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Alternatives to coal and candles: wind power in China

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Abstract

China is in a unique position to be able to exploit her vast wind resources to satisfy both the rapidly growing energy demand which fuels her economy as well as needs of approximately 72 million people who live in rural areas and have no access to conventional electricity services. China, mainly through the efforts of the Inner Mongolia Autonomous Region, has already successfully disseminated over 150,000 small-scale wind electric generators which power households in rural areas, through a well-coordinated combination of local research and development, technology transfer, industry support, end-user incentives, and an infrastructure for information dissemination and technical training. In this paper, we review China's utilization of wind energy and discuss how it can be increased for both rural electrification and the rapidly growing power sector. We find that novel approaches in technical implementation of wind power use may help to better meet China's needs. Use of hybrid systems may help to provide higher quality, more reliable power for rural households and villages than is currently provided through wind-only systems. Grid-connected wind power, which currently is more costly and less reliable than coal power, can become cost-competitive and more reliable through local, mass production of wind turbines combined with storage systems. We examine governmental support, through policy, infrastructure development and financial incentives, that have fostered the successes of dissemination of small-scale wind turbines and also the support, or lack thereof, that has hindered commercial development of large-scale wind power. We find that a better policy and regulatory framework is the most important measure that China can take to increase the use of this indigenous, clean resource.

Keywords: Wind power; Market development; China

1. Introduction

Along with economic growth of nearly 10% per year over the last two decades, China's energy use has been rapidly increasing. During the last decade, capacity has grown at an average annual rate of 9.3%, reaching 250 GW in 1997. Annual generation has increased only slightly slower at an average of 8.7% annually in this period, to 1135 TWh in 1997 (Pacific Northwest National Laboratory, 1998; China Energy Watch, 1998). While China is the second largest generator of electricity in the world, per capita consumption in 1997 was only 946 kWh, an order of magnitude less than in OECD countries (Energy Information Administration, 1998). What makes the Chinese situation particularly compelling, however, is the coal-intensive nature of the Chinese economy. While coal represents about 30% of commercial energy consumption worldwide, it represents 75% for primary energy consumption[1] and 75–80% of total power generation in China (Ni and Sze, 1998). Coal use is expected to keep pace with increased power needs in the next couple of decades, as China strives to meet its development targets of 290 GW of capacity and 1400 TWh of generation by the year 2000.

China's large population combined with its dependence on coal results in a significant contribution to world CO_2 emissions. Chinese CO_2 emissions in 1994 were 828 Mt C/yr, about 13.4% of the world total (Marland and Boden, 1997). If current energy use and economic trends continue, various studies have projected that carbon emissions in the year 2020 will reach 1354–2045 Mt C/yr (National Environmental Protection Agency, 1996; Asian Development Bank, 1993; United Nations Development Program and World Bank, 1994). By that year,

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[1] This does not include traditional consumption of biomass for cooking and heating.

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annual world emissions are estimated to range from 6000 to 12,000 Mt C/yr (Intergovernmental Panel on Climate Change, 1994). If the US is able to reduce emissions by 7% from their 1990 levels of 1336 Mt C/yr, as they have pledged in the Kyoto protocol, or even to stabilize emissions, then it is likely that in the next couple of decades, China will lead the world in emissions of CO_2 (Nielson and McElroy, 1998).

In addition to the global effects, there are local impacts of the large and growing coal use that afflict China. Severe local air pollution problems can be attributed to coal use. In the northern cities of Beijing and Shenyang, average particulate concentrations over the past decade have remained at about 4–5 times the World Health Organization's recommended limits; sulfur dioxide concentrations have been 2–4 times the recommended limits (Xu, 1998). Utilities and industry control particulate emissions; as a result aggregate emissions have stabilized. But utilities scrub only 6% of their sulfur dioxide emissions, and total sulfur dioxide emissions have been steadily increasing over time (Yang, 1995). The resulting emissions of particulate matter have led to increased respiratory disease and reduced pulmonary function (Xu, 1998); sulfur emissions have led to acid rain damage to urban buildings, forests and cropland in the south, with damage as far as Japan. Within China, damage from acid rain is estimated to total $5–13 billion (Nielsen and McElroy, 1998; Pacific Northwest National Laboratory, 1998). It is clear that to reduce both global and local environmental effects of coal power, China must consider alternatives to the current business-as-usual energy scenarios.

At the same time, China has 72 million people who live in rural areas and have no access to conventional electricity services (Energy Information Administration, 1998). Through extensive decentralized rural energy programs, China has been highly successful in commercial (or near-commercial) dissemination of household-scale renewable energy systems. They have deployed over 120 million improved biomass cookstoves, 5.4 million biogas digesters, 3 million square meters (equivalent to 1.5 million typically sized panels) of solar water heaters, 150,000 small wind turbines, 60,000 micro-hydro units, and tens of thousands of solar home systems (Smith *et al*., 1993; Lin, 1997; Fang *et al*., 1998; Lew *et al*., 1998; Byrne *et al*., 1998). All of this has been accomplished through minimal subsidies, a decentralized network infrastructure, and extensive training and marketing.

Wind power has been used most successfully in the Inner Mongolia Autonomous Region (IMAR), where one-third of the rural, remote herdsmen use wind electric generators to charge batteries to power televisions, radios and lights. This region now has extensive distribution and marketing infrastructure. China produces more wind turbines than any country in the world and now has 40 manufacturers of small-scale wind turbines, 17 of which, including the largest manufacturer, are located in IMAR (World Bank, 1996).

China's wind resources are world-class, with many sites of class 5–7[2] (World Bank, 1996; Elliott and Schwartz, 1998; Dai and Twidell, 1988). Moreover, wind farms located in regions with class 5 resources can typically provide electricity at the same or lower cost than new coal power plants in the US.[3] An international joint study team examined mitigation options for greenhouse gas emissions in China and found wind power to be one of the most cost-effective energy supply options,[4] less expensive than incremental hydropower, nuclear power or photovoltaics (United Nations Development Program and World Bank, 1994). Energy planners in developed and developing countries are realizing the benefits of wind power: no greenhouse gas emissions; modular components leading to flexibility in meeting diverse demands and rapid construction times; and cost-effectiveness on large or small scales of implementation. This combination makes wind ideal for utility generation in all areas with sufficient wind resources.

In addition to being a potentially cost-competitive power source, the wind resource generally complements the coal and hydropower resources. The winds along the southeastern coast complement the seasonal nature of the hydropower resource in the southwest and provide a local power source which can help to alleviate rail bottlenecks from transporting coal in from the north. However, only 167 MW of wind power, or less than one-tenth of one percent of total installed capacity, was installed in China by the end of 1997 (Ministry of Electric Power and State Power Corporation of China, 1998). The government's goal is to realize 1000 MW of wind power by the year 2000; however, at current installation rates and with current policies, it seems highly unlikely that this goal will be reached.

The purpose of this paper is to investigate what can be learned from China's successes in the dissemination of small-scale wind turbines and what can be done to implement utility-scale wind to meet these targets. We discuss technological options that can expand the use of wind for rural electrification as well as for utility-scale generation. Finally, we discuss some critical barriers to

[2] Using the wind power classification standards for the US, this corresponds to wind speeds and wind power densities at 10 m (50 m) of 6.0–9.4 m/s (7.5–11.9 m/s) and 250–1000 W/m^2 (500–2000 W/m^2) (Elliott *et al*., 1981).

[3] Wind energy costs have decreased from over $1/kW h in 1981 to less than $0.05/kW h today and are expected to further drop to $0.03–0.04/kW h (Cavallo *et al*., 1993; Office of Technology Assessment, 1995).

[4] In addition to these energy supply options which had positive net costs to reduce greenhouse gases, several options had *negative* net costs: energy conservation, improved cattle production, industrial restructuring, high-yield fuelwood plantations, coal-bed methane, and high-yield commercial timber plantations.

be overcome to develop wind power on a large-scale in China. Taken together, the Chinese effort to utilize wind on both utility and household scales has the potential to meet China's growing power needs with low environmental impact.

2. Wind resources

China is endowed with large wind resources in the north, from Xinjiang Autonomous Region through Gansu Province to IMAR, and in the southeast, along the coastline. The total available wind energy in China has been estimated at 3.2 TW; however, the Ministry of Electric Power estimates the exploitable electric potential (at a 10 m height) to be 253 GW (Dai and Twidell, 1988; Dai *et al*., 1992). Because wind speeds typically increase with height above the ground,[5] the total electric potential could be twice this figure at a modern turbine hub height of 50 m. Thus far, about 200 MW has been developed through large- and small-scale projects. Fig. 1 shows the overall distribution of wind resources. The parameters listed are averaged over the region; specific sites which can be hundreds of square kilometers may have much higher wind energy densities and durations.

Coastal wind resources in China have very good economic prospects. For example, along the southeast coast of China, winds are high; electricity demand is growing rapidly; and electricity prices are high. Because local coal resources are scarce, coal must be transported in the region via rail. This strains an already overburdened transport system, where coal already uses 40% of the rail capacity in the country (Fang *et al*., 1998). Hydropower is currently transmitted to this region from the west, and there is good complementarity between the wind and hydro resources. Monsoon winds, generally confined to the islands and a strip of land several tens of kilometers wide along the coastline, often complement hydropower production, because the winds are greatest during the dry season when hydro can only produce 20–25% of its capacity (Shen, 1995).

The IMAR, in the north, along the Mongolian border is home to the largest wind resource in China. The winds across these plateaus are generally steady, with little turbulence and few gales. Very few people live in IMAR (18 people/km^2), and much of the land is flat grassland and well suited for large-scale wind power development. The barren plateaus of IMAR are conducive to transport of large equipment, and large (600 kW) turbines have already been installed here.

The Ministry of Electric Power's assessment of wind resource shows that the best wind resources in IMAR cover an area of 83,000 km^2 with an average power density at 10 m of 286 W/m^2 and with 6950 usable hours[6] (Zang and Feng, 1995). Assuming that the 6950 usable hours correspond to the hours per year in which wind speeds are 4 m/s or larger, a Weibull distribution with $k = 2.19$ and $v_c = 7.7$ m/s can be fit to the data. Assuming a k-value at 50 m of 2.51, which is the measured value at 40 m at Huitengxile (Inner Mongolia Electric Power Prospecting & Design Institute, 1995), and a wind shear factor $\alpha = 1/7$, the Weibull distribution at 50 m can then be approximated by $v_c = 9.69$ m/s. This yields an average wind power density of 520 W/m^2 with nearly 7900 usable hours/year at 50 m hub heights.

This land area could support nearly a million turbines with more than 500 GW nameplate capacity. Assuming that modern wind turbines can convert 35% of the energy in the wind into electricity, that array and other losses amount to 14%, and that turbines have a spacing of 10 diameters downwind and 5 diameter crosswind, the 83,000 km^2 of land with the best wind resources in IMAR (equivalent to 0.9% of the land area of all of China) could support nearly a million turbines with an average annual wind electricity production of nearly 1800 TWh/yr (see Lew *et al*., 1998). This represents 60% more energy than is consumed currently in China.

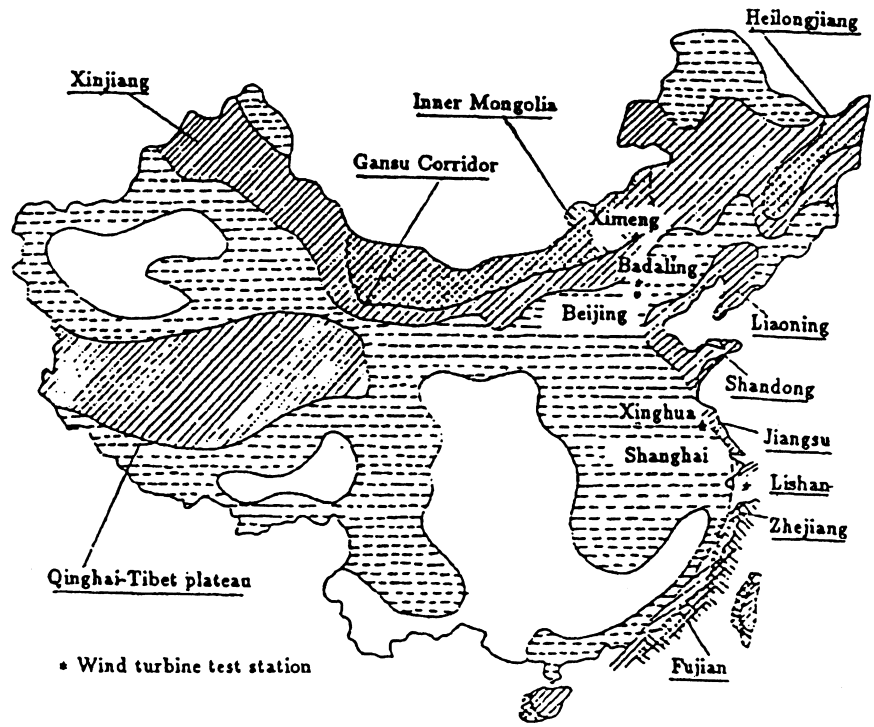
While less than 5% of the total land in a wind farm is actually needed for the wind power equipment and infrastructure and thus excluded from use in farming, grazing or other applications, some of this 83,000 km^2 of wind-swept land in IMAR might be dedicated to other uses and unavailable for wind development. While the actual land-use in IMAR must be determined empirically, crude estimates of the exploitable wind electric resource are presented here, based on the assumption that the Inner Mongolian region is similar to North Dakota in the Great Plains of the US, both of which are characterized by low population density and the virtual absence of forested areas. Using a *moderate* exclusion scenario, which excludes all environmental and urban areas, 50% of the forested lands, 30% of the agricultural lands and 10% of the rangeland (Elliott *et al*., 1981), this richest wind area is reduced by 29%. Under this scenario, the richest wind area of IMAR could provide about 1250 TWh/year, comparable to total electricity demand in all of China.

[5] The wind speed, v_2, at height h_2, relative to a reference wind speed, v_1, at height h_1 can be estimated as:

$$\frac{v_2}{v_1} = \left(\frac{h_2}{h_1}\right)^{\alpha}.$$

For flat land with little surface roughness, the wind shear factor α is approximately 1/7 (Gipe, 1993), which is in good agreement with Huitengxile data.

[6] This corresponds to Wind Class 5, and technically feasible wind power generation 79% of the time.



The criterion of division

	high	moderate	marginal	poor
wind potential region				
time duration above wind speed of 3 m/s (hours/year)	> 5000	5000-4000	4000-2000	< 2000
time duration above wind speed of 6 m/s (hours/year)	> 2200	2200-1500	1500-500	< 500
wind energy density (w/m^2)	> 200	200-150	150-50	< 50

Fig. 1. Wind resources in China (Source: Meteorology Institute, National Meteorology Bureau, China).

2.1. New techniques for wind resource assessment

This and other rough estimates reveal huge potential for wind energy in China, and the need for further investigation of the resource (FT Energy World, 1998). Conventional assessments of wind resource primarily depend upon surface meteorological station data. However, this data in many cases does not accurately represent the wind energy resource. These surface stations were typically installed to provide weather information and forecasting as opposed to wind energy resources, and thus are often located in areas where people live or where airports have been built, both of which are likely to be areas with lower wind speeds. The anemometers which collect the surface station data must be well-maintained in order to remain accurate. In addition, they must remain well-exposed to the wind. Growth of vegetation and construction of buildings near the anemometers may block their exposure. In the case of Mexicali Airport, Mexico, surface station data shows a decreasing wind over time, with wind power densities decreasing by a factor of seven from the mid-1970s to early 1990s (Schwartz and Elliott, 1995). Further analysis of this data indicates that the anemometer is degrading over time. Similar trends of decreasing wind were found in surface station data from many stations in southeastern China. For example, data from Pingtan station in Fujian province shows the wind power density steadily decrease from 500 to 600 W/m^2 in the late 1950s to 100 W/m^2 in the early 1990s (Elliott and Schwartz, 1998).

With the use of large computers and recently available data sets of detailed meteorological and topographical information, a new level of wind resource assessment has been reached. In addition to the surface meteorological stations, these data sets now include upper air weather balloon data, ship data, and satellite data. Using these data sets and geographic information systems (GIS) techniques, very detailed wind resource assessments can be made. Depending upon the level of the data, the resource can be evaluated over large areas to determine those areas which should be monitored to determine feasibility, or very small areas, where the detailed wind maps can actually assist in *micrositing* of turbines.

The US National Renewable Energy Laboratory has recently applied these techniques to update the wind resource assessment of several provinces in China. The areas analyzed include two regions: the coastal areas of Fujian and Guangdong provinces and the Poyang Lake area in northern Jiangxi province. Through this mapping process, good-to-excellent wind sites were identified in both regions, with exceptional sites along the Fujian coast (Elliott and Schwartz, 1998).

One result is that the wind resources, as assessed through these new techniques, are much greater than previously estimated. For example, Guangdong province was estimated to have about 7000 MW of wind power potential along the coast. The NREL study indicates that the potential for only a 10-km wide coastal strip in Fujian and Guangdong province is about 26,000 MW for class 4 winds and higher (Vaupen, 1999; Elliott and Schwartz, 1998). Annual energy potential from this resource is estimated at 68,000 GWh.

Once specific areas have been pinpointed for wind energy evaluation, monitoring the resource can be conducted using anemometers. This provides the most detailed assessment for that particular site. Wind speed and direction, solar insolation and temperature can be monitored to provide diurnal and seasonal variations as well as average power densities.

3. Small-scale wind: over 100,000 turbines in rural China

Despite the reputation for large mega-cities, China's population is largely rural, with about 850 million people living in rural areas (Energy Information Administration, 1998). For many rural areas around the world, the combination of dispersed populations, expensive grid extension, and low-energy consumption results in distributed small-scale renewable energy systems as a least-cost option for electrification (Cabraal *et al*., 1996; Foley, 1995; Liebenthal *et al*., 1994). China's goal is to provide electricity access to 95% of the rural population by the year 2000. To do this, the national and provincial governments have implemented a number of programs to electrify rural areas with renewable energy. China has been quite successful in dissemination of small-scale energy systems. A huge demand, stemming from large rural populations; targeted research and development of energy technologies, and the extensive roles that local governments have played have led to successes. Although some are well-documented, such as the improved biomass cookstoves and biodigester programs (Smith *et al*., 1993), other efforts are only beginning to be discussed outside of China, such as the solar water heaters, micro hydro, and small wind.

One of the big successes in deployment of household renewable energy systems is the dissemination of small wind turbines in China. Although the central government provided research and development of wind technology, they played a relatively minor role in this success story of small-scale wind turbine dissemination. Local governments in some rural, windy regions — Xinjiang and Qinghai, for example – have only been mildly successful in disseminating small-scale wind turbines. It is the local government of IMAR that has had the most aggressive policy of wind power utilization and this is reflected in the tremendous number installations in this region. Fig. 2 shows that over 90% of the small-scale turbines in China are located in IMAR.

IMAR is an autonomous region in northern China, bordering Mongolia. IMAR has about one-eighth of the total area of China, but less than 2% of the total population. Most of the land is grassland, and many of the rural people are herdsmen and farmers. Average per capita

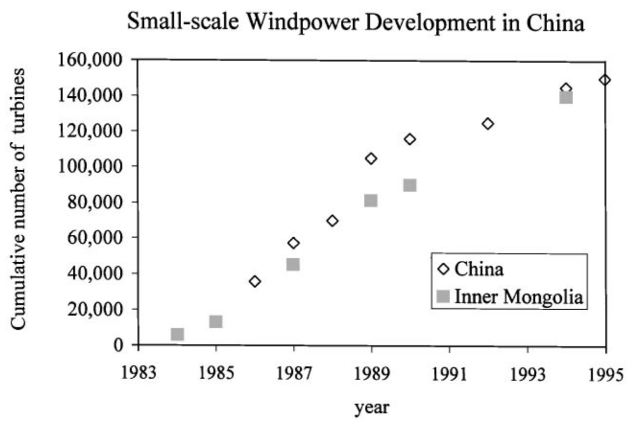


Fig. 2. Cumulative number of installations of small-scale wind turbines (typically 50-300 W) for rural electrification in IMAR and China. Solid squares represent IMAR and open diamonds represent China (Sources: Li, 1988,1990; Lin, 1988,1997; Chen *et al*., 1991; UNESCAP, 1993; Wang, 1993; Shi, 1995; Yan, 1996; Long, 1996; Qiu *et al*., 1996; Zhou, 1996; Ma, 1998).

annual incomes are about 2000 Yuan ($240), which is fairly wealthy for a rural, unelectrified population in an underdeveloped Chinese province. It is estimated that 300,000 households in 1100 villages and 198 townships currently lack electricity access (Byrne *et al*., 1998).

By 1995, there were about 150,000 small turbines in rural China, providing electricity for lighting, radios, televisions and small appliances. Today, approximately 140,000 small wind turbines (and about 10,000 PV systems) are located in IMAR (Long, 1998; Ma, 1998). These small wind serve about half a million people and contribute over 17 MW to installed capacity.

In this section, we discuss the development of small wind in China, from excellent policy and planning and a well-established infrastructure to the development of a domestic industry to the use of hybrid systems to increase the reliability of current systems.

3.1. Policy, planning and infrastructure

The Chinese have a long history of using wind energy, beginning with the use of windmills for pumping water 2000 yr ago. By 1959, there were 200,000 canvas windmills pumping water, mostly in north Jiangsu province (Shen and Li, 1988). In the 1950s the Chinese government began research on wind electricity generation, and by the 1970s they were able to begin a campaign to electrify rural areas with small-scale distributed renewable sources, including wind and photovoltaics. By 1985, there over 80 types of small wind turbines had been developed, about 10 of which were put into mass production after testing and adaptation (Shen and Li, 1988).

The local Inner Mongolian government has long viewed wind power as an exploitable energy source, a boost to the local economy and solution to rural electrification. In 1980, the Science and Technology Commission of IMAR declared renewable energy development and utilization a priority program. They emphasized local development and implementation with these guidelines: to develop stand-alone wind, PV and balance of systems components for remote areas; to develop systems that were reliable and convenient to operate and maintain and affordable for rural people; to integrate needs for production and daily life of the herdsmen; and to ensure that local people were in charge of the program, with the State providing appropriate support (Lin, 1997).

The local government integrated the research, production and outreach components of their program into a single continuous system. In 1984, the New Energy Office was established to manage the renewable energy program. This agency set policies for renewable energy development, conducted near- and long-term planning for renewable energy, and coordinated activities in research, production and dissemination.

During this same time, the central government was establishing an extensive network of rural energy offices to disseminate information and provide technical training and service at the county level. These offices have been instrumental in deployment of the small-scale renewable energy technologies. In 1979, the Ministry of Agriculture established the management system of rural energy offices. These rural energy offices now exist in 1800 of the 2200 rural counties in China. The original programs of the early 1980s focused on single technologies such as improved biomass cookstoves, biogas digesters and small hydropower. In 1983, they began a pilot project for integrated rural energy development in six counties. The success of the pilot led them to expand it to twelve counties during 1986–90 and then into the "One hundred counties" program during 1991–95. These integrated rural energy development programs focused on the interdependence of the energy and environmental sectors as well as social, economic and environmental development (Deng *et al*., 1996).

In addition to the central government's rural energy offices, the local IMAR government has set up new energy service stations in over 60 of the region's 88 counties (Chen, 1993). These provide information and subsidies specifically for renewable energy systems. Their technical and training sites provide additional technical support.

3.2. Technology push and market pull

The State and local governments supported development of wind turbine technology through a number of mechanisms. From the late 1950s, research and development was conducted at many universities and research institutions throughout China. During the Seventh Five-Year Plan (1986–90), low-interest loans were given to local industries to build up manufacturing capabilities (Shen and Li, 1988). During this time, a trade association, the China National Wind Machinery Association, was established to coordinate the industry (Shen and Li, 1988).

The Chinese realized that to accelerate development of wind power, they needed to introduce advanced wind turbine technologies from abroad. Technology was acquired from foreign research institutions and industries. By 1987, 38 types of wind turbines had been imported for technology transfer and cooperation — nearly all of which were micro and small turbines (Shi, 1988). Technical cooperations between the Chinese and the Swedish, Dutch, German, and Italian governments led to joint design, development, and testing of small wind turbines and wind pumps. In addition to the joint efforts, four foreign technologies were licensed for production: Aerowatt from France, Sencenbaugh from the US, Wind Harvest Company from the US, and Swedish Wind Power AB from Sweden (Shi, 1988). In one of the more successful technology transfers, the Shangdu Livestock Machinery Works acquired technology to produce the

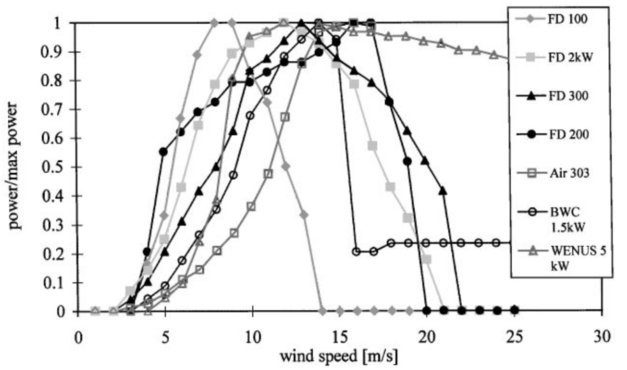


Fig. 3. Comparison of scaled power curves from small wind turbines manufactured in China (FD 100W, FD 200W, FD 300W, FD 2 kW), US (Southwest Windpower Air 303 and Bergey Wind Company 1.5 kW) and Germany (WENUS 5 kW).

Swedish SVIAB 650 W turbine in 1988 and have since improved the technology, simplified the structures, and adapted the design to a 300 W microturbine. Today they produce the largest number of wind turbines in China, and probably in the world.

The Chinese microturbines have been designed to perform well at the low wind speeds found at their typical hub height of less than 10 m. Fig. 3 compares the power curves of the Chinese turbines with those of similarly sized turbines from abroad, showing that the Chinese turbines begin producing power near their rated power output at much lower wind speeds than typical small turbines from the US and Germany.

With the dissemination and management infrastructure and local production of wind turbines established the local government developed the market for the turbines by reducing a critical barrier: affordability. In 1986, the Inner Mongolian government began offering a financial incentive of 200 Yuan per turbine (or PV panel) and 50 Yuan[7] per battery for components manufactured in IMAR (Lin, 1988). This is the first subsidy that the Chinese government has offered for development of renewable energy. The process for obtaining the subsidy was quite simple: the herdsmen went to their local new energy office and obtained a coupon which they brought to the Inner Mongolian turbine manufacturer of their choice. This helped to build up the local industry. The local government and utility each provided 5 million Yuan annually for these programs. Currently, subsidies are about 100 Yuan per 100 W rated capacity for the wind turbine and they do not apply for batteries. This program was completely driven by the local government until 1990, when the central government began contributing about one-third of the wind power subsidies.

These programs have been successful in creating a domestic industry of wind turbine manufacturers. Today, China produces more turbines than any other country through its 40 local manufacturers. These are mostly 100 W units used in single households, although 300 W units have recently become very popular. Shangdu Livestock Machinery Works reports production growth of 58% per year to about 10,000 units in 1996 (Yang, 1997). In 1996, total annual production in China was estimated at 20,000 units. China also exports these turbines to various Asian countries including Mongolia, Malaysia, Vietnam, Pakistan, Sri Lanka, and Japan. In addition to creating a manufacturing industry, by 1989, over 10,000 people were trained for construction, installation, and/or maintenance of wind turbines (Li, 1988).

In the 1990s IMAR began collaborations with international partners to advance their technologies, especially in hybrid and centralized systems. Utility-scale wind farms and other renewable energy technologies also became more widespread during this time. The development goals for the region are to disseminate a total of 150,000 small wind turbines, 150 kW of PV, and 150,000 m^2 of passive solar buildings by the year 2000. By 2010, electrification of remote areas in the region is planned to exceed 50% (Lin, 1997).

3.3. Hybrid systems

The small wind systems used in IMAR, although widely disseminated, suffer from low winds during the summer. The power of the wind increases as the cube of the wind speed, so that the power available in the high wind months of winter can be 3–4 times greater than that in the low wind months of summer. Since the *solar* resource peaks during the summer, the addition of PV may provide a means for electricity production year-round. See Fig. 4.

The second major problem with the small wind systems is that they are typically used with automotive lead-acid batteries. These batteries are designed for continuous charge, for low depth of discharge and for providing a large amount of power over a very short period of time. However, in use with wind electric chargers, the batteries are discontinuously charged and are severely discharged, especially during the summer. In this mode of use, the batteries only last about 1 yr, and thus comprise a significant expense. Rising battery costs further aggravate this problem. In comparison, when used in solar chargers, these batteries reportedly have lifetimes of 2 or more years (Shen, 1998).

It has been found that in some situations, power can be more cost-effectively supplied through hybrid systems (systems with more than one type of electricity generator), e.g., wind/diesel) than through a wind-only or diesel-only system (Lew *et al.*, 1996; Baring-Gould *et al.*, 1997; Corbus and Bergey, 1997). Hybrid systems are

[7] With the 1998 exchange rate of 8.3 RMB = US$1, this is equivalent to $24 per turbine or PV panel and $6 per battery.

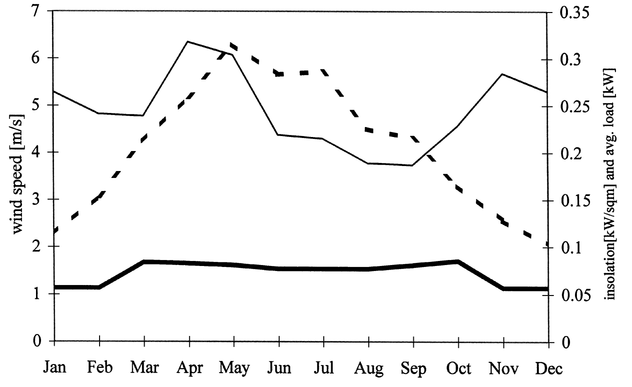


Fig. 4. Wind and solar resource data for one county in IMAR (Source: Lew *et al.*, 1997). Average wind speeds (m/s) are represented by the solid, thin line; average insolation (kW/sqm) by the dashed line; and average load (kW) by the solid, thick line.

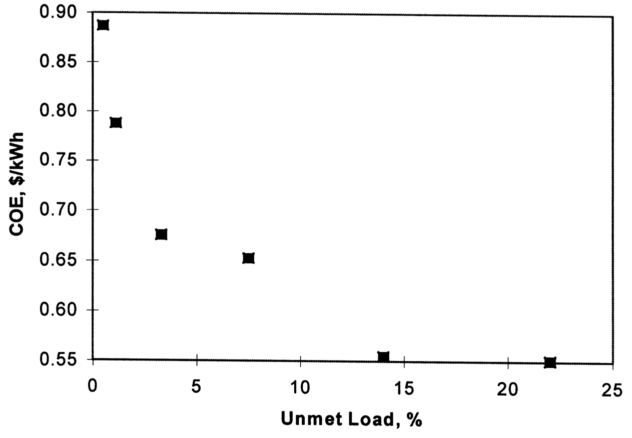


Fig. 5. Hybrid2 analysis of medium demand household (633 kWh/yr) in Scenario A for an average wind speed of 4.9 m/s. Cost of energy (COE) and unmet load are shown for the following configurations:

Case	Wind (W)	Solar (W)	Battery (kWh)
A	400	0	1.26
B	400	0	2.52
C	400	50	3.78
D	400	50	6.30
E	400	150	6.30
F	400	200	7.56

(Source: Barley *et al.*, 1997).

expected to provide a higher level of service, both in terms of power produced and reliability, than a single power generator. Hybrids have been introduced as retrofits to diesel-only systems, where they can increase the availability of the power from several hours to 24 hours per day, and where they may decrease the cost of energy by displacing fuel, maintenance and repair costs. In some cases, grid-extension costs can be prohibitive, and hybrids can provide the same or even better level of service for less cost. More importantly, the inherent flexibility of decentralized hybrid systems allows for variations in load, resource, and economics parameters without greatly affecting the cost of energy (Lew *et al.*, 1996).

In order to assess the least-cost options for decentralized energy systems, including diesel and hybrid systems, optimization and simulation models have been developed. An analysis of IMAR was performed using the HOMER model (Lilienthal *et al.*, 1995) to optimize system configurations for three household load sizes given wind and solar resource conditions for two counties in IMAR. The analysis indicated that a 300 W wind turbine/100 W PV system were ideal for a medium-demand household with consumption of 633 kWh/yr (loads included lighting, TV, and during the warmer months, refrigeration). The time-step simulation model Hybrid2 (Baring-Gould *et al.*, 1996) was then used to fine tune the system design and predict technical and economic performance.

The results indicated that a combination of wind and PV could more effectively meet the household load at lower cost than either wind or PV alone (Lew *et al.*, 1997; Barley *et al.*, 1997). In addition, there is a trade-off between the cost of energy and the amount of unmet load. While a low cost of energy, \$0.55/kW h, could be reached with a wind-only system, the unmet load was 14–22% of the total demand. This unmet load occurred during the low-wind summer months of August and September. With a wind/PV system of 400 W wind, 50 W PV and 6.3 kWh of battery storage, the amount of unmet load could be reduced substantially, to about 3%, but with a similar cost of energy of about \$0.67/kW h. See Fig. 5.

In these results, the calculated costs of energy are higher than values calculated for existing systems in Inner Mongolia (Byrne *et al.*, 1998), partly due to the use of high-quality (and more expensive) system components, and partly due to the fact that excess energy in this analysis is not utilized and is considered to have zero value.

Depending on their specific resource, the 140,000 households in IMAR which are already powered by wind generators may be able to benefit from the addition of photovoltaics to their systems. The Chinese herdsmen have already recognized the limitations of the wind-only systems and the advantages of hybrid wind/PV systems and have begun adding photovoltaic panels to their wind systems. The relatively high cost of PV is currently the greatest obstacle to their widespread use. The local government has begun collaborations with the US, Germany and the UNDP to study the design and application of hybrid systems in the region.

Through economies of scale, hybrid systems may be able to provide low-cost electricity to villages for an even lower cost. There are already several hybrid systems in IMAR for town and village use. The Chinese experience with these has been mixed. The biggest problem with hybrid systems to date has been the control systems, which are finicky and require skilled technicians (Shi, 1996).

3.4. Reliability, quality and technology transfer

While the IMAR programs have clearly been successful from a deployment perspective, the sustainability of these systems has not been well-established.[8] Estimates from the early 1990s indicated that of all wind turbines in IMAR, 85% were in good condition (Chen, 1993). This is remarkable in light of the fact that these wind turbines have reported lifetimes of 10–12 yr (Lin, 1988), and that parts of the turbines are reportedly of questionable quality, especially the blades, which must be replaced more often. More recent anecdotal evidence suggests that these figures have overestimated the real situation and that many turbines are now inoperational.[9] There is a need to formally survey these systems to ascertain the performance of these turbines and the sustainability of the systems.

In order to improve the quality of wind turbine and electronic components and also develop larger components to fill the gap of Chinese turbine production, specifically in the 5–10 kW range, the China ministry of Machinery industry and the German Gesselschaft fur Technische Zusammenarbeit (GTZ) began the Sino-German Technical Cooperation Project in 1990. This provided information exchange and training, and also transferred technology for industrial production of wind turbine and electronic components for hybrid systems. These components included 200 W to 4 kW inverters, 200 W battery chargers, and 5 kW wind turbines (from the German manufacturer WENUS). In 1993, the Hua De New Technology Company was founded to receive the technology transfer. Local production of 71% of the wind turbine is planned to reduce the cost of the turbine by 50%. Additional reductions in cost are expected as a result of mass production of the turbine. Already, the joint venture Hua De New Technology Company can replicate and sell the equipment. To go the next and very challenging step of transferring a deeper understanding of the design such that the local company could improve upon and modify the original design would require much more training of and experience by the joint venture.

Bergey Windpower Company in the US has also recently begun technology transfer in China. A joint venture between the US company and the Xiangtan Electrical Machinery Group Corporation has recently been formed to produce 10 kW wind turbines. The hope is that the high quality of the Bergey wind turbines can be married to the low labor costs, huge demand and high production volumes in China to create low-cost, reliable wind turbines.

3.5. Financing

In many developing countries, the relatively high cost of small-scale renewable energy systems has led many dissemination programs to develop credit mechanisms for financing systems to rural users (Cabraal *et al*., 1996; Gunaratne, 1994; Barua, 1998). However, in China, costs are lower due to local production of renewable energy technologies. Moreover, there is little experience with credit in many rural areas of China. Nearly all installations to date of household wind systems have been cash sales.[10] A combination of a relatively wealthy rural population, relatively low-cost locally manufactured equipment, and the government financial incentive has made the systems affordable for the users. However, in order for the dissemination program to reach less affluent segments of the population, financial mechanisms such as credit, leasing, or fee-for-service, may become an important component of future programs (Cabraal *et al*., 1996).

4. Large-scale wind power in China

While the small-scale wind power market fills a need to electrify rural areas, the main driver for use of wind power on a utility scale is to provide a clean, and in some cases, local, alternative to coal power generation. Coal use in China places a heavy strain on the local and global environment and on the transportation infrastructure. The local effects of China's coal use are the increased acid rain and respiratory health hazards. The global ramifications of fueling China's development with coal are huge increases in emissions of greenhouse gases. Finally, transportation of coal accounts for 40% of the rail capacity (Fang *et al*., 1998). While wind resources are abundant in much of China, it is the southeastern coastal regions that

[8] About 4000 small-scale PV systems have been installed in the Pacific Islands. Liebenthal *et al*. (1994) describes some past projects in the Pacific Islands as being unsustainable due to a number of reasons: inappropriate design, unreliable components, improper installation, and poor maintenance. For example, of 100 systems installed in 1983 in Fiji, only 11 were still functioning in 1991, and most of these were performing suboptimally. Despite extensive dissemination of PV water pumping systems in Thailand (over 700 units), Khuanmuang *et al* (1997) finds that 45% have failed, mainly due to sedimentation in the pumps and inverter failures. Some early programs of PV household kits in the Philippines have suffered from a variety of technical and non-technical problems including typhoons, battery failures, collection problems, and trained technicians leaving rural areas for better jobs in the city (Cabraal *et al*., 1996; de Bakker, 1996).

[9] Personal communications from program managers at the Chinese Academy of Sciences, with the US DOE/China collaboration and with the GTZ/China collaboration.

[10] A similar experience is seen in Kenya, where cash sales have been the primary means for dissemination of PV systems to an estimated 70,000 households (Acker and Kammen, 1996; Hankins *et al*., 1997).

tend to be coincident with areas of high demand and low coal resources, and that complement the seasonal hydro power that is transmitted from the west. In the north, the wind resources tend to be coincident with coal resources, and far from areas of high demand. In this section, we discuss some ways in which these wind resources can be tapped, such that they provide a cost-competitive alternative to coal.

The worldwide grid-connected capacity at the end of 1997 was 7600 GW, virtually all of which is located in the US, Europe, and India (Wind Power Monthly, 1998). Although China has far more small-scale wind turbines than any other country, their large-scale wind installations have been outshadowed by markets in India and Germany. This is not due to superior wind energy resources in India and Germany, but rather due to very favorable policies for wind energy in these countries.[11] The previous section discussed the similarly advantageous policies of the IMAR which have successfully disseminated over 140,000 small-scale wind turbines, created a domestic wind industry and trained a cadre of technicians.

China began utility-scale wind development in 1986 with the installation of three Vestas 55 kW turbines, but it wasn't until 1989 that the first MW scale wind farm was established in Dabancheng, Xinjiang Autonomous Region. The Chinese large-scale wind market is growing, with 166 MW of grid-connected wind power installed by the end of 1997; however the government did not meet its target of 200 MW by the end of 1995, and more aggressive policies will be needed to achieve China's goal of 1000 MW by the end of 2000 (Dai *et al*., 1992). See Fig. 6.

Another important difference between the small-scale and large-scale wind turbine markets is that there is a large, mature small-scale wind turbine industry. Most of the large-scale technology, in the form of turbines as well as operations and maintenance, is currently imported from Europe. China will need to develop its own large-scale domestic industry and technicians. Chinese industry for manufacturing medium- and large-scale turbines is very immature. China's Eighth and Ninth Five Year Plans included research and development of 100 kW and larger units. However, because electric generating capacity was so urgently needed, the strategy in the early 1990s was to import proven technology from abroad. The strategy today has changed. Although China continues to import proven technology, especially when it is accompanied by favorable loans from foreign governments, China has begun programs specifically to foster the development of local manufacturing capabilities.

[11] The best wind farm site in India (Muppandal in Tamil Nadu) only has an average wind speed of 6.08 m/s at 10 m, while China has many sites with average annual wind speeds at 10 m of 6 m/s and higher (World Bank, 1996).

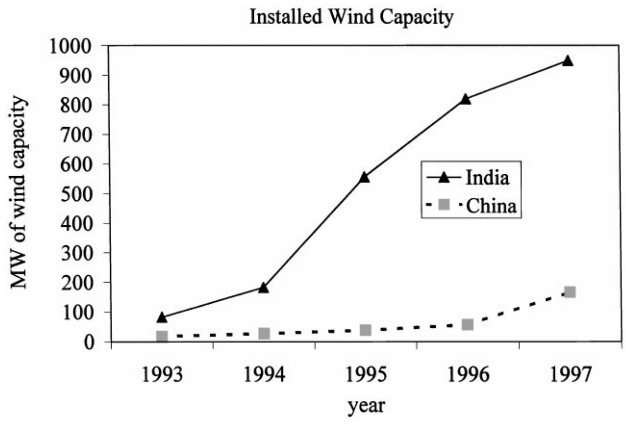


Fig. 6. Comparison of cumulative wind capacity during 1993–97 in China and India.

The large-scale wind market in China is emerging from a demonstration stage, with many installations of small windfarms, financed through subsidized loans from foreign governments. The challenge for China is to guide the transition of this nascent market into a commercially sustainable market for wind power.

4.1. Exploiting wind resources that are far from demand centers

Unfortunately, many windy areas, such as those in the IMAR and Xinjiang Autonomous Regions, are far from most demand centers. For example, Beijing is located about 500 km and Harbin about 1400 km from an exceptional wind resource at Huitengxile, IMAR. Although coal resources, centered in IMAR and northern Chinese provinces, are also typically far from demand centers, coal can be transported on rail or ship to power plants near demand centers and coal power can be transmitted to demand centers through long distance transmission lines. Wind energy cannot be transported without the use of expensive energy storage such as batteries or hydrogen; in addition, while wind power can be transmitted in the same long-distance transmission lines, the intermittency of the wind power makes for inefficient use of what may be expensive long distance transmission. Combining "oversized" wind farms with long distance transmission lines and large-scale electricity storage systems (Cavallo, 1995) makes it possible to efficiently fill the transmission line and deliver "baseload wind power" to electricity demand centers.

An oversized wind farm is simply one where the peak wind turbine capacity exceeds the peak transmission line capacity. Oversizing increases the transmission line capacity factor because peak winds, and thus the utilization of peak turbine capacity, is infrequent, whereas medium speed winds are more frequent and increased turbine output at medium wind speeds leads to more effective transmission line capacity utilization. Initially, overbuilding leads to a reduction in the cost of delivered electricity, because the reduction in the unit cost of transmission exceeds the cost of electricity spillage. As the number of turbines in the wind farm increases, a point is eventually reached at which the cost of spillage exceeds the reduction in the unit cost of transmission, so that the cost of the delivered electricity begins to rise as more wind turbines are added to the wind farm. Beyond this point, one can still continue to increase the capacity factor of the transmission line with little or no increase in the cost of delivered electricity by adding a peaking power source or an electrical storage system, such as pumped hydro or compressed air energy storage (CAES).

While imported wind turbines are not cost-competitive with coal power in China, it is possible that *local, mass production* of wind turbines in China could be competitive on a lifecycle cost basis, even in northern China, where coal is especially low in cost. As mentioned earlier, the Sino-German technology transfer program hopes to achieve a 50% reduction in cost through local production of 71% of a 5 kW wind turbine, and further cost reductions may be possible with local, mass production. Luo and Zhang (1995) have estimated that if 60% of more of a wind power plant is manufactured in China, the cost can drop to less than 6000 Yuan/kW ($723/kW). Based on a disaggregation of wind turbine costs and local manufacture in China, that a cost reduction of 40% in wind turbine costs, or 5000 Yuan/kW ($600/kW), may be feasible when efforts are made to maximize the extent of Chinese manufacture (Lew *et al*., 1998). Economies of scale of production would help to further reduce these costs.

By exploiting the reduced costs from local production and economies of scale of mass production, and combining oversized wind farms with compressed air energy storage, baseload wind power may be able to compete with coal power in China on a lifecycle cost basis (Lew *et al*., 1998). This is shown in Fig. 7.

This baseload wind power development strategy appears to be well-matched to China's large, remotely sited wind resources. Moreover, because electricity demand is growing rapidly, China could well be the first country to implement this wind energy utilization strategy, a novel approach that requires no new technologies.

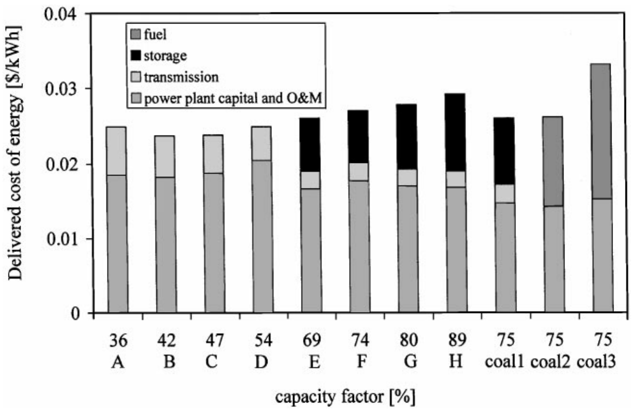


Fig. 7. Cost of electricity for several wind turbine/compressed air energy storage (CAES) configurations, showing the slow increase in cost with increasing capacity factor. For capacity factors up to 54%, storage is not required for a reasonable delivered cost of energy; above that, 350 MW of CAES can increase the capacity factor to baseload levels at modest cost increases. Porous media is assumed to be available for the CAES. The delivered cost of energy for the 1 GW wind (storage) system in Inner Mongolia with a 500 km AC transmission line to Beijing. For comparison, coal power plants are shown for comparison. All coal power costs reflect Chinese production of equipment and flue-gas desulfurization.

Case	Wind (MW)	CAES (MW)	CAES (hr)
A	1000	0	0
B	1163	0	0
C	1350	0	0
D	1800	0	0
E	1800	350	160
F	2130	350	160
G	2220	500	160
H	2460	750	160
Coal1	Inner Mongolia		Dry cooling
Coal2	Beijing		Wet cooling
Coal3	South China		Wet cooling

(Source: Lew *et al*., 1998)

4.2. Technology transfer

Successful transfer of technology for large-scale wind turbines still appears to be elusive in China. Prior to the Ride the Wind Program, Husumer Schiffswerft (HSW), Nordtank (now NEG-Micon), and Bonus had all been involved in technology transfer programs. HSW has cooperatively produced 250 kW machines with China First Tractor and Construction Machinery Corporation. Local content in these machines started at 20% and was slated increase to 80% as the Chinese learned to manufacture large turbine components. A Nordtank joint venture assembly in Urumqi, Xinjiang, was closed down, as training of local workers there proved to be ineffective (Brennand, 1995).

For successive installations of Bonus turbines at the Dabancheng wind farm in Xinjiang domestic component manufacture increased from none to foundation bolts to towers. In 1994, 10 Bonus 120 turbines were made with Hangzhou Generating equipment factory under a technology transfer agreement and installed in Zhurehe, IMAR. Although there were some delays and quality problems, Bonus reported good experience with local manufacturing (Stiesdal, 1995; Wang *et al*., 1995).

In order to develop local production of large-scale wind turbines and thus achieve cost reductions and also decrease dependency on foreign equipment, the Chinese government is trading opportunities to develop wind farms for the transfer of foreign turbine technologies to local companies.

The State Development and Planning Commission (SDPC) began their Ride the Wind Program in March 1996. This program aims to develop local manufacturing capability by supporting sales of 190 MW of foreign wind turbines in exchange for technology transfer. The China First Tractor and Construction Machinery Corporation and Xian Aviation Company are the two local companies which have been selected by SDPC to receive the technology. The first foreign bid was won in 1997 by Nordex Balcke-Dürr, which has accumulated experience through its Shandong, Zhangbei and Nan'ao Island installations. Nordex Balcke-Dürr receives royalties only on the first 100–200 MW of turbines. Xian Aviation Company will then be free to produce the technology themselves (Feifel, 1998). The second bid was recently won by Made, and the Spanish government is supporting these sales through a $200M concessional loan.

4.3. Bilateral subsidies

Development for utility-scale wind power has been an uphill climb for China. One reason is the lack of a commercial wind market. It is estimated that 90% of wind power installations were funded through concessional financing. While capital may be limited in China, the willingness of foreign government to give subsidized loans for the capital cost of wind turbines has eroded the Chinese willingness to pay full cost. The availability of concessional finance has led to limited development in China, with only as much development as could be funded by these subsidies.

In 1988, the Danish government announced new soft loans for $150 million of wind turbines, at zero interest over 10 yr. While the Danish wind industry benefits in the short-term, they may realize that the long-term repercussions outweigh the benefits. For example, after the OECD countries introduced partial concessional financing for Chinese wind power projects in 1994, one Danish wind manufacturer noted that the fledgling commercial market which had existed prior to the soft loans had vanished. As a result, no turbines had been sold on commercial terms in China in 1994 (Buus, 1995). There is a limited amount of bi-lateral, multilateral, and national government funding available, in comparison to the great wind potential and great demand for power. Only the private sector has the levels of funding which can fuel the huge wind development found in Europe, India and North America, and only the private sector can begin to source the amounts needed to seriously exploit the 253 GW of wind power potential. By making soft loans available, foreign governments have impaired development of commercial wind markets and privately financed wind development for the near term.

The bilateral funding is not limited to one government. The Spanish, American, German, and Belgian governments have all supported their wind industry's sales to China[12] (Vaupen, 1999). The availability or possibility of subsidized loans has reduced the Chinese willingness to pay full cost for commercial machines. Unfortunately, because the Chinese are only beginning to produce large turbines, wind power development will be stalled.

In addition to distorting the market and limiting the amount of wind power development, the bilateral subsidies reduce competition and encourage high capital costs. In order to overcome this barrier, the World Bank and Global Environmental Facility are implementing a project to promote the commercialization of wind energy in China through competitive bids for wind farms. For the wind project, the Bank will lend 50% of the total investment with about 7% interest per year and a payback time of 25 years. The World Bank wind projects are planned to total 190 MW, and include development in IMAR, Hebei, Shanghai and Fujian. In addition, the World Bank hopes this project will establish clear and consistent guidelines for power purchase agreements and foreign investment.

Although the donor-driven market is in full swing, the installation of some commercial, private sector projects show the potential to transition out of the demonstration phase of wind power and into a commercial phase. A notable commercial project is the 24 MW wind farm on Nan'ao Island by a Dutch-Chinese joint venture. In this case, the power purchase agreement is structured so that the foreign venture is paid in hard currency and indexed 3% annually for the first 10 yr (Mostert, 1997; Vaupen, 1999).

4.4. Policy and regulatory framework

The lack of domestic technology and the availability of soft loans are not the only reasons why utility-scale wind development in China has been so difficult. One of the main reasons is that there is no clear, fixed policy for wind power sales. Each power purchase agreement (PPA) must be negotiated individually. The power purchase price varies from province to province, as expected for different avoided costs, but in China, the price also can

[12] In a "donor-driven market", the best subsidies win. For example, the World Bank has been packaging a 200,000 solar home systems project for several provinces in China, including Xinjiang province. At the same time, the Dutch government has been supporting subsidized solar home systems projects for several regions, including Xinjiang province. The World Bank project may be unable to compete with the Dutch project and forced to withdraw from Xinjiang province if the Dutch project is implemented. This underscores the problems inherent in a donor-driven market, and at the least, a need for better donor coordination in development assistance.

vary by a factor of two in the same province. Fiscal incentives to promote renewable energy are limited and vary from province to province. The process of securing project approvals from the regional and national government,[13] PPA from the utility, and project financing appears to be difficult, time-consuming and confusing. Utilities want a complete financing package in place before agreeing to a firm power purchase price; or the SDPC may revoke some approvals for projects in which costs have risen because complete financing packages were not in place before approvals were granted (Vaupen, 1999).

Foreign investment is also hindered by the fact that the Chinese have an unstated policy to generally limit returns on investments (ROI) for foreign companies to 15% (Vaupen, 1999). Typical power purchase agreements are negotiated on a cost-plus basis in China, with the ROI added to costs which are passed through to the purchaser. This results in negotiations over the ROI, as the purchaser tries to cut costs. Competitive bid mechanisms for build-operate-transfer (BOT) projects may help to eliminate this problem, by allowing comparisons of total costs for projects which provide a specified amount of power to the grid. In this way, a project can increase their ROI by using a better wind site or more efficient turbine.

In comparison, neighboring India has quite a different story to report. While China is adding to their wind capacity at 50 MW or so per year, the Indian market has been growing by leaps and bounds. Foreign investment flowed into the country and local technological capability grew. Fig. 6 shows the difference in growth between the Chinese and Indian grid-connected wind power development.

India initially tried to promote renewables through government subsidies through certain agencies and technology R&D. While this established a manufacturing base, it did not create a market for the technologies. In 1993, the government switched to fiscal incentives and favorable loans. Markets were opened to foreign investment and companies and the result has been rapid growth in wind capacity until 1997 (Mathur, 1996; Wind Power Monthly, 1998). From the early 1990s onward, private sector projects outpaced demonstration projects, which were the bulk of the early installations.

Although India has successfully installed more wind power than any other developing country and has the fourth highest capacity in the world, her markets have not proven to be sustainable. Growth has stalled recently, first because of political uncertainties surrounding national elections and then by an economic slowdown which led to limited credit and high interest rates. Installed capacity in 1997 was minimal. Moreover, in some cases, performance of existing projects has been poor, partly due to an overestimation of wind resources, inadequate transmission facilities, and poor project design and operation. A key lesson learned was that incentives which encourage investment in wind do not necessarily lead to successful wind farms. This situation was to some degree a replay of the US in the 1980s, when large investment subsidies led to some poorly performing wind farms (Gipe, 1995). As the US did in the early 1990s, India is now moving away from the large *investment* incentives and towards *production* incentives which encourage generation of electricity from wind. While there are still problems to be worked out in India, the result of the liberalized market and a consistent set of fiscal incentives is remarkable.

The State Development and Planning Commission, State Economic and Trade Commission, and Ministry of Science and Technology have developed a New and Renewable Energy Development Program, outlining development of renewable energy sources through technology and infrastructure development and deployment. Total wind power capacity targets for 2000 continue to be 1000 MW and will rise to 3000 MW by 2010. In addition, they are investigating the implementation of incentives for renewable energy.

While the State government considers fiscal incentives, some provinces have already begun to offer their own. For example, Guangdong province reduced the VAT on wind-generated electricity from 17 to 6%. Jilin province, which is currently building its first wind farm, is offering reduced VAT and a three year tax holiday (followed by a 50% reduction of income taxes for an additional two years) (Vaupen, 1999). Despite the efforts of several provinces to issue favorable power purchase prices, investors are still wary because the prices do not escalate with inflation, thus increasing investment risk (World Bank, 1996).

Probably the most important actions that China can take to increase wind power development on a large scale are to put into place a national policy and regulatory framework that invites foreign investment and offers reasonable ROIs, and coordinates donor aid so that foreign governments can provide support to China in a way that allows for competition and maximizes foreign investment. The approvals process should be streamlined; power purchase agreements should be standardized; and fiscal incentives, which are indexed to inflation and which encourage electricity production, should be established.

5. Conclusions

The Chinese renewable energy community has instituted some of the most extensive small-scale renewable

[13] Projects which are less than $30M need only approvals from the provincial planning commission; projects which are more than $30M also need approvals from the SDPC (Vaupen, 1999).

energy programs in either the developing or industrialized world. Among these is the world's largest small-scale wind turbine dissemination effort, led primarily by the local government of IMAR. They have been successful through a well-coordinated effort in targeted R&D, technology transfer from industrialized countries, government-enabled, market-based support to the industry and end-users, and the establishment of infrastructure of training networks and information centers. Promising efforts are currently underway to raise the quality of the wind turbines through technology transfer and the level of service through the use of wind/PV hybrid systems.

Can China build upon these successes to expand large-scale wind power as an alternative to coal? It will be critical to expand the use of utility-scale wind power, if this energy source is to have any impact in offsetting coal use. China is a key player in global climate issues because of its huge coal power use, rapid economic growth, and tremendous population. Development of cost-competitive, clean ways to replace coal power is a challenge to the international community. One possibility may be the generation of baseload power through a combination of oversized wind farms and compressed air energy storage.

The role of the international community is essential in helping to instill competition in the utility-scale markets to reduce wind costs in China; technology can be transferred to local manufacturers; and *sustainable, commercial markets* for wind power can be developed. The key action that the Chinese government needs to take in order to facilitate development of and foreign investment in wind farms is the establishment of a better policy and regulatory framework.

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