# Building a national wind turbine industry: experiences from China, India and South Korea

Joanna I. Lewis

Edmund A. Walsh School of Foreign Service,
Georgetown University,
37th & O Streets NW, ICC 305-Q,
Washington, DC 20057, USA
E-mail: jil9@georgetown.edu

**Abstract:** This paper explores the strategies used by the domestic wind power technology companies in China, India and South Korea in order to understand how these countries have acquired and assimilated advanced technologies. It finds that the primary technology transfer and acquisition strategies utilised included licensing arrangements and Mergers and Acquisitions (M&A) that resulted in the transfer of technology ownership and partnerships for the joint development of new technology. As technology development becomes increasingly global, firms in the emerging economies can take advantage of their increasing access to technological know-how that was previously developed by and for the developed world.

**Keywords:** technology transfer; innovation systems; wind power; China; India; South Korea.

**Reference** to this paper should be made as follows: Lewis, J.I. (2011) 'Building a national wind turbine industry: experiences from China, India and South Korea', *Int. J. Technology and Globalisation*, Vol. 5, Nos. 3/4, pp.281–305.

**Biographical notes:** Joanna I. Lewis is an Assistant Professor in the Edmund A. Walsh School of Foreign Service at Georgetown University. She conducts research on renewable energy industry and policy development, mechanisms for low-carbon technology transfer in the developing world and expanding options for multilateral engagement in international climate change agreements, with a primary geographic focus on China.

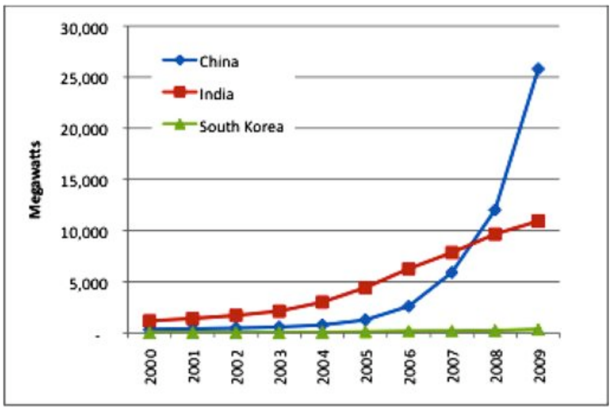
## 1 Introduction

While modern wind power technology originated in Europe and the USA, the emerging economies are quickly becoming the centre of the global wind power industry. India, the early emerging economy leader in wind power development, has now been surpassed by China, the largest wind energy market in the world for the year 2009. South Korea is still a relative newcomer to the wind industry, but the recent entry of many large Korean industrial firms makes it well positioned for future growth (Figure 1).

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 emerging economies, limited indigenous technical capacity and quality control can make entry even more difficult. International technology transfers can be a solution, although leading companies in this industry are unlikely to transfer proprietary information to companies that could become competitors. This is even riskier for technology transferred from developed to developing countries, where an identical but cheaper turbine potentially could be manufactured.

This paper explores the strategies used by the domestic wind power technology companies in each of these three countries to develop wind turbine technology. It begins by reviewing the evolution and current status of wind power development in each country. Turning to the current industry leaders, it then examines how these companies acquired the technological know-how and Intellectual Property Rights (IPR) 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. It concludes with an assessment of the outlook for the future development of the Chinese, Indian and South Korean wind power industries and a discussion of the policy lessons for facilitating low-carbon technology transfer that can be drawn from these three cases.

**Figure 1** Wind power development in China, India and South Korea 2000–2009 (see online version for colours)




## 2 Industrial strategy in the newly industrialising countries

Countries that were not part of the group of early wind turbine innovators – namely Denmark, The Netherlands, Germany and the USA – 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. Technology transfers can occur through different models. One model is through a licensing agreement that gives the licensing firm access to a certain wind turbine model, often with some restrictions on where it can be sold. Another model includes establishing joint venture partnerships between two companies, either to share a license or for collaborative Research and Development (R&D). Firms also can opt to collaborate to jointly develop a new technology design and then share the associated intellectual property. If a firm has the capacity and means, it can also obtain access to technology through the purchase of ownership rights in a company with the desired technology or other forms of M&A.

The larger domestic context in which the innovative activity is taking place, often referred to as the national innovation system, is likely an important determinant of the ultimate success of a technology transfer, particularly concerning a country's ability to adopt an externally sourced technology and apply it internally – also called absorptive capacity. The organisation and distribution of innovation-related activities often differs among countries and regions, with some similarities among the Asian 'late industrialising countries' (Freeman, 1995; Lall, 1998; Amsden, 2001). These nations all played the game of technological 'catch-up', a concept that in the most dramatic of cases is referred to as technological 'leapfrogging', which has been documented across industries and technologies (Lee and Kim, 2001; Lee, 2005; Gallagher, 2006; Nelson, 2007).

Regional and global learning networks have likely played a large role in the development of wind turbine technology over time. The wind industry – characterised by its small number of firms, highly specialised 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 hypothesised 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). Just as the early wind development in Denmark and the USA provided a crucial learning ground in the 1970s and 1980s, the emerging wind markets of India, China and South Korea are serving as valuable regional learning networks for new firms. The increasingly global reach even of new firms, facilitated by technology transfer partnerships with overseas firms, has also provided a valuable resource to global learning networks of knowledge and innovation.

As the two largest developing country wind power markets in the world, China and India are now pertinent places to examine models of technology transfer that have facilitated the emergence of several leading wind power technology firms. South Korea, several years behind China and India in terms of its own domestic wind power development, has a very strong industrial base upon which it builds a wind power industry. The similarity in technology transfer models being used by South Korean, Indian and Chinese firms, as well as the impending global competition among these countries in the wind industry, provides a rich basis for comparative analysis.

## 3 China's wind industry

### *3.1 Origins and status*

In 2009, China became the largest wind power market in the world, having surpassed the annual capacity additions of the USA and European leaders like Germany and Spain (and prior developing country leader India) with 13.8 GW of new installations.[1] That year, China had a total cumulative installed capacity of 25.8 GW, making it the second-largest wind power base in the world after the USA (GWEC, 2009a).

Wind power technology has been particularly successful in China due to excellent wind resources and rapid technological improvements in China's domestic wind industry.

According to recent studies, China has an estimated 2380 GW of exploitable onshore wind resources and 200 GW offshore (Zhu, 2010).[2] Installed electric power generation capacity in China totalled about 882 GW at the end of 2008, with wind power capacity (25 GW) representing just about 3% of total installed power capacity and less than 1% of total electricity production.

China's best wind resources are concentrated in the northern and western parts of the country where there is less electricity demand. This increasingly requires transmission to be built to bring the power to provinces that need it. However, the northern and western provinces, such as Gansu and Inner Mongolia, are less developed, and poor electric grids cannot manage the fluctuations in electricity production inherent in wind power (Wang, 2009). As a result, some problems with power delivery due to grid challenges have been reported.

### *3.2 Government wind energy policy support*

A new era of policies to support renewable energy development began in China in 2005 with the launch of the National Renewable Energy Law. A key driver of wind development between 2003 and 2007 was the wind resource concessions for government-selected sites through a competitive bidding process to potential developers. Each concession project included approval to develop the selected project site, a PPA for the first 30,000 h of the project, guaranteed grid interconnection, financial support for grid extension and access roads, and preferential tax and loan conditions all granted to the winning bidder by the central government. Projects were usually 100 MW in size and had to use wind turbines over 600 kW in capacity that initially used 50% local content, increasing to 70% in later rounds of concessions.

The 2007 Mid and Long Term Renewable Energy Implementation Plan first announced the Chinese Government's plans for developing large-scale wind power bases, with plans refined further in the March 2008 11th Five-Year Renewable Energy Development Plan. Plans include the building of seven wind power bases with a minimum capacity of 10 GW each by 2020. The wind bases are located in Gansu, Xinjiang, Hebei, Jilin, eastern and western Inner Mongolia and Jiangsu. Few countries in the world are pursuing wind power development of this scale. In addition, government-announced plans for large wind bases allow for transmission planning to occur around these bases and are also designed to promote the development of a local wind power industry in the surrounding area. This is causing turbine manufacturers to shift at least portions of their facilities to the region near the base. In addition, several of the wind base projects have set a specific size for the turbines to be installed there in the range of 1.5–2 MW.

While China has experimented with feed-in tariffs for wind power over the years with various levels of success, a July 2009 central government announcement set four feed-in tariff levels across the country, varying by region based on wind resource class. Tariff prices range from 0.51 Yuan/kWh for wind power in regions with the most wind resources, such as Inner Mongolia, to 0.61 Yuan/kWh for regions with the least wind resources (US cent 7.5–8.9/kWh). Setting a higher tariff in low wind resource regions encourages wind power development there, despite less opportunity for electricity production. In addition, the July 2008 Mid and Long Term Renewable Energy Implementation Plan announced that China's share of non-hydro renewables should reach 1% of total power generation by 2010 and 3% by 2020 for regions served by centralised power grids. A specific obligation was placed on any power producer owning a total generation portfolio of more than 5 GW to increase its actual ownership of power capacity from non-hydro renewables to 3% by 2010 and 8% by 2020. This obligation falls upon the large power companies and is one of the primary reasons these companies have been developing large wind projects in the last few years.

China has taken several steps to directly encourage local wind turbine manufacturing, including policies that encourage joint ventures and technology transfers in large wind turbine technology, policies that mandate locally made wind turbines, differential customs duties favouring domestic rather than overseas turbine assembly and public R&D support. The Ministry of Science and Technology (MOST) 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 Eleventh Five-Year Plan (2006–2010). In April 2008, the Chinese Ministry of Finance issued a regulation stating that the tax revenue for the key components and raw materials for large turbines (2.5 MW and above) would be returned to the state to channel the money back into the technology innovation and capacity building in the wind industry. In the same year, the Ministry of Finance announced funding support for the commercialisation of wind power generation equipment. For all ‘domestic brand’ wind turbines (with over 51% Chinese investment), the first 50 wind turbines over 1 MW produced would be rewarded with RMB 600/kW (60 Euro) from the government. The rule specified that the wind turbines must be tested and certified by China General Certification (CGC), must have entered the market, must have been put into operation and must be connected to the grid.

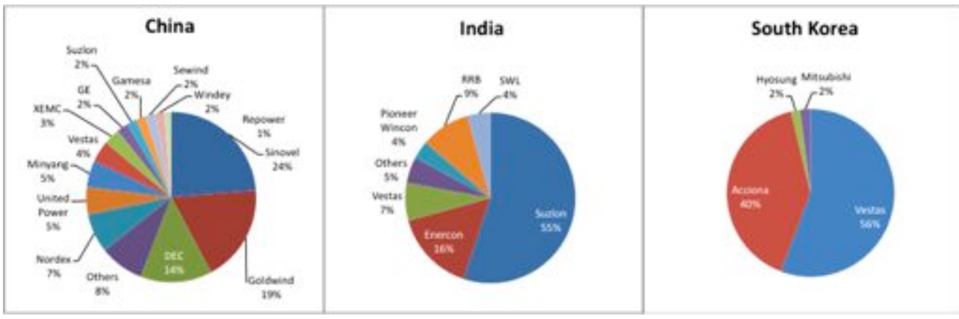
Beginning in about 2003, all wind farms in China were subject to a local content requirement of 70%. This was primarily carried out in the selection criteria for qualification of manufacturers in the concession projects. However, in 2009, the US Department of Commerce Secretary Gary Locke travelled to China to ask for the removal of the local content requirement, arguing that it was a trade barrier for foreign firms, and China agreed. In early 2010, however, the Chinese Ministry of Industry and Information Technology (MIIT) released a call for comment on the newly released draft “Access Conditions For Wind Power Equipment Industry”, which aimed to “promote the optimisation and upgrading of the industrial structure of the wind power equipment manufacturing industry, enhance enterprises’ technical innovation, improve product quality and restrict the introduction of redundant technology” to “guide the industry’s healthy development”. This was to be accomplished by restricting the operation of wind turbine manufacturers that did not have the capability to produce a 2.5 MW or larger turbine, did not have at least 5 years of experience in a related industry and did not meet various financial, R&D and quality control requirements (MIIT, 2010; Baker Botts, 2010).

### *3.3 Industry structure and key players*

When large-scale wind power development began in China in the early 1990s, there were no Chinese wind turbine manufacturers in the market, and most wind technology was being imported from abroad. The picture has changed dramatically since then, with around 80 Chinese wind turbine manufacturers reportedly in the market today. While not all of these companies have produced commercially available wind turbines, several leading Chinese companies have larger Chinese market shares than the leading global foreign-owned wind turbine manufacturers and are beginning to export their turbines abroad.

The Chinese market is now split among the domestic Chinese turbine manufacturers and the large global turbine manufacturers – all of which are now locally manufacturing wind turbines in China. Today, the largest market share is held by Chinese firm Sinovel, a relative newcomer to the industry, with 24% of the market in 2009 (Figure 2). Sinovel obtained its 1.5 MW wind turbine technology through a licensing agreement with German firm Fuhrländer. It later partnered with American Superconductor (AMSC) and its wholly owned, Austrian-based subsidiary Windtec to jointly develop 3 MW and 5 MW turbines (May and Wienhold, 2009a). In second place is Chinese firm Goldwind, the most established Chinese manufacturer, with 19%. Goldwind obtained its technology through licensing agreements with REpower and by acquiring ownership over Vensys, as elaborated below. Another relatively new Chinese manufacturer, Dongfang, follows closely with 14% of 2009 market share. Based in Deyang in Sichuan Province, Dongfang is a subsidiary of Dongfang Electric Group (SOE) and obtained its technology through a licensing agreement with REpower for its 1.5 MW wind turbine. Another emerging Chinese firm, A-Power,[3] obtained its technology through a licensing agreement with German firm Fuhrländer for a 2.5 MW turbine and with Danish firm Norwin for 225 kW and 750 kW wind turbine models, which also included the establishment of a joint venture company (A-Power Signs, 2008).[4]

**Figure 2** Wind turbine sales in China, India and South Korea: 2009 market shares (see online version for colours)




The leading global wind turbine manufacturers with a notable presence in China in 2009 include Germany's Nordex with 7% of market share, Denmark's Vestas with 4%, the USA's GE with 2%, India's Suzlon with 2%, Spain's Gamesa with 2% and Germany's REpower with 1%. The rest of the market is divided among smaller Chinese manufacturers, including United Power, Minyang, Xiangtan Electric Manufacturing Corporation Ltd. (XEMC), Sewind, Windey, SEC, Xiangdian, Changzhou, Beizhong, Guodian, Hanwei, Envision, Huayi and CSR (Shi, 2009).

## 3.4 *Key industry player: Goldwind*

Goldwind (*Jinfeng*) was China's first leading wind turbine manufacturer. An investigation of how Goldwind acquired its wind turbine technology provides a clear example of how China is obtaining advanced wind power technology through international technology transfers. While every firm in China has adopted a different strategy and established different technology partnerships, most firms have used licensing, M&A and joint development strategies similar to that of Goldwind.

Goldwind, which began as Xinjiang Wind Energy Company, obtained its first wind turbine technology license from Jacobs, a small German wind turbine manufacturer that has since been purchased by REpower, to manufacture 600 kW wind turbines in 1999. In 2001, Goldwind also obtained a license from REpower for a 750 kW turbine and later another license from German company Vensys for a 1.2 MW direct drive turbine. Vensys is a design rather than a manufacturing company and was looking for a partner with the manufacturing capability to produce its turbine designs. The Vensys direct-drive turbine technology was then (and is now) still somewhat uncommon in wind turbine designs but is thought to have many advantages over the traditional gearbox design, including being lighter weight, which makes for easier installation, and using fewer components, meaning fewer things that can become damaged and require replacement (de Vries, 2007). When Vensys developed a low wind speed version with a larger 64 m diameter rotor that increased output to 1.5 MW, Goldwind acquired the license for that turbine as well. Goldwind is currently working with Vensys to produce 2.5 MW gearless turbines for onshore use and 5 MW turbines with a view towards offshore applications.

In the early 2008, when several other firms made a bid to purchase Vensys, Goldwind opted to purchase a 70% stake in the company outright so that it could continue its partnership. Becoming the controlling owner of the company gave Goldwind more control over the direction of the R&D of Vensys, as well as less constraints over access to its intellectual property. Goldwind, somewhat surprisingly, has opted to encourage rather than discourage Vensys' partnerships overseas, including its licensing arrangements with overseas companies that include Enerwind of Argentina, IMPSA in Brazil, ReGen Powertech in India, Eozen in Spain and CKD NOVÉ Energo in the Czech Republic and Slovakia. Wu Gang, Goldwind's CEO, believes that it is important to give the designers at Vensys the creative freedom that they need, and by allowing them to directly engage in the manufacturing process, they may improve the quality of their designs through more direct learning by doing (Wu, 2009).

As the company has expanded, it has become increasingly able to compete for the most skilled workers in the wind turbine industry and reportedly has been able to attract former employees of GE, Gamesa, Vestas and Siemens. Goldwind is currently manufacturing turbines for the Chinese market almost exclusively, but it is in the process of building a small demonstration wind farm in Minnesota and has plans to expand in the USA and Australian markets. The company reports they invested more than $17 million in R&D in 2009.

## 4 India's wind industry

### 4.1 Origins and status

As of 2009, India ranked 5th in the world after the USA, China, Germany and Spain in cumulative wind power installations with 10,926 MW. It was also the fifth-largest wind market in the world in annual installations in 2009 behind China, the USA, Spain and Germany, with 1271 MW installed that year. The Indian Government had set a target for 10,500 MW by 2012 as part of the 11th five-year plan, which it has already surpassed. Wind power still comprises less than 1% of India's total electricity generation.

The potential for wind power in India is estimated at 45,000 MW, though due to a lack of detailed national resource assessment, many estimate that the actual number maybe far higher (Parthan and Lemaire, 2007). India's wind resources are best in the east and southern parts of the country, particularly near the coasts. The highest wind energy potential is believed to be located in the Indian states of Karnataka (11.5 GW), Gujarat (10.6 GW) and Andhra Pradesh (8.9 GW), followed by Tamil Nadu (5.5 GW), Rajasthan (4.8 GW) and Maharashtra (4.5 GW) (GWEC, 2009b).

India's wind power industry began to take off in the early 1990s, though it has experienced periods of boom and bust over the past two decades. In the late 1990s in particular, the industry experienced a slowdown, reportedly due to the reduction in government tax benefits, delays in processing land approval and technical problems related to poor installation practices in the preceding years. In 2003, growth started to take off again with the 2003 Electricity Act. Over the past few years, both the government and the wind power industry have succeeded in injecting greater stability into the Indian market, encouraging larger private and public sector enterprises to invest in wind.

### *4.2 Government policy to support wind energy*

The Indian Government has a stated target for renewable energy to contribute 10% of total power generation capacity by 2012. It has been supporting R&D in wind power technology since the 1980s (Mizuno, 2007). Tax exemptions and accelerated depreciation for up to 80% of project costs in the first year, in addition to a Generation-based Incentive (GBI) scheme, have served as key incentives for wind power development. In June 2008, the Ministry of New & Renewable Energy (MNRE) announced a national GBI scheme for grid connected wind power projects less than 49 MW, providing an incentive of 0.5 rupees per KWh. In the early 2009, this was expanded to all projects to provide this incentive to investors for a period of 10 years, provided they do not claim the depreciation benefit. This expanded tariff incentive was meant to provide an incentive for wind development that was attractive to investors that because of their small size or lack of tax liability cannot draw any benefit from accelerated depreciation.

In addition to the MNRE incentives, many Indian states have set feed-in tariffs to support wind power development. Tariff rates range from 3.14 rupees per KWh in Kerala to 4.5 rupees per KWh in Rajasthan. The 2003 Electricity Act required each state should fix its own minimum percentage for purchase of renewable energy, taking into account availability of such resources in the region and its impact on retail tariffs. As a result, most states have established mandatory renewable energy shares. One of the more aggressive Renewable Portfolio Standards for wind is found in Tamil Nadu, where the standard is set at 10% between 2008 and 2009, increasing to 13% between 2009 and 2010 and to 14% between 2010 and 2011 (GWEC, 2009b).

India has taken some direct steps to encourage local wind turbine manufacturing. For example, India has manipulated customs duties in favour of importing wind turbine components over importing complete machines (Rajsekhar et al., 1999). India has also developed a national certification programme for wind turbines administered by the Ministry on Non-Conventional Energy Sources (MNES) based in large part on international testing and certification standards.

### *4.3 Industry structure and key players*

India now has a rather concentrated local wind power industry of relatively few but powerful turbine manufacturers and developers. India has a solid domestic manufacturing base, led by Indian company Suzlon, which held 55% of the Indian market share in 2009. While Suzlon originated in India, it now sells turbines all over the world. Other key players in the Indian market include Germany's Enercon with 16% market share in 2009, Vestas with 7% and RRB with 9 %. RRB was formed through a 1987 joint venture with Vestas that dissolved in 2006 (May and Weinhold, 2009b). There are also some smaller manufacturers including Pioneer Wincon, SWL, Inox Wind and Ghodawat Energy. Several other international turbine manufacturers have established production facilities in India, including GE, Gamesa, Siemens, ReGen Power Tech, LM Glasfiber, WinWinD, Kenersys and Global Wind Power. Overall, a dozen international companies now manufacture wind turbines in India, through either joint ventures under licensed production, as subsidiaries of foreign companies or as Indian companies with their own technology (GWEC, 2009b).

The current annual production capacity of wind turbines manufactured in India is about 3000–3500 MW, projected to rise to 5000 MW per year by 2015 (GWEC, 2009b). This annual production capacity includes turbines for the domestic as well as for the export markets. Some foreign companies now source more than 80% of the components for their turbines in India and export them around the world to the USA, Europe, Australia, China and Brazil. Almost all Indian manufacturers are now looking at the export market, where better prices can be achieved than in the domestic market.

### *4.4 Key industry player: Suzlon*

Indian wind turbine company Suzlon is now well established in the international wind market beyond India, operating in 20 countries around the world and supplying turbines to projects in Asia, North and South America and Europe. Suzlon is owned by Indian entrepreneur Tulsi Tanti and his siblings. Tanti started in the textile industry and turned to a few wind turbines to power his business when faced with soaring power costs and the infrequent availability of power. This led him to establish Suzlon, India's first home-grown wind power company. Within five years, Suzlon had made in the list of top 10 wind companies, and the company has remained there since. Co-investors include two major US investment funds, City Group and Chryscapital, each of which injected $25 million into the company. 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 (Moller and Rajgor, 2004).[5] Suzlon has also developed sales offices in Australia, China and the USA (as well as India) and R&D centres in Germany, the Netherlands and India.

Suzlon first obtained its wind turbine technology in a 1995 technical collaboration agreement with a German company, Südwind, in which Südwind shared technical information relating to the manufacturing of its 270, 300, 350, 600 and 750 kW wind turbine models, in return for royalty payments. Then 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 (Red Herring, 2005).

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. In 2006, Suzlon purchased Belgian company Hansen, the second-largest gearbox manufacturer in the world, expanding its access to gearbox technology and marking the second largest foreign corporate takeover by an Indian company in any industry at that time.[6] 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. In May of 2007, Suzlon acquired 33.85% of REpower's shares, and by December 2009, it had acquired 92%. The two companies are still operating somewhat independently of each other, with little technology cooperation or knowledge exchange, due to German regulations requiring Suzlon to buy out the remaining shareholders to exercise full control and integrate the two companies (Beckett, 2009).

Suzlon currently offers wind turbines that range in size from 600 kW to 2.1 MW. The company's manufacturing strategy has been to build upon the licensing and joint venture agreements described above with its own R&D, and to manufacture as many wind turbine components as possible in house. The firm believes that increasing its in-house manufacturing capabilities will help it to lower wind turbine costs by giving it 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 USA. Like several other leading global wind turbine manufacturers, Suzlon established a large production facility in Tianjin, China in response to the local content requirements promulgated by the Chinese government.

Suzlon has also established R&D centres throughout the world, with over 550 staff engaged in technology development and R&D activities split between India and Western Europe (Suzlon, 2010). Its investments in R&D, including design changes and technological upgrades, as well as certification, product development and quality assurance, have increased substantially in the last few years.[7] One research centre based in The Netherlands benefits from local Dutch expertise in turbine blade development, while another research centre located in Germany benefits from local gearbox expertise.

Suzlon experienced a technological setback in 2007 when instances of blade cracks were discovered during the operation of some of its wind turbines in the USA, requiring it to retrofit its total fleet of 1251 blades (Suzlon Completes Blade Retrofit Program, 2009). After this incident, there were reports of order cancellations (GE Energy to Re-enter India's Wind Energy Market, 2009).

## 5 South Korea

### *5.1 Origins and status*

South Korea has been installing a stable but relatively small annual wind power capacity in recent years. It ranks number 27 in the world in terms of total installed wind capacity, with 348 MW installed at the end of 2009 (IEA, 2008).

South Korea's promise lies more in its domestic manufacturing base rather than in its domestic wind development potential. Wind resources in South Korea are adequate but land area is limited. As a result, most wind development to date has been focused in the coastal areas, including Jeju Island, and there is a lot of interest in pursuing offshore development. The Korean Wind Industry Association estimates South Korea's theoretical onshore wind resource potential at about 369 GW, with 18.5 GW of technical potential. Its offshore potential is estimated at 309 GW, with 31.4 GW of technical potential at an average depth of 20 m (Korean Energy Economics Institute, 2009). There are currently 8 GW of offshore wind projects either under development or in the planning stages (IEA, 2008).

## *5.2 Government policy to support wind energy*

South Korea's national energy plan sets a target for the share of new and renewable energy in primary energy consumption to be 3% in 2006 and 5% in 2011 (IEA, 2008). Wind generation is expected to provide the largest contribution (up to 25% or 5.2 TWh) of the total generation (20.5 TWh) by new and renewable sources in 2011. In addition, the government's 'Energy Vision 2030' plan targets a 9% share of renewables by 2030.

To achieve these targets, the government is providing attractive incentive programmes such as a 15-year guaranteed feed-in tariff, tax incentives and subsidies for the local wind market (Jong-Heon Lee, 2009). Wind generation is eligible for a 15-year feed-in tariff of 107.29 Won/kWh that is to be reduced by 2% every year after October 2009 (South Korean Players Open New Front in Global WTG Battle, 2009). In addition, the central government is providing subsidies of up to 70% to local governments, if demonstration projects or stand-alone small wind installations are less than 10 kW. There is also a cost reduction of one-tenth from income or corporate tax for the installation of new renewable energy facility, and import duties on grid-connected wind generators and blades have been reduced.

Other programmes that support wind power development include compensation by the government for losses to commercial banks when long-term project financing to renewable energy construction is offered at lower than commercial rates. In addition, a renewable construction facility can make a proposal to Korea Energy Management Corporation for a maximum of $20 million loan that is payable over 10 years following an initial 5-year grace period (AAER sells wind turbine to Hyundai Heavy Industries, 2009). South Korea's January 2009 'Green New Deal' Stimulus Package included additional funding for renewable energy development. In addition, the Comprehensive R&D Plan on Green Technology called for a two-fold increase of R&D spending on Green Technology by 2012 in 27 key technology areas. South Korea has also adopted a voluntary greenhouse gas reduction target of 30% below expected BAU levels in 2020 or an estimated 4% below 2005 levels.

The autonomous government on windy Jeju Island has promised to support the installation of wind power plants on the island, having set a target for 500 megawatts by 2020, including 300 megawatts from maritime wind power (Lee, 2009). Electricity from wind currently accounts for just 3.4% of power demand for the island's population of 560,000, but the Jeju Government aims to increase the figure to 20% by 2020 and 50% by 2050. Jeju has also become the site of South Korea's first electric smart grid, allowing for real-time monitoring of electricity demand and output with digital technology that enables communication between consumers and utility firms.

### 5.3 Industry structure and key players

Traditionally an importer of equipment for wind power projects, South Korea does not have a long history of manufacturing wind turbines. Since 2006, many Korean firms have entered the wind industry, including some of South Korea's largest industrial conglomerates. While there are several Korean firms poised to succeed in the industry, there has not yet been one firm that has emerged as an industry leader. Today, Korean firms undertaking wind turbine technology development at various stages include Daewoo, Doosan, Hyosung, Samsung, Hyundai, Hanjin, STX, Rotem and Unison.

Daewoo Shipbuilding and Marine has been developing a 2 MW onshore turbine since about 2005 that is expected to enter serial production around 2011. Daewoo recently acquired ownership of German manufacturer DeWind from its US owner Composite Technology Corporation, giving Daewoo immediate access to a product programme consisting of a 1.25 MW model and two 2 MW models, along with R&D facilities and production lines in Germany and the USA, and the development rights for the 629 MW Little Pringle project in Texas.

Doosan Heavy Industries, South Korea's top power plant builder and the world's biggest seawater desalination plant provider, has partnered with AMSC affiliate Windtec for the development of a 3 MW direct drive offshore wind turbine. The first prototype was installed onshore in October 2009 on Jeju Island in South Korea, with serial production expected in the late 2010 for onshore and in 2012 for offshore applications. Hyosung is another company that has been involved in the wind industry for several years, though primarily through R&D activities, including the development of 750 kW and 2 MW onshore turbines as well as a 3 MW offshore turbine.

Samsung Heavy Industries began developing a 2.5 MW onshore turbine with UK design firms Romax and Garrad Hassan in 2008, with its first turbines installed in 2010. It includes the use of blades from LM Glasfiber in conjunction with a 5-year supply contract. It has also begun work on the development of a 5 MW offshore turbine, with production targeted for 2013. Samsung has planned additional manufacturing facilities in South Korea and is opening office facilities in Portland, USA and Germany.

Hyundai Heavy Industries Co Ltd., the world's largest shipbuilding company, announced its entry into the wind industry in 2008 when it signed a deal with AMSC affiliate Windtec to license technology for 1.65 MW and 2 MW wind turbines. Hyundai's marketing and sales rights for both turbines under the license extend to dozens of countries around the world, including the USA. Hyundai is also working with Avantis Energy (Germany) to develop a 2.5 MW turbine under license. Rotem, a subsidiary of the Hyundai Kia motor group, has received support from the Ministry of Knowledge Economy to develop a 2.0 MW low wind speed direct drive wind turbine, along with cooperation from several other research institutes and companies. In June of 2010, AMSC announced plans to jointly develop a 5 MW wind turbine with Hyundai for offshore use (AMSC-Windtec, 2010b).

Hanjin, a relatively small company within the plastic and synthetic fibre industry, began developing a 1.5 MW turbine in 2003 in corporation with German firm Idaswind that has been in serial production in 2008. STX Corporation, the world's fourth-largest shipbuilder, has been involved in the wind industry since 1999 when it developed projects in South Korea using Vestas turbines. In 2009, STX signed a deal to completely acquire Harakosan Europe BV, a Dutch manufacturer of gearless wind turbines.

The Unison Corporation began developing its 750 kW wind turbine in 2001 under a Korean government-sponsored consortium that included Bokuk Electric, Hankuk Glass Fiber and the Pohang University of Science and Technology (POSTECH). In 2005, it began development of a 2 MW model. It has also served as the owner of the first two commercial wind projects in South Korea that used Vestas 2.0 MW and Suzlon 2.1 MW turbines.

While Korean manufacturers have entered the wind industry late in the game, their technology acquisition and transfer strategies have focused on advanced wind power technology and offshore wind technology in particular. This is likely due to the fact that there is very little potential for domestic market sales in onshore turbines within South Korea, but there is potential for offshore development. Korean firms are also primarily targeting export markets with offshore potential. Samsung, Daewoo (via DeWind) and Hyundai have already announced orders for the US market, while Hyundai and Unison have announced orders for the Chinese market (all onshore projects) (China's Fuxin, 2009).

Through the acquisition of or partnerships with smaller wind turbine manufacturers or design firms, Korean firms are attempting to leapfrog directly to advanced wind turbine technology. The fact that most of the Korean firms are not small companies, but rather huge conglomerates with significant industry experience and a worldwide client base, ensures good financial backing and resources for M&A. Most South Korean firms are heavily reliant on foreign engineering and design firms, even if they are developing in-house technology and intellectual property. There are still many key components being imported rather than locally manufactured for the Korean market.

## 6 Chinese, Indian and South Korean wind power industrial strategies compared

While firms in China, South Korea and India have used different strategies to acquire or develop wind power technology, there are many common sources of the wind power technology knowledge being acquired by firms in these countries. Companies from these three countries have different advantages and face different obstacles to their continued success based on the characteristics of their respective domestic environments, and the competition they face in other markets.

### *6.1 Technology transfers and acquisition strategies*

Although there are several technology transfer models available to a company looking to enter the wind industry, there are many similarities in the models adopted by wind power technology firms from China, India and South Korea. Three primary models of technology development emerge: licensing, M&A and joint development. In addition, there are several common sources of technology information that have worked with firms across these three countries.

*Licensing*

Several companies began their ventures into the wind industry by setting up licensing agreements, most commonly with small European wind turbine 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 that may already have been field tested or even have substantial operating experience.

There is a disincentive for leading wind turbine manufacturers to license proprietary information to companies that could become competitors, however, particularly when technology is transferred from developed to developing countries, where a similar technology potentially could be manufactured with less expensive labour and materials. 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. 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 utilised less and therefore has less operation experience. Alternatively, companies may be willing to license outdated models of their technology (often smaller turbine sizes) or to license technology that comes with restrictions on any turbine exports outside of the market in which the home manufacturer is based.

Suzlon began its wind turbine manufacturing with a license from German company Südwind. Goldwind similarly began its operations based on licenses from German firms Jacobs and REpower. More recently, Chinese newcomers Sinovel, Dongfang, CSIC and Beijing Beizhong have benefited from licenses acquired from Fuhrländer (Germany), REpower (Germany), Aerodyn (Germany) and DeWind (UK/USA). Other Chinese licensing agreements include the licenses that A-Power acquired from Norwin, CSIC acquired from Aerodyn, Beizhong acquired from DeWind, Windey acquired from REpower and Zhuzhou acquired from Windtec. South Korea's Hyundai also obtained a license from AMSC Windtec.

*Mergers and Acquisitions (M&A)*

As wind companies become more established, or if they have sufficient financial resources, M&A provide another strategy for technology transfers. M&A gives more authority and flexibility to the acquiring company in how it decides to use the technology, unlike a licensing agreement, which typically has strings attached. Technology acquisitions through M&A can only be successful if the acquiring company has the ability to integrate the new business knowledge into its current business. In addition, there can be a significant financial investment involved.

While Suzlon began its operations based on licenses, it later acquired majority ownership of REpower. Goldwind similarly began its operations based on licenses, and later acquired majority ownership of Vensys. In contrast, the large industrial Korean conglomerates Daewoo and STX used M&A to obtain wind turbine technology early on, purchasing US firm DeWind and Dutch firm Harakosan Europe BV, respectively. While Goldwind's acquisition of Vensys seems to have resulted in the sharing of knowledge as witnessed through the joint development of new turbine designs, Suzlon's acquisition of REpower has until now been restricted by M&A regulations, and the operations of the two companies are still somewhat separate.

*Joint development*

As firms develop their own design and manufacturing expertise, they may be more interested in co-developing wind turbine technology with firms that bring a different set of experience to the partnership. An advantage of joint development is that there is no initial concern about market competition, and when multiple manufacturers are involved, arrangements for the sharing of any resulting IPR are almost always made prior to the start of the joint work. This arrangement can be more straightforward when joint development involves a firm that primarily focuses on design working with a firm that primarily focuses on manufacturing. The risk with this model, however, is that if the design firm has no manufacturing experience and the manufacturer has no design experience, the resulting product may look great on paper but fail in the factory or in the field.

Several Korean firms are pursing the joint development of wind turbine designs, including Hyundai with Avantis, Doosan with Windtec, Samsung with Roman and Garrad Hassan and Hanjin with Idaswind. This form of technology acquisition is also becoming increasingly common in China, particularly among the larger firms. Examples include Sinovel's joint development with AMSC/Windtec, Dongfang's joint development with AMSC/Windtec and with Aerodyn, Goldwind's joint development with Vensys, A-Power's joint development with Norwin and Hewind and Sewind's joint development with Aerodyn.

Several firms, particularly in China and South Korea, have relied on government support for R&D to design wind turbines, often in conjunction with a consortium of research institutes or universities. While this is a less common model, it is being used by Hyundai Rotem and Unison in South Korea, as well as by several smaller Chinese manufacturers like Windey, which originated at China's Zhejiang Institute of Mechanical and Electrical Engineering.

*Global learning networks*

The global reach of a firm's innovative activities can also play an important role in its technology development strategy. Of particular note is the difference in strategy pursued by Suzlon and Goldwind in this regard. Many of the differences between the original technology development strategies of the two companies are related to how they opted to position themselves with respect to domestic and global learning networks (Lewis, 2007).

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. This combination of licensing arrangements with foreign firms and internationally based R&D and manufacturing facilities, complimented by the hiring of skilled personnel from around the world, created a global learning network for Suzlon that was customised 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 centres of Denmark and the Netherlands. This is in contrast to Goldwind's early years of technology development, where it remained almost exclusively focused on the Chinese market and conducted very little R&D or manufacturing outside of China.

In recent years, however, Goldwind too has expanded its access to global learning networks, most notably through its acquisition of Vensys. This gave Goldwind access to a network of skilled engineers and a company with a different geographic focus, allowing it to better integrate European wind industry experience into its operations. Even more recently, as Goldwind looks to expand into the USA and Australian markets, it has hired US and Australian workers with extensive experience in their home markets to help it better understand how to operate within these domestic contexts.

While they are in an earlier stage of technology development, South Korea's new wind industry entrants are also looking globally for their technology partnerships. As the South Korean companies are already looking to export markets outside of South Korea and need to be positioned to compete with global industry leaders, they are not restricting their technology development activities to within Korea.

### *6.2 Origins and networks of technology transfer*

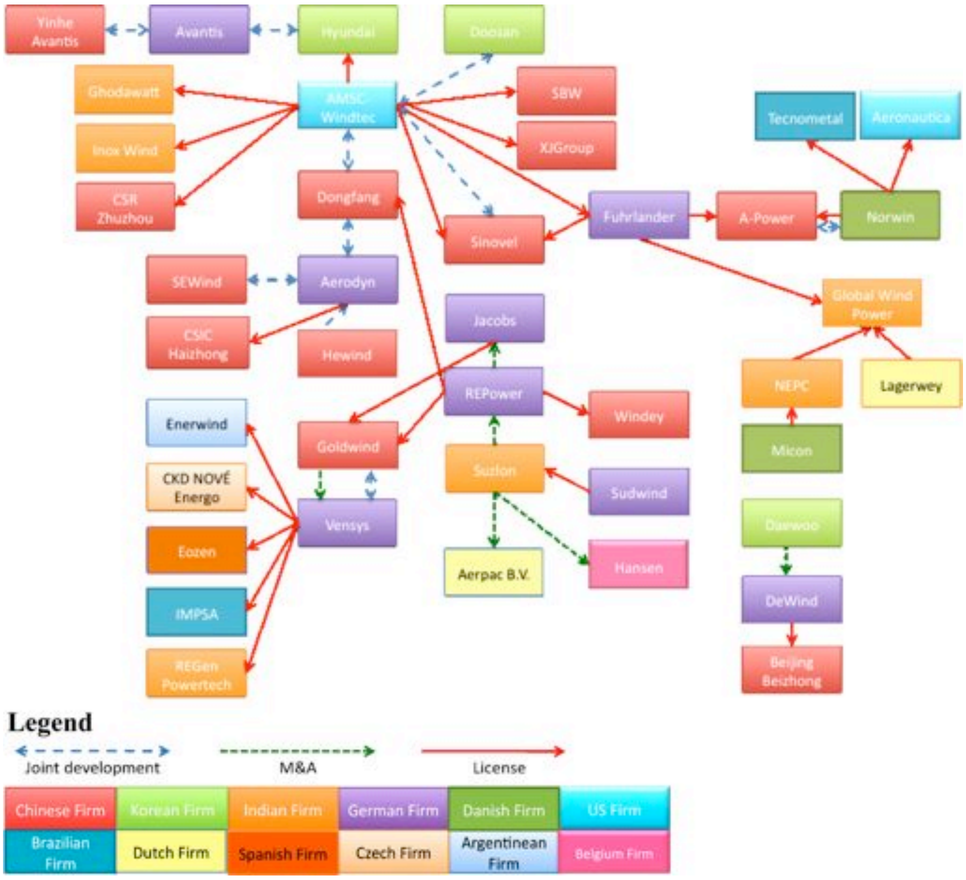
An investigation of the origins of the wind power technology being acquired by firms in India, China and South Korea reveals many common sources of such knowledge. When a firm shares licenses with multiple firms, or engages in joint development with multiple firms, this creates a network between firms through which knowledge can be shared. While such sharing of information is often restricted through contractual agreements, in other cases, it is encouraged. This can have both positive and negative consequences for firms. Such networks increase access to global learning and experience worldwide, which is likely beneficial. However, networks that facilitate information sharing in this way can also create competitors and make it harder to safeguard valuable or sensitive information.

There are several firms that have served as sources of wind power technology for firms based in China, India and South Korea, as illustrated in Figure 3. Key companies that have served as the source of wind power technology transfer for many of the key manufacturers located in China, India and South Korea (and beyond) are Avantis, Windtec, REpower, Aerodyn, Fuhrländer, Norwin and Vensys. It is notable that these companies are either small manufacturers that are not competing with the companies they have licensed to in the Chinese, Indian or Korean markets or they are primarily engineering design firms with little to no manufacturing experience. One exception is REpower, which has become a top-10 global manufacturer in recent years and is now selling directly to many overseas markets.

Avantis, based in Germany, is working with both Hyundai in South Korea and Yinhe in China to develop wind turbines. Windtec, now a subsidiary of AMSC, has not only transferred wind turbine technology to China (Sinovel, Dongfang, CSR, SBW, and XJ Group), South Korea (Hyundai and Doosan) and India (Inox Wind and Ghodawat) but also partnered with companies to produce wind turbines in Germany, Japan, Turkey and Taiwan (AMSC-Windtec, 2010a).[8] China's Dongfang has also benefited from a license from German firm REpower: the same firm that is now owned by India's Suzlon and provided licenses to China's Goldwind. Dongfang is also conducting joint development with German firm Aerodyn: the same firm that works with Chinese firms CSIC Haizhong, Hewind and Sewind. German firm Fuhrländer has licensed wind turbine technology to China's Sinovel and A-Power as well as India's Global Wind Power; Fuhrländer originally obtained this technology from Windtec. Chinese A-Power is also working with Danish firm Norwin. Norwin has licensed and jointly developed wind technology with A-Power of China and Global Wind Power of India, as well as Tecnometal in Brazil and Aeronautica in the USA. Global Wind Power also licensed technology from Dutch firm Lagerwey and NEPC of India, the latter obtained its technology originally from Micon of Denmark. German firm Vensys, now owned by Chinese firm Goldwind, has licensed wind technology to several firms around the world including Enerwind of Argentina (primarily selling to the Brazilian market), IMPSA in

Brazil, ReGen Powertech in India, Eozen in Spain, a Canadian subsidiary of Vensys, and most recently, CKD NOVÉ Energo in the Czech Republic and Slovakia.

**Figure 3** Wind power technology transfer networks in China, India, Korea and beyond (see online version for colours)




As firms expand their presence around the world by expanding manufacturing bases or R&D facilities, they are also increasingly able to tap into an expanded global knowledge base. Just a few years ago, Goldwind was principally a Chinese wind turbine company, operating its manufacturing and R&D facilities primarily in China. This domestic focus changed with the acquisition of Vensys in 2008, when it then began to increase its R&D activities in Germany. In contrast, Suzlon has been a company with global presence for much longer than Goldwind, beginning with its European partners early on in its technology development process. It 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. Suzlon also has overseas operations across five continents, including subsidiaries, research centres and sales offices. Although it conducts R&D abroad, Suzlon still relies primarily on components made in India, most of which are made in house based on experience gained through its overseas research efforts.

## *6.3 Domestic environments*

While the leading wind turbine manufacturers in China, India and South Korea have to some extent used similar models of technology acquisition, they have different advantages and face different obstacles to their continued success based on the characteristics of their domestic environment. This includes their home country's wind resource regimes, and the domestic policy environments in which they originated.

Historically, it has been common for wind turbine manufacturers to get their start in their home country markets. Home market experience was important for many of today's leading wind turbine manufacturers, with a few exceptions. All of today's top 10 wind turbine manufacturers: Vestas (Denmark), GE (USA), Sinovel (China), Enercon (Germany), Goldwind (China), Gamesa (Spain), Dongfang (China), Suzlon (India), Siemens (originally Bonus of Denmark) and REpower (Germany), got their start in their home markets. In addition, all of them are dominant suppliers in their home markets, with the exception of the Danish manufacturers because there is little remaining potential for onshore wind development in Denmark.

There are only a handful of leading global turbine manufacturing companies that did not primarily rely on their home markets in the early stages of their technology development, including Mitsubishi (Japan), which may be the model of the new Korean manufacturers. South Korea and Japan are not pursuing much domestic wind power development, primarily due to land availability and wind resource constraints. While China and India have proven to have sufficient wind resources to support a domestic market, South Korea would need to rely primarily on offshore sites to develop a domestic market for wind power. This is a key reason that Korean manufacturers have had to leapfrog directly to larger, offshore wind turbine technology, rather than starting with smaller onshore models as the Indian and Chinese companies did. As the Korean manufacturers are well-established firms with sophisticated manufacturing and innovation capabilities, this was another way they could complete with more established manufacturers from other countries.

China, India, and now South Korea have all benefited from aggressive government subsidy policies to support wind power development, although China's support has arguably been the most stable in recent years. By beginning their industry experience in a home market, companies can benefit from national government R&D support or policy support for demonstration projects (Lewis and Wiser, 2007). It is particularly important that government policies be used to create a sizable, stable annual demand for wind power to give companies the long-term planning horizon necessary to allow for investing in the future. Feed-in tariffs which provide long term price support for wind energy have been particularly effective in all three of these markets.

Despite the importance of national policy support, there are clear limits to understanding the success of these firms based exclusively on the national innovation systems in which they operate. The presence of these companies in different international markets, the frequency with which these firms look globally to pursue forms of technology development or acquisition outside their national borders, and the clear linkages between the origins of technological know-how among companies in different countries point to the need for a more global approach to examining innovation systems. As a result, the Sectoral Systems of Innovation (SSI) (Malerba and Mani, 2009; Bergek et al., 2008a) and the Technological Innovation System (TIS) (Carlsson and Stankiewicz, 1991; Bergek et al., 2008b) approaches seem better suited to understand the innovation dynamics of even national wind industries, particularly in the newly industrialised countries, than purely national systems of innovation approaches. Such models allow for a focus on the firm as the unit of analysis, encompass the various technologies within a particular sector and account for globally based learning activities.

## *6.4 Competitive advantages*

In China, the overall outlook for the wind industry is strong. An increasingly stable and favourable policy environment for wind in China will continue to make it one of the largest markets for wind power development in the world, and Chinese firms will continue to benefit from a domestic policy and business environment that awards them the majority of domestic projects. As the domestic market becomes saturated and as Chinese technology becomes more advanced, however, Chinese firms will increasingly look to export markets and have to compete globally. In some markets, they maybe able to compete if they are able to continuously offer lower-priced products, though there are already some concerns about quality. Few firms in China have sufficient operating experience to fully assess the quality of their technology, and it is very common for companies in the early stages of developing a new product to experience technical challenges and setbacks.[9] Recent data on wind farm performance in China has in fact raised concerns about quality control in Chinese wind turbine manufacturing, with performance further impeded by the sub-optimal siting of wind farms, and limitations of the Chinese electricity grid in handling wind's intermittency.

Goldwind's success in assimilating the technology it acquired is reflected in its increased knowledge and sophistication in the industry, financial status and global reputation. Its increased technical knowledge is reflected in its increasing turbine sizes; the company first developed a 600 kW turbine in 1999 – with a purchased license, and in 2010, it is now developing a 5 MW turbine prototype – through joint development with a design firm that it owns. Ranked number 5 in 2009 in terms of wind turbine sales, Goldwind is financially secure due to its ties with the Chinese Government and support from domestic banks. While it still has a very limited global reputation, and has exported only a handful of turbines outside of China directly, its acquisition of Vensys has greatly expanded its global reach.

The outlook for India's wind power industry is generally positive, though somewhat uncertain. While the policy environment for wind power in India has improved in recent years, the industry is still heavily dependent on tax incentives that tend to attract a narrow range of investors. In addition, the Indian power sector is plagued with inefficiencies and severe reliability problems that create a difficult environment for wind power growth. Indian wind turbine manufacturers, while still relatively new entrants into the wind power industry compared with some early European and US firms, have many more years of operating experience than most Chinese and Korean firms. While Indian wind turbine manufacturers possess advanced technology and solid operating experience, their global reputation is still somewhat uneven.

Within the Indian market, there are only a handful of firms competing for market share, unlike in China, where the number of firms increases daily and is reportedly greater than 80. Indian firms like Suzlon have developed a global reach, allowing them to sell their product in leading markets all around the world, while most Chinese firms have yet to leave China's borders. With this global reach comes market flexibility – when the Indian market slows, Indian firms can continue to sell their products to other markets.

This reduces their vulnerability to one particular policy system. With this global reach, however, also comes increased risk. The larger and more distributed a firm's operations, the more financially extended it becomes.

Suzlon is a company that has been able to successfully absorb the knowledge gained by its technology licenses and acquisitions, and through its own R&D, to manufacture increasingly sophisticated technology. Beginning with a 270 kW turbine in 1995, it is now selling primarily 2.1 MW machines. While Suzlon's acquisition of REpower illustrated its financial power and technical foresight, it now seems that assimilation of the know-how and experience that REpower holds will be more difficult than Suzlon initially anticipated, and both companies continue to operate independently.

South Korean firms, unlike Chinese and Indian firms, do not have a sizable domestic market or favourable domestic policy environment. This means that most South Korean firms are externally focused, targeting export markets around the world. As a result, they will be competing with manufacturers already active in those markets, including Chinese and Indian manufacturers. A clear advantage of Korean wind firms is their focus on advanced wind turbine designs, including offshore turbine designs. The ability of Korean firms new to the wind industry to leapfrog directly to some of the most advanced technology available is a result of their strong existing industrial base and ample resources to support technology partnerships with leading international firms. Without a large domestic market to demonstrate their technology and build market share, however, Korean firms are embarking on a high-risk venture into a competitive marketplace full of firms with many more years of experience.

It is worth noting that Chinese, Indian and South Korean wind turbine manufacturers all have plans for expansion into North American wind markets. For example, both Samsung and Sinovel are in the early stages of developing projects in Ontario, Canada. In Minnesota, where Goldwind already has a small wind farm, and Unison and Sinovel are also looking at projects. Samsung and A-Power are developing projects in Texas. Other projects using Hyundai, Minyang, Guodian United and Windey turbines are also in the early planning stages. Suzlon already has multiple projects in the USA and plans for further expansion, as does its affiliate REpower. As a result, it will be interesting to see how the emerging Asian wind turbine manufacturers compete against each other in the Canadian and US markets.

## *6.5 Policy implications*

As national governments consider policies and regulations to promote a wind power industry, these cases show that companies in China, India and South Korea have benefited from not only policy support for wind power deployment but also direct support for local manufacturers. This has particularly been the case in China, where local content requirements and preferential project selection for Chinese manufacturers have been instrumental in helping them build an industry. Such policies have not necessarily resulted in technology transfers, however, as only companies that do not compete in the Chinese market, or design firms which do not manufacture, have been the primary sources of technological know-know for Chinese firms. Other programmes may better facilitate technology and learning transfer, for example China's recently established low-carbon industry learning clusters, which provide incentives for wind turbine manufacturers to develop their technology within specific regions of the country (Ford, 2009; China Green Energy, 2009).

Since many wind turbine models coming out of China, India and South Korea have little operating experience, there is still room for government regulation to ensure quality control in products now being manufactured in all three countries. This could include the establishment of independent research and testing centres, or requiring companies to meet international standards for technology certification, particularly as domestic companies look to export markets. For wind power to ultimately be successful in these countries, a focus on the operation and maintenance of the wind farms, and not just the manufacturing of the wind turbine technology, will also be crucial. This is an area in which all of these markets can benefit from experience in countries that have been operating wind farms for decades.

As governments negotiate an international climate change treaty, at the forefront of discussions is how to best facilitate low carbon technology transfer. This research illustrates how payments for licensing the intellectual property for commercially-available technology have not necessarily served as barriers to technology transfer and that technology transfers are occurring between private companies, via commercial channels, with little government interference. There may be a role for the government in facilitating technology transfers in the private sector, however, for example by large-scale procurements that aggregate demand and can make a particular market look more appealing to the transferring company. In addition, with advanced or with pre-commercial technology, leaders may not be as willing to give up IPR to competitors. As a result, the government maybe able to help facilitate collaborative R&D and joint design for pre-commercial technologies that are deemed of great need and for which private companies are less willing to collaborate. Examples would include carbon capture and sequestration technologies or advanced solar power technologies.

## 7 Conclusions

This examination of how China, India and South Korea acquired their ability to manufacture wind turbines provides a look at how three emerging economies have acquired and assimilated advanced technologies in relatively short amounts of time. 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 primary technology transfer and acquisition strategies utilised by firms in China, India and South Korea included licensing arrangements, M&A that resulted in the transfer of technology ownership, or the joint development of new technology. All of these technology development or acquisition strategies were conducted within the constraints of national and international intellectual property law. As technology development becomes increasingly global, firms in the emerging economies can take advantage of their increasing access to technological know-how that was previously developed by and for the developed world.

It took firms in China, India and South Korea less than 10 years to go from having no wind turbine manufacturing experience to having the ability to manufacture complete wind turbine systems that are state-of-the-art and either already available or soon to be available on the global market. Each of these countries already had an existing industrial base, however, and similar technology development or manufacturing capabilities may not be easily replicable less developed countries. It is clear, however, that licensing is a relatively inexpensive way to acquire knowledge and allowed many of the early entrants in latecomer countries to initially enter the wind industry. The future potential of licenses is limited, however, particularly if the license includes little technological 'know-how' and limits future design modifications or innovations, or comes with market restrictions which limit global expansion. Access to global learning networks can be highly valuable for assimilating technological expertise and can be done through international research, development or demonstration partnerships or even through something as simple as hiring specialised workers from abroad. For firms with access to substantial financial resources, M&A are ways to acquire technical knowledge and assimilate expertise among firms with similar corporate cultures and baseline expertise, as long as M&A regulations can be successfully navigated. Partnerships to jointly develop new models of wind turbine technology often work well between design firms and manufacturing firms with little conflict of interest, though IPR sharing and market access arrangements must still be navigated.

## References

AAER Sells Wind Turbine to Hyundai Heavy Industries (2009) Windtec, 16 March [Online], Available: http://www.windtech-international.com/content/view/2263/2/

American Superconductor – Windtec (AMSC-Windtec) (2010a) *About AMSC Windtec, A Wholly-Owned Subsidiary of AMSC* [Online], Available: http://www.amsc-windtec.com/about_amsc_windtec.html

American Superconductor – Windtec (AMSC-Windtec) (2010b) *Press Release, AMSC and Hyundai Heavy Industries Expand Wind Power Strategic Alliance*, 9 June [Online] Available: http://www.amsc-windtec.com/pdf/HHI%205MW%20Alliance%200610%20Final.pdf

Amsden, A. (2001) *The Rise of the Rest: Challenges to the West from Late-Industrializing Economies*, Oxford Usniversity Press, New York.

A-Power Signs (2008) 'A-power signs second wind turbine deal, enters exclusive agreement with Norwin A/S to manufacture and sell 750 kW and 225 kW wind turbines in China', *Electric Energy*, 20 January [Online]. Available: http://www.electricenergyonline.com/?page=show_news&id=82409

Baker Botts (2010) *Translation from Chinese of "Entry Standards for Wind Power Equipment Manufacturing Industry, Draft for Solicitation of Opinions"*, Ministry of Industry and Information Technology, 31 March.

Beckett, P. (2009) *Suzlon Aims for Full Control of Repower*, *Wall Street Journal*, 10 December [Online], Available: http://online.wsj.com/article/SB10001424052748703514404574587753147027832.html

Bergek, A., Hekkert, M. and Jacobsson, S. (2008a) 'Functions in innovation systems: a framework for analysing energy system dynamics and identifying system building activities by entrepreneurs and policy makers', in Foxon, T., Köhler, J. and Oughton, C. (Eds.): *Innovation for a in Low Carbon Economy: Economic, Institutional and Management Approaches*, Edward Elgar, Cheltenham UK, Northampton, MA, pp.79–111.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008b) Analysing the functional dynamics of technological innovation systems: a scheme of analysis', *Research Policy*, Vol. 37, No. 3, pp.407–429.

Carlsson, B. and Stankiewicz, R. (1991) 'On the nature, function and composition of technological systems', *Journal of Evolutionary Economics*, Vol. 1, No. 2, pp.93–118.

China Green Energy (2009) *China Green Energy Technology Fund was Created in Tianjin Raising RMB1 to 1.5 Billion*, Zero2ipo.com.cn, 5 February [Online], Available: http://www.zero2ipo.com.cn/en/n/2009-2-5/200925140015.shtml

China's Fuxin (2009) *China's Fuxin to Purchase South Korea's Wind Turbines*, China Coal Resource, 14 August [Online], Available: http://en.sxcoal.com/NewsDetail.aspx?cateID=176&id=24143

de Vries, E. (2007) *Innovation: The Ingenious is Always Simple*, Renewable Energy World, 1 November.

Ford, P. (2009) *The World's First Carbon Positive City Will Be … in China? The Mayor of Baoding is on a Crusade to Make It a Hub of Renewable Energy*, *Christian Science Monitor*, 16 August [Online], Available: http://abcnews.go.com/International/JustOneThing/story?id=8327868&page=1

Freeman, C. (1995) 'The 'National System of Innovation' in historical perspective', *Camb. J. Econ.*, Vol. 19, No. 1, February, pp.5–24.

Gallagher, K.S. (2006) 'Limits to leapfrogging in energy technologies: evidence from the Chinese automobile industry', *Energy Policy*, Vol. 34, pp.383–394.

GE Energy to Re-enter India's Wind Energy Market (2009) Forbes India, 26 October [Online], Available: http://www.moneycontrol.com/news/business/wherewind-blows_420818.html

Global Wind Energy Council (GWEC) (2009a) *Global Wind Report 2009* [Online], Available: http://www.gwec.net/fileadmin/documents/Publications/Global_Wind_2007_report/GWEC_Global_Wind_2009_Report_LOWRES_15th.%20Apr.pdf

Global Wind Energy Council (GWEC) (2009b) *Indian Wind Energy Outlook 2009*, September [Online], Available: http://www.gwec.net/fileadmin/documents/test2/GWEO_A4_2008_India_LowRes.pdf

International Energy Agency (IEA) (2008) *Korea Goes for Green Growth*, 11 September [Online], available: http://www.iea.org/papers/Roundtable_SLT/korea_oct08.pdf

Kamp, L., Smits, R. and Andriesse, C. (2004) 'Notions on learning applied to wind turbine development in The Netherlands and Denmark', *Energy Policy*, Vol. 32, pp.1625–1637.

Karnoe, P. (1990) 'Technological innovation and industrial organization in the Danish wind industry', *Entrep. Reg. Dev.*, Vol. 2, pp.105–123.

Korean Energy Economics Institute (2009) *National Energy Plan* [Online], Available: http://www.keei.re.kr/main.nsf/index_en.html?open&p=/web_keei/en_Issues01.nsf/view04/59641581090E81B349256E2900483FAF&s=%3FOpenDocument

Lall, S. (1998) 'Technological capabilities in emerging Asia', *Oxford Development Studies*, Vol. 26, pp.213–243.

Lee, J.H. (2009) *South Korea's Doosan goes all out for Clean Energy*, 20 November, UPI Asia [Online], Availble: http://www.upiasia.com/Economics/2009/11/20/south_koreas_doosan_goes_all_out_for_clean_energy/7639/

Lee, K. (2005) 'Making a technological catch up: barriers and opportunities', *Asian Journal of Technology Innovation*, Vol. 13, No. 2, pp.97–131.

Lee, K. and Lim, C. (2001) 'Technological regimes, catching up, and leapfrogging: findings from the Korean industries', *Research Policy*, Vol. 30, pp.459–483.

Lewis, J.I. (2007) 'Technology acquisition and innovation in the developing world: wind turbine development in China and India', *Studies in Comparative International Development*, Vol. 42, Nos. 3–4, October, pp.208–232.

Lewis, J.I. and Wiser, R.H. (2007) 'Fostering a renewable energy technology industry: an international comparison of wind industry policy support mechanisms', *Energy Policy*, Vol. 35.3, pp.1844–1857.

Malerba, F. and Mani, S. (2009) *Sectoral Systems of Innovation and Production in Developing Countries*, Actors, Structure and Evolution, Edward Elgar, London.

May, H. and Weinhold, N. (2009a) *New Turbines on Offer*, New Energy [Online], Available: http://www.newenergy.info/index.php?id=1542

May, H. and Weinhold, N. (2009b) *Going Global* [Online], Available: http://www.newenergy.info/index.php?id=1430

Ministry of Industry and Information Technology (MIIT) (2010) *Gongkai zhengji dui "fengdian shebei zhi zao hangye zhunru biaozhun" (zheng qiu yijian gao) de yijian*, Draft wind power equipment manufacturing industry access standards, March 25 (in Chinese) [Online], http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/13101771.html

Mizuno, E. (2007) *Cross-border Transfer of Climate Change Mitigation Technologies: The Case of Wind Energy from Denmark and Germany to India*, PhD Dissertation, Department of Urban Studies and Planning, Massachusetts Institute of Technology, June.

Moller, T. and Rajgor, G. (2004) *Windpower Monthly (WPM)*, "Denmark picked for global headquarters", Windpower Monthly News Magazine A/S, Denmark, p.25.

Nelson, R.R. (2007) 'The changing institutional requirements for technological and institutional catch up', *International Journal of Technological Learning. Innovation and Development*, Vol. 1, pp.4–12.

Parthan, B. and Lemaire, X. (2007) *Wind Power in India, Behind the Success Story*, Presentation at the UN CSD, 8–15 May.

Rajsekhar, B., Van Hulle, F. and Jansen, J. (1999) 'Indian wind energy programme: performance and future directions', *Energy Policy*, Vol. 27, pp.669–678.

Red Herring (2005) *Prospectus: Suzlon Energy Limited* [Online], Available: http://www.sebi.gov.in/dp/suz.pdf

Shi, P. (2009) *2008 Wind Power Market Shares in China*, Personal Database, 2 March.

Suzlon (2010) *Suzlon Annual Report 2009–2010: Sustaining Development Across 5 Continents, 25 Countries*.

Suzlon Completes Blade Retrofit Program (2009) *India PRwire*, 13 October [Online], Available: http://www.indiaprwire.com/pressrelease/information-technology/2009101335732.htm

van Est, R. (1999) *Winds of Change: A Comparative Study of the Politics of Wind Energy Innovation in California and Denmark*, International Books, Utrecht.

Wang, S. (2009) 'The answer to China's future energy demands may be blowing in the wind', *Scientific American*, 10 September.

Wu, G. (2009) Goldwind CEO, in conversation with author, October 8, 2009.

Zhu, R. (2010) *Study on Wind Resources Potential for Large Scale Development of Wind Power*, [PPT] Chinese Metrological Association, National Climate Center, 13 April.

## Notes

[1]Only 65% or about 8.97 GW of China's total wind capacity was reportedly connected to the grid by the end of 2009, primarily due to delays in the extension of transmission lines.

[2]Until recently, the Chinese Meteorological Association (CMA) estimated that the total wind resources onshore were just 250 GW. Recent estimates for onshore resources assume a 50 m hub height and only include areas technically and geographically feasible for wind development. Offshore resources are measured between at depths between 5 m to 25 m but estimates are still rather uncertain (Zhu, 2010).

[3]A-Power conducts operations through two Chinese companies: Liaoning GaoKe Energy Group Company Limited (GaoKe Energy), a wholly owned subsidiary of Head Dragon Holdings, and Liaoning High-Tech Energy Saving and Thermoelectricity Design Research Institute (GaoKe Design), 51% of which is owned by GaoKe Energy. The two companies are collectively referred to as Gaoke, which A-Power gained control of when it acquired Head Dragon Holdings and made it its wholly owned subsidiary.

[4]A-Power's Chinese operating subsidiary, Liaoning GaoKe Energy Group ('GaoKe'), entered into an agreement with Norwin A/S of Denmark ('Norwin') that gives GaoKe the exclusive right to produce and sell Norwin's 750 kW and 225 kW wind turbines in China. As part of the agreement with Norwin, a joint venture company was established in Shenyang, China that is 80% owned by GaoKe. GaoKe and Norwin also established a joint research and development facility in

Shenyang to develop new wind turbine technology for both the Chinese and the international markets. To secure these rights, GaoKe has reportedly agreed to pay Norwin a license fee of $3.5 million.

[5]Placement of Suzlon's international headquarters in Denmark was particularly strategic in 2004 now since many former workers for the leading Danish wind companies, Vestas and NEG Micon, had been recently laid off after streamlining in conjunction with the merger of the two companies.

[6]In late 2009 Suzlon divested some of its interest in Hansen, reportedly to reduce debt it acquired in its take-over of REpower, but still holds a 26% interest in the company.

[7]According to Suzlon's annual reports, the company spent 29.17 Rs crore on R&D, certification and product development and quality assurance in 2009, and 73.57 Rs crore on this same category in 2010. It spent 63.11 Rs crore on design change and technological upgrade charges in 2009, and 81.07 Rs crore on this same category in 2010.

[8]Windtec was founded in Austria in 1995, acquired by Germany's Pfleiderer Group in 2001, became an independently owned company in 2005, then became a wholly-owned subsidiary of AMSC in 2007.

[9]Goldwind, one of the few Chinese firms with several years of operating experience, experienced major failures in hundreds of their wind turbines that had been installed across China, which was later traced to a material defect. While Goldwind was able to repair the turbines and recover from this setback, unexpected technical failures can be extremely costly and can threaten the financial stability of a company.