- Supervise the catchment area and signal changes that might affect the flow rates
- O&M of the mini grid (pole cables, insulators, etc.)
- Assisting and advising customers about use and connection of appliances

Mini-hydro systems require annual maintenance by skilled personnel. For daily operation, trained people are needed (but not necessarily electricians). Larger sized systems usually need skilled operators as a standard practice.

3 Stand-alone Combustion Power Systems (CPS) (diesel and petroleum fueled)

3.1 CPS Design

Diesel and petrol are reasonably widely available in China but price, transportation and reliability of fuel supply must be taken into account before deciding to install such a system.

Genset Capacity[1]

As mentioned in Chapter 2, in many existing cases, the capacity of a diesel genset has been based on the system peak load power, resulting in a very low operating efficiency under normal load conditions. To optimize the performance of

[1] At high altitude sites, the rated power of diesel generator will be reduced (10% lower per 1000m altitude increased).

Mini-Hydro generator

Hydro generator

a CPS, a good practice is for the CPS to consist of several differently sized gensets instead of a single large genset, even if the single large genset is lower cost then multiple gensets. The number of diesel gensets and capacity of each diesel genset will be determined by the load and load profile. Usually the ratio of capacities between two adjacent gensets is about 0.8. The number of gensets could be 2-4, or even up to 6. The capacity of the smallest diesel genset is close to the average lowest point of the load profile, and the total capacity of the multiple diesel gensets should be larger than the peak load. Adopting such a "multiple unit" approach is especially important for large diesel plants. For example, take a village where the lowest load is about 30-50kW, and the peak load is 300kW. Based on this profile, a set of multiple diesel gensets combining a 75kW unit, with a 125kWunit and a 200kW unit should be adopted. Marking the three diesel gensets in order of increasing capacity as #1, #2, and #3, some working combinations of the units are illustrated in Table A2.4.

When the size and combination patterns of a multiple diesel genset have been determined, we need to consider the conditions for switching between patterns. If loads are quite predictable, switching between diesels can also be predetermined with a high degree of accuracy. Nevertheless, it is common to have enough capacity overhead in operating diesel(s) to cover any sudden load increase. It is also quite common in small communities for the owners/operators of any large loads to notify the diesel plant operators prior to starting those loads. Combustion engines, and particularly diesel engines, are designed for continuous operation, and if switched on and off at short intervals decreases in fuel efficiency and engine lifetime will result. Once started, a diesel genset should remain operational for a minimum period of time as specified by the manufacturer. The text box provides some general rules for diesel switching.

Table A 2.4 Possible Working Modes of a Multiple Diesel Unit System

Combination	Max. output capacity	Range to match load
3＋2＋1	400KW	160～400KW
3＋2	325KW	130～325KW
3＋1	275KW	110～275KW
3	200KW	80～200KW
2	125KW	50～120KW
1	75KW	30～75KW

3.2 Component Selection

Features of Diesel and Petrol Generator Systems

Tips for Diesel System Operation Strategy:

- Observe the long-term average load instead of short changes,
- Based on the tolerance of the system for voltage and frequency changes, determine the minimum diesel running time (below which it is unnecessary to start-up an additional genset).
- Consider the possible maximum load that is likely to be added to the grid.

The basic control functions of a CPS include the followings:

- Start/stop diesel genset(s) based on significant changes of load,
- Synchronizing of multiple diesels,
- Dispatch the working capacity and idle capacity among diesel gensets,
- System failure protection,
- Manage diesel genset status (working, spare, emergent) so that diesel gensets will share an even working time based on the total working time.

- Rotating Speed Diesel Generator: 1000 r/min (Petrol Generator: 3000 r/min)
- Capacity of fuel tank: 1-8 hours
- Engine Speed Governor: to maintain constant voltage and frequency for different loads
- Exhaust system: include muffler
- Engine start-up: manual hand crank device and/or electric start-up (need battery and starter motor)
- Power output: generally 380/240V/three phases or 220V/single phase
- Absorbing chassis and base normally connected to a solid foundation
- Cooling system: by air (simple), by water (more complex)
- Control panel: ammeters, voltmeter, switches, lights and alarms to indicate the status of the system (located near the machine)
- Fuel pressure and temp gauges
- Auto-stop protections: Over-speed, under-speed, over temperature, low oil pressure, high or low output voltage

Petrol versus Diesel Generators

- Are lighter and more readily portable
- Are cheaper for small, short-term loads
- Require more maintenance as they operate at a higher speed (3000 rpm)
- Consume more fuel for the same output, and fuel costs are generally higher
- Are more noisy
- Have shorter running time before refueling (due to smaller tanks)
- Have a life-span of only 1000 hours on average while that of a diesel engine is commonly 5 - 10,000 hours, depending on the size

For a reliable stationary generator that is used frequently, select a diesel driven set. If the generator is to be used only occasionally, a petrol generator may be more effective

There are two types of diesel: light diesel and heavy diesel. For power generation, light diesel is normally used

Diesel is graded into several types: 10#, 0#, -20#, and -35#. The sign indicates the freezing temperature and the fuel selection will depend on the climate of the location.

Selection of Lubricating Oil and Cooling Water

a) Lubricating Oil

Also select according to environmental temperature:

- > 25℃ , use HC — 14# oil;
- 0-25℃ , use HC — 11# oil;
- < 0℃ , use HC — 8# oil.

b) Cooling Water

The quality of cooling water can greatly affect the operation and life of diesel generators. Generally, soft water should be used, such as boiled water, rainwater, snow water, etc. Hard water, like river water, under-ground water, and water containing minerals and salts may cause deposits to effect the cooling system.

3.3 Installation

Diesel generator must be mounted firmly onto the ground. In case diesel genset is used to charge a battery, the distance between diesel generating room and battery room should not be great.

The distance from diesel room to residential households should not be less than 100 meters to avoid disturbing people. Fuel storage should be carefully sited with suitable precautions and restricted access to minimize fire risks.

3.4 Commissioning Checks for Diesel Generators

- Housing and foundations for diesel generator
- Profile checking
- Wiring
- Oil tank and water tank
- Starter voltage and electrolyte
- Switching on and off
- Metering
- Full load operation
- Insolation and leakage of electricity

3.5 O&M of Diesel Generator

O&M tasks for a diesel system include:

- Secure stock of diesel fuel
- Start, run and stop the system according to operating procedures
- Check the lubricating oil
- Keep-up fittings and replacements (e.g. air filters)
- Additional annual checks and replacements according to manuals
- Assist and advise customers about installations and connections, etc

Proper use is critical for prolonging life and assuring correct operation. Note:

- Pre-heating diesel up to 60 deg C and making sure of normal working of other parts before output
- Note oil pressure, charging ampere and water temperature of the generator
- Avoid operation at low or high temperature and avoid over load operation
- Avoid low-level load operation (< 0.35). Otherwise the lifetime of the diesel generator will be shortened and fuel consumption increased

Diesel genset

Petrol generator

Diesel systems require regular yearly maintenance by skilled personnel. For daily maintenance a regular operator is enough, but for more complicated machinery maintenance an experienced operator is needed. When different kinds of diesel generators are used, switching must strictly follow the standard operating procedures. Even though the load may vary frequently, the operating patterns should not be constantly switched, because frequent starting and stopping of diesel generators will cause high fuel consumption and shorten their lifetime.

4 Wind/battery Systems

4.1 Wind Resource Evaluation

The purpose of the resource monitoring program is to provide specific information about the wind resource in order to obtain representative data for estimating the performance and/or the economic viability of selected wind turbines and to compare potential wind turbine installation sites.

- The available wind resource determines not only the power output but also the efficiency or capacity factor of a wind generating system
- The first indicator of the resource is the average wind speed. The output power of wind turbine is in direct proportion to the cube of the wind speed, known as the “Cubic Law”. This means that when the wind speed doubles, the output is increased by a factor of 8. Thus the difference in output power between a wind turbine at wind speeds of 3.58m/s and of 4.47m/s will be 100%

An indication of the local wind resource can be estimated from historical data provided by the closest weather station. However, on-site measurement will always be required to confirm the relevance of this data at the specific project location.

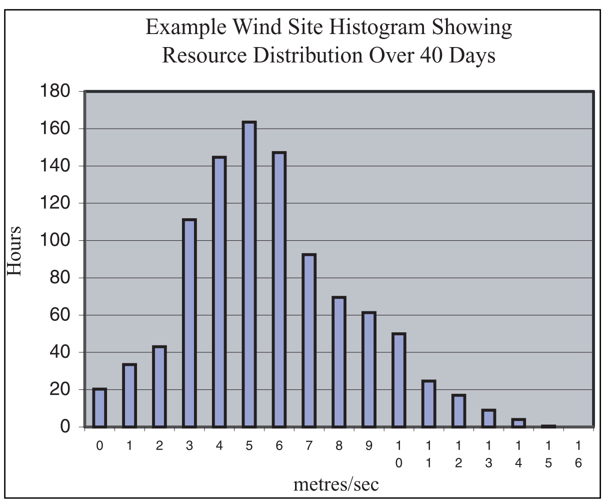
A standard Chinese classification of wind resources according to average wind speed is given in the table below.

The average wind speed is only of limited value in determining the amount of wind power available. Wind speeds in the range of 2. 5 m/s do not contain a lot of energy while those of above 5 m/s will contribute much more to power generation. A good way to analyze the effective available wind resource is to plot a wind speed histogram showing the windspeed distribution. Each bar of the histogram shows the number of hours of a given windspeed range of width of 1m/s (see example chart below). The wind energy resource is exploitable when the average wind speed exceeds 4.5m/s. For small wind turbines, if the average wind speed is 3 to 4 m/s for the lowest wind month of the year, then wind power is still an option.

Regional wind resource maps often use wind power density data. This gives a better indication of the wind resource than windspeed because of the cubic dependence on wind speed.

Table A2.5 China Traditional Windspeed Classification

Wind speed m/s	0.0~ 0.2	0.3~ 1.5	1.6~ 3.3	3.4~ 5.4	5.5~ 7.9	8.0~ 10.7	10.8~ 13.8	13.9~ 17.1	17.2~ 20.7	20.8~ 24.4	24.5~ 28.4	28.5~ 32.6	>32.6
Class	0	1	2	3	4	5	6	7	8	9	10	11	12



The following table can help for the conversion of wind density data into the equivalent range of wind speeds or vice-versa.

Table A2.6 Wind Power Density and Wind Speed

Wind Power Density Class	Wind power Density at 10 m height (W/m2)	Wind Speed at 10m height (m/s)
1	0-100	0-4.4
2	100-150	4.4-5.1
3	50-200	5.1-5.6
4	200-250	5.6-6.0
5	250-300	6.0-6.4
6	300-400	6.4-7.0
7	400-1000	7.0-9.4

After system installation, wind resources should be continually measured to monitor wind turbine performance and to establish how a certain period's wind conditions compare to the expected long-term norm. Performance evaluation is important for revenue enhancement and includes monitoring energy production, turbine availability (or lost production), power curve monitoring and turbine status. Confirming the resources experienced on-site can be especially important during the first few years of a project so that, if necessary, long-term strategies can be designed to mitigate any unanticipated shortfalls. On-going resource monitoring will also help to provide a reliable picture of the local wind resource for new systems in the area.

4.2 Wind Power System Design

Wind power system selection and sizing

Wind power system output can be DC or AC. DC output is often used for communication systems and AC output used for village power projects. AC output needs an inverter, which reduces the system efficiency to about 66%. For DC loads, the conversion rate is about 70%.

Wind turbines should be selected according to a good match between their power output characteristics with the given wind resource. A power curve for a wind turbine shows the output (generally after the generator) versus wind speed, while a power coefficient curve shows the efficiency, The power coefficient is a fraction that shows the output power of wind turbines over the power in the wind. The maximum theoretical value for the rotor is 59%, known as Betz's Law. The rated power refers to the rated wind speed and also depends on the size of the turbine generator. The selection of different generator sizes for the same rotor diameter means that some turbines may produce more energy than other turbines at a rather low wind speeds. Hence these parameters can vary widely between wind turbines.

The following table shows the relationship between monthly average wind speed, the rated output power of wind turbine and monthly average load consumption.

Matching load output requirement with installed turbine capacity can be done by using a single larger turbine or multiple smaller turbines. Use of multiple small turbines versus one large turbine may have the following advantages:

- More flexible system sizing
- More effective use of low wind speed (depends on the turbine selected)
- Increase the overall reliability - if one turbine is down due to maintenance/failure, there is still some power available

Figure A2.5 Example Wind Turbine Power Curve

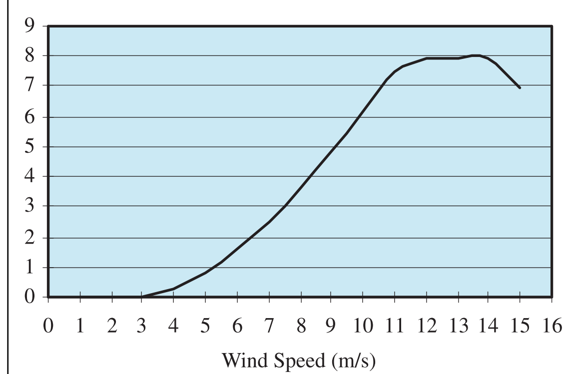


Table A2.7 Power Production of Various Wind Turbines In Different Wind Regimes

Rated Power of Wind Turbine (W)	Monthly Average Wind Speed(m/s)					
	2.68	3.58	4.47	5.36	6.26	7.15
	Average Monthly Power Production (kWh)					
50	1.5	3	5	7	9	10
100	3	5	8	11	13	15
250	6	12	18	24	29	32
500	12	24	35	46	55	62
1000	22	45	65	86	104	120
2000	40	80	120	160	200	235
4000	75	150	230	310	390	460
6000	115	230	350	470	590	710
8000	150	300	450	600	750	900
10000	185	370	550	730	910	1090
12000	215	430	650	870	1090	1310

4.3 Component Selection

Wind Turbine Types

Drag Device: A drag device is where the wind pushes on the blade or rotor and the blade can never move faster than the wind. Drag devices use a lot of material per rotor swept area. There are no commercial drag devices for generating electricity. Examples are the farm windmill and the Savonius (two half cylinders offset from each other)

Lift: A lift device uses an airfoil for the blade and the blade can move faster than the wind. The tip speed ratio is the ratio of the speed of the tip of the blade over the wind speed. Lift devices have tip speed ratios of 4 to 8. Lift devices are 100 times more efficient than drag devices in terms of power output per blade material. Lift devices can further be classified into Horizontal Axis Wind Turbines (HAWT or propeller) and Vertical Axis Wind Turbines (gyromill or cycloturbine, Darrieus).

The advantages of the VAWT are:

1) Generator /gearbox can be ground mounted for easy maintenance;
2) No tail or yaw drive required to orient the blades; and
3) Simple tower design in some cases.

The disadvantages are:

1) Lower efficiency since during each rotation blades must move through a zone where they do not generate torque (torque ripple in the drive train on each cycle);
2) Difficulty in controlling blade speed for over speed;
3) Not self-starting.

Overall efficiencies (includes generator) for the vertical axis wind turbines can reach 40% and HAWTs can reach 50%. The horizontal axis wind turbine is the most common type (at present there are no commercial VAWTs for generating electricity). The HAWTs can be divided into upwind and downwind types. Upwind is where the rotor is on the same side of the tower as the ground wind, and downwind is where the rotor is on the opposite side of the tower. The rotor must be kept perpendicular to the wind, which is accomplished by a tail, yaw drive, or coning on a downwind unit. With coning, blades are not in the plane of rotation, the pressure of the wind on the blades keeps the rotor correctly oriented to the wind. However it is possible for a downwind rotor with coning to start in the upwind condition after a calm period.

The farm windmill and the Savonius turbine have low rotor speeds (rpm) and are not suitable for power generation. However, they have high torque, which makes them suitable for pumping water. Lift devices, with airfoils have a high rotor speed and are more efficient. The rotor of a farm windmill can reach 30% efficiency with a conversion of wind into energy for water pumping of 18%.

Wind Turbine Features

Basic Features

Wind turbines have two primary modes of operation, variable and constant rotation speed. Variable rpm is the aerodynamically more efficient mode (operation at constant power coefficient). In constant rpm operation, the rotor reaches peak efficiency at only one wind speed. Constant rpm uses synchronous and induction generators. Actual energy output from the two modes of operation is about the same, because for a variable frequency turbine, variable voltage operation needs an inverter for AC output. Most small wind turbines used fixed pitch blades and operate at variable rpm.

Small wind turbines do not have a gearbox, and increases in rotor speed are passed on to the generator. Larger turbines are commonly fitted with gearboxes to give greater power output control. There are also large wind turbines, which do not have a gearbox, however the multi-pole generators are quite large.

Control:

All wind turbines must have a way to control power output, especially in high wind speeds and for over speed in case of loss of load. Control methods for limiting output of wind turbines in high winds include furling (yawing the rotor out of the wind with a tail), passive and active pitch control on the blades, fixed pitch (stall control with constant rpm), brakes (mechanical, hydraulic, air, and electric) and even yawing the total rotor out of the wind using a furling tail. Large wind turbines usually use active pitch control, even with induction generators and constant rpm operation (stall control). For small wind turbines, actual application has found that passive pitch control, or adjusting the pitch angle of the blades, is a simple and effective way to provide system control and safety.

The following features can be observed for the small wind turbines that adopt pitch control:

- Lower start up wind speed (called the cut in wind speed) that results in improved energy capture
- Ability to limit the power output to avoid over loading
- Stabilize turbine performance under extreme conditions
- Reduce stress from blades and other machine parts during a machine shut down sequence
- Improved high wind speed survivability

4.4 Site Selection and System Installation

Site Selection

Siting usually goes through two basic steps:

1) Preliminary Layout Identification

The goal of preliminary site identification is to determine the preferred location and layout for the wind turbines, control system and battery housing, and mini-grid.

2) Wind Turbine Siting

The objective of the final stage of the siting process is to position the individual wind turbine, or to layout an array of turbines, on a site in such a manner so as to maximize overall performance. This process of "micro siting" aims to optimize siting by accounting not only for natural variations in the local wind flow but also for wind disturbances (i.e., wakes) induced by the wind turbines themselves.

Wind turbines should not be installed near buildings, trees and other obstacles to avoid turbulence and loss of energy production. General rules are as follows:

(1) Upwind a distance of more than two times the height of the building;

(2) Downwind a minimum distance of ten times the building height; or

(3) At least twice the building height above ground if the turbine is immediately downwind of the building.

The above rule is not foolproof because the size of the wake also depends upon the building's shape and orientation to the wind (Figure A2.7). Downwind from the building, power losses become small at a distance equal to 15 times building height. However, a small wind turbine cannot be located too

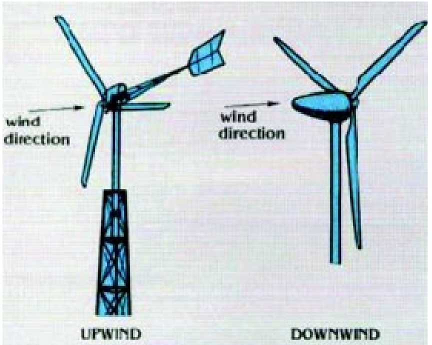


Figure A2.6 Horizontal Axis Wind Turbine Upwind Type and Downwind Type

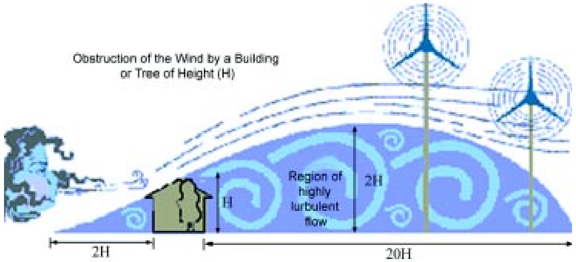


Figure A2.7 Height of small wind turbine close to obstacles. Image from American Wind Energy Association.

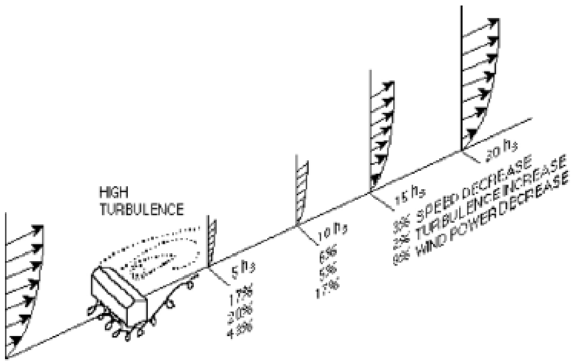


Figure A2.8 Estimate of speed and power decrease and turbulence increase for flow over a building. Estimates shown are for height of the building, hB.

far away from the load, as the cost of wiring will become prohibitive[1].

A further consideration of micro siting is the height at which turbines are to be mounted. In general, wind speed increases with height, called wind shear. Hence there is a trade off between more energy output and the cost of a taller tower. Micro wind turbines should be mounted on towers of at least 3m in height. As turbines increase in size, taller towers should be used. For example, 10 kW wind turbines are normally mounted on 20 to 30 m towers. As a general rule, wind turbines should be 2 m above any buildings or obstacles in the area.

- The site for wind turbine should be as near as possible to the control room to reduce the line losses as much as possible
- The tower of wind turbine has to be grounded to protect it from lightning. Controls, especially electronic, also have to be well grounded

For more tips on siting of small wind turbines, see the American Wind Energy Association website, *http://www.awea.org*.

Installation

Install according to manual and/or guidelines. Note:

1) Build foundations for both wind generator tower and earth anchors
2) For towers installed with a gin pole, the lay down direction of the tower should be in same direction as predominate wind. Do not lay down tower in high winds.
3) The anchor should follow manufacturers guidelines for the tower used.
4) Install the generator, blades and tail in turn.
5) Install the shut-down system and check its operation;
6) Final inspection and raising of the tower: Check all connections and cables, short circuit the output of permanent magnet generators during installation and/or ensure the blades cannot rotate, raise up the tower after final inspection. Be sure electrical connections to rest of system are open.
7) Installation of the electric appliances: must be strictly operated within the power available from the system.

4.5 Commissioning Checks

Wind Turbine and Systems

- Wind turbine foundation
- Check guy cables, anchors and tower base attachment, even a single broken strand on a guy wire is not acceptable
- Painting of the wind turbine and the tower
- Grounding system, check for resistance and be sure procedures are followed
- Guyed wire size and quality
- Check rotation of the turbine and no twisting of wires on generator output in yaw or proper phase operation
- Proper operation of shut-down mechanism
- Wiring to other equipment (controller, damp load, battery, etc.)
- Check the power output as soon as possible (Is it producing expected power for that wind speed range?)
- Operation noise of the wind turbine
- Check measurement meters

[1] Vaughn Nelson, Wind Energy and Wind Turbines, Alternative Energy Institute, West Texas A&M University, May 2002.

The commissioning usually consists of two stages: before operation and after operation. After checking, a complete commissioning report should be well prepared.

4.6 O&M

a) Operation
Wind turbine charge batteries via controller and batteries supply electricity to DC loads or through DC/AC inverter to power AC loads.

In a normal situation, a wind turbine automatically starts and stops and does not require manual operation. Battery charging or discharging is also carried-out automatically. The operator's main task is to monitor the system performance (power generation/battery status) and to carry out maintenance tasks.

When the wind speed reaches the cutout wind speed, the wind turbine should be controlled immediately. Many turbines have an in-built mechanism to disengage in high winds but some may require the operator to stop them manually.

b) Maintenance
Regular maintenance is very important for wind turbines, especially in harsh environments. The following tasks should be carried out regularly:

- Check the ground anchors for loosening
- Watch the wind turbine to see if it is running normally, listen to check that the sound is normal
- Check the yawing system or shut down system to ensure it provides reliable protection when the wind reaches the shut down speed
- Check the current and voltage of the system to make sure electric parameters are acceptable
- The components of the wind turbine and all mechanical parts need to be oiled and/or greased periodically as per instructions in the user manual. This is normally done on semi-annual or annual basis

5 PV Systems

5.1 Resource Assessment

The three components of solar insolation are global, direct, and diffuse insolation. Average monthly and annual global solar radiation data can be obtained from the closest weather stations. The design of PV power systems should be based on medium to long-term statistical average data. For simple design, only monthly and yearly global insolation data is required. For complicated designs, solar radiation is calculated for tracking and fixed angles of the solar array. (Angle of the array could be changed manually by month or season.) For these tracking arrays, direct and global insolation data is required.

5.2. System Design

Design of a solar PV system includes: calculation of load, energy consumption, solar insolation, capacity calculation for both PV and batteries, calculation of tilt angle of solar array, output expectation, expectation of battery state of charge (SOC) and economic analysis. Detailed system design is normally done by computers. Some principles and tips for system design are provided below.

1) Load Calculation
See section 1.2

2) Solar PV Capacity Design
Key parameters to determine are the DC bus line voltage, the number of PV modules connected in series in a single string to give this voltage, and the number of parallel strings required to deliver the total system current.

a) System DC voltage will depend on the load and DC Bus line voltage V_B. (The V_B can be 12V, 24V, 48V, 120V or even 240V). From the DC Bus line voltage, determine the series number of solar modules required Ns:

Using standard solar modules (37W or 50W) capable of charging a 12V battery,

$$Ns = V_B / 12$$

b) From the load calculated in 1) above, determine required current from the PV modules (I_A)

$I_A = L / Tm \times (\eta 1 \times \eta 2 \times \eta 3)$

L= Daily load consumption (Wh)
Tm = Sun peak hours*
η1= Charging efficiency of battery, usually 0.9
η2 = Degradation and dusting coefficient of solar array, usually 0.9-0.95
η3: Combination loss coefficient, usually 0.95-0.98.

*Sun Peak Hour calculation, Tm

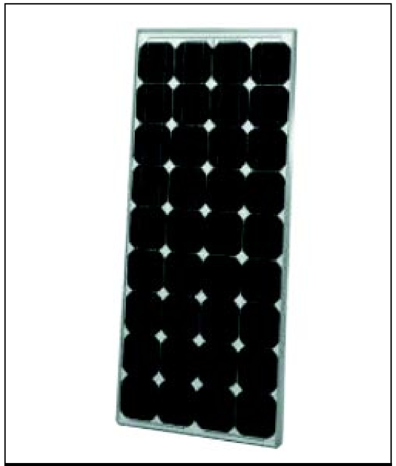
$Tm = P \times Ic$
P = peak hours equivalent
Ic = coefficient of an inclined surface = 1.15

c) The number of parallel strings of solar modules (Np)

$Np = I_A / Im$

I_A = Total current as calculated in b) above
Im = Rated current of solar module (e.g 4Ah for a 37W module or 3Ah for a 50W module)

d) Total modules required : $Nt = Ns \times Np$


Crystal Silicon Solar Module


Amorphous Silicon Solar Modules

3) Tilt angle

Based on the resource information, a computer program can be used to calculate the optimal tilt angle . Solar systems located in the northern hemisphere, like in China, should face the south. The tilted angle of a fixed solar array should be added extra 5 - 15 degrees to increase solar energy reception during winter.

5.3 Component Selection

There are three different types of PV modules: single crystal silicon, polycrystalline silicon and amorphous silicon. Each of these has advantages and disadvantages: the materials used in single crystal silicon cells have the same quality as those used in semiconductors, leading to a high efficiency but also a higher cost. The random arrangement of crystals in polycrystalline silicon cells means positive and negative charge cannot be separated completely by the PN electric field. At the same time, the random arrangement will lead to charge loss, causing a lower efficiency. Because the polycrystalline solar cell can be made by casting, its cost is lower than that of single crystal cell. The amorphous silicon cell is a film cell, which is cheap but has low efficiency and low stability. Amorphous cells are commonly used in small power supply devices, such as watches, calculators, etc.

Table A2.8 Qualitative Comparison of PV Module Types

Module Type	Efficiency	Degradation	Cost
Single Crystalline	Highest	Low	Highest
Polycrystalline	High	Low	High
Amorphous	Low	High	Low

5.4 Siting and Installation

- Solar array should face the south
- Solar array should not be shadowed
- Solar array should be mounted firmly on ground and support structure strong enough to resist high winds
- The connecting cables between solar modules should be resistant to weather and UV radiation, and wire connections should be in a sealed box
- The cable between solar array and the controller should be as short as possible

5.5 Commissioning Checks for

- The foundation of solar array and cable channels
- Solar modules
- Wiring
- Wire Connections, no open circuits
- Supporting structure and tilt angle of solar array
- Grounding
- The output of each individual module and the total power of solar array

5.6 Operation and Maintenance

- Keep the sun-facing surface of the solar array clean (may require daily cleaning in dusty periods)
- If solar array becomes shaded, trim infringing vegetation or move the array as appropriate
- The rated power of the solar array should be tested regularly
- The solar array should be cleared after rain, hail or snow
- The terminals and junction boxes should be checked regularly

6 Hybrid Renewable Energy Power Systems

Hybrid systems combine two or more types of renewable energy to build an optimal power supply system. Under appropriate circumstances, hybrid systems make power production more stable by relying on more than one resource and improving the cost-effectiveness of a single technology-based renewable energy power system. Hybrid system design is complex and computers are normally used to balance and optimize the system to make best use of available resources to meet load requirements at a minimum cost.

If the wind resource is good, wind power would provide the major share in a wind-PV system (diesel plays the role of a back-up power source). In some places, as in Tibet, where high altitudes mean low air density, PV may be more attractive than wind. In this case, PV will provide the major share in the wind-PV hybrid power system. Once the energy type and the system configuration are confirmed, the components of the system can be designed according to individual design rules (see sections 2 to 5). The relevant installation, commissioning and O&M guidelines for hydro, wind, solar and diesel components can also be found in the above sections.

7 Balance of System

Balance system includes: battery, controller, inverter and testing systems etc.

7.1 Battery

Batteries can reduce the short-term fluctuations, and also provide power from 1 to 3 days if there is no diesel in the system. However, batteries are often the weakest component of the whole system. The type, operation and maintenance of the battery bank are very important.

Battery banks are made up of multiple interconnected individual batteries. Batteries are connected in series to form "strings" of as many as120 batteries or even more. A battery bank usually contains no more than four parallel battery strings, although some batteries can be paralleled up to seven strings. Most batteries are available in 2V, 6V, and 12V sizes. For each of these sizes, manufacturers produce a range of batteries with different capacities. 2V batteries could be up to 1500Ah, while 12V batteries are up to 200Ah. The lifetime of a 2V battery will be longer than that of a 12V battery, but the cost will also be higher.

The effective capacity of the battery is lower than the rated capacity and will be reduced as the battery gets older. The faster and the deeper the battery is discharged, the faster the effective capacity of the battery will decline. Another indicator of the status of the battery is the self-discharge rate. In conditions of 25 ℃, this should not exceed 5%. If sound battery management and maintenance techniques are followed (no more than discharge rate specified by manufacturer), average battery lifetime should not be less than 5-8 years.

Design of battery bank capacity (C)

$C = Wh = L \times D / [DOD \times E_1 \times (1-E_2)]$

L= Daily load consumption (Wh)

D= Number of continuous days without sunlight/ required minimum number days of power storage.

DOD= Maximum depth of discharge = 50% to 80%

E1= System power conversion efficiency (approx.80%-90%)

E2= Distribution losses (approx. 5%)

7.1.1 Battery type selection

The battery is a key component of a stand-alone renewable energy system. Today there are not any specialized batteries for solar PV and wind power systems in China, so ordinary

Stationary Type Battery

Industry Type Sealed Battery

Small Size Sealed Battery

Car Starting Battery

lead-acid batteries are used. The main types of batteries are:

1) Stationary lead-acid battery
Mostly used in large scale solar PV, wind generating systems and communication applications. They require maintenance (adding purified water); medium price and have a long life span (8-10years);

2) Industrial sealed battery
Mainly used in communication systems, military applications and some medium size solar PV systems. There are not any maintenance requirements, are easy to installed, relatively expensive and have a life span of about 5-8 years.

3) Small size sealed battery
2V, 6V and 12V integrated battery that is mainly used in solar home systems. They are relatively cheap and have a 3-5 years life span.

4) Car or motor battery
These are the cheapest batteries but have the shortest lifetime (1-3 years). They require maintenance and may cause pollution and corrosion due to acid vapor.

Wind power systems and hybrid systems incorporating wind power must use stationary batteries due to large voltage and current fluctuations resulting from changes in wind speed. PV power systems can use industrial sealed batteries because of steady voltage and little current. Small size sealed batteries are best for residential PV systems less than 1kW.

7.1.2 Installation of battery

- All batteries, including their packaging, should be able to survive transportation over poor road conditions
- Batteries should be installed inside strong and rain-proof building
- The positive and negative poles should not be misconnected
- There is no any other electronics in the room where stores the battery
- Check if the batteries have been fully charged before their first application
- The lowest temperature allowable in the battery room is -5℃, therefore room heating may be necessary
- Do not use batteries of different types, different capacities together, or mix new and used batteries together
- Parallel battery strings are usually not more than four, although some batteries can be paralleled up to seven strings
- The connections and terminals of the battery should be greased and isolated after installation
- The newly installed battery must be fully charged before first use. Dry charged batteries must be charged for at least 5 hours at the 10 hours charging rate. For non-dry charged battery, at least 20 hours charging at 10 hours rate
- “No fire” and “No smoking” should be marked on the wall of the battery room

7.1.3 Battery testing

- Check the battery cases, covers and terminals
- Check connections
- Cable size and groundings
- Check if the battery has been fully charged (to 2.35 V for each single battery cell)
- Check the temperature of each battery
- Check the voltage of each battery
- The voltage drop between two batteries should not be more than 3mV
- Checking the density of electrolyte.

7.1.4 Battery operation and maintenance

The battery is the heart of a renewable energy power system. The state of the battery will affect the quality of the system operation and the lifetime of the system.

The most important issue is to avoid over charging and over discharging.

Battery management and maintenance should follow the following rules:

Daily checks:
The operator should check the following items every day or every shift:

- Lighting, aeration and temperature in the battery room - clean away dust, keep room clean
- Case and cover of the batteries-clean away electrolyte leakage
- Level of the electrolyte - add distilled water or electrolyte
- Density of the electrolyte, voltage and temperature of each battery - adjust density as required
- Connections - regular vaseline painting
- Charging and discharging current - record the status of battery operation.
- Examine and repair unqualified battery (refer to those charge slowly and discharge rapidly)
- Maintenance tools.

Monthly checks should include:

- Density of the electrolyte and voltage of each battery
- Level of the electrolyte
- Color and shape of the battery plates
- Thickness of any deposit

- Connections
- Isolation of the battery.

All daily and monthly checks and actions must be recorded into the operator's logbook.

7.2 Controller

The controller protects the battery or battery bank from over-charging and over-discharging and also has some testing functions. The capacity of the controller should match the input generator system and output load. The controller is important since the battery lifetime will be reduced if the battery suffers frequent over-charging or over-discharging. According to the position of switches in the circuit, there are two types of controllers: series type or shunt type. The shunt type has less voltage drop while the series type is simple in circuit design. The control models could be PWM type or two-point switch type. And the switches can be relays or MOSFET.

7.3 DC/AC Inverter

DC/AC inverter changes DC power into AC power. For a DC power source to power AC loads, a DC/AC inverter is always necessary. There are two types of inverters, the square wave inverter and the sine wave inverter. The square wave inverter is simple and low cost but has more harmonics. The square wave inverter is usually used in small systems. Sine wave inverters are high cost but are suitable for powering all kinds of loads.

The critical factors for selecting an inverter are:

- Reliability
- Conversion efficiency
- Idle power consumption

Of these, the reliability is the most important factor.

The capacity of DC/AC inverter should match with load type and rated power, especially the capacity for inductive and capacitive load should be 5-7 times of its rated power.

Table A2.9 Inverter Design Coefficients

Load	Rated power	Capacity of inverter	Design coefficient
Light	20W	30W	1.5
TV	60W	120W	2.0
Refrigerator	150W	900W	6.0
Washing machine	150W	300W	2.0

7.4 Testing Equipment

Small size solar PV systems only require simple testing, such as battery voltage, charge current and load current. In this case, the measuring system is always built into the charge controller. For village power systems or large renewable energy power systems, a more sophisticated data acquisition system is required. More parameters must be recorded, including solar insolation, wind speed, cumulated ampere-hours of charging and discharging, environment temperature, etc. In this case a specially designed computer monitoring system usually is part of the system. Sometimes, remote control or remote monitoring is also available.

7.5 Electronic Component Checks (controllers, inverters, and testing equipment)

- Appearance of the equipment
- Wiring
- Switching on and off
- Metering
- Full load operation
- Protection functions
- Isolation and leakage
- Grounding of the casing
- Fault indicators and trouble shooting functions
- No interference effects on sensor loops
- Marked specifications and indicators of the equipment.

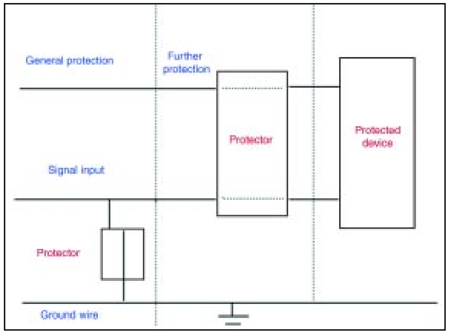
8 Lightning Protection and Grounding

Grounding precautions:

- Wind turbines and all the frames of a solar array should be grounded. Solar arrays need to add resistors at the output and input of connection box.
- Add lightning protection isolation box for the input of the controller.
- All cases of electronic components should be grounded
- All cable inputs and outputs in the control room should be equipped with lightning protectors.
- Loads connected to electrical source should be equipped with lightning protection equipment.
- Grounding body must be corrosion protected to make sure it stays in good condition for a long time
- Grounding resistance should be less than 10 ohms.
- Install lightning protection security wire. Size: 500 (H) × 400(W) × 200(D) mm

In general, it is not necessary to build another separate lightning pole if the solar array and the tower of the wind turbine have been grounded and line lightning protectors have been installed. Some measures should be followed as shown in

Figure A2.9 Lightning protection



Lightning protector

Figure A 2.9.

9 Power plant house and building construction

Village power systems need at least independent control and battery rooms. The requirements are:

- The temperature of the battery room should not be lower than -10℃ to avoid electrolyte freezing
- Battery room with open batteries should have ventilation system
- The door of the control room must be large enough so that equipment can be moved in or out
- The conduits for cables between the battery room and control room and input/output cable of control room should be constructed in advance
- Prepare the grounding cable of the control room for easy connection to the grounding point of the control panel later
- The foundation of wind generator and solar array should be built as per the specifications of the manufacturer
- Do preparations for grounding

10 Transmission line to end-users

Low voltage transmission lines are necessary to compose the distribution grids of village power systems. A standard 3-phase/4-line or a single-phase line and input line should be built by professionals. If power has been previously supplied by a diesel generator, the existing 3-phases/4-line low voltage line maybe used but great care must be exercised to ensure it will be safe and reliable in the new application. In terms of testing the transmission lines, the following should be noted:

- Secure the poles
- Cable size
- Cable installation
- Short circuiting check
- Wiring in the distribution boxes
- Metering (kWh) on end-user side (if not using fee-for-service model)
- Installation of energy saving equipment
- Lighting protection and/or circuit breakers
- Switching on the power system

Annex III : Main Assumptions for Economic and Financial Calculations

Present Case Scenario Assumptions

Main assumptions		Grid	Hydro	Diesel	Wind	W/D/B	PV
Investment assumptions							
Investment distribution							
Equity	%	20	20	20	20	20	20
Loan	%	30	30	30	30	30	30
Grant	%	50	50	50	50	50	50
Spare parts (of inv.)	%	1	1	2	1	0.75	0.75
Total Investment Costs	Yuan						
Transfer value (of inv.)[1]	%	10	10	10	10	10	10
Year of transfer	Years	20	20	20	20	20	20
Rates used							
Standard Conversion Factor (e/f)[2]		0.95	0.95	0.95	0.95	0.95	0.95
Exchange rates	US$/RMB	8.27	8.27	8.27	8.27	8.27	8.27
Financial discount rate[3]	%	8	8	8	8	8	8
Economic discount rate[4]	%	8	8	8	8	8	8
Equity discount rate[5]	%	8	8	8	8	8	8
Economic rate electricity (e/f)		1.1	1.1	1.1	1.1	1.1	1.1
Domestic bank loan rate	%	3	3	3	3	3	3
Domestic loan repayment	Annual	5	5	3[6]	5	5	5

[1] This is the value of the equipment on transfer from the first owner; the value is a low 10 %.

[2] This value is used as a very general indicator of bringing current costs to economic ones. Such a value is normally used for economic evaluations in China and is to be obtained in general planning offices of the Government.

[3] The financial discount is a fixed value reflecting the % interest set for the financial analysis. When applied to the cash flow, and resulting in a Net Present Value (NPV) of 0, it is equal to the Return on Investment (RoI). It thus serves as a reference value for the financial viability.

[4] Idem but then for economic analysis.

[5] Idem but then for the equity part analysis.

[6] The loan term of diesel project will be considered as 3 years since we assume the lifespan of the diesel is just four years.

Present Case Scenario Assumptions

Main assumptions		Grid	Hydro	Diesel	Wind	W/D/B	PV
Equity capital repayment	Years	8	8	8	8	8	8
Return of Equity (RoE)	%	12	12	12	12	12	12
Return of Investment (RoI)	%	12	12	12	12	12	12
Losses							
Technical/energy efficiency losses	% of sales	10	0	0	10-30	30	30
Administrative	% of sales	2	0	0	0	0	0
Project development exp. (Yuan)(300hh village)		40,000	25,000	10,000	25,000	25,000	25,000
(60hh)		40,000	10,000	2,000	10,000	10,000	10,000
Operation costs							
O&M (of inv.) (300hh)		10,000	10,000	15,000	10,000	6,000	15,000
(60hh)		10,000	6,000	6,000	6,000	6,000	6,000
Annual Growth percentage	%	0.5	0.5	0.5	0.5	0.5	0.5
Insurance (of inv.)	%	0	0	0	0	0	0
Annual Growth percentage	%	0	0	0	0	0	0
Taxes and levies							
VAT	%	17	0	0	0	0	0
Income tax	%	33	0	0	0	0	0
Natural resource fee (of sales)	%	0	0	0	0	0	0
Technical Parameters							
Primary line	Km	30-100	0	0	0	0	0
Secondary line	Km	2	2	2	2	2	2
System lifetime	Year	25	20	20	20	20	20
Primary component lifetime[7]	Years	25	20	4	20	20/4	20
Battery Lifetime	Years	-	-	-	8	8	8

[7] Key components: Power lines for grid-extension; Hydro generator for hydro option; Diesel genset for diesel option; Wind turbine for wind energy option; PV panels for solar option, and, wind turbine and diesel genset for hybrid. Battery lifetime is assumed as 8 years for wind, PV and hybrid systems.

Commercial Case Scenario Assumptions

Main assumptions		Grid	Hydro	Diesel	Wind	W/D/B	PV
Investment assumptions							
Investment distribution							
Equity	%	30	30	30	30	30	30
Loan	%	70	70	70	70	70	70
Grant	%	0	0	0	0	0	0
Spare parts (of inv.)	%	1	1	2	1	0.75	0.75
Total Investment Costs	Yuan						
Transfer value (of inv.)	%	10	10	10	10	10	10
Year of transfer	Years	20	20	20	20	20	20
Rates used							
Standard Conversion Factor (e/f)		0.95	0.95	0.95	0.95	0.95	0.95
Exchange rates	US$/RMB	8.27	8.27	8.27	8.27	8.27	8.27
Financial discount rate	%	8	8	8	8	8	8
Economic discount rate	%	8	8	8	8	8	8
Equity discount rate	%	8	8	8	8	8	8
Economic rate electricity (e/f)		1.1	1.1	1.1	1.1	1.1	1.1
Domestic bank loan rate	Annual	6	6	6	6	6	6
Domestic loan repayment	Annual	5	5	3	5	5	5
Equity capital repayment	Years	8	8	8	8	8	8
Return of Equity (RoE)	%	12	12	12	12	12	12
Return of Investment (RoI)	%	12	12	12	12	12	12
Losses							
Technical/energy efficiency losses	% of sales	10	0	0	10-30	30	30
Administrative	% of sales	2	2	2	2	2	2

Commercial Case Scenario Assumptions

Main assumptions		Grid	Hydro	Diesel	Wind	W/D/B	PV
Project development exp.	Yuan	40,000	25,000	10,000	25,000	25,000	25,000
Operation costs	%						
O&M (of inv.)	%	10,000	10,000	15,000	10,000	12,500	6,000
Annual Growth percentage	%	0.5	0.5	0.5	0.5	0.5	0.5
Insurance (of inv.)	%	0	0	0	0	0	0
Annual Growth percentage	%	0	0	0	0	0	0
Taxes and levies							
VAT	%	17	6	17	8.5	8.5	8.5
Income tax	%	33	33	33	33	33	33
Natural resource fee (of sales)	%	0	2	0	0	0	0
Technical Parameters							
Primary line	Km	30					
Secondary line	Km	2	2	2	2	2	2
System lifetime	Year	25	20	20	20	20	20
Primary component lifetime[7]	Years	25	20	4	20	20/4	20
Battery Lifetime	Years	-	-	-	8	8	8

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