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Technology Acquisition and Innovation in the Developing World: Wind Turbine Development in China and India

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Abstract Although China and India rely on coal to fuel most of their electricity generation, both countries are also home to burgeoning wind power industries. India currently leads the developing world in manufacturing utility-scale wind turbines, and China is close behind. This study examines the technology development strategies that have been pursued by the companies Suzlon and Goldwind, India and China's leading wind turbine manufacturers. While the institutional and other barriers present in large, developing countries such as China and India certainly challenge any simplistic notions of energy leapfrogging, an examination of wind turbine development in these countries has shown that substantial technical advances are possible in a relatively short time. While both Suzlon and Goldwind pursued similar licensing arrangements to acquire basic technical knowledge, Goldwind's technology development model lacks Suzlon's network of strategically positioned global subsidiaries that contribute to its base of industry knowledge and technical capacity. This examination of how two leading developing-country firms have acquired and assimilated advanced technologies provides crucial insights into facilitating international technology transfers, which will be an important component of any technological leapfrogging strategy to achieve lower greenhouse gas emissions in the developing world.

Keywords Energy leapfrogging · Technology transfer · Wind power industry

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Introduction

The energy development pathways of China and India are a frequent topic of international attention. In the climate change arena, the current and future energy growth trajectories of the two countries raise concerns about rising greenhouse gas emissions. China has recently surpassed the United States as the largest national emitter of greenhouse gases, and India will soon surpass Russia to become the fourth largest emitter after the European Union. China and India use coal to fuel most of their electricity generation, and both countries have plans to expand their coal power capacity considerably in the coming decade. For these reasons, China and India are perhaps two of the least likely places one might expect to find a burgeoning wind power industry.

While there are many potential benefits to local wind manufacturing, there are also significant barriers to entry into an industry containing companies that have been manufacturing wind turbines for more than 20 years. In developing countries, limited indigenous technical capacity and quality control makes entry even more difficult. International technology transfers can be a solution, although leading companies in this industry are unlikely to license proprietary information to companies that could become competitors. This could be even riskier for technology transferred from developed to developing countries, where an identical but cheaper turbine potentially could be manufactured.

Nevertheless, India and China are both home to firms among the global top-10 leading wind turbine manufacturing companies. India currently leads the developing world in the manufacturing of utility-scale (multikilowatt) wind turbines, and China is close behind. Initiatives by domestic firms, supported by national policies to promote renewable energy development, are at the core of wind power innovation in both countries. This study examines the technology development strategies pursued by Suzlon and Goldwind, respectively India's and China's leading wind turbine manufacturers. It examines how these companies acquired the technological know-how and intellectual property rights associated with their respective wind turbine designs; how the domestic and international contexts in which these companies operate shaped their technology development strategies; and whether differences in their respective technology development strategies contributed to differences in the performance of the companies in the marketplace.

The contributions of this research are three-fold. First, this study explains how Suzlon and Goldwind, two developing-country firms, became leading wind-turbine manufacturers. Second, the study compares the innovation trajectories of the two companies to account for differences in their success. Although Suzlon and Goldwind were established approximately a year apart, Suzlon is far ahead in terms of its global market presence, having exported its turbines abroad to the U.S. and various other countries. Suzlon is already producing a two-megawatt (MW) turbine model, while Goldwind is just beginning to sell its one-MW model. Third, as a contribution to this special issue investigating the sustainability potential of developing-country firms, this study provides insights into the behavior of "green" technology firms in the developing world. The actions of both companies are examined in the context of their national political and regulatory environments, as well as in the context of the global market for low-carbon energy technologies. Consequently, the information presented explores the motivations and circumstances both at the national and global level that may enable developing-country firms to act as agents of environmental sustainability.

Theorizing Developing-country Technology Innovation

This study analyzes empirical cases of successful energy technology "leapfrogging." Energy leapfrogging has been described as a strategy for developing countries to shift away from an energy development path that relies on traditional energy sources, such as fossil fuels, and onto a new path that incorporates the broad utilization of advanced energy technologies—generally those that have been developed within more industrially advanced countries. As a means of climate change mitigation, observers have argued that developing countries need not adopt the dirty technologies of the past—rather, they can "leapfrog" over them, opting instead for modern, clean technologies as an integral part of capacity additions (Goldemberg 1998).

Promoters of the leapfrogging concept generally give the impression that leapfrogging is feasible, provided that it meets some basic conditions, including strong incentives for firms to reduce their environmental impacts, and the participation of transnational corporations in the development process (Perkins 2003). As some studies have illuminated, this optimistic picture of leapfrogging is not generally supported by empirical studies, and therefore meeting the objectives of clean development in industrializing countries will doubtlessly prove more complex and challenging than many would lead us to believe (Gallagher 2006; Van De Vegte 2005). This study weaves together insights from a range of literatures to identify the facilitating conditions for energy technology leapfrogging in developing-country contexts. It draws both from general theories on technology transfer and from the country-specific literatures on technology transfer to China and India.

Technology Transfer

International technology transfer typically refers to the transfer of technology from industrialized to developing countries.[1] The mechanism of transfer is either private-sector arrangements such as foreign direct investment (FDI), licensing, and joint ventures, or bi- or multilateral technology agreements among governments. In the wind technology domain, countries that were not part of the group of early wind turbine innovators—namely Denmark, The Netherlands, Germany, and the United States—have used different strategies to foster the development of their own domestic large wind turbine manufacturing companies. A common strategy has been to obtain a technology transfer from a company that has already developed advanced wind turbine technology. This can be done through a licensing agreement, or developed through collaborative research and development (R&D). Another model includes establishing joint-venture partnerships between foreign and domestic companies in which a technology license is usually transferred. In a third form of technology transfer, no license is transferred and the know-how and intellectual

[1] Although less common, there is a growing recognition of the potential of "south-south" technology transfer (technology transfer between developing countries.)

property associated with the technology remains primarily in the hands of foreign firms. For example, if a foreign-owned firm locally manufactures its wind turbines in China, this may constitute an incomplete transfer: the hardware (technology) without the software (intellectual property rights and know-how). In this situation, the technology physically has been transferred, and the foreign firms may facilitate learning by employing local workers, but it is unlikely that much expertise will end up in the hands of domestic firms.

There is a substantial literature describing the challenges associated with technology transfer in general (Hirschman 1967; Rosenberg and Frischtak 1985; Kranzberg 1986; Goulet 1989; Reddy and Zhao 1990; Mowery and Oxley 1995; Brooks 1995; Nicholson 2000; IPCC 2000), and a growing literature concerning technology transfer challenges that are specific to China (US OTA 1987; Mansfield 1994; Guerin 2001; Miesing et al. 2003) and to India (Kathuria 2002; Vishwasrao and Bosshardt 2001; Kinge 2005; Kumar and Jain 2003). Two challenges to successful technology transfer particularly relevant to India and China are the domestic policy environment and firms' ability to acquire new knowledge.

National Innovation Systems

A complete leapfrogging strategy must include innovation at the receiver's side, which leads to a need to investigate the enabling conditions for technological innovation nationally. The larger domestic context in which the innovative activity is taking place, or what some refer to as the "national innovation system," is likely an important determinant of the ultimate the success of a technology transfer, particularly concerning a country's ability to adopt an externally sourced technology and apply it internally (or its "absorptive capacity"). This transfer includes the policy structures and institutions that contribute to the development and diffusion of new technologies (Lundvall 1992; Metcalfe 1995; Johnson and Jacobsson 2003). Studies have emphasized how the organization and distribution of innovation-related activities often differ fundamentally between developed and developing countries (Liu and White 2001), or as distinguished by regional characteristics (Freeman 1995), with some similarities among the Asian "late industrializing countries" (Amsden 2001).

In the field of innovation economics, there is a growing characterization of how transnational firms may work outside of national innovation systems, and may eventually render them obsolete (Patel 1995). The rise of the multinational corporation with global presence has created a new model for innovation through the global generation of technology. As described by Archibugi and Michie (1995), multinational firms now take advantage of global experience to shape their innovative activity, rather than relying on a national innovation system. They described this as the third in a three-stage process of "technological globalization" which began with global exploitation (firms accessing global markets), then transitioned to global technological collaboration (international technology transfers), and has evolved to a stage in which technological innovation is conducted within the global network of the multinational firm. This process of transition suggests that a conducive national innovation context is necessary but not sufficient for successful technology transfer. Firms themselves must play an active role in the acquisition of new technology and know-how.

Learning Networks—Regional and Global

Regional network-based industrial systems have been identified in many parts of the world and in many historical periods. Characterized as horizontal networks of firms in which producers deepen their own capabilities by engaging in close, nonexclusive relations with other specialists in their field (Saxenian 1994), or "learning by interacting," learning networks have likely played a large role in the development of wind turbine technology over time. The wind industry—characterized by its small number of firms, highly specialized technology, and geographically specific hubs of innovation (often near wind development locations)—is likely to exhibit many of the characteristics of the regional learning networks that have been observed in other industries and locales. Studies have hypothesized that learning networks are a crucial determinant in a firm's ability to obtain success with a new technology (Van Est 1999; Kamp et al. 2004; Karnoe 1990). In the innovation systems of Denmark, where "the focus was on knowledge transfer between turbine producers, turbine owners and researchers... conditions for learning by interacting were optimal; in this way, wind turbines were successfully, though slowly, scaled up and improved" (Kamp et al. 2004). In contrast, the U.S. wind industry has been characterized by a lack of collaboration, and actions taken by firms to impede information flow among firms, that "inhibited the transfer of hard-won experience" (Gipe 1995).

This research identifies national-level technology innovation systems and firm-level learning networks as central to the success of Suzlon's and Goldwind's wind technology innovation trajectories. The study examines the national innovation systems in which Goldwind and Suzlon have operated, with a particular focus on the political and policy drivers supporting and hampering domestic wind power industry development in India and China, respectively. The study also maps the learning networks in which both firms are embedded. It explains why the two companies chose to acquire foreign technology in the way they did, and how the technology transfer models utilized influenced the technological success of the respective firms.

Case Selection and Data Collection

As Steinberg (2001) states, there is a "widely held [assumption] that developing countries are too preoccupied with the challenges of poverty and development to give serious consideration to environmental protection;" an assumption that does not always hold true but the rhetoric persists, particularly in the international climate change arena. It therefore follows that sustainability practices and leadership in green technology innovation are also less likely to be found in the developing world, as a wide body of literature has portrayed the link between environmental regulation and innovation behavior in environmental technologies (Porter 1991; Norberg-Bohm 1999; Frondel et al. 2004). Furthermore, as the two largest coal producing and consuming countries in the developing world, China and India may represent the least likely places in which renewable energy technology industries might be expected to thrive.

One rationale for investigating wind turbine manufacturing in India and China is to confirm that the above statements no longer represent the empirical reality exhibited in the developing world. Although the challenges of poverty and development certainly remain, environmental concerns are being integrated increasingly into national development and poverty alleviation strategies, as are energy security concerns. Renewable energy is not just viewed as an environmental solution, but also as a strategy for energy diversification that contributes to security, and as an industrial diversification strategy into a major global growth sector. Following this line of thinking, these cases represent least-likely case studies since, if the successful development of green energy technologies is occurring in the two developing countries with the largest commitment to coal utilization in the world, it may in fact be occurring (or should be occurring) elsewhere in the developing world as well (George 1979, Sartori 1991, Odell 2001).

From an empirical perspective, the cases represent the leading wind turbine manufacturers from two developing countries that play crucial roles in today's energy and climate debates, which upon initial inspection have taken two different technology development pathways in the wind power sector. Due to the scale of energy use and expected future growth in these countries, these cases represent perhaps two of the most important applications for technological leapfrogging if this model for acquiring wind power technology has wider applications within other industries and sectors in these countries. Consequently, discerning the differences in approaches between these two countries may provide useful lessons for future firms in both national contexts (George 1979).

Although India and China are key places to explore these interactions, they certainly do not represent the entire diversity of the developing world, and there are distinct differences among countries that make the lessons learned in these cases potentially difficult to apply elsewhere. An important distinction is that the technology transfer models used in China and India may not be easily replicable in less developed countries with less indigenous technical capacity within their borders. China and India, while both developing countries, are perhaps more accurately categorized as rapidly industrializing or emerging economies. GDP growth rates in the last few years (2001–2005) averaged 7% annually for India and 9.5% for China (UNDP 2006). Countries with different levels of economic development will have different technology transfer goals and will use different transfer models; for example, countries looking to obtain access to advanced, foreign technology that are not hoping to assimilate the technology into their local manufacturing base will pursue different models of technology transfer from those that are.[2] While many developing countries are encouraging the utilization of renewable energy technology, China and India are promoting utilization as well as the development of robust technology industries.

This study also focuses on one specific type of renewable energy technology: wind turbine manufacturing. Many proponents of the case study research method have written that much can be learned through in-depth studies of specific renewable energy technologies, as lessons learned can often apply to other regions in that country, or to other countries. For example, the Intergovernmental Panel on Climate

[2] In this situation, IPR concerns are less substantial, and foreign companies can continue to sell their technology without risk of local competition. However, the major barrier to technology transfer in such situations is likely to be the technology cost.

Change, in its publication, *Methodological and Technological Issues in Technology Transfer*, included a section highlighting specific case studies "to demonstrate the distinctive problems and special opportunities that managers and implementers are likely to encounter in dealing with technology transfer" (IPCC 2000). Wind turbines provide a model of a mature, low-carbon energy technology with its origins in the developed world, which is now also widely used in the developing world. Consequently wind turbine development in the developing world provides an example of North–South technology transfer that has enough years of experience to provide lessons on the successes and failures of such transfers. The empirical data for this study were gathered through a combination of semi-structured interviews and informal conversations conducted in the United States and China with government officials, wind turbine company representatives, academics, and other stakeholders in the wind industry from 2003 to 2007. Most of the information supporting the development of the case studies was collected from an investigation of primary source information released directly by wind power technology companies, and from secondary source literature on the global wind industry and market performance of various companies, including news articles, articles from wind industry publications, and conference presentations and proceedings.

Data collection focused on firm-, national-, and international-level dynamics of wind technology innovation in India and China. While differences in international context and national innovation systems other than at the firm level most certainly play a role in ultimate success of technology transfer, many of these international and national structures are manifested at the firm level, therefore the examination of the global context and national innovation systems primarily focuses on how they have directly influenced firm decisionmaking. Moreover, the analysis does not discuss in detail India and China's differing intellectual property rights regimes. Studies find that there is little relationship between the strength of the intellectual property regime in the recipient country and the preferred mode of technology transfer (e.g., license vs. FDI), although there is some variance across industries (Mansfield 1994), or as a result of the nature of the technological knowledge at stake (e.g. rival vs. non-rival) (Marcusen and Venables 1999).

China's and India's Wind Power Industries in a Global Context

At the end of 2006, some 74 GW of wind power capacity were installed worldwide. Wind power is currently the fastest growing energy source in the world, with growth rates of over 20% annually. As illustrated in Fig. 1, Germany leads the world in wind power utilization, followed by Spain and the United States. India has about 8% of the world's total installed wind power capacity with 6,228 MW, and China about 3% with 2,588 MW.

Modern, utility-scale wind turbine technology originated from R&D that began in the late 1970s, most notably in Denmark, The Netherlands, Germany, and the United States. While Danish manufacturer Vestas still has the largest global market share of any one company, the German manufacturers encompass a larger market share in aggregate, followed by Spanish and U.S. manufacturers. About 75% of global wind turbine sales come from only four turbine manufacturing companies: Vestas, Gamesa, GE, and Enercon, as illustrated in Table 1. Indian and Chinese manufacturers still lag these

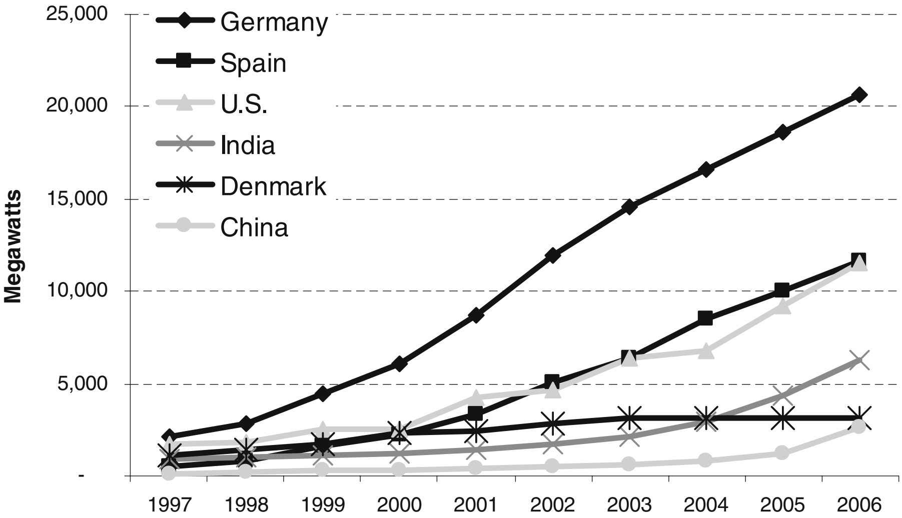

Fig. 1 Wind power installations 1997–2006, selected countries. The author compiled wind power installation time series data from a variety of sources, including in-country wind energy associations, government reported data, *Windpower Monthly* (WPM, March 2007), BTM 2007, and Wiser and Bolinger 2007

developed-country manufacturers, but their market share has been steadily increasing in recent years. Indian manufacturers obtained just over 8% of global market share in 2006, while Chinese manufacturers had 3%. China's leading wind turbine manufacturer, Goldwind, entered the top 10 manufacturers list for the first time in 2006.

China and India are the only developing countries with notable wind turbine manufacturing industries. Both countries have relatively advanced manufacturing bases which are the result of multiyear, aggressive policy campaigns to support domestic wind power development. The rest of this article describes how firms in both countries came to be among the global top 10 wind turbine manufacturers and compares Suzlon's and Goldwind's divergent innovation trajectories. It begins by describing national energy and policy in both countries and then shifts to a detailed account the growth of Suzlon and Goldwind.

Wind Power Development in China and India

Wind in the National Energy System

India and China have excellent wind resources, and the promise of years of wind turbine sales has kept overseas turbine manufacturers closely involved in all three markets.[3] Yet fundamental risks in the Indian and Chinese markets remain, making

[3] Both countries have vast wind resource potential; China has an estimated 1,000,000 MW of total exploitable wind resources, including about 250,000 MW on land and 750,000 MW offshore, although the amount that is technically and economically viable may closer to 300,000 MW overall (SDPC 2000). Estimates of India's wind resources are less readily available; one estimate puts the range from 20,000 to 45,000 MW (WEC 2001) though this range is likely quite conservative.

Table 1 Largest wind markets and domestic wind companies

Country	Cumulative wind capacity (2006) (MW)	Leading domestic wind companies (Global rank in 2006)	Global market share of manufacturers[a] (%)	Installed turbines made by a domestic company (2006) (%)
1. Germany	20,652	Enercon (#4), REpower (#8), Nordex (#7), Fuhrlander (#14), Siemens (formerly Bonus) (#6)[b]	30	55
2. Spain	11,614	Gamesa (#2), Ecotecnia (#12), EHN/Ingetur (#11)	18	76
3. United States	11,575	GE Wind (#3)	16	37
4. India	6,228	Suzlon (#5)	8	52
5. Denmark	3,101	Vestas (#1)	28	100
6. China	2,588	Goldwind (#10)	3	39
7. Italy	2,118	None	0	0
8. United Kingdom	1,967	None	0	0
9. Portugal	1,716	None	0	0
10. France	1,585	None	0	0
Total World	74,246			

Sources: BTM 2007; Wiser and Bolinger 2007; company financial reports, and authors' calculations. The home country listed is based on the country in which the current ownership is primarily based, although many wind turbine manufacturing companies are increasingly global in their reach.

[a] The total shares sum to more than 100% due to discrepancies between supplier information and national installation figures.

[b] Bonus, a Danish company, was purchased by Siemens, a German company, at the end of 2004, so the current company (Siemens) is listed as a German company.

some investors reluctant to enter. In addition, both countries have been undergoing varying degrees of power sector reforms, and the full impact of such reforms on wind power development is still uncertain.

China's vast electricity sector faces critical challenges surrounding regional resource disparity, and the growing complexity of coordinating supply with demand. Although China currently ranks second in the world in both installed generating capacity and annual power generation, per capita electricity consumption is only 10–15% that of developed countries, thus is expected to increase substantially as China's economy grows. Growth rates for new electricity generation capacity have increased substantially since 2003, and 2006 was the largest capacity addition yet. Most of this new capacity is from coal power plants (about 80%). This continued reliance on coal not only has tremendous local and global environmental implications, but also poses a huge technical challenge for a sector plagued by inefficient state-owned enterprises, aging capacity and transportation bottlenecks. Despite constant discussions of a national, interconnected power grid, China still relies on often unconnected, regional grids that vary in quality and reliability throughout the country. China's booming economic development in its eastern coastal regions has resulted in supply disruptions and boom and bust cycles in planning for power sector capacity additions.

Wind is still a small share of China's total electricity generation—less than 1% nationally, with about 2.66 TWh produced in 2005. The highest saturation of wind power is found in the Inner Mongolia and Xinjiang Autonomous Regions due to the relatively small total power demand and relatively large amount of installed wind power capacity in these provinces. Despite excellent wind resources, wind power's total percent contribution to electricity generation will probably remain low, particularly in the eastern coastal provinces. Even though wind power capacity is growing very quickly, capacity in other generation technologies is growing more. Wind energy could still play a crucial role in meeting demand, especially in eastern coastal China where wind resources are abundant, and electricity demand has seen unprecedented growth rates in the last few years.

India is in a similar situation to China, where electricity demand is growing rapidly, and most of this demand is being met with domestic coal resources. The demand for electricity is projected to more than double in the next 10 years, and projections are even higher if economic growth rates increase.

Less than 2% of India's electricity generation comes from wind power (with about 7.66 TWh produced in 2005), despite record growth rates in new wind capacity of 40% annually for the past 3 years. India had 137.5 GW of installed electricity capacity at the end of 2005, of which wind comprised 3%. The vast majority of India's wind power is located in two states with relatively aggressive wind power support policies: Tamil Nadu (with over 51%) and Maharashtra (with 20.5%). Tamil Nadu is also a wind turbine manufacturing base, home to both Indian and Danish system and component manufacturers.

Despite aggressive forecasts for future development and substantial wind resources, future growth may be limited by a lack of transmission capacity (particularly in Tamil Nadu), and by voltage and reliability problems with the Indian power grid. Problems with inaccurate resource data, poor installation practices, and poor power plant performance have also slowed wind power development in India.

National Policy Support for Wind Power

China and India have undertaken extensive policy support schemes to catalyze wind power development, in turn creating market opportunities for their own domestic turbine manufacturers. While some policies aim to create a demand for wind power, others specifically aim to promote the development of local wind power technology industries, as discussed below.

India has been an active supporter of wind development since the 1990s, and has a government ministry exclusively devoted to renewable energy promotion: the Ministry for Non-Conventional Energy Sources (MNES). However, India's policy support has been somewhat unstable over the years, which led to uneven wind development in the 1990s.

Recent years have seen the market rebound, driven in part by more policy stability and more aggressive support mechanisms. For example, India's Electricity Act of 2003 requires all state-level energy regulatory commissions to encourage electricity distributors to procure a specified minimum percentage of power generation from renewable energy sources. Many states therefore have aggressive renewable energy targets and policy support mechanisms in place; for example, the Karnataka Energy Regulatory Commission has stipulated a minimum of 5% and maximum of 10% of electricity from renewables, and the Madhya Pradesh Energy

Commission has stipulated 0.5% of electricity from wind power by 2007. The state government of Maharashtra has implemented a feed-in tariff for wind electricity, which means wind power producers are guaranteed a long term contract for their power at a subsidized price that declines over time. Maharashtra has also imposed a small, per unit charge on commercial and industrial users to be used in support of nonconventional energy projects. In Gujarat, the government has signed agreements with Suzlon, NEG Micon (now Vestas), Enercon, and NEPC India to develop wind farms on a build–operate–transfer (BOT) basis, with each manufacturer given land for the installation of between 200 and 400 MW in the Kutch, Jamnagar, Rajkot, and Bhavnagar districts (WPM March 2004:57).

Early wind policy in India included the National Guidelines for Clearance of Wind Power Projects implemented in July 1995 (and further refined in June 1996), which mandated that all state electricity boards take the necessary measures to ensure grid compatibility with planned wind developments. Financial incentives were offered as well, with 100% depreciation of wind equipment allowed in the first year of project installation, along with a 5-year tax holiday (Rajsekhar et al. 1999).

More recent Indian polices have been directed at encouraging local wind turbine manufacturing. For example, the government has set customs and excise duties that favor importing wind turbine components over complete machines. India has also developed a national certification program for wind turbines administered by MNES and based on international testing and certification standards to support the development of domestic turbine manufacturers. By 2006, India had reached 6,228 MW of installations, surpassing its long-held target of 5,000 MW of wind capacity by 2012 several years early (WPM March 2006:44).

The development of large-scale wind farms in China has been invigorated in the past few years with the introduction of the government's wind concession program. In this program, government-selected sites are auctioned off through a competitive bidding process to potential wind project developers (Wind Concession Group 2003). To promote the use of locally manufactured wind turbines, a local content requirement has been placed on the developers of the concession projects mandating that 70% of the turbine content used be made in China.[4] Approximately 4,000 MW of new wind power capacity is expected to be installed through the concession process by 2010. The wind concession model was further promoted by China's 2005 National Renewable Energy Law and in the subsequent power pricing regulations that were released in 2006. The Renewable Energy Law stipulates that concession-based pricing be used for the majority of wind power development in China, although in some cases negotiated feed-in tariff or other fixed price contracts are being agreed to for discrete projects.

The 70% local content regulation essentially has forced wind turbine manufacturers wishing to sell to the Chinese market to establish China-based manufacturing facilities to locally source its turbines. Yet many of the foreign-owned companies that have done this have opted to not partner with Chinese-owned companies except for some smaller components, and have not transferred know-how or intellectual property rights as a license. Although Chinese-owned technology (in addition to

[4] Local content is generally calculated according to cost, therefore 70% local content represents domestically produced components totaling 70% of the wind turbine cost.

China-produced content) is not an official requirement for selecting wind concession projects, Chinese-owned manufacturers like Goldwind have dominated the selection process thus far (WPM November, 2006:27).

Several other government programs have encouraged wind turbine manufacturing in China, including the 1997 “Ride the Wind Program” that established two Sino-foreign joint ventures to manufacture wind turbines with limited success (MOST et al. 2002). In addition, the Ministry of Science and Technology (MOST) has subsidized wind energy R&D expenditures at varied levels over time, beginning most notably in 1996 with the establishment of a renewable energy fund (MOST et al. 2002; Liu et al. 2002). MOST had also supported the development of megawatt-size wind turbines, including technologies for variable pitch rotors and variable speed generators, as part of the “863 Wind Program” under the Tenth Five-Year Plan (2001–2005). China has a national target to achieve 30 GW of wind power by 2020, and is well on its way toward meeting this ambitious goal.

Wind Turbine Technology Companies: Suzlon and Goldwind

Suzlon

Suzlon, an Indian-owned company, emerged on the global scene in the past decade, and is proving itself to be a worthy competitor among the more established wind turbine manufacturers. As of 2006, it had captured 8% of market share in global wind turbine sales—a modest share, but one that has been increasing annually. Even more impressive, is the company’s success in its home market. Suzlon is currently the leading manufacturer of wind turbines for the Indian market, holding 52% of the market share in India (Fig. 2). Its success has made India the developing-country leader in advanced wind turbine technology.

The company is owned by a family that diversified into the wind energy business from the textile industry, incorporating the company in 1995. Within 5 years, it had made the list of top 10 wind companies and has remained there since. Investors include two major American investment funds, City Group and Chryscapital, which each injected $25 million into the company (WPM October 2004:25). In September 2005, Suzlon went through an initial public offering in which requests to purchase its equity shares were reportedly five times oversubscribed.

Not just an equipment supplier, Suzlon is also a full wind farm project developer and operator. Its varied services are offered by its associated company subsidiaries that also cover specific regional markets. Suzlon’s wholly owned subsidiaries include technological development centers in Germany and The Netherlands, a rotor blade manufacturing company (Suzlon Energy B.V) in The Netherlands, a U.S. market subsidiary (SWECO), and an Australian market subsidiary (Suzlon Energy Australia Pty Limited). A representative office in Beijing and manufacturing facility in Tianjin have also been set up in China to expand Suzlon’s presence in the Chinese market. In 2004, Suzlon established its international headquarters in Aarhus, Denmark, strategically selecting Denmark due to its base of wind energy expertise and extensive network of components suppliers (WPM October 2004:25). Placing

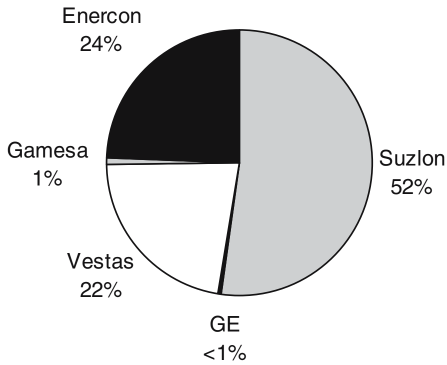

Fig. 2 Indian wind turbine market shares, 2006. Note: 1,778 MW total capacity. Source: BTM 2007

the international headquarters in Denmark was timely, since in 2004, many former workers for the leading Danish wind companies, Vestas and NEG Micon, had been laid off in conjunction with the merger and streamlining of the two companies. Suzlon Group headquarters is still located in Pune, India, and the Global Management Center is located in Amsterdam, Holland.

Most of Suzlon's manufacturing facilities are still located in India, where the company has increased access to capital, and to low manufacturing and labor costs, giving it an edge over competitors manufacturing turbines in higher cost regions such as Western Europe. Within India, facilities typically are located closest to states that the company believes offer the best wind energy development potential. The firm maintains that it still views India as its key market, but is actively exploring growth opportunities overseas. It has plans for extensive international expansion in the next few years, with targeted markets including North America, Europe, China, and Australia. Its wind turbines are already being exported to the United States, Europe, Australia, South America, and China.

Suzlon obtained wind turbine technology expertise in various ways. In 1995, it entered into a technical collaboration agreement with a German company, Südwind GmbH Windkrafttanlagen, and subsequently an agreement with Südwind Energiesysteme GmbH (Südwind) which took over the former company in 1996. The new agreement called for Südwind to share technical know-how relating to 270, 300, 350, 600, and 750 kW wind turbines, in return for royalty payments for each wind turbine sold over the course of 5 years from the starting date of the agreement: September 30, 1996 (Red Herring 2005). In 2001, Suzlon obtained a license to manufacture rotor blades from Aerpac B.V, and entered into an agreement with Enron Wind Rotor Production B.V. in which Suzlon made a one-time payment to acquire the necessary moulds, production line, and technical support to produce another model of rotor blades in India.

Suzlon currently offers wind turbines that range in size from 350 kW to 2.1 MW.[5] The company's manufacturing strategy has been to build upon the licensing

[5] Models include 350 kW, 950 kW, 1 MW, 1.25 MW, and 2.1 MW turbines.

agreements described above with its own research and development, and to manufacture as many wind turbine components as possible in-house. The firm believes that increasing its in-house manufacturing capabilities will help them to lower wind turbine costs by giving them greater control over the supply chain, and enable quicker and more efficient assembly for faster delivery times to customers (Red Herring 2005). This strategy of developing integrated manufacturing capability is particularly aimed at supporting high-growth regions, including India, China, and the United States. The strategy also allows Suzlon to respond to local demand and not have to rely on a supply chain of components suppliers to ensure turbine orders. It also allows the company to cut logistics and transaction costs since fewer parties are involved along the chain. In particular, the integrated wind turbine manufacturing facility in Tianjin, China, and rotor blade manufacturing facility in the Pipestone, United States are examples of Suzlon's strategy to support high growth regions with dedicated delivery capability. The Tianjin facility has an annual manufacturing capacity of 600 MW (Suzlon.com 2007), but production costs are reportedly still lower at the Indian facility due to lower labor costs (Soares 2007b).

Suzlon's manufacturing capabilities include rotor blades for its larger turbines (1 MW and larger), tubular towers, control panels, and nacelle covers. In 2006, Suzlon purchased Hansen, the second largest gearbox manufacturer in the world, expanding its access to gearbox technology. This deal marked the second largest foreign corporate takeover by an Indian company in any industry. Some components not manufactured in-house include blades for some of the smaller turbine models and a few minor components, but recent expansion of gearbox and generator manufacturing means that Suzlon's supply chain is becoming increasingly comprehensive. In 2005, the firm began manufacturing generators through a subsidiary, Suzlon Generators, of which it owns 74.9% and is a joint venture with Elin EBG Motoren GmbH of Austria. Suzlon also has an arrangement with Winergy AG, the leading gearbox supplier in India, which allows for the use of domestically manufactured gearboxes, while it continues to work to advance its own technology. Most recently, in May 2007, Suzlon acquired German manufacturer REpower for approximately €1 billion (which had licensed wind turbine technology to the Chinese manufacturer Goldwind).

Research and development activities at Suzlon are currently focusing on the design and development of new wind turbine models (focusing on a gearless 1.25, 1.5, and 2.1 MW capacity models), upgrading current models, and advancing rotor blade technology to improve efficiency. Its research center, based in The Netherlands, is located there specifically to take advantage of Dutch expertise in aerodynamic rotor blade design and material sciences, while the German site is taking advantage of German wind turbine engineering capabilities, focusing on gearbox prototypes (Red Herring 2005). This model of establishing R&D centers in the middle of regional learning networks related to a specific technical expertise is a practice that other wind turbine or components manufacturers with global presence (e.g. Vestas, Gamesa, and GE) have experimented with as well. However, these companies have relied primarily on regionally differentiated expertise within their own corporations, and have not established the extensive international partnerships that Suzlon has such as licensing arrangements, R&D centers, and the joint manufacturing ventures described above (Table 2).

Table 2 Suzlon's international activities

Location	Activity
India	Group headquarters; manufacturing of turbines, rotor blades, gearboxes (planned), generators, control systems, towers
Germany	Technology development (gearboxes), cooperation with REpower (planned)
Netherlands	Global management center, technology development (rotor blades)
China	Manufacturing of turbines, rotor blades, control systems, generators (planned), gearboxes (planned)
USA	Manufacturing of rotor blades
Belgium	Manufacturing of gearboxes (with Hansen)
Austria	Joint venture to manufacture generators
Denmark	International headquarters
Australia	Sales
Portugal	Sales
Brazil	Sales

Sources: Soares, 2007a; WPM, October 2004:25; Suzlon.com 2007.

Goldwind

Goldwind has recently emerged as the leading Chinese wind turbine manufacturer. The company currently holds 2.8% of market share in global wind turbine sales, reaching the top 10 for the first time in 2006. Within China, it captured 31% of sales in 2006 (Fig. 3). The company is rapidly expanding production, and has been benefiting from Chinese government policies that promote the utilization of domestically manufactured wind turbines in China's wind farm projects (described in the previous section). In 2006, Goldwind installed 442 MW—by far its largest annual installation to date. Thus far, the company has only supplied the Chinese market, and has not yet exported any turbines outside of China.

Xinjiang Goldwind Science and Technology Company Limited (Goldwind/*Jinfeng*) is a subsidiary of the Xinjiang Wind Energy Company (XWEC) and was established in 1998. It is based in Urumqi in Xinjiang Autonomous Region in northwest China, the first site of large-scale wind power in China. Goldwind, a fully Chinese-owned company, is also 55% state-owned, and receives research and development funds from the Xinjiang Science and Technology Commission.

Goldwind sells 250, 600, and 750 kW turbines, and more recently is supplying a 1.2 MW turbine. It first obtained its wind turbine technology through purchasing a license from Jacobs, a small German wind turbine manufacturer that has since been purchased by REpower, to manufacture 600 kW wind turbines. The license commands a €5,000 royalty[6] per machine produced (Brown 2002). Subsequently, Goldwind also obtained a license from REpower for its 750 kW turbine, and a license from another German company, Vensys Energiesysteme GmbH for a gearless 1.2 MW turbine. The terms of the REpower license prohibits Goldwind from exporting its turbines outside of China. When Vensys developed a low wind speed

[6] 10,000 DM was the amount specified in the arrangement; the conversion to Euros is an estimate.

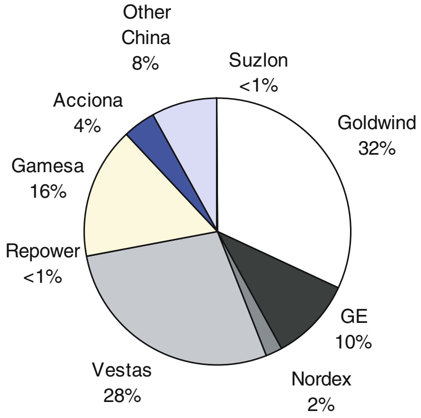

Fig. 3 Chinese wind turbine market shares, 2006.
Note: 1,337 MW total capacity.
Source: BTM, 2007; WPM, March 2007

version with a larger 64 m-diameter rotor that increased output to 1.5 MW, Goldwind acquired the license for that turbine as well. The company is currently working with Vensys to produce 2.0 and 2.5 MW turbines with a view toward offshore applications.

Goldwind has produced more than 100 of its 600 kW wind turbines for use in China. In 1998, XWEC's turbines contained 33% local content, and by the next year, the share of locally manufactured materials had increased to 72%. It was previously estimated that once China obtained the capability to manufacture blades, at least 96% of wind turbines could be manufactured locally. Since these estimates, at least two companies have begun to exclusively manufacture turbine blades in China: Baoding and LM Glasfiber, as have several international turbine manufacturers (including Suzlon) (Composites-Asia 2007). Goldwind reportedly now uses locally manufactured generators, gearboxes, control systems, blades, yawing systems, hubs, and towers for its turbines, while purchasing several of its components from domestic suppliers (Yu and Wu 2004) so it should be approaching 100% local content. Quality and reliability among Chinese suppliers are still a problem, particularly for key components such as rotor blades, gearboxes, generators, yaw systems, and electric control systems. A technology certification program recently established by the Chinese government hopes to increase in quality of locally made components, and help to boost the image of Chinese-made turbines, which are still thought to be less reliable than foreign-made turbines. Goldwind's 600 kW turbine was certified under the ISO 9001 quality certification system in September 2000, and is thought to be one of the most reliable Chinese made models available.

Since 1996, Goldwind has pursued a business model that allows it to implement "modern foreign technologies," while promoting its own technological advancement, with the goal of creating new ideas and eventually gaining benefit from its own products and gaining proprietary results from research and development (Yu and Wu 2004). The firm believes strongly that holding trademarks and property rights improves "progressive production engineering," as well as "sales of the products without geographical boundaries" (Yu and Wu 2004). It recognizes that patents in particular have been used in the wind industry to defend market share; a famous example is the U.S. patent for variable speed turbine technology acquired by GE after its purchase of Enron Wind, serving to limit competition in the U.S. wind turbine market.[7] Perhaps hoping to use a similar strategy in the Chinese marketplace, and recognizing its role as the leader in wind turbine innovation in China, Goldwind is ensuring that it registers for patents for all newly developed products as soon as possible. It is also playing a watchdog role to ensure that other domestic companies do not attempt to register for similar patents.

In addition to its license arrangements, Goldwind works to improve its technical capacity by sending its employees abroad to obtain advanced training. The company reports that two-thirds of its staff has already attended events for technical exchange or further training by foreign companies or institutes, and several high-level managers have been sent abroad to participate in MBA programs. In addition, as Goldwind expands it is reforming its stock ownership policies to allow employees to be shareholders, hoping to further encourage employee commitment by giving them a share of the company's future profit and assets.

The firm received at the end of 2003 a high-profile order to supply one of the first two government wind concession projects, the Huilai project in Guangdong province. The concession tenders highlighted the fact that Goldwind could offer turbines for about 25% less than the price that was offered by the European manufacturers selling in China, making its turbines particularly attractive to developers trying to win the concession projects by bidding the lowest possible tariff price. Goldwind's selection for the 2003 Guangdong project—and because it was selected over several foreign turbine manufacturers—was a key turning point in the company's market credibility and has resulted in increased publicity for the company.

Goldwind has taken several strategic investors to raise capital, including some venture capital firms. In addition, it announced in April 2006 that it plans an initial public offering, with reports speculating that after the Suzlon IPO performed very well, as did the IPO of China's leading solar equipment manufacturer, Suntech Power, in December 2005, that Goldwind hoped to follow suit (LeeMaster 2006). Despite reports during the past year that Goldwind would have a U.S.-based IPO, or a Hong Kong-based IPO, it reportedly has decided against either and plans instead to list in China (Leung 2006; Hua 2007).

The firm will probably continue to lead the Chinese market in coming years. It currently has orders worth 9 billion CNY and recently signed a long term strategic agreement with LM Glasfiber's China division to supply blades for its 1.5 MW turbines over 6 years, as well as to develop blades for its next generation of turbines 2 MW and above for both onshore and offshore applications (WPM March 2007). Although Goldwind may well be able to rely on the expansive Chinese market for years to come, it is reportedly considering exporting its turbines overseas. The company has a goal of becoming the eighth largest global producer of wind turbines by 2010.

[7] In 1995, U.S. Windpower sued Germany's Enercon for patent infringement and won, preventing Enercon —a major competitor—from selling its variable speed technology in the U.S. (WPM, May 2003:30). Since purchasing Enron in 2002, GE has filed similar patent infringement suits in Europe and Canada, and recently in China (WPM, May 2003:29).

Explaining Successful Wind Turbine Technology Transfer and Innovation

The Suzlon and Goldwind cases share certain distinguishing characteristics. Both firms benefited from a supportive national policy environment for wind energy development. Both firms also successfully used licensing as a mode of international technology transfer. The key difference distinguishing the two cases are the learning networks in which the Chinese and Indian wind turbine manufacturers operate, and particularly the variation in how each firm accessed global networks, providing further empirical evidence that access to such networks is highly valuable for emerging wind turbine manufacturers.

National Innovation and Policy Contexts

Both China and India have excellent wind resources and aggressive, long-term government commitments to promote wind energy development. Both countries have been supporting wind energy for more than 10 years through a variety of policy mechanisms. Some of the early support mechanisms in China and India, in particular, led to market instability as developers were faced with regulatory uncertainty, especially concerning pricing structures for wind power. In the early years of wind development in China and India, difficulties also resulted from a lack of good wind resource data, and a lack of information about technology performance stemming from little or no national certification and testing.

Policy reforms in the electric power sectors of both countries, combined with national legislation to promote renewable energy, has led to a series of regional renewable energy development targets in India, national targets in China, and additional financial support mechanisms for wind in particular. There are two key differences in the policy support mechanisms currently used in China and India: (1) China's recent reliance on local content requirements to encourage locally sourced wind turbines, which does not exist in India, and (2) India's use of a fixed tariff price for wind power, versus China's reliance on competitive bidding to set the price for most of its wind projects.

The local content requirement in China has encouraged several foreign-owned companies to shift their manufacturing to China. Yet the primary beneficiary of this policy to date has been the Chinese-owned turbine manufacturer that could meet the local content requirements before the other companies could—namely Goldwind. In regard to pricing policies, several Indian states have adopted feed-in tariffs for wind electricity, while such a policy has yet to be adopted wide-scale in China.[8] Many studies have cited feed-in tariffs as the most effective policy mechanism for promoting wind power development due to the stability and regulatory certainty it provides (Mitchell et al. 2006; Sijm 2002; Lewis and Wiser 2007). The difference in pricing policies are most likely to affect the stability of each country's domestic wind market, and it appears that India's fixed tariff structure has been most successful in

[8] Despite some indications that the Chinese government would implement a nation-wide feed-in tariff program, it instead based the pricing structure for wind power on a competitive bidding model in the 2006 pricing regulations of the renewable energy law (WPM, February 2006:25). Certain provinces (namely Guangdong) and projects have continued to utilize fixed feed-in tariffs.

providing this stability (reflected in its large annual capacity additions in recent years). Since each country has used both forms of pricing structure over time, it is difficult to draw a direct relationship between the growth occurring in India and China and their respective pricing policies.

Although both countries have manipulated customs duties and related taxes to promote the use of domestically manufactured wind turbines or components, India has generally been much more hands-off than China in promoting local wind turbine manufacturing by not mandating the use of local content in domestically installed wind turbines. India's local manufacturing industry seems to have emerged organically as companies shifted their facilities to India to meet the local market demand. China has not experienced the same magnitude of annual capacity additions as India, and is still several thousand megawatts behind India in terms of total installed capacity.

Technology Development Strategies

An examination of the technology development strategies of Suzlon and Goldwind shows several similarities in licensing intellectual property, as well as some key differences regarding the globalization of operations and access to global and local learning networks.

Licensing IPR

Although there are several technology transfer models available to a company looking to enter the wind industry, both Suzlon and Goldwind opted to pursue multiple licensing arrangements with established, although somewhat second-tier, companies. The acquisition of technology from overseas companies is one of the easiest ways for a new wind company to quickly obtain advanced technology and begin manufacturing turbines; however, there is a disincentive for leading wind turbine manufacturers to license proprietary information to companies that could become competitors.[9] This is particularly true for technology transferred from developed to developing countries, where a similar technology potentially could be manufactured in a developing country with less expensive labor and materials, resulting in an identical but cheaper turbine. Consequently, developing-country manufacturers often obtain technology from smaller wind power companies that have less to lose in terms of international competition, and more to gain in license fees (Lewis and Wiser 2007). The technology obtained from these smaller technology suppliers may not necessarily be inferior to that provided by the larger manufacturing companies, but it likely has been utilized less and therefore has less operation experience.

India's licensing arrangements with Südwind, Aerpac, and Enron Wind provided it with the necessary base of technical knowledge needed to enter the wind turbine manufacturing business. Building on the knowledge gained through international

[9] An example of this fear has been realized by Vestas, the Danish company that licensed its wind turbine technology to Gamesa, a Spanish company (initially for use only in Spain) and now views them as a major competitor in the global market.

technology transfers in licenses, Suzlon also formed many overseas subsidiaries. Some overseas partnerships were formed with foreign-owned companies, either to manufacturer a specific component such as its gearbox company in Austria, or to undertake collaborative R&D, such as its Netherlands-based blade design center and its Germany-based gearbox research center. Suzlon also situated its international headquarters in Denmark—a major industrial center of the wind turbine industry.

Goldwind's licensing arrangements with REpower allowed it to jump into the wind turbine industry with little indigenous knowledge, but the arrangements provided the transfer of enough know-how to enable Goldwind to innovate upon the transferred technology. It has more recently chosen to also pursue licensing arrangements with Vensys to gain experience related to larger turbine designs.

While Goldwind has relied only on licensed technology to date, Suzlon has expanded beyond the license model, and has purchased majority control of several wind turbine technology and components suppliers. These acquisitions include leading gearbox manufacturer, Hansen, and German wind turbine manufacturer REpower. In purchasing REpower, Suzlon not only gained access to REpower's wind turbine technology, it may have also obtained the ability to restrict Goldwind's future expansion into global wind turbine markets. Goldwind currently relies on its REpower license to produce the majority of its sub-MW wind turbines, and the terms of the license restricts Goldwind from exporting its turbines outside of China. The potential risk associated with this situation is doubtlessly not lost on Goldwind, which is reportedly in negotiations to purchase Vensys, the company holding the licenses to its turbines over 1 MW. This action would prevent similar restrictions being placed upon the turbines that could well comprise the majority of Goldwind's future sales as they expand into larger turbine models.

Regional and Global Learning Networks

Many of the differences between the technology development strategies of the two companies are related to how they opted to position themselves with respect to domestic and global learning networks. Suzlon differs from Goldwind since it has not contained its technological learning and innovation networks primarily to India as Goldwind has to China. Suzlon established many overseas operations to build upon the knowledge gained through its technology licenses, even before it had established a substantial market share in its home market of India. In addition, it has gained significant technical know-how through its acquisitions of foreign companies, including leading gearbox manufacturer, Hansen. Goldwind reports that it sends employees abroad for training, but has not established global innovation networks equivalent to Suzlon's, and has no overseas offices or subsidiaries. Yet Goldwind has conducted some R&D with its technology partner REpower in German wind turbine test facilities.

While looking overseas for technical expertise in wind turbine manufacturing, Suzlon did not neglect to bolster its Indian manufacturing base. Although it conducts R&D abroad, it relies primarily on domestically made components, most of which it makes in-house, based on experience gained through its overseas research efforts. As India's largest Indian-owned wind turbine manufacturer, Suzlon has access to local networks that foreign companies lack. It has been able to build its Indian supply chain through a network of subsidiaries, allowing it to maintain control of the intellectual property associated with its turbine designs.

Goldwind is also looking to strengthen a domestic supply chain based in China, but it is already competing with international firms with substantial China-based supply chains, including GE, Vestas, and Gamesa. Although Suzlon also faces competition from foreign wind companies manufacturing turbines in India, such as Vestas and Enercon, it has been able to maintain its role as the sales leader in the Indian market.

This combination of licensing arrangements with foreign firms and internationally based R&D and other facilities, complimented by the hiring of skilled personnel from around the world, has created a global learning network for Suzlon, customized to fill in the gaps in its technical knowledge base. Suzlon has been able to draw upon this self-designed learning network to take advantage of regional expertise located around the world, such as in the early wind turbine technology development centers of Denmark and The Netherlands. Suzlon differs from Goldwind because it has not restricted its technological learning and innovation networks primarily to India, as Goldwind has remained centered on China.

Goldwind's lack of internationally oriented expansion does not necessarily mean that it has been unable to tap into regional, or even global, learning networks. The company's origins in northwestern China's Xinjiang autonomous region put it at the center of wind turbine technology experimentation in China in the early 1990s. As wind development momentum has shifted eastward, Goldwind has also established manufacturing facilities in eastern China, including in the new manufacturing hub around Beijing and Tianjin. Popular wind farm sites such as Dabancheng in Xinjiang and Huitengxile in Inner Mongolia have served as test sites for almost all of the leading global wind turbine manufacturers. Vestas, NEG Micon, Nordex, Bonus, Zond, and Tacke (among others) all installed turbines in China throughout the 1990s. Consequently, Goldwind would have been able to benefit from much of the learning shared among these manufacturers coming from the other wind learning hubs of the world, as they all tested their designs in China. In addition, Goldwind has hired many employees trained by foreign-owned firms (often when they were based in China), taking advantage of the small but specialized work force that the presence of these foreign wind power technology firms brought to China.

Since both Suzlon and Goldwind are still most successful in their own domestic markets, each company's outlook for future success presumably will be related to its continued ability to thrive there. India's wind power policies, although lacking a clear national direction, seem to be thriving on a regional basis. Goldwind has relied greatly on China's policies that mandate local content, as well as an unstated but ubiquitous preference for Chinese-owned technology. In addition, its status as a partially state-owned company has provided it with direct government support for technology development.

Looking to the future, both companies' continued success will also depend on how their turbine technology stands the test of time in terms of reliability, as well as their ability to continue to design larger and more efficient turbines. If Indian and Chinese manufacturers are able to capture significant cost savings by manufacturing turbines locally, there would be excellent potential for both locations to serve as manufacturing bases for regional export. Suzlon and Goldwind believe that they are able to beat the prices being offered by their foreign competitors by locally sourcing their turbines. However, as foreign companies move toward local manufacturing of wind turbines, they will probably realize cost savings through use of local labor and materials. In addition, the overall scarcity of wind turbines worldwide, particularly within the last year, has meant that this potential price differential may not be playing as important a role as it may in a more competitive market.

Conclusions

This investigation of how the dominant, locally owned wind turbine companies of India and China acquired their ability to manufacture wind turbines provides a look at how two leading developing-country firms have acquired and assimilated advanced technologies. Such insights are crucial to facilitating international technology transfers, which will be an important component of any technological leapfrogging strategy to achieve lower greenhouse gas emissions in the developing world.

The institutional and other barriers present in large, developing countries such as China and India certainly challenge simplistic notions of energy leapfrogging. Yet, as an examination of wind turbine development in these countries has shown, substantial technical advances are indeed possible in relatively short amounts of time. It took China and India less than 10 years to go from having companies with no wind turbine manufacturing experience to companies capable of manufacturing complete wind turbine systems, with almost all components produced locally. This was done within the constraints of national and international intellectual property law, and primarily through the acquisition of technology licenses or via the purchasing of smaller wind technology companies. While both companies pursued similar licensing arrangements to acquire basic technical knowledge, Goldwind's technology development model lacks Suzlon's network of strategically positioned global subsidiaries contributing to its base of industry knowledge and technical capacity.

Suzlon's growth model particularly highlights an increasingly popular model of innovation practices for transnational firms: a model of globally dispersed operations that utilizes regional variation in technical expertise and low input costs to its advantage. Its expansive international innovation networks allow it to stay abreast of wind technology innovations around the world so that it can then incorporate into its own designs through its extensive research and development facilities. It has developed this network of global innovation subsidiaries while maintaining control of enough intellectual property rights to remain at the forefront of wind turbine manufacturing and sales around the globe. In contrast, Goldwind has pursued research and manufacturing operations that are primarily China-based, which has limited its interaction with hubs of wind power innovation expertise outside of China. Yet China is becoming such a hub in its own right, with diverse international players actively manufacturing wind turbines there, many in close regional proximity.

These illustrations of energy leapfrogging demonstrate how two developing country firms used a creative blend of strategies to enter new technology markets. A combination of licensing intellectual property—creating strategic technology partnerships, accessing regional and global learning networks, and taking advantage of regional advantages like lower labor costs—were all important components of each company's successful business model. As technology development becomes increasingly global, developing-country firms can and should take advantage of their increasing access to technological know-how that was previously developed primarily by and for the developed world. The lessons of Suzlon and Goldwind's success in harnessing global technology for local (and potentially global) use illustrate new models of technology development in the developing world.

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