6.1 Overview

A sector is characterized by a specific knowledge base, technologies, and inputs which play an important role in defining a given sector. Knowledge differs across sectors in terms of source firms, universities, domains (i.e. the specific scientific and technological fields at the base of innovative activities in a sector), and applications (Malerba 2002).

Knowledge also has different degrees of accessibility (i.e. opportunities of gaining knowledge that are external to firms and may be internal or external to the sector) with major consequences on entry and concentration, and may be more or less cumulative (i.e. the degree by which the generation of new knowledge builds upon current knowledge). Knowledge may also flow more or less intentionally across individuals and organizations (Cowental 2000).

In this chapter an attempt has been made to the broad identification of the main characteristics and effects of knowledge in the wind power sector and specific type and structure of knowledge, its effects on innovation and the organization of innovative activities in the sector. There is a two-way relationship between knowledge evolution and industry evolution in different sectors (Malerba 2002). Evolution of wind power generation is no different and knowledge and technological capability have played an important role in the evolution of the industry.

In a SIS, technological base plays an important role in the innovation and production. Knowledge has particular characteristics that it becomes highly idiosyncratic at the firm level, does not diffuse automatically and freely (Malerba 2002). This results in the concentration of knowledge expertise in few firms of the sector.

A typical knowledge domain of wind power sector includes comprehensive assessment of wind resource base, availability of appropriate wind turbine
manufacturing base and readiness of the grid for power evacuation. Each domain requires effort at different levels with different capabilities. Public institutions have a role in resource assessment and formation of standards, whereas firms have inherent advantage in terms of manufacturing. Each domain has its specific knowledge base and characteristic learning. Actors and networks are highly affected by the characteristics of and changes in the knowledge base and differ greatly across sectoral systems.

The changes in knowledge and learning processes also have implied changes in the organization and characteristics of R&D. In most sectors R&D has been increasingly decentralized, externalized and internationalized. This has happened in conjunction with an increasing focus on market-oriented R&D, the growth of external sources of knowledge and the need to obtain access to knowledge about markets or to key technological or scientific resources. The organization and the features of R&D have differed greatly across groups of sectors (Coriat & Weinstein 2004). Indian Wind power sector has also undergone similar changes by the increased role and influence of external agents. Thesis discusses these points in detail in following sections.

Suppliers and users have also affected the boundaries of sectoral systems, by greatly affecting sectoral linkages and interdependencies. Demand, as composed by users and by consumers, has often resulted in the redefinition of the boundaries of a sectoral system. In addition, the emergence of new demand or the transformation of existing demand has been one of the major elements of the change in sectoral systems over time (Malerba 2004). In a dynamic way, the focus on knowledge and technology places the issue of sectoral boundaries at the centre of analysis. In sectors in which innovation is quite rapid, sectoral boundaries are not fixed but change over time. Knowledge and basic technologies constitute major constraints on the full range of diversity of the behaviors and organizations of firms. Links and complementarities among artifacts and activities also play a major role in defining the real boundaries of a sectoral system. These links and complementarities can be static (as input-output links are) or dynamic. Dynamic complementarities take into account interdependencies and feedback, both at the demand and at the production levels. They are major sources of the transformation
and growth of sectoral systems, and may set in motion virtuous cycles of innovation and change (Malerba 2004). Indian wind power sector’s knowledge base and inter linkages have also transformed in its evolution. As a sector with concentration of knowledge in few firms and geographical regions its boundaries have although remained more or less same.

RETs have generally remained laggard in their adoption due to technological “lock-in” in conventional technologies and no realization of their carbon advantage. With a sudden rise in demand for wind power and, as a result, increasing use of this source of energy, it has become more competitive relative to fossil fuels and thus more attractive as a target for research and investment (Lee 2008). The entry into force of the Kyoto Protocol in 2005 has only intensified this interest in wind power. Priorities given to RETs in a carbon constraint world have reinvigorated interest in the RET R&D.

Research and development (R&D) and patent data have emerged as important indicators of the innovativeness of an economy or sectors. Measuring technological change presents a common and well-known problem for innovation output research. In practice, four different types of measures are generally used to quantify technological change. The first one represent input measures such as R&D expenditures, R&D personnel, the number of researchers, and innovation expenditures. Second, there are direct measures of innovative output like the number of innovations, descriptions of individual innovations or data on sales of new products. The third class comprises indirect measures derived from aggregate data such as changes in resource efficiency or productivity using decomposition analysis. The fourth class represent intermediate output measures, including the number of patents and the amount and type of scientific publications (Oltra et al. 2009). Thesis has used the innovation output measures as number of innovations, descriptions of individual innovations or data on sales of new products. Innovation intermediate output measures, the number of patents have been discussed in detail due to the relevance to our research question.

Chapter has a detailed analysis of patenting landscape in the Indian wind power sector. Patents have several advantages over R&D expenditures,
i. they explicitly give an indication of inventive output,

ii. they can be disaggregated by technology group, and

iii. they combine detail and coverage of technologies (Lanjouw et al. 1998).

Moreover, because patents are granted on the basis of novelty and utility, they are based on an objective and slowly changing standard (Griliches 1990). Furthermore, patents are intermediate output measure for innovation, to be distinguished from input measures (such as R&D expenditures), direct measure of innovative output and indirect measures derived from aggregate data. To look in the innovation dynamics and diffusion of technology patent data serve as a useful resource it has high level of authenticity and is relevant to our research questions. A detailed analysis of patent landscape has been made in this chapter.

In this chapter a detailed analysis of different innovation indicators in wind power sector are taken which have relevance in the operation and performance of the WTG technology. Design of tower and materials, blade, rotor, generator and integration of WTG are discussed in the following sections.

A particular feature of Indian wind power sector is the relative specialization of public funded R&D in wind resource assessment. A detailed analysis is done on the R&D by these centers and labs in wind resource assessment and forecasting of wind regimes. Such type of research although not of direct technological relevance, it provides a suitable base for the development of wind power generation. Scientific output by papers and patents in University and research lab. has been found to be of very low order in preliminary investigation. Hence, they are discussed along with the respective agents in the chapters on actors in the wind power SIS. Universities play a key role in basic research and human capital formation, but as the wind power sector in India presents a case of dominant role of firms in the sector, this has not been discussed in detail. Human capital formation and domestic pool of talented labor is an important determinant of the sectoral innovation base. In the case of wind power sector, diverse specialization is needed in different technological domains, thus aggregate data on human capital would either give a wrong picture or would not be able to give a clear picture of
the sector at all. Firm level data has been incorporated and discussed along with the relevant actors in the chapter on actors in wind power SIS. Finally, sectoral dynamics by way of new R&D initiative is discussed in the chapter.

6.2 Measures of Innovation

As a measure of innovation in any sector, output measures are direct measures of innovative output like the number of innovations, descriptions of individual innovations. In the following sections a detailed analysis of various innovation indicators in wind power generation like system-level design and optimization, design of towers, rotors and blades, pitch systems, drive trains, generators, and power electronics and manufacturing learning is made in following sub sections.

![Fig.6.1: Technological trajectory of wind turbine](source: adapted from Inoue and Miyazaki (2008))

### 6.2.1 System-Level Design and Optimization

Wind power plants and turbines are sophisticated and complex systems that require integrated design approaches to optimize cost and performance.
At the plant level, considerations include the selection of a wind turbine for a given wind resource regime, wind turbine siting, spacing, and installation procedures, O&M methodologies and electric system integration (Burton et al. 2001).

Optimization of wind turbines and power plants therefore requires a whole-system perspective that evaluates not only the wind turbine as an individual aerodynamic device, mechanical structure and control system, but that also considers the interaction of the individual turbines at a plant level (GWEO 2011).

Indian wind power sector has evolved from a installation based approach to a generation based approach guided by the change in institutional dynamics in the sector. This requires considerable learning in system optimisation and integration. System integration to a large extent depends on the reliability of components particularly generator sets and grid parameters. New Grid code of CERC has specifically addressed the problem of wind power integration in the grid giving due weightage to the variable nature of production and system instability consequent to it.

Firms such as Suzlon have advance expertise in the optimisation and integration of their WTG despite having not very advanced features in their WTG sets (see Table7.1). It is mainly due to their wind farm approach that looks into the integration of several machines in the grid with stability in operation. CWET has a dedicated test stations for the measurement and improvement of WTG system level parameters in their Kayathar testing station.

A major part of system integration is dependent on the wind profile of a particular region and power curve of an individual WTG set. This demands considerable level of expertise in project execution and installation. Firms having large share in the installed base thus have better system optimisation parameters than firms with fewer installation. Larger firms have expertise in a system-level analysis of the potential challenges e.g., manufacturing processes, installation processes and structural integrity of their WTG sets.
Advanced turbine control and condition monitoring are also prerequisite to improve turbine reliability and availability and increased energy capture, for both individual turbines and wind power plants. Advanced controllers also help in better controlling the turbine during turbulent winds and thereby reduce fatigue loading and increased energy capture.

### 6.2.2 Design of Towers

Taller towers allow the rotor to access higher wind speeds in a given location, increasing annual energy capture. The cost of large cranes and transportation, however, acts as a limit to tower height (Burton et al. 2001). Towers being used by most of the developers are lattice or of tubular steel design. Lattices towers are generally used for low rated WTG as it is easy to assemble. Tubular steel towers are used in higher rated towers with hub height above 50m. Considerable technological capability is needed to manufacture, and install such tall towers at remote locations. Tubular steel towers have become an industrial standard in the wind power sector. Shriram EPC Ltd’s SEPC 250T, Suzlon’s S52/600 kW models use lattice type towers. Use of heavy duty cranes have become an important factor in determining the choice of tower.

**Fig. 6.2: Average Size Of Wind Turbine Generator (KW) installed each year**

Innovation by the use of new materials for the tower construction is also reported in some WTG models like Suzlon’s latest S series model S95 DFIG 2.1 MW uses 80m.
concrete tower. The use of advanced tower concepts in usage in wind power sector in India can be judged from the fact that India started with unit size of 55 KW in 1986 followed by 90 KW, 110 KW and 150 KW in the early 1990’s. Present day large WTGs are above 2000KW rated capacity like the recent Kenersys India’s K100 model with rated capacity of 2500KW and hub height of 100 metres.

6.2.3 Rotors and Blades

Rotor blades are an important component of WTG sets as they determine the operational aspects of the WTG. Use of innovative material for constructing blades and design parameters suitable for the particular wind profile determine the success of a given turbine model. Cracks in Suzlon’s domestically developed WTG blades led to the recall of its WTG sets from USA, it was an important factor in Suzlon’s strategy to acquire overseas R&D based companies in Europe.

Wind turbine blades have become lighter by the use of new generation materials. If advanced R&D can provide even better blade design methods, coupled with better materials (such as carbon fibre composites) and advanced manufacturing methods, then it will be possible to continue to innovate around the square-cube law in blade design(GWEO 2011).

The structural properties of the blade can be improved manifold using the unique attributes of composite materials, they can be used in higher rated turbines with lower weight and improved strength.

Development in materials for rotor blades is an important area of R&D. NAL of CSIR has domestically developed turbine blades suited for Indian conditions. NAL-Sangeeth wind turbine blades are successfully transferred to the private firm also. NAL, as a spinoff of its aircraft research has developed carbon composite blades that are to be produced by the Kemrock Enterprise, Vadodara. Firms such as LM Glasfiber, which have long been the world’s largest independent blade supplier have established its production facility outside Europe in India to serve the Asian region. Major players like Enercon use fibreglass blades that are light and have considerable strength.
Blade testing is the important process before the WTG set can be successfully introduced in the market. Testing ranging from characterisation of constituent materials, through blade sub-components to whole blades is vital for the integrity of any new designs. CWET is the national testing agency with facilities for testing of WTG blades. NAL, a CSIR lab. has plans for a dedicated wind tunnel for the testing of parameters of the blades and other wind turbine components. As the wind industry has matured, proof testing, ultimate load testing and fatigue testing of new rotor blade designs has become the norm (GWEO 2011).

The handling and transport issues with very large blades also poses serious challenges particularly in country like India with connectivity issues and poor road infrastructure. It becomes a deciding factor in the introduction of higher rated WTG sets in remote locations with poor connectivity. Establishment of road infrastructure forms a sizeable share in the cost of land development in any wind farm. Use of jointed blades is a possible remedy for the problem. The world’s largest wind turbine, the Enercon E126, adopts a jointed blade design. In the E126 blade, an essentially standard outer blade section with a conventional blade root attachment is bolted to a steel inner blade spar. The trailing edge of the inner blade is a separate composite structure (GWEO 2011). Enercon has not introduced the above model in India and has only introduced models E 48 and E53 with rated power of 800KW. Gamesa has also developed a jointed blade design for the G10X.

6.2.4 Pitch Systems

The pitch control system is one of the most widely used control techniques to regulate the output power of a wind turbine generator. The method relies on the variation in the power captured by the turbine as the pitch angle of the blades is changed. Hydraulic actuators are used to vary the pitch angle. The wind turbine generator describes the design of the pitch controller and its performance is dependent on pitch system in the presence of disturbances. Considerable advancement has taken place in the power regulation in the WTG machines. It is one of the most innovation intensive area as improvement in power regulation results in better power curve and enhanced efficiency of WTG. Table 7.1 describes the different power regulation techniques used by different firms in their
WTG models. Lower rated turbine generally uses stall regulation and have no pitching available. Indian WTG manufacturers such as CWEL, Pioneer Wincon with no foreign collaboration also uses stall regulation. Stall regulation results in sub optimum performance of WTG as the machine is stalled and ceases operation. Higher rated machine uses pitching system by default as the high turbulence produced by stall regulation results in considerable stress on large rotor blades with possibility of breakdown.

Different firms use different techniques for power regulation. Suzlon’s new S series S9X design describes it advanced pitch system as\(^1\),

“to maximize turbine reliability, leading to the inclusion of the following features and sub-systems. A new pitch system with a new pitch master and battery box have been designed and incorporated for better pitching control and operation, resulting in higher reliability and better safety systems. A sturdier fourth yaw drive with better yawing control, improved balancing and load sharing makes the turbine more stable. [...] Advance features such as Hydrodynamic Fluid Coupling, Precise Micro-Pitching and the Unique flexi-slip Mechanism for maximizing performance. With a proven and reliable backing of technology, Suzlon assures 95% machine uptime on its wind turbine generators.”

Regen Powertech Pvt. Ltd which has sourced technology under sub-license agreement with Vensys Energy AG, Germany describes its power regulation methodology in V-77 1500 KW direct drive wind turbine as\(^2\)

“it employs almost wear-free toothed belts in the pitch drives, instead of the more common hydraulic cylinders or geared electric pitch motors. One key advantage claimed for this innovation is insensitivity to shock loads, since such impact forces are distributed over multiple meshing teeth pairs. A second advantage is that the drive system does not require grease lubrication and is almost maintenance free.”

Vestas, a leading Danish firm has introduced its latest V82-1.65 MW turbine, claimed to be ideally suited for low to medium Indian wind conditions. It describes about power regulation as,

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1 Suzlon Product Brochure for S-series WTG.  
2 Regen-Vensys Product Brochure for V-77 WTG
“It uses patented Active Stall technology, which ensures that the rotor gathers the maximum power available from the prevailing wind, while minimising loads and controlling output.”

Pitch control ensures that output does not fall with variable wind speed and ensures operation at rated speed. Use of pitch control results in increased conversion efficiency of the WTG.

6.2.5 Generators, Drive Trains, and Power Electronics

Generators, drive trains and power electronics form the most essential component of WTG. They determine the efficiency and sturdiness of a WTG and are the most technology intensive. Synchronous, Asynchronous, DFIG and Permanent magnet SG are the generators generally used in WTG machines. A detailed description is made in the table 7.1 of generator types used by different firms. Asynchronous generator is the technologically old and has many limitations. It is used generally in low rated machine by Indian developers. Suzlon uses asynchronous generator in all of its models whereas Enercon a global leader in wind power uses advanced synchronous generators. Doubly Fed Induction Generators (DFIG) have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and electrical system. Doubly fed machines are used in applications that require varying speed of the machine's shaft for a fixed power system frequency. The rotor circuit is connected to the grid through an ac- dc-ac inverter so that the frequency of the rotor voltage can be matched to the grid frequency. DFIGs are used by the Gamesa, Inox and Norwin.
Table 6.1: Technological Features of WTG sets of different Firms

<table>
<thead>
<tr>
<th>Firm</th>
<th>Power Regulation</th>
<th>Generator</th>
<th>Transmission</th>
<th>Generator (Type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern W/F (NEPC India)</td>
<td>Stall</td>
<td>Dual speed</td>
<td>Geared</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>CWEL</td>
<td>Stall</td>
<td>Dual speed</td>
<td>Geared</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>Pioneer Wincon</td>
<td>Stall</td>
<td>Dual speed</td>
<td>Geared</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>Shriram EPC (TTG)</td>
<td>Stall</td>
<td>Dual speed</td>
<td>Geared</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>Siva Windturbine</td>
<td>Stall</td>
<td>Dual speed</td>
<td>Geared</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>RRB Energy</td>
<td>Pitch</td>
<td>Single Speed</td>
<td>Geared</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>Suzlon</td>
<td>Pitch</td>
<td>Single Speed</td>
<td>Geared</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>Global Wind Norwin</td>
<td>Active Pitch</td>
<td>Dual Speed/Variable Speed</td>
<td>Geared</td>
<td>Asynchronous/DFIG</td>
</tr>
<tr>
<td>Pioneer Wincon</td>
<td>Semi-Pitch</td>
<td>Dual Speed</td>
<td>Geared</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>Enercon</td>
<td>Pitch</td>
<td>Variable Speed</td>
<td>Gearless</td>
<td>Synchronous</td>
</tr>
<tr>
<td>Gamesa</td>
<td>Pitch</td>
<td>Variable Speed</td>
<td>Geared</td>
<td>DFM/DFIG</td>
</tr>
<tr>
<td>Winwind Power</td>
<td>Pitch</td>
<td>Variable Speed</td>
<td>Geared</td>
<td>Permanent Magnet SG</td>
</tr>
<tr>
<td>Leitner Shriram</td>
<td>Pitch</td>
<td>Variable Speed</td>
<td>Gearless</td>
<td>Permanent Magnet</td>
</tr>
<tr>
<td>GE Wind Energy</td>
<td>Active Pitch</td>
<td>Variable speed</td>
<td>Geared</td>
<td>DFM</td>
</tr>
<tr>
<td>Regen-Vensys</td>
<td>Pitch</td>
<td>Variable speed</td>
<td>Gearless</td>
<td>Permanent Magnet SG</td>
</tr>
<tr>
<td>Vestas Wind</td>
<td>Active Stall/Pitch</td>
<td>Single Speed/Variable Speed</td>
<td>Geared</td>
<td>Asynchronous</td>
</tr>
<tr>
<td>Inox Wind</td>
<td>Pitch</td>
<td>Variable Speed</td>
<td>Geared</td>
<td>DFIG</td>
</tr>
<tr>
<td>Kenersys</td>
<td>Pitch</td>
<td>Variable Speed</td>
<td>Geared</td>
<td>Synchronous</td>
</tr>
</tbody>
</table>

Source: Compiled by author from WTG Model Brochures of the firms

Synchronous generators do not need gears for power transmission and thus have advantage over asynchronous machines. Direct-drive generator (removing the need for a gearbox) improves the efficiency of WTG. They have a high pole count and are large in diameter, imposing a weight restriction. The availability and cost of rare-earth permanent magnets also affect the permanent magnet generators. Permanent-magnet generators are advanced generators that have reduced electrical losses in the windings. Leitner and Vensys uses permanent-magnet generators in their WTGs.
Operating speed of the turbines has also increased from low speed, fixed speed system to dual speed/variable speed. Variable speed generators have better operation under varied wind conditions and have better power curve than fixed speed or dual speed generators. Table 7.1 enumerates the firms that use different generators.

Power transmission in an energy conversion devise can be either made through drive trains using gear box or directly fed to generator as in case of synchronous generators. Geared and direct drive are the two approaches for power transmission. Gearless design is technologically sophisticated and is used by Enercon and Vensys only. Gearless drive does not require the gear box and thus higher efficiency and lesser mechanical losses. Table 7.1 describes the different drive mechanism used by Firms.

Power electronics components determine the quality of power generated by the WTG. They condition the power as required by grid. In the modern WTG they form an integral part in controlling every aspect of the WTG. Control of yaw motors, rotor supply in DFIG and grid integration all require power electronic component. Power electronics that provide full power conversion from variable frequency Alternating Current (AC) electricity to constant frequency 50 or 60 Hz are also capable of providing ancillary grid services. The growth in turbine size is driving larger power electronic components as well as innovative higher-voltage circuit topologies. Power conversion devices are also required to be compliant with grid codes to ensure that wind power plants do not degrade the reliability of the electric system.

6.2.6 Manufacturing Learning

Manufacturing learning refers to the learning by doing achieved in serial production lines with repetitive manufacturing. Improvements in the turbine design, their reliability and robustness improves by usage over a time. If increase in the power generation is taken as a proxy for the improvement in design and reliability we can deduce that considerable learning has taken place in Indian wind power generation sector.
Figure 6.3 shows the cumulative installed capacity and electricity generated. A close examination reveals that generation lagged the total installed capacity up to 2003-04. After that the generation picked up at a very high rate.

**Fig. 6.3: Cumulative Installed Capacity and Electricity Generated: Wind Power Sector**

![Graph showing cumulative installed capacity and electricity generated](image)

*Source: compiled by Author*³

Note: Year means Financial Year 1st April 2010 to 31st March 2011

There could be many factors contributing to the above phenomenon, one being improvement in the design parameters and installation of more efficient turbine than previously used imported turbine less suited for Indian conditions. This phase also coincides with the emergence of domestic firms like Suzlon that grew by high rate during the given period. Indian wind power sector although dominated by foreign firms and their designs which better suits more windy conditions in Europe have undergone a lot of indigenisation in design and approaches towards the installation. Institutional factors also changed from an capital subsidy based accelerated depreciation to more generation oriented measures. But institutional factors can

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³ Ministry of Statistics & Programme Implementation, Govt. of India. (ON78), IWTMA, India Wind Power Reports, Ministry Of New and Renewable Energy Annual Reports, MNRE database.
provide a conducive ecosystem for change in the sector, the transformation has to be in technological and organisational innovations in actors present in the sector. This underscores the role of organisational and technological innovation in the firms in the wind power sector.

6.3 R&D in the Wind Power Sector

R&D institutions, resources and outputs are at the centre of the Systems of Innovation analysis. Wind power is a technology intensive sector with R&D playing a key role in the development of the turbine and associated equipments. Wind Turbine Generator (WTG) in itself includes many components that demand advanced integration and precision in performance. Need for R&D is in diverse range of wind power technologies, for improving the efficiency of generators, enhancing blade pitch control, diminishing generator noise, and methods for improving the efficiency of generators at low or middle wind velocity. Other areas of research include novel turbine, generator, and systems designs aimed at reducing unit costs and intelligent control systems to optimize the operation of turbines.

6.3.1 Research and Development Programmes

Public and private R&D programmes have played a major role in the technological advancement in the wind power sector. Government support for R&D by way of improvements in resource assessment, technical standards, electric system integration and wind energy forecasting has played an important role in creating a sound foundation for private sector to grow and take advantage of the available appropriative conditions. Whereas private sector has shown advances in WTG system and component level technologies.

Government-sponsored R&D programs in the wind power sector have emphasized on long term innovation in key areas of wind resource assessment and standards, while industry-funded R&D has focused on short-term production, operation and organisational innovations.

Wind energy research is generally found to be concentrated in European countries of the west and the USA, developing countries are generally net technology receivers in this regard. The role of government in deciding institutional environment and private
sector’s enhanced capability in the globalised environment have led to their complementary role in the R&D.

Wind power systems certification (new turbines and components), wind energy integration (grid integration); and wind energy resources (wind resource assessment and design conditions) are the areas where government has a major role. Wind resource assessment and forecasting are the areas where public R&D has been substantial. These two areas are discussed in detail in following sections.

Private sector R&D effort in the sector are lately coming by three approaches. One is acquisition of foreign firms with high R&D capability by domestic firms. This can be seen in the case of Suzlon, that has acquired Hansen and Repower to gain a strong R&D base. The second is the setting up of R&D labs by foreign firms in India that are attracted by low cost economy and high appropriability conditions provided by the higher demand. This has been the case with one of the largest player in the sector, Vestas. Vestas has set up its largest R&D centre outside Denmark in Chennai that employ 300 personnel. Third approach is by domestic players that have their own R&D centres in the country. RRB Energy Ltd has R&D centre in Sri Perambadur that has come out with an indigenously developed above 1 MW WTG, as claimed by the company. Firms such as BHEL, CSIR Labs such as NAL have spin offs from their primary research in other fields.

In general, R&D efforts are increasing in the wind power sector. A basic difference in R&D; in wind power sector is that, unlike, pharmaceuticals or biotech sector there has not been a radical change in the fundamental design of wind turbines. Instead, the development has come by incremental technology advances, that resulted in significant improvements in the levelised cost of wind energy as well as development of larger turbines.

6.3.2 Wind Resource Assessment

Wind resource assessment is a prerequisite for the development of wind power. The Government of India has set up the Centre for Wind Energy technology (C-WET) to map wind energy potential in the country. Consequently, the C-WET has set up more than 1,000 wind monitoring and wind mapping centres across 25 states. Later Government also allowed wind mapping at 50 meters (C-WET) and more than 50 metres at 60-80 meters height by private companies (CWET 2011).
The total potential for wind power in India was first estimated by the Centre for Wind Energy Technology (C-WET) at around 45 GW, and was recently increased to 48.5 GW (CWET 2011). This figure was also adopted by the government as the official estimate.

The C-WET study was based on a comprehensive wind mapping exercise initiated by MNRE, which established a country-wide network of 1050 wind monitoring and wind mapping stations in 25 Indian States. Wind measurements are being carried out at 5 levels (10, 30, 60, 90 and 120m). This effort made it possible to assess the national wind potential and identify suitable areas for harnessing wind power for commercial use (CWET 2011).

With collaboration of RISO National Laboratory for Sustainable Energy, Denmark CWET has prepared recently an Indian Wind Atlas. It uses Karlsruhe Atmospheric Meso Scale Model (KAMM) of RISO National Laboratory for the preparation of the wind atlas (CWET 2011).

However, industry body IWTMA claims that the wind measurements were carried out at lower hub heights and did not take into account technological innovation and improvements and repowering of old turbines to replace them with bigger ones. At heights of 55-65 meters, the Indian Wind Turbine Manufacturers Association (IWTMA) estimates that the potential for wind development in India is around 65-70 GW (IWTMA 2011). The World Institute for Sustainable Energy, India (WISE), a not for profit research organisation even estimates potential to be 100 GW considering availability of larger turbines, greater land availability and expanded resource exploration (Wind Power Monthly Mar, 2012).

Wind Resource assessment by different agencies vary as they take different parameters into consideration. For example, MNRE assumes 1% of land availability for wind farms requiring @12 ha/MW in sites having wind power density in excess of 200 W/m² at 50 m hub-height whereas most of the private players takes hub height beyond 50 m.

6.3.3 Wind Power Forecasting

It is very technology intensive and complex task that determines adequate operation and utilisation of installed capacity. Wind being highly variable and erratic in nature, a proper advance estimation demands use of meteorological data and modelling.
Wind Power Forecasting (WPF) basically deals with two major variables. First, it is the wind speed that varies corresponding to weather and second, generation from a Wind Power Project that varies in cubic proportion of wind speed (Burton et al. 2001). To get accurate details large amount of varied data and proper modelling algorithm is required. A basic model includes Numerical Weather Prediction (NWP), Wind to Power model and Regional Up-Scaling. The input data by meteorology needs to be accurate to forecast short and long term variation and for utility grid, the forecasting should be on day ahead and hourly basis for proper planning. Wind Power Project requires forecasting at three different scales. Firstly, in seconds for turbine control. Secondly, in hours for grid management and thirdly in days for maintenance planning (Burton et al. 2001). Some of the popular wind power forecasting models are described in the table below.

Table: 6.2: Wind Power Forecasting Models

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Model</th>
<th>Developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>PREDIKTOR</td>
<td>RISO, Denmark</td>
</tr>
<tr>
<td>2.</td>
<td>WPPT</td>
<td>IMM DTU/ENFOR, Denmark</td>
</tr>
<tr>
<td>3.</td>
<td>Zephyr</td>
<td>RISO and IMM. DTU, Denmark</td>
</tr>
<tr>
<td>4.</td>
<td>GH Forecaster</td>
<td>Garrad Hassan, UK</td>
</tr>
<tr>
<td>5.</td>
<td>eWind</td>
<td>AWS Truewind, USA</td>
</tr>
<tr>
<td>6.</td>
<td>Power Sight</td>
<td>3 TIER, USA</td>
</tr>
</tbody>
</table>

Source: WISE, 2011

As can be seen from the table most of the models are developed in Europe and USA keeping the local conditions in mind. Most of the wind power developer use models developed by their parent company that is more suited for the western countries. India has still not able to come out with its own model suited for Indian conditions that are generally less windy than in other countries. Indian monsoon also affects the wind regime in a large part of Indian subcontinent. Indian Institute of Tropical Meteorology, Pune and Meteorological Department are still working on a robust monsoon prediction model. Thus, our limited understanding of monsoon system is a major drawback in accurate and well advanced forecasting of wind regime.
The main constraint for forecasting at a higher accuracy level is non-availability of large number of ground meteorological stations also. Despite India’s proven strength in satellite and remote sensing and availability of satellite data very few ground meteorological stations and anemometry still pose hindrance as they are required to facilitate necessary correction for local wind conditions. None of the manufacturers with foreign collaboration who are using the software developed in their parent country are able to forecast with reasonable accuracy in view of the above mentioned constrain (CECL 2011).

Forecasting also requires advance computing facility which is very costly and requires huge investment. Governments initiative is highly desirable in this field. In the 12th plan draft report it is envisaged that C-WET shall acquire the expertise and provide services on forecasting (CECL 2011).

Forecasting of generation is not only useful for the utility to do advance planning but it would be useful also for the power traders. As India moves towards the free market of power and open trading in power it is of prime importance. Also an optimum forecast would help in better scheduling and improvement in capacity utilisation factor of wind power projects.

6.4 Patents as an Innovation Indicator

Patents are exclusive rights to an invention providing protection for a period of usually 20 years, granted by national or regional patent offices. This invention can be a device or process and is required to meet three patentability conditions: be ‘new’ (novelty), involve a non-obvious inventive step (non-triviality) and be considered industrially applicable (usefulness) (OECD, 2004, p.8). The earliest application date worldwide is referred to as the priority year.

Patent data is the main indicator for measuring the development layer of technical change. Patents also are a good indicator of innovation activity, sorted by their application date. They are used by many scholars to ascertain the innovation and diffusion of various technologies as in studies Griliches (1990) and Reinstaller (2005).

Before patent data could be extracted the relevant technological devices needed to be defined for each regime. Using patent classes, one can identify patents specifically pertaining to RETs. One can use data on the inventor to identify the source and
‘priority’ year of each patent. However, patent protection is only valid in the country that grants the patent. An inventor must file for protection in each nation in which protection is desired. Thus, the choice of an inventor to file a patent in multiple countries suggests that the inventor views these countries as potential markets for the innovation. This means that patent data can also be used as a means to assess the international diffusion of technologies (OECD, 2009).

 Nonetheless, when working with patent data, it is important to be aware of its limitations⁴. The existing literature on the benefits and drawbacks of using patent data is quite large. One potential concern is that, although the decision to file a patent obviously follows from the decision to perform R&D, but not all successful research results are patented. In return for receiving the monopoly rights inferred by a patent, the inventor is required to publicly disclose the invention. Rather than make this disclosure, inventors may prefer to keep an invention secret. This is particularly common in corporate R&D where a particular company may fear of reverse engineering in other low protection countries.

 Levin et al. (1987) with an extensive surveys of inventors indicate that the rate at which new innovations are patented vary across industry. But, when studying the development of a single technology, this is less of a concern than when using patent data to measure innovation trends across several dissimilar industries. In addition, patent laws and the standards which must be met vary in each country. For instance, some countries require multiple patents for the same innovation that a single patent would cover in others. Thus, it is a drawback in comparing the level of patenting activity across countries. In the thesis the use of single country data set that too of one sector is made. Thus, the problem does not affect our analysis.

 Patents data also has a limitation as they shed no light on quality. Because of the random nature of the innovative process, the quality of individual patents no doubt varies widely. Some inventions are extremely valuable, whereas others are of almost no commercial value (OECD, 2009). Hence, aggregate counts provided in this thesis include all such inventions.

 Hascic et al. (2012) have done an extensive survey of patent landscape in the clean energy sector using EPO database. They have found that the rate of patenting in

⁴ Griliches (1990) provides a useful overview of the problem.
the clean energy sector has substantially increased in recent years, patenting is dominated by a handful of OECD countries with a number of emerging economies showing increasing specialisation in some individual sectors and patents on clean energy technologies in low income countries are relatively rare. According to a report of UNEP, EPO and ICTSD (2010, p.64), patenting in clean energy generation technologies has increased at a rate of 20 percent annually since the adoption of the Kyoto Protocol (1997), outpacing traditional energy sources of fossil fuels.

Patenting trends must also be viewed in the context of government efforts to internalize the costs of greenhouse gases by finding ways to put a price on GHG emissions (Reichman et al. 2008). It is surely no accident that Germany, whose legislators have taken major steps to implement the Kyoto Protocol, is also currently among the top three innovators in green technologies. By the same token, governments that invest heavily in funding relevant R&D, including Germany, Japan, China, and India, have compiled impressive patent portfolios in numerous sectors.\(^5\)

The same report has found that six industrialised countries – Japan, the United States, Germany, the Republic of Korea, the United Kingdom, and France – accounted for almost 80 percent of patent filings in clean energy generation technologies (UNEP, EPO & ICTSD Report 2010). Another study indicates that in some of these emerging economies, such as Argentina, Brazil, China, India, Russia, the Philippines, and the Ukraine, patent applications on green technologies could reach 4,000 annually (Dechezlepretre et al. 2009, p.16). A number of commentators have seen international technology-oriented agreements as a potentially useful complement to emissions-based agreements at the international level. In particular, measures which support international collaborative research activities across countries can be a helpful mechanism to encourage the development and diffusion of climate mitigation technologies internationally (Popp 2011).

The evidence shows that there has been a general surge in international patent applications in recent years, with global patent ownership concentrated in a few

industrialised countries. Further, emerging economies, particularly China, are playing an increasing role in the global patent system. According to 2010 World Intellectual Property Organization (WIPO) statistics, 71 percent of PCT applications originate from five countries – the United States, Japan, Germany, China, and the Republic of Korea.⁶

In a study, analysing the co-invention rates by technological field using patent data set of different industries, Authors have found that in wind power industry co-invention rate is only 3.9% out of all 10060 inventions. This clearly highlights the lack of collaboration and concentration of patents in the handful of OECD countries (Hascica et al. 2011).

6.4.1 International Trends in Wind Power Patenting

RETs particularly wind power in recent years has seen new vigour in patenting throughout the world. This could be attributed to the growing awareness and consequent adoption of clean technologies; and to the policy impetus in most of the countries for their diffusion (Ackermann et al. 2000).

A very detailed analysis of patenting activity in the wind power is done by the WIPO in its Patent based Technology Analysis Report-Alternative Energy Technology, 2010. Using PCT data and data at EPO, USPTO and JPO it has traced the leading applicant and their countries of origin. It reports that Aloys Wobben (owner of Enercon) is the leading applicant for wind power technologies, ahead of Mitsubishi Heavy Industries, General Electric (GE Wind), and Vestas Wind Systems. Five major companies (Enercon, Siemens, Vestas, GE Wind Gamesa) based in countries with highly developed wind power industries control 86 percent of the total market in the field as measured by production capacity (including production of components, installation, and construction but excluding power generation services) (WIPO 2010).

These five companies – Enercon and Siemens (Germany), Vestas (Denmark), GE Wind (United States), and Gamesa (Spain) – have established themselves as leaders, often by strengthening their competitiveness through mergers and acquisitions. For example, Vestas extended its market share through its merger with NEG Micon in

2003, making it the top company in the field worldwide and in 2001; GE Wind overtook Enercon to become the second largest company in the field (Lee 2008). Another major player in the wind energy market is the Enercon of Germany established by Aloys Wobben in 1984. It is a leading company in the field of wind power installations and has filed 320 patents related to wind power at the patent office’s examined in the study, out of which 34 percent belong to triadic patent families. Enercon controls around 40 percent of the German market for wind power, basing its operations on a strategy of self-supply in terms of components and filing patent applications for technologies covering all aspects of wind power generation. A particular focus of Enercon’s patenting activity is on blade and system control as well as equipment technologies such as generation tower installation and monitoring technologies (WIPO 2010).

Mitsubishi Heavy Industries of Japan leads the field of wind power turbine manufacturing, in particular with respect to medium and large-scale wind power turbines. It has recently expanded its business operations to include offshore wind power generation facilities and announced a plan to establish new factories for manufacturing turbine blades and other components outside of Japan by 2011. The company intends to supply these components to countries in Europe and North America in which demand is particularly strong. In terms of patenting activity, Mitsubishi Heavy Industries has emphasized blade and turbine control technologies (Lee 2008).

To a large extent, the operations of GE Wind and Vestas Wind are vertically integrated, allowing them to cover whole sections of power generation equipment. At GE Electric, wind power is the fastest growing among the different fields of alternative energy production, with an annual growth rate of 25 percent (Lee 2008). GE Wind has filed patent applications mainly in the field of power generation control. Vestas Wind Systems controlled around 33 percent of the worldwide market for wind power generation equipment and held the top position in the market for wind power generation systems (Lee 2008). The main focus of Vestas Wind Systems’ patenting activity has been on systems elements such as rotors, gear boxes, and power converters.
6.4.2 Patenting Activity in Wind Power Sector in India

Patents no doubt provide an objective and precise view of the research and innovation ecosystem in any sector. The growth path of RET’s, as new emerging technology are particularly guided by the new techniques and innovative products. Apart from geographical constraints RET’s adoption is particularly guided by the advance technology.

The thesis uses patent application numbers as indicators of technological development in the field of wind power technology. Patent information can be used to analyse the evolution and the level of maturity of this particular technology.

Wind Turbine Generator (WTG) is the main technological artifact to which other ancillary equipments are connected i.e. hardware and software related to its integration with the grid or to optimum supply to the load. Wind turbine in itself is a complex product that consists of nacelle, generator, gear box, power electronics and support structures.

Patent data about the Wind Turbine Generator is covered by the International Patent Classification sub classes that includes wind motor, rotor, controlling wind motors and component parts there of. The specific patent classes pertaining to these technologies are even used in WIPO’s Patentscope for RETs that covers patent granted under Patent Cooperation Treaty 1970. The data set used in the thesis is of the patents granted by Controller General of Patents, India. Relevant patent information was extracted using a structured search of Controller General of Patents, India’s dataset by IPAIRS Version 2.0. Dataset was further manually culled for the irrelevant entries in the Patent Family which were not related to the Wind Power or any associated field.

A patent analysis of the wind power sector poses a major challenge as the varied technologies are scattered across different patent classes. That is, by identifying certain patent classes it might be possible one does not account for patents that are filed in other classes. On the other hand, a class could also not be perfectly defined in the sense that it contains technologies that do not strictly pertain to the wind power

7 see Annexure 1 for detailed description of relevant patent classes.
sector. Thus, there might either be an under or overstating of the amount of patents for the technology one is interested in studying (Oltra et al. 2009).

To remove the above stated drawbacks a structured search was designed. Firstly, IPC classes pertinent to wind power sector were searched from the raw database of the Controller General of Patents, Designs, and Trade Marks of India. Secondly, a random search was done of entire raw data for the technology-specific keywords as an input in the search process (WIND* TURBIN*). This resulted in the inclusion of relevant patents in the other IPC classes not directly related to the wind power but have substantial application in the wind power sector. Thirdly, the dataset generated was manually culled for any duplicity and double counting. The abstract of each single patent, as contained in the set generated in the second stage, was screened in order to determine whether indeed the patent was relevant. To ensure data consistency the relevant patent classes recognised by the WIPO were included and also the classes used in previous studies. This finally resulted in an improved quality of the patent data set related to wind power sector. A detail of all the classes and sub classes is given in the annexure I.

6.4.3 Technology S-curve

It has been empirically observed that the number of cumulative patent applications over time generally follows a trend which resembles an S-shaped curve (Merino 1990). There is consensus on the interpretation of this specific S-shape of application evolution. The S-curve, also known as the logistic curve or sigmoid curve, is helpful for estimating the level of technological growth or decline at each stage in the life cycle and for predicting when a specific technology will reach a particular stage. Fig.6.3 illustrates the S-curve of a technological life cycle.
In this case, the cumulative number of patents is plotted over time. In the curve, four different growth stages can be identified:

- A first stage, emerging, where the number of patent applications is low.
- A second stage, growth, where the patent activity increases.
- A third stage, maturity, where the number of patent applications starts to decline.
- A fourth stage, saturation, where the technology asymptotically approaches a natural or physical limit.

After the fourth stage, the existing technology has reached its full potential and a new technology (S-curve) has to be searched for (Andersen 1999). Fig. 6.4 shows the theoretical progress development of patent activity over time. In this case, three different stages of development can be observed.

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Phase I is the emerging phase of a new technology and first products, based on the new technology, are introduced on the market. At this stage, the number of patent active companies is small. In phase II, the consolidation phase, the patent activity is lower than in the previous phase. In phase III, the market penetration phase, the total activity increases considerably. In addition to old applicants, new companies start to file patents in that particular technology (Andersen 1999).

However, there are some difficulties related to the S-curve concept. The measurement of patent applications requires a complete statistical study of all patent applications of the considered technology field. With regard to majority of most technologies this study is very difficult, i.e. most technologies cannot easily be defined with a clearly defined set of technical search terms when using patent databases. The reason is that the IPC classification does not offer classes that precisely correspond to a certain technology (Marinova 2008).

Another problem is that some companies choose to protect their inventions by other means than patent applications. This means that valuable patent data, for the specific technology, is missing and hence could affect the shape of the S-curve.

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This in turn could lead to a misinterpretation of the current stage of the specific technology (Marinova 2008).

From Fig. 7.5, it can also be seen that the accumulated number of patents, i.e. the S-curve, for wind power technology follows the theoretical behavior seen in Fig. 6.3.

**Fig. 6.6: Cumulative Number of Patents Granted By Controller General of Patents, Designs, and Trade Marks of India in Wind Power Sector**

![Cumulative Number of Patents](chart.png)

*Source: Compiled by the Author*

The technology has passed the first two stages (emerging and growth), and is about to enter into the third stage (maturity). The slope of the curve is gradually decreasing from the 2004 onwards indicating relative maturity of the technology as compared to previous phases. A particular point to be noted here is that in a sector dominated by foreign patentee firms; this could well be argued that the present technologies available in the developed countries are already deployed in the sector. The opportunities of appropriation and domestic institutions also have an important role in the diffusion of wind power technologies. Patenting activity that is dominated by foreign firms, also can be seen as there increased participation in the domestic sector. This in turn requires the role of institutions and demand in the sector. Demand is also consequent upon the institutions as they create favorable conditions for the firms to act in a particular way. Institutions play an important role by creating a “technology push” or “demand pull” in the sector.

IPR regulations in a country play a determinant role in the introduction of an advanced technology that is protected by patents.
Emergent phase up-till 2001 and the rapid growth thereafter in the patenting activity underscore our basic assumption of role of institutions in the diffusion of technology. This point is further elaborated in the sub section 7.4.4.

Patent data of the wind power technologies sector clearly indicates that the development and current status of a technology follows the theoretical technological development and the S-curve. This implies that patent data analysis could well be used in order to predict the different phases and stages of a specific technology. As can be seen from Fig.7.6 the curve has an oscillatory behavior in its emergent phase (before 2001). Fluctuations in the technology growth are explained by various authors. In the studies fluctuations are attributed to the death of the technology, interaction with another technology or to effects by macroeconomic business cycles (Andersen 1999).

In our thesis we attribute this to the availability of appropriability conditions in the sector which are a function of domestic institutions, number, and nature of agents and technological development. Creation of demand in the sector has led to the emergence of higher number of patent filing. This can also be seen by the number of foreign players in the sector. Major players in the wind power sector in the world were present in the sector before the high growth phase also, but there mechanism of operation was different. Earlier foreign players used the technology licensing route for the introduction of new or novel technology, whereas in the high growth phase they set up their own subsidiary. In the study by Muzino (2011), author has used the entry and exit of foreign players to show the changing dynamics of the wind power sector in India. Thesis also confirms their finding that post exit the companies introduced higher rated turbines that are more technology intensive than previously introduced lower rated one. Apprehensions about the IPR climate and technological secrecy are the main factors that have determined the introduction of new technologies and consequent patent filing.

A general theory of trends in patenting activity is developed by Anderson (1999). To understand the stages of development of a particular technology Anderson (1999) divides the growth in patenting into different phases. Initially on the introduction of a new technology, only a small number of applicants are involved in patenting in the field and only few applications are filed. Following this growth period, the technology enters a development period, during which the technology develops rapidly as a result of active competition between numerous applicants,
who together file many applications. As research and development continues, the growth in the number of applications stagnates or declines as does the number of applicants. This period can be termed a “maturity period.” As new technologies or even entirely new technology paradigms emerge, a period of decline begins for the original technology, at which point the number of applications and applicants in that field declines strongly. It is possible for a revival of interest to occur in the original technology, if a new application can be found for it, leading to resurgence in the number of applications and applicants.

Fig. 6.7: Patents Granted (Number) by Controller General of Patents, Designs, and Trade Marks of India in Wind Power Sector.\(^{10}\)

The development of patenting activity in the Indian wind power sector is shown in the figure 6.6. It closely matches and fits with the theoretical model in the figure 6.4. As it can be seen in the patenting activity across all the sub classes of the wind power generation technology, Indian wind power sector has passed the initial (I), emergent (II) and is in the last phase of market penetration. The double dip in the graph in the late phase can be attributed to the changed institutional stance in 2003 and 2005. The market development is not a linear process and there are various phases of growth and consolidation and it can be clearly seen in the figure 6.6.

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\(^{10}\) Year here means the priority year. This is the year in which the initial application pertaining to this patent was filed. If a patent is granted, protection begins from the priority date.
As far as the growth in patenting activity is considered, the theoretical model fits into and explains the various phases effectively. But the underlying reasons for the particular behavior might not be fully captured in the theoretical model. Indian wind power sector presents a typical case of few dominant firms, imported technology and weak R&D base as far as “basic” wind power technology is concerned. Role of institutions is overarching in the sector and the given patenting trend can be explained only by taking these factors in account.

As discussed previously the wind power in itself a complex technology involving various sub technologies. Different technologies themselves have different patenting activity among themselves.

Emergence of pitch regulation for the control of wind turbine, power electronics for the advanced level of integration has positively affected the wind power generation from a given turbine. The relative share of different IPC classes in the overall patents in the wind power sector is enumerated in the figure 6.7.

**Fig. 6.8: Share of Technological Fields\textsuperscript{11} in the Patents Granted**

![Pie chart showing the share of technological fields in the patents granted.](image)

*Source: Compiled by the Author*

It can be seen from the pie chart that IPC sub class F03D 11 has highest share of 24%, this corresponds to the design of rotor blades wind turbine structures.

\textsuperscript{11} See Annexure I for detailed description of different IPC sub classes
Blade design is critical for the proper functioning of the turbine during different windy conditions. Blade design is one of the technology-intensive areas with use of different material components from resins, glass fiber to carbon composites. Advances in polymer and chemicals are far ahead than in other areas of technology in general and this can be seen in the wind power sector also. One of the leaders in blade design in the world, L M Glafisiber (India) Pvt. Ltd., a German firm reports production of advanced rotor blades in India with its facility capable to serve entire Asian market. In higher rated WTGs advanced technology is used in structures to withstand high wind shear and pressure differences.

F03 D1 has a share of 20%; it corresponds to the wind motors that are central to the power conversion from mechanical to the electric one. No doubt it has second highest patents.

F03D7 has a patent share of 20% and it corresponds to the controlling of wind motors. It is one of the research-intensive areas related to regulation of wind turbine. From earlier wind power turbine with stall regulation, different companies have developed advanced technologies for the regulation of wind turbine like Enercon has patented ActiveStall™ technology. Most of the WTG manufacturers report use of regulation technologies such as pitching that enables wind turbine operation in varied wind conditions with improved power curve.

F03D 9 and F03D 3 corresponds to the adaptations of wind motors for special use; combinations of wind motors with apparatus driven thereby and wind motors with rotation axis substantially at right angle to wind direction respectively. Use of wind turbine technology to have specialized application are covered in these classes. They have a share of 10% and 9% respectively.

Subclass F03D* “wind motor” has overall share of 82% in the patents in the wind power sector. This is obvious as the wind motor is central to the wind power generation technology.

Other sub-classes of IPC also have some stated applications in the wind power generation technology. They are E04H (towers; masts, poles); H02K (dynamo-electric machines); H02J (circuit arrangements); F16H (mechanical gearings); B29C (Shaping or joining of plastics). The respective share of these technologies is shown in the figure 7.7.
In the figure 6.8 patents granted by technological fields in the wind power sector are plotted year wise. Different technological fields have varying patenting activity in different years.

![Fig. 6.9: Patents Granted (Number) by Technological Fields](image)

*Source: Compiled by the Author*

As seen in overall patenting activity in the wind power sector before 2001, different technological fields also have very few patents granted that too in an oscillating nature. A clear surge in patenting can be seen from 2001. Institutional role, as setting up of electricity regulatory authorities and a clear mandate for RETs heralded a new phase of dynamism in the RET sector. Major patent holder in wind power sector in India Enercon, although established in 1994 it started introducing higher rated turbines with patented technology in the period.

A rise and consequent fall in the patenting activity post 2001 underscores introduction of latest turbines in India that have high technology content. All the technology fields except the F03 D9 have shown such behaviour. F03 D9 has been steadily rising from the very initial phase. As a class representing application of wind turbine for special uses, it also registers most of the domestic patents that too by individuals. For the purpose of analysis, this is insignificant and represents the noise in our data. It also indicates about the inherent weakness of the patent data that presents invention not commercial applicability of the patent.
Technology fields such as F03 D1 and F03 D11 have seen rapid increase in the patenting activity. These two classes represent the core of the wind power generation technology and have 20% and 24% respective share in the total patents of all the classes in the wind power generation technologies.

In an attempt to know the underlying factors in the patenting activity observed, a correlation between the number of patent applications and technological growth (installed capacity) has been made. The adoption of wind power technology by the cumulative installed capacity in the sector and cumulative number of patents granted in wind power sector are plotted in the figure 6.9. They show a very high correlation (0.9965).

![Fig. 6.10: Cumulative Patent Applications and Installed Power](image)

This points that as installed capacity increases, the patent activity also increases. Literature on technological learning (Rosenberg 1982) explains this by learning by doing as diffusion of a given technology increases. A close examination of the patent data will reveal that it’s the bulk patenting by foreign firms that have contributed to the increased patenting rather than on any domestic increase in technological capability. Patents and trade secrets are highly guarded in the corporate world with considerable time needed for their diffusion by movement of personnel and enhanced ability of the domestic firms to absorb the technological knowledge. Creation of demand is a more convincing argument for explaining the observed phenomenon. In a globalised world with limited barriers for trade, it is
the demand created by conducive institutional environment that has altered the appropriability of the technology.

6.4.4 Foreign versus Domestic Patent Filings

Inventors who desire patent protection in other nations must file applications in those nations, either directly or by using a Patent Cooperation Treaty (PCT) that designates the countries in which protection is desired, within one year of the priority date. If the inventor does file abroad within one year, the inventor will have priority over any patent applications received in those countries since the priority date that describe similar inventions. Thus, the priority year is typically the year in which an application was filed in the inventor’s home country. This corresponds to when the inventive activity took place, as patent applications are usually filed early in the inventive process. For analysing the source of patenting activity, patent counts were generated by the home country of the patent grantee

Patent filing by foreign firms in a country may also be used to measure international technology diffusion. Patent applications at multiple countries are indicative of international diffusion of the knowledge contained in the patent (Eaton and Kortum, 1996, p. 254). Because patenting is costly, inventions are typically protected in only a small fraction of the countries of the world. This is the case even among large and technologically advanced countries, as over 70% of patent families consist of only one patent (Putman, 1993). When an inventor wants to enlarge his protection, he has to apply for patent protection in foreign countries, which is very costly. Because the legal protection granted by a patent only applies in the country in which the patent has been granted, inventors must file patent applications in each country for which they desire protection.

In the analysis, we focus primarily on patents granted to inventors in one country i.e. India, as this shows inventors expectation of use or deployment in that country. Thus, as discussed in preceding paragraph it could be used as a proxy

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12 In the case of multiple inventors from different countries, thesis uses the home country of the patent grantee listed first.

13 the set of patents in different countries protecting the same invention.
for diffusion of a given technology in that country. It is an important factor in a
developing or under-developed country with weak domestic innovation system in
a given technological domain to develop technological capability.

For the purposes of determining the origin of patent, patent applications were
classified according to the nationality of the first-named applicant. All applications
filed by India nationals were considered as domestic patent applications. Figure
below enumerates the source of patents in the wind power sector in India.

**Fig.6.11: Patent Grantee’s country of origin in wind power sector in India**

![Bar chart showing patents by country](image)

*Source: Compiled by the Author*

In the figure 6.10 majority of the patentee’s country of the origin is in Germany
and Denmark. These are the two countries with high level of technological
capability and a historically dominant position in the wind power sector. Majority
of the firms in Indian wind power sector trace their roots to Germany or Denmark.
56% of the patentee’s country of origin is Germany where as Denmark accounts
for 12%. Enercon that holds 43.4% of patents in wind power sector in India is a
German firm. It is no surprise that Indian behemoth Suzlon has acquired two
German firms to develop R&D expertise in wind power sector in India.

Lee et al. (2009) have also found that the US, Japan and Germany are clear leaders
in energy innovations. The leading emerging countries such as China, Brazil and
India have no companies or organisations in the top 10 position in these sectors. The study concluded that companies and institutions in the OECD countries will determine the speed of diffusion of the most advanced energy technologies in the next decade. A similar pattern can be seen in Indian wind power sector also with Germany, Japan and USA occupying majority of patents.

In the wind power patent portfolios, Germany, USA and Japan owned around 60 percent of wind technology patents approved in 1998-2007, while Denmark, Spain, UK, France and the Netherlands together accounted for another 23 percent. China may be the largest owner of patents in emerging economies for wind technology but its share of claimed priority patents was only 1.5% (Lee et al. 2009).

Although India has fifth position in installed wind power. Its innovation capability is limited as evident in most of the developed countries. India figures in the top five countries by patent grantee’s country of origin in wind power sector in India, but this could be due to the more likelihood of applicant to file patent in the domestic country than abroad.

Wind power sector is a technology intensive sector with lot of technological learning and capability required in development WTG machines. World over a few firms dominate the market with a strong entry barrier by way of technology and organizational capability required. Indian wind power sector is no different with presence of few dominant firms.

In the case of patents owned by firms granted by Indian patent authority Aloys Wobben (owner of Enercon) has 43% of total patents. A very high level of concentration of patent ownership is very peculiar of wind power sector. Enercon also has a world leadership in patent portfolios in wind power sector as discussed in previous section on international trends in wind power patenting. Majority of the firms have less than 10 number of patent count.
Indian public sector firm BHEL has seven patents, but these patents are from its single establishment, a turbine manufacturing facility. Firm manufacture small aero generators that have limited role in overall market and production. Its patents also have limited market potential. Public funded laboratory of CSIR, NAL has one patent for its 500 KW wind turbine generator.

If we add the patent numbers of Hansen and Repower that are now owned by Suzlon, we can say that Suzlon also has 6% of the total patents granted by Indian patenting authority.
6.5 Dynamics in the Wind Power SIS

This knowledge is the source of sectoral boundaries and it is dynamic and change over time rather than to be fixed. New areas of the research and upcoming opportunities in the sector change the sectoral boundaries. Actors and networks respond to these factors in different ways. Sectoral dynamism can be attributed to the technological challenges presents by the new areas in the sector. Offshore wind power sector is an emerging area which presents tremendous opportunities for appropriation.

Wind power SIS has various layers of actors with each having their domain specificity and expertise. Overall development and innovation in the sector is dependent on their interaction and relations. They interact through exchange, cooperation and competition and can be in market or non-market relationships. Industry value chain of the wind power SIS is discussed in the following paragraphs to show the dynamism of the sector.

6.5.1 Offshore Endeavours

Research into offshore wind power generation has been driven primarily by the shortcomings of onshore wind power production. Compared to onshore wind power, offshore wind power benefits from higher wind velocities and smaller variations in wind direction. It results in much large scale installations. It is quite well known that capital cost for off-shore project is 2.5 to 3 times higher than on-shore projects14.

Denmark, Netherlands, Germany, and the United Kingdom are developing offshore wind power generation facilities with turbines installed at a depth of between 5 and 20 meters and at a distance of several kilometres from the shore. The high installation cost represents a significant barrier to the practical implementation of such facilities but the large scale of the facilities ensures that the unit cost of producing power is low (KEMCO 2007).

Offshore wind research is in a nascent stage in India with data collection exercises being undertaken at present. The Centre for Wind Energy Technology as apex public funded research organisation is coordinating offshore wind efforts including involvement of bilateral and multilateral agencies. Though apparently there is not much of potential available yet Govt. of India has initiated steps to assess the viability of the off-shore potential. Key organisations and work areas in the field are following:

- Centre for Wind Energy Technology (C-WET), a Chennai based organisation under the administrative control of MNRE serves as the technical focal point for wind power development. Although offshore wind development is at an early stage, the MNRE 12th five year plan approach paper outlines a projected general grant to C-WET including R&D expenditure at USD 4.3 Million per annum for offshore installations. CWET has planned to conduct a feasibility study in Dhanushkodi near Rameswaram to set up offshore windmills.

- CWET is also working with Scottish Development International to build a 100-metre mast to measure offshore wind levels. Scottish Development signed a co-development deal with the Indian government in 2009.

- National Institute of Ocean Technology (NIOT) has recently started research on offshore wind energy, including plans to install a demonstration platform in India. The institute is in the process of identifying the location, data collection (wind & wave) and analysis procedures.

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6.5.2 Industry Value Chain

Wind power sector in itself has inter linkages with various sectors of the economy like infrastructure, manufacturing, energy and considerable overlaps with them also.

Wind power industry value chain is complex with various actors and agencies operating at various levels. At the upstream end are the component suppliers which include gearbox, generators transformers manufacturers, fixings, machined parts etc.. OEMs and wind farm developers are connected to turbine manufacturers that are instrumental in manufacturing and assembling the turbines and constructing the wind farms. Independent wind farm developers may or may not exist depending upon the operating business model of the OEMs.

Innovative business models have emerged in the sector like in certain cases, the OEMs are responsible for the project development, before eventually selling it to the downstream partner, while providing some after sales maintenance support. Emergence of wind farm concepts pioneered by Suzlon is an example in this regard.

The downstream members in the value chain include utility companies which would take the electricity generated to the consumer; or private wind companies operating the wind farms for independent electricity. An integral part of the industry structure comprises of the project support firms and management teams which would ensure ongoing services and maintenance post installation of the wind farm. The owners in this case reflect the demand side of the wind energy generation industry, while the OEMs and developers would be indicative of the supply side.

Wind industry being a capital intensive one, requires ample financial support. Hence the presence of financial institutions provides a much required external support throughout the industry chain.

Growth of the wind power sector has seen new modes of organisational innovation where an OEM firm act as project developer and does maintenance also of the wind farm where as owners remain shielded from the technical details.
Use of project based financing and venture capital have also significant contribution in the industry value chain.

6.6 Summary

Knowledge base and technological capability in the sectoral innovation system are often shaped by the institutions that determine the appropriability, and influence the demand. A specific knowledge base, technologies, and inputs play an important role and define a given sector also (Malerba 2004). A typical knowledge domain of wind power SIS includes comprehensive assessment of wind resource, availability of appropriate wind turbine manufacturing base and readiness of the grid for power evacuation. Each domain requires effort at different levels with different capabilities. Public institutions have a role in resource assessment and formation of standards. In a developing country technological learning is often facilitated by the institutions and thereafter firms play a dominant role.

To analyse the knowledge and innovation in the wind power SIS, different measures of innovation such as design and innovations in tower, rotor blades and wind turbine generators by different firms were analysed in detail in the chapter. Foreign firms with accumulated knowledge and technology are the leaders in introducing novel and patented technology. Domestic firms have gained technology mostly through licensing route. Pitch system and WTG sets are the two most knowledge intensive domains of wind power technological system. In these respective domains also, select foreign firms have technologies that are far ahead of their domestic competitors. As evident on the global scale, in India also Enercon, Vestas have WTG sets that are technological superior than other firms with novel design and next generation technologies.

Over a period of time WTG machines regardless of their manufacturer being domestic or foreign firm have become more efficient with higher available time per WTG. Technological learning has taken place as evident from the installation and corresponding production data.

Public sector R&D is mainly focused in the areas such as improvement in resource assessment, technical standards, electrical system integration and wind energy
forecasting. These areas need governmental support due to advantageous position public institutions have vis-a-vis private firms in these areas.

CWET a dedicated institute for the development of wind power in India is particularly engaged in the wind resource assessment and forecasting. Foreign collaboration is evident in both the areas for the development of advanced assessment and forecasting models.

Private sector R&D is primarily engaged in the improvements in the WTG features, its efficiency and higher rated WTG sets. Suzlon, a dominant firm has acquired R&D capability by acquisition of foreign firms such as SudWind, Hansen Transmission and Repower. Vestas and RRB Energy report their R&D labs in Chennai and Sriperambadur respectively.

Government sponsored R&D programmes in the wind power sector have emphasized on long term innovation in the key areas of wind resource assessment and standards; whereas, industry funded R&D has focused on short term production, operation and organizational innovations.

Analysis of patenting activity reveals that the global firms such as Enercon have a dominant share in patent portfolio compared to other firms. Patenting is found to be higher in upcoming technologies such as pitching and WTG motor sets that have a direct bearing on the efficiency and availability of WTG machines. Major source areas of patents are Germany and Denmark that have a strong technological base in the wind power R&D.

The theoretical S curve fits to the observed patenting activity in the wind power sector and explains effectively the various phases of patenting activity. But the underlying reasons for the observed pattern such as domestic technological development over a period of time might not be fully captured in the theoretical model. Indian wind power sector presents a typical case of few dominant firms, imported technology and weak domestic R&D base as far as “basic” wind power technology is concerned. Role of institutions is overarching in the sector and the given patenting trend can be explained only by taking these factors in account.
Offshore wind power development and improvements in the industrial value chain of the wind power SIS are the dynamic developments in the wind energy SIS. These endeavors have changed the boundaries of wind energy SIS and provided new dynamism and appropriability conditions.