Cross-border Transfer of Climate Change Mitigation Technologies: The Case of Wind Energy from Denmark and Germany to India

by

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Abstract

This research investigated the causal factors and processes of international development and diffusion of wind energy technology by examining private sector cross-border technology transfer from Denmark and Germany to India between 1990 and 2005. The motivation stemmed from the lack of active private sector participation in transfer of climate change mitigation technologies. Special attentions were paid to the role and effects of: government policy and institutional settings; co-evolution of policy, market, industry, and technology; and industrial competitiveness management.

The research found that the centrality of government policy, in particular market value creation/ rewarding policy, in successful wind energy technology development and diffusion at the technology frontier of Denmark and Germany. Sources of technological change were complex, but it was the policy-induced substantial market size and performance-oriented demand characteristics that determined the speed and direction of technology development and diffusion. Yet, the change was only materialized by the successful establishment of co-evolving mechanism of policy, market, industry, and technology; again, policy was central in the creation and timely adjustment of such virtuous cycle. The research also found strong connections between technological characteristics/specificity and industrial competitiveness management, and their intertwined transformations.

On the Indian side, the increasing technology gaps in both product and capability with the frontier and the transformed structural relationship between market development and the number of new technology introduction were evident from the mid 1990s. Non-performance-oriented market mechanism, policy inconsistency, institutional problems of power sector, persistent infrastructure deficiency, along with the intertwined competitiveness management and technology transformations at the frontier, all contributed to the structural transformation; the failed virtuous cycle creation was due to strong technology- and industry-related external factors and weak demand-pull and supply push internal policy. India lost the potentials for replicable technology transfer and the larger development benefits.

The process-oriented nature of replicable technology transfer requires simultaneous and continuous demand-pull and technology-push policy; performance-oriented market development through market value creation and rewarding policy as well as technology-push supports connected to technology-specific learning mechanisms and market trials are central for the advancement of both climate change mitigation and sustainable development.

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Abbreviation and Acronyms

AC = Alternate Current
ASTA = Average Ship Turn Around
ASBO = Average Ship Berth Output
BHEL = Bharat Heavy Electricals Ltd. (India)
BMF = Federal Ministry of Education and Science (Germany)
BMBF = Federal Ministry of Education, Science, Research, and Technology (Germany)
BMFT = Federal Ministry of Research and Technology (Germany)
BMU = Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Germany)
BMWA = Federal Ministry of Economics and Labor (Germany)
BMWi = Federal Ministry for Economics and Technology (Germany)
BWE = Bundesverband Windenergie = German Wind Energy Association (Germany)
CDM = Clean Development Mechanism
CEA = Central Electricity Authority (India)
CER = Certified Emission Reduction
CERC = Central Electricity Regulatory Commission (India)
CF = Carbon Fiber
CFD = Computational Fluid Dynamics
CFRP = Carbon-fiber Reinforced Plastic
CHP = Combined Heat and Power
COP = Conference of Parties
CUF = Capacity Utilization Factor
DANIDA = Danish International Development Assistance (Denmark)
DC = Direct Current
DEA = Danish Energy Authority (Denmark)
DEWI = Deutshce Wind Energie Institut (Germany)
DFIG = Doubly-Fed Induction Generator
DKK = Danish Knøne
DM = Deutsche Mark
DNES = Department of Non-conventional Energy Sources (India)
DOE = Department of Energy (United States)
DPR = Detailed Project Report (India)
DtA = Deutsche Ausgleichsbank (Germany)
DWTOA = Danish Wind Turbine Owners Association (Denmark)
DWTMA = Danish Wind Turbine Manufacturers Association (Denmark)
DWIA = Danish Wind Industry Association (Denmark)
EC = European Commission
ECN = Energy research Center of the Netherlands (the Netherlands)
EEC = European Economic Community
EEG = Renewable Energy Source Act (Germany)
EEP = Energy Research Program (Denmark)
EFL = Electricity Feed Law (Germany)
EMD = Energi- og Miljødata (Denmark)

EPR = European Recovery Program
ERUs = Emission Reduction Units
EU = European Union
EUR = Euro Dollar
FACT = Fatigue of Composite for Wind Turbines
FDI = Foreign Direct Investment
FOI = Swedish Defense Research Agency (Sweden)
GE = General Electric (the United States)
GEDA = Gujarat Energy Development Agency (India)
GEF = Global Environmental Facility
GFRE = Glass-fiber Reinforced Epoxy
GFRP = Glass-fiber Reinforced Plastic
GHG = Greenhouse Gas
GNP = Gross National Product
GOI = Government of India (India)
GTZ = German Agency for Technical Cooperation (Germany)
HSW = Husumer Schiffswerft
IEA = International Energy Agency
IEC = International Electrotechnical Commission
IFU = Industrialization Fund for Developing Countries (Denmark)
IGBT = Insulated Gate Bipolar Transistor
INR = Indian Rupees
IPCC = International Panel on Climate Change
IRR= Internal rate of return
ISET = Institut fur Solare Energieversorgungstechnik
ISO = International Standards Organization ()
JI = Joint Implementation
KfW = German Development Bank (Germany)
KVRRH = Quantum of Reactive Power (India)
M&A = Merger & Acquisition
MAT = Minimum Alternative Tax (India)
MBB = Messerschmidt-Bölkow-Blohm (Germany)
MEDA = Maharashtra Energy Development Agency (India)
MOD = NASA modification program (the United States)
NACA = National Advisory Committee on Aeronautics (the United States)
NASA = National Aeronautics and Space Administration (the United States)
NEPC = Non-conventional Energy Product Company (India)
NOC = No Objection Certificates (India)
NPV= Net Present Value
ODA = Official Development Assistance
PMSG = Permanent Magnet Synchronous Generator
PSO = Public Service Obligation (EU)
PSU = Public Sector Undertaking (India)
PURPA = Public Utility Regulatory Policies Act (United States)
RD = rotor diameter
R&D = Research and Development

R&DD = Research, Development, and Demonstration
rpm = revolutions per minute
SCADA = Supervisory, Control and Data Acquisition
SCIG = Squirrel Cage Induction generator
SERC = State Electricity Regulatory Commission (India)
SMEs = Small-and-medium sized enterprises
SNA = State Nodal Agency (India)
SEB = State Electricity Board (India)
T&D = Transmission and Distribution
TAPS = Turbine Approval Provisional Scheme (India)
TNEB = Tamil Nadu Electricity Board (India)
UBA = Federal Environmental Agency (Germany)
UNFCCC = United Nations Framework Convention on Climate Change
USD = US Dollar
UVE = Development Program for Renewable Energy (Denmark)
VAT = Value Added Tax
WAsP = Wind Atlas Analysis and Application Program
WCED = World Commission on Environment and Development
WPD = Wind Power Density
WRIG = Wound Rotor Induction Generator
WRSG = Wound Rotor Synchronous Generator
WTO = World Trade Organization
ZIP = Investment Program for the Future (Germany)

Chapter 1:
Introduction and Context

Section 1.1: Research Motivation and Research Question

Why is it so difficult to transfer more advanced climate change mitigation technologies from developed countries to developing countries? How can we stimulate private sector involvement further in cross-border transfer of such technologies in order to advance not only global climate change mitigation but also sustainable development? This research tries to find some answers to these questions by examining a case of wind energy technology transfer from Denmark/Germany to India from 1990 through 2005.

Global climate change mitigation is one of the most significant agenda for human race to face in the coming decades. Technology holds a key for the process, as it plays the central role in mitigating global climate change by reducing the emissions of greenhouse gases (GHGs) while advancing our welfare creation capacity by increasing productivity. Incentive creation for robust private sector participation is an essential part of this process, because a large part of capacity and capability to advance such global efforts by innovating and diffusing new technologies now belongs to private sector. The past two decades of privatization efforts and process of globalization have led to the increase in capacity and capability of private sector, while transforming the role of public sector into the one inducing private sector to contribute to public welfare creation. In this context, public and private partnerships are not a choice but a necessity to advance climate change mitigation. Also, international collaborations are crucial in order to increase productivity and efficiency of the climate change mitigation efforts as well as to expedite the diffusion of the efforts worldwide. And transfer of climate change mitigation technologies and investments from developed to developing countries is considered vital to this process. However, in reality, the progress has been slow and technology transfer remains the most conflicted aspect of climate change negotiations between developed and developing countries.

This research argues the importance of replicable technology transfer for both the advancement of climate change mitigation efforts and the materialization of long-term developmental benefits through technological capacity and capability building. However, such technology transfer is far more challenging than the initiation of transfer itself under the increasing global competition with intensifying technology control by technology holders. As one of the reasons of the difficulty, this research claims the process-oriented characteristics of technology transfer; it is not only the factors which control the mode of transfer but also the processes of the factor transformations that determine transfer outcomes. In particular, the research argues the centrality of government policy, in particular market value creation and rewarding policy, in creation and continuation of virtuous cycle of market, industry, and technology in new climate change mitigation technology development and transfer; such cycle is only triggered and supported by policy incentives that create both demand-pull and technology-push forces simultaneously. Replicable technology transfer can only happen as a part of such virtuous cycle, which has continuous technology upgrading market demands supported by sizeable market and ability of transforming technological capacity/capability backed by robust firm-level competitiveness management. Such competitiveness management has strong connections to the specificity of each technology component and value activity as well as to the way of their integration as technology system, hence strongly sector- and technology-specific. Without replicable technology transfer as a part of such virtuous cycle, technology gaps will increase and long-term sustainable development benefits will diminish even with successful initial technology transfer. This centrality of policy and the importance of virtuous cycle creation are same for both technology provider and receiver countries. However, due to the lack of stable macroeconomic and infrastructure environments as well as the lack of appropriate technological capacity and capability, along with various technology controls by technology providers, it is far more difficult for technology receiver countries to create and sustain such cycle.

In order to support the above arguments, this research takes an approach not to assemble short-term transfer cases of various technologies but to explore a historical path of one technology transfer case in depth. The research focuses on the following factors and processes of the case. First, it focuses on the role and effects of government policy and institutional settings on domestic and international technology development and diffusion, because the role of government has been transformed under the growing privatization and globalization as mentioned above and because the development of climate change mitigation market, industry, and technology is strongly policy-driven due to the presence of both negative and positive socio-environmental externalities related to climate change mitigation activities in the present market mechanism.

Second, the research focuses on the co-evolution of policy, market, industry, and technology, in order to see the effects of the processes of interaction among the factors on technology transfer outcomes. While the role and effects of government policy and institutional settings are the first focus of this research, they are not the only factor in creating necessary dynamics of technology development and diffusion. With this reason, analyzing the co-evolution of market, industry, and technology factors together with policy factors is important to understand the processes of technology development and diffusion. Every aspect of our society is continuously changing. This research examines technology transfer not as a static but as a dynamic process; hence, the factors and processes necessary for replicable technology transfer are considered in dynamic way.

Third, this research pays a special attention to the role and effects of industrial competitiveness management in cross-border technology transfer. Competitiveness creation and control through technology and cost management are central to the current and future business activities. In technology transfer, firm competitiveness management plays a significant role in determining the transfer mode and has significant interactions with the co-evolving policy, market, industry, and technology dynamics over time. This research follows the evolution of firm competitiveness management strategies and their relationship to technological characteristics, and examines their effects on technology transfer outcome, in order to deepen the understanding of how to utilize the power of private sector in international development and diffusion of climate change mitigation technologies.

Section 1.2: Theoretical Basis of Research

This research draws upon different bodies of literatures. This section introduces theoretical arguments and some empirical study results regarding international technology transfer and technological change for general economic and sustainable development.

1.2.1 Technological Change and Economic Growth

From empirical point of views, technical change has been recognized as the most vital dynamic force for economic growth, since Solow (1957) found that the productivity growth occurs mainly not through the accumulation of capital but through technical change, which was a residual component not explicable by the measured increases in capital intensity. The main cause of Solow's technical change was recognized as the improvement of technology (Scherer 1999; Solow 1957).[1]

Technology is defined as the process of physical transformation of inputs to outputs, and knowledge and skills that structure the activities involved with such transformations (Kim 1997). Technological change is the change in the way in which inputs are transformed into outputs, including changes in output quality (Fransman 1984); technological change involve in both changes in product and in production process.

The existing economic growth theories are largely formed around neo-classical approach (including endogenous new growth theory) and evolutionary approach (including capability and other structural analyses). Both approaches emphasize the importance of high-level physical and human investment, and reject linear model of technology development. However, their perception on the sources and causal mechanisms of technological changes and their process at firm level, the markets surrounds them, and the necessary failures to be addressed differ greatly.

Neo-classical Theories of Technical Change and Economic Growth

Neo-classical approaches take highly simplified assumptions on technology development. In the neo-classical theories, firms are small and homogeneous, operating in perfectly competitive markets, where all technological options are known, i.e., well-behaved production functions. Choices to optimize allocation are made costlessly based on capital and labor costs. Because technology is codified information, and information on sources and characteristics of all technologies are available to all firms equally, technology is absorbed and used without further effort and cost. Firms operate in isolation, without inter-linkages and spillovers.

In the mainstream traditional models, technical change takes the form of shifts of production function resulting from exogenous innovation; technology is an exogenous factor, which means technical changes come in the form of scientific discoveries through academic research, and it is not directly influenced by the economic system, but rather influencing it (Solow 1956; Solow 1957).

On the other hand, in the new growth models, technology is an endogenous factor and technical change takes the form of shifts of production function resulting from firms optimizing Research

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[1] Solow found that only 12.5% (later corrected to 19%) of the long-run change in labor productivity in the US economy between 1909 and 1949 could be attributed to increased capital intensity (Solow, 1957).

& Development (R&D) choices by devoting human capital on top of ordinary labor and capital, in order to orchestrate an interaction with the pool of design knowledge as public good and create specified designs embodied in products. The more knowledge there is as public good, the more productive R&D efforts using human capital are. Economies with very limited human capital, e.g., developing countries, however, cannot create a comparable interaction with the pool of knowledge, and therefore they are unable to sustain the production of capital goods essential to rapid economic growth. Hence, underdevelopment and low productivity persist (Romer 1986; Romer 1990; Scherer 1999).

In either way, innovations are assumed as the movements of production function rather than along it and are a totally different activity from mastering and adapting technology to different conditions, which are restricted to the movements along the function, because the only admissible country-wise differences in theory are capital/labor ratios. In addition, the theories assume that all major innovations occur only in advanced industrial countries and developing countries select and costlessly apply those innovations.

In developing country context, thus, the neo-classical theories on economic growth stress the role of investments in physical and human capital in moving the economies "along" their production function. Nelson and Pack (1997) called this line of thinking "Accumulation" theories, which were applied to the explanations of the growth of the Asian Tigers (South Korea, Taiwan, China, Singapore, and Hong Kong) by several economists who explained the large percentages of the increased output per worker in those countries were due to the increases of physical and human capital per worker (Kim and Lau 1994; Krugman 1994; Young 1993).

In the neo-classical framework, the assumption of competitive equilibrium leads to the logical conclusion that free markets optimize resources, hence welfare. Government policy interventions are very limited to correct only restricted cases of market failures, e.g., under-investments through stimulating R&D, inaccessibility of knowledge through Intellectual Property Right (IPR) protection, market imperfection due to monopoly through antitrust laws, and information asymmetries by providing information. For developing countries, policy prescriptions are confined to the ones such as "get price right," "reduce or eliminate protection," or "free international flows of capital and technology' and "cut back on government intervention in industrial activity" (Lall 1992). And the accumulation theories simply stress the investments in physical and human capital. This neo-classical framework is the central notion of the Washington Consensus - minimal government intervention and trade liberalization.

Evolutionary Theories of Technical Change and Economic Growth

Various empirical researches on firm technology development have cast serious doubts on the neo-classical theories and resulted in the formation of evolutionary theories of economic growth (Dosi, Freeman, and Fabiani 1994; Metcalfe 1993; Nelson 1993; Nelson and Winter 1982).

In the evolutionary theories, technology is treated as endogenous factor. Technology cannot be fully codified and has important tacit elements and idiosyncratic features. Firms do not have full information on technical alternatives; hence costless and instantaneous mastery of existing technologies does not happen. Firms require time and efforts to choose technology, learn to use efficiently and master technology, and improve and innovate technology. Thus, firms do not operate on a common production function, which is the starting point of the evolutionary theories, and can explain the "permanent existence of asymmetries among firms, in terms of their process technologies and quality output" (Dosi et al. 1988). Technological knowledge is not shared equally among firms, and technical efforts are undertaken in relatively risky and uncertain world of imperfectly understood information.

In the evolutionary approach, innovations take place at firms along certain familiar and known paths in order to deal with uncertainties, resulting in non-optimal outcomes and technology lock-in. Firms cope with the situations not by maximizing clear and well-defined objective functions but by developing and adapting organizational and managerial routines.

The evolutionary theories also stress the costs of technological learning. Technological learning is to increase the ability to make effective use of technological knowledge in production, engineering, and innovation, in order to sustain competitiveness in price and quality (Kim 2001), and it strengthens technological capability and its acquisition. Both technical and organizational capabilities are essential to spur the process of technological change.

Process of technological change occurs in all or a part of the three stages of permeation of new technology – invention, innovation and diffusion (Schumpeter 1942; Schumpeter 1935).[2] Technological capability incorporates additional and distinct resources (skills, knowledge and experience, institutional structures and linkages) necessary to generate and manage technological change (Bell and Pavitt 1992; Bell and Pavitt 1993). Although there are various ways to categorize technological capability at firm level, basically it can be categorized into three elements: project execution capability; production capability, and innovation capability (Amsden 1989; Amsden and Hikono 1994; Bell and Pavitt 1992; Westphal, Kim, and Dahlman 1985).

The evolutionary theories, however, cover far larger aspects of technology development than that involves at firm-level. In industrial network approach of the evolutionary theories, technology development is seen as the result of interaction among various economic actors and takes place in the realm of economic relationship that belong to neither market nor hierarchy, and firms never innovate in isolation. Actors are embedded in industrial networks that serve as a coordinating mechanism and play significant roles in creating and accessing tacit knowledge and have constraining and enabling function to important external resources.

Extending this to the far larger context, the system of innovation approach considers technology development as an interactive learning process, characterized by complex feedback mechanisms and relationships among actors in the system or networks of private and public sector institutions, whose interactions produce, diffuse and use economically useful knowledge. Technology development is a social process, not automatic or predictable, because technological learning required for technological change is collective, cumulative and path-dependent. This

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[2] Schumpeter defined these three concepts as follows: 1) invention as creation of a new device, idea, process, or system; 2) innovation as activity that entails commercial or practical application of the new device; and 3) diffusion as process whereby a new technology or techniques is adopted over the course of time (Schumpeter, 1935). He actually provided the ideas that innovation lay at the heart of economic development, facilitating the growth of material prosperity, and acts of entrepreneurships is required to make innovations happen. His works laid out the foundation for later works concerning technological changes and economic growth such as Solow's. See (Schumpeter, 1934, 1911 in German).

approach has a national, regional, or cluster focus towards technology development. The components and the interactions are determined by culturally defined norms, historically determined institutional development, national priorities, geographic borders and national policies (Dosi et al. 1988; Freeman and Soete 1997; Lundvall 1992; Metcalfe 1993; Nelson 1993).

In developing country context, the evolutionary theories on economic growth stress the importance of firm ability and skillful entrepreneurship of firms and learning, which developing economies have to go through before they could master new technologies that they are adopting from more advanced industrialized nations. Nelson and Pack (1997) called this line of thinking "Assimilation" theories (Nelson and Pack 1997), and many economists support this view on explaining the rapid growth of the Asian Miracle since the 1960s (Amsden 1989; Amsden 2001; Pack and Westphal 1986; Westphal, Kim, and Dahlman 1985).

In the evolutionary framework, government intervention policy takes various forms and in far more selective ways than the neo-classical approach, e.g., the ones to address the market failures created by externalities due to the costs of technological learning and capability building.[3] In addition to policy, a large volume of literatures expressed the significant role of institutions in economic development (Powell and DiMaggio 1991; Rodrik 1995; Rodrik 2000).

1.2.2 Theories on Mode of International Technology Transfer

Technology transfer is the diffusion and inculcation of new technical equipment, practices and development know-how from one region or company to another (Forsyth 1999). Empirical studies suggest the complexity of international technology transfer, far greater than the simple description above.

Theories of International Technology Transfer

In both the neo-classical and evolutionary theories as well as in empirical evidences, international technology transfer has been a key mechanism of technological change for developing countries where the levels of domestic R&D innovations are low. Technology transfer can take different mechanisms: 1) trade; 2) internalized mode within a multinational company, taking a form of foreign direct investment (FDI); and 3) externalized mode, taking a form of partnership (licensing, franchising, joint venture, management contract, turnkey contract, production-sharing contract, and international subcontracting).

A large volume of literatures are dedicated to the studies of international technology transfer. Yet, no overreaching theory on technology transfer has been developed. Theories of international technology transfer largely derive from the studies of multinational enterprises and FDI, and those theoretical arguments are mostly concentrated on mode of entry, but the perspectives of arguments vary greatly.

Mode of technology transfer/entry is studied greatly in both theoretical and empirical manners and is the focus and important framework of these arguments, because different choice of entry

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[3] Learning and information is the most imperfect market, and market failures are caused by imperfect and costly information. Problem of development is the acquisition of technology, knowledge, information about technology and methods of production (Stiglitz, 1989).

mode is considered creating great differences in benefits and spillovers from developmental perspectives. In the neo-classical theories, there are no differences between various modes of technology transfer, because free markets yield the best set of choices. In the evolutionary theories, however, the mode of transfer is not neutral to the resulting developmental effects and the benefits greatly differ (Lall 1992), as technology transfer is linked to capability building and catching up. Theoretical arguments are divided into several different groups.

According to the transaction cost and industrial organization/internalization theories of international technology transfer and determinants of FDI, firms choose the entry mode and organizational form, which minimize the overall transaction costs (Anderson and Gatignon 1986; Buckley and Casson 1976; Erramilli and Rao 1993; Gatignon and Anderson 1988; Williamson 1985). Imperfection in markets for intangible assets, intermediate products, and information makes it more efficient for firms to integrate rather than interacting as number of independent single-plant firms. Internalization overcomes transaction costs, risks and uncertainties in arm's length market and creates advantages in control, market power, scale and scope economies, and transfer pricing. Transaction costs and barriers to entry are key elements for FDI. According to this line of theory, if technology transfer of a product requires high cost due to high degree of asset specific resources, technology providing firm is expected to choose higher entry modes such as FDI instead of lower entry modes such as blueprint. Also the entry mode is influenced by the bargaining power of provider and receiver of technology, as technology transfer is usually costly due to high level of investments required for new and different legal, administrative, and operating infrastructure (Davidson and McFertridge 1985). From the perspective to see internationalization as stage process, technology providing firms originally choose low risk indirect options of market entry mode and gradually increase their market commitments overtime, shifting to equity investment and sales operations (Johanson and Vahlne 1977). Overall, as the external mode of entry can reduce political and economic risks associated with FDI, it is taken when risks are relevant.

The organizational capability perspective argues that the mode of technology transfer is influenced by the perspective of donor on ownership effects (the ratio of embedded-to-generic firm specific know-how) and location effects (the ratio of embedded-to-generic market specific knowledge) as well as by the perception of recipient of its own technological absorption capability, because value creating activities of a firm are a function of its resources and capability (Madhok 1997; Pfeffer and Novak 1976; Teece, Pisano, and Shuen 1997). According to this perspective, technology provider would avoid low entry modes if technology is advanced or unfamiliar with the potential users. Also, if a technology receiver believes it has higher technology absorptive capability, it will choose licensing options, but if a receiver has low belief in its own absorptive capability, it would opt for financial and higher forms of provider involvement.

Arguing no single theory could explain the existence of FDI, Dunning (1980) formulated the O-L-I framework of FDI, a more eclectic form of theory applied to entry mode. In his theory, firms will select their entry mode structure by considering three sets of variables: 1) ownership advantages (advantages derived from controlling of firm specific assets such as know-how, labor skills and technologies, control over markets, trade monopoly, scale advantages, managerial capabilities, and patents); 2) location advantages (advantages derived from availability and cost of inputs such as transportation, labor, and natural resources); and 3) internalization advantages (advantages derived from reduction of transaction and coordination costs through internalization) (Dunning 1993; Dunning 1995; Dunning and McQueen 1982; Dunning 1980). These three sets of variables influence the firm's entry mode decision by affecting management's perception of asset power (ownership advantage), market attractiveness (location advantage), and costs of integration (internalization advantage) (Agarwal and Ramaswami 1992). According to this framework, firms will prefer more integrated modes of entry when the O-L-I advantages are high. Empirical studies by various scholars have showed the superiority of the O-L-I framework over the transaction cost approach in explaining the selection of entry mode (Agarwal and Ramaswami 1992; Brouthers, Brouthers, and Werner 1996; Dunning and Kundu 1995; Dunning and McQueen 1982; Tse, Pan, and Au 1997). The Dunning's OLI framework is now widely accepted.

Related empirical studies verify that the issues in control and ownership dominate the decision for mode of technology transfer (Stewart and Nihei 1987). However, many other influential factors have been also found, including: national culture; political environment; needs for local identity; intellectual property right (IPR) regime; education level of host country; risk diversification of foreign market entry; government constraints; concerns for sovereignty rights of management; personal characteristics of top management; and technology provider's growth strategy in the home market (organic vs. radical) (Davidson and McFertridge 1985; Kogut and Singh 1988; Kumar, Cray, and Kumar 2002; Lee and Mansfield 1996; Maskus 2000; World Trade Organization 2002).

Technology Diffusion through International Technology Transfer

In terms of developmental effects of international technology transfer, active spillover (technological know-how that disseminates from foreign production plants into domestic economy through learning about foreign technology by active participation of technology receiver) is said to be created by technology transfer, rather than passive spillover derived from using technologically advanced intermediate products invested abroad.

There are four basic effects/channels of interaction between technology provider and receiver firms that lead to technology diffusion through FDI and external modes of technology transfer: 1) backward and forward linkages (both linkages make technology provider firms support their host country firms in inventory and quality control methods, standardization, etc. to raise their quality and service standards); 2) demonstration effect (copying, imitating and reverse engineering of new technologies and adoption of managerial, marketing and production processes of higher efficiency); 3) competition effects (local firms start adopting new managerial habits and imitating new technologies when they feel the pressure of foreign competitors with an advantage consisting of superior technologies or organizational methods in the market); and 4) learning-by-doing. The effectiveness of these four channels depends on characteristics and mode of technology transfer as well as economic conditions of host country such as IPR regime, general level of education, labor mobility, etc (Blomstrom and Kokko 1998; World Trade Organization 2002).

Empirical evidences show the mixed presence of spillovers and there is a systematic pattern where various host industry and country characteristics influence the incidence of spillovers

(Blomstrom 2001). They are positively related to the host economy's capacity and technological capacity of indigenous firms to absorb. Although spillovers should not be expected in all kinds of industries, they are weak in enclave, where neither products nor technologies have much in common with those of local firms (Cantwell 1989; Hadda and Harrison 1993; Kokko 1994). The size of national market and high level of local competition and competence are the important determinants of spillovers (Blomstrom and Kokko 1998).

Technology transfer can be divided into two forms by the extent of integration with local market and with local labor force, which determine its potential to diffuse technology for a given level of intensity of technology transfer. Vertical technology transfer, typical for technology transfer from developed countries to developing countries, has lower potentials of technology transfer, because firms fragment their production chain into stages, matching factor intensities of their activities with factor endorsements of host countries. Only training and learning-by-doing is the channel of technology transfer. On the other hand, horizontal technology transfer has higher potential of technology transfer, as it concerns the production of goods for the local market of host country where multiple firms produce similar goods in all locations. This is more common between developed economies, and all possible channels act as a mechanism of technology transfer (Forsyth 1999; World Trade Organization 2002).

1.2.3 Technological Change and Sustainable Development

Concepts of sustainability and sustainable development cannot be separated from economic growth.

Although sustainability is an essentially vague concept, Solow (1991) defines it as an obligation to conduct ourselves so that we leave to the future generation the option or the capacity to be as well off as we are (Solow 1991). During the 1970s, the sustainability concept emphasized the notion of environment as simply an additional constraint on economic growth; hence long-term sustainability requires limiting the volume of economic activities to what is compatible with the sharply constrained natural capital (carrying capacity, rates of renewable resources, assimilation capacity by ecosystems of wastes). This led to the old proposition for zero-growth of economic activities based on technological pessimism, advocated by the Report of the Club of Rome (Daly 1991; Kryer and Gillete 1985; Meadows et al. 1972).

On the other hand, during the 1980s, a new concept of sustainable development emerged based on technological optimism, aiming at reconciling the pursuit of economic growth with ecological protection, by drawing an inspiration from the neo-classical capital theory that extended to include natural capital. The view of sustainable development concept presumes that technological change/progress can, automatically through market mechanism, offer some relief from environmental constraint, through some combination of substitutions (from natural capital toward human and produced capital) and secular increases in factor productivity (Ausbel 1996; Faucheux, Muir, and O'Connor 1997; Faucheux 2000; Solow 1991). The United Nations Conference for Environment and Development (the Earth Summit at Rio) in 1992 endorsed this concept of sustainable development as a new social project.[4]

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[4] The term "sustainability" has since been defined with reference to scientific principles.

Thus, the role of technology and technological change/progress is central to achieve sustainable development, in particular decoupling economic growth from environmental degradation and unsustainable resource use that have led to the global environmental concerns, including the loss of biodiversity, climate change, ozone layer depletion, and desertification. The importance of technological change for sustainable development was enunciated in the definition of sustainable development in the World Commission on Environment and Development (WCED) as follows:

> *The concept of sustainable development does not imply limits – not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities. But technology and social organization can both be managed and improved to make way for a new era of economic growth (World Commission on Environment and Development (WCED) 1987).*

However, the relationship between technological change and sustainable development is not very straightforward. While technological innovations can bring remedy for environmental degradation and vehicle of economic growth simultaneously, they can also bring new risks to society and can be new sources of environmental degradation. Many historical examples showed this kind of ambiguity of technology in light of the concept of sustainable development.

Section 1.3: Practical Background of Research

1.3.1 Role of Technology Transfer in Climate Change Mitigation

Global climate change mitigation is one of the most significant sustainable development challenges. Technology is central to the transition toward more climate-friendly social system, because it plays the central role of mitigating global climate change by reducing the GHG emissions while advancing our welfare creation capacity by increasing productivity. A frequently expressed view on technology and global climate change has been as follows: "If the introduction of technologies created the problem, other new technologies will help us in solving it (IPCC Working Group III 2000)."

International collaborations are also crucial in order to increase productivity and efficiency of the climate mitigation efforts as well as to expedite the diffusion of the efforts worldwide. Global economic growth is currently increasing energy use and the GHG emissions. In many cases, technologies that could be used to mitigate the increase in the GHG emissions do exist but not in locations where they could be best used, in particular, in developing countries that are experiencing rapid economic growth but not in sustainable ways. Therefore, transfer of climate change mitigation technologies and investments from developed to developing countries have been considered vital to the transition toward more climate-friendly social system, ever since the launching of the United Nations Framework Convention on Climate Change (UNFCCC)[5] in

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[5] The UNFCCC is an intergovernmental treaty developed to address the problem of climate change. The UNFCCC was opened for signature at the Earth Summit at Rio in 1992 and entered into force on March 21, 1994. Article 4.1.c requires the parties "to promote and cooperate in the development, application, diffusion, including transfer, or prevent anthropogenic emissions of greenhouse gases." Then, Article 4.5 states "The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as

1992. The Kyoto Protocol adopted in 1997 emphasizes more on the role of private investment and on the actions by and in developing countries themselves in technology transfer than the UNFCCC, and it formally recognizes the role of private sector[6] (UNFCCC 1997a).

In the climate change mitigation context, technology transfer involves not only private sector entities, which are the foremost focus of developmental economic literatures, but also other stakeholders such as governments, financial institutions, NGOs and research/educational institutions, although private sector-driven pathways are considered more dominant than government-driven and/or community-driven pathways of technology transfer (IPCC Working Group III 2000).

1.3.2 Technology Transfer in the Kyoto Protocol

The Kyoto Protocol is a protocol to the Convention that the parties to the UNFCCC negotiated and first agreed in December 1997. It entered into force as a legally-binding document on February 16th, 2005, following the ratification of the Russian Federation in November 2004. Although the United States, the world's largest GHG emitter, rejected the Kyoto Treaty in 2001, a majority of other Annex I Parties (industrialized countries and countries of the former Soviet bloc) including Canada, Japan, and the countries of the European Union ratified the treaty.

The Kyoto Protocol obliges Annex I Parties to cut their GHG emissions by an average of approximately 5% compared to the 1990 levels for the first commitment period of 2008-2012.

The Kyoto Protocol has three innovative "flexibility mechanisms" (Emissions Trading,[7] Joint Implementation,[8] and Clean Development Mechanism) to lower the overall costs of achieving its

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appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country parties, to enable them to implement the provisions of the Conventions. In this process, the developed country parties shall support the development and enhancement of endogenous capacities and technologies of developing country Parties (UNFCCC. 1992).

[6] Before the Kyoto Protocol, there was very limited progress on determining what constitutes technology transfer, the roles of governments and private sector, and how compliances with Article 4.5 of the UNGCCC should be measured. Article 10c of the Kyoto Protocol asks all parties to "cooperate in the promotion of effective modalities for the development, application and diffusion of, and take all possible steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formation of policies and programmes for the effective transfer of environmentally sound technologies that are public owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to environmentally sound technologies." See (UNFCCC. 1997a).

[7] Emissions Trading (defined by Article 17 of the Kyoto Protocol) provides for Annex I Parties to acquire units from other Annex I Parties and use them towards meeting their emissions targets under the Kyoto Protocol by allowing Parties to grasp the lower cost opportunities to reduce emissions. Only Annex I Parties to the Kyoto Protocol with emissions limitation and reduction commitments inscribed in Annex B to the Protocol can participate in the Emission Trading (UNFCCC, 1997b).

[8] Joint Implementation (JI, defined by Article 6 of the Kyoto Protocol) is another project-based mechanism of the Kyoto Protocol that may be used by Annex I Parties to fulfill their Kyoto targets. Under JI, an Annex I Party (with a commitment inscribed in Annex B of the Kyoto Protocol) may implement an emission-reducing project or a project that enhances removals by sinks in the territory of another Annex I Party (with a commitment inscribed in Annex B

emissions reduction targets by enabling the Parties to access cost-effective options to reduce emissions or to remove carbon from the atmosphere in other countries. The mechanisms are based on the fact that while the costs of reducing emissions vary considerably from region to region, the global effects of mitigation efforts are the same regardless the locations of actions.

Among the three mechanisms, the Clean Development Mechanism (CDM, defined by Article 12 of the Kyoto Protocol) is a project-based mechanism, which greatly concerns cross-border transfer of climate change mitigation technologies between developed countries and developing countries. As Emission Trading and Joint Implementation (JI) are not applicable to developing countries, only the CDM provides considerable scope for creative partnerships involving private parties by stimulating international investments for cleaner economic growth in developing countries. The CDM provides opportunities for Annex I Parties to implement project activities that reduce emissions in non-Annex I Parties, in return for certified emission reductions (CERs). The CERs generated by such project activities can be used by Annex I Parties to help meet their emission reduction targets under the Kyoto Protocol. Thus, carbon credits to help finance emission reduction projects of GHGs are called "carbon finance." "Carbon finance" is an additional value creation mechanism to the existing monetary value system in order to mobilize more private-sector projects to spur the international diffusion of climate change mitigation and adaptation technologies.

The CDM has two-fold objectives: while it assists Annex I Parties to comply with their GHG emission reduction targets, it supports non-Annex I Parties in contributing to the climate change mitigation efforts and achieving sustainable development. The emission reductions by the CDM must be real and measurable as well as additional. The last is called the "additionality" criteria; the CDM projects activity is considered to be additional only if the GHG emissions are reduced below those that would have occurred in the absence of the CDM project activity, which is the baseline for the project. Various tools for identifying and measuring additionality have been developed and they are still evolving. Operational criteria for additionality include: that the project is not duplicating a common practice; that the project is economically or financially less attractive; that the project exceeds current legal or regulation requirements; that the project uses more advanced technology with higher performance uncertainty than the normal practice in the country; and, that the project cannot be implemented in normal course due to barriers, etc (Ministry of Environment of Japan 2006).

Also, the CDM projects must satisfy the sustainable development criteria; they must assist developing countries in achieving some of their economic, social, environmental criteria for sustainable development, but the specification of the criteria is left for each individual host country of the CDM projects (UNFCCC 1997d).

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of the Kyoto Protocol) and count the resulting emission reduction units (ERUs) towards meeting its own Kyoto target (UNFCCC. 1997c)

1.3.3 Issues in Climate Change Mitigation Technology Transfer

Although the CDM was devised to stimulate private sector transfer of climate change mitigation (and adaptation) technologies from developed countries to developing countries, many issues remain to be considered and addressed by more progressive efforts.

Changing Global Business Environments

One of the issues is how to effectively incorporate the rapidly changing business environments into the CDM and other climate change mitigation efforts. While the importance of private sector technology transfer is increasingly recognized, the global environments surrounding private sector cross-border business activities have been rapidly changing since 1980.

First, since the 1990s the types and magnitudes of international financial flows that drive private sector cross-border technology transfer to developing countries have greatly changed due to the liberalization of certain domestic sectors and capital markets in many countries with access granting to foreign investors, lowered interest rates in developed countries, development of stronger domestic legal and financial systems, and development and diffusion of information technology. On the other hand, both official development assistance (ODA) and domestic resource mobilization have fallen short of the commitments made (French 1998; IPCC Working Group III 2000). While this has greatly increased the opportunities for obtaining private sector financing for technology acquisitions and changed the structure of international financial flows, private sector investments in general has been very selective and remains highly erratic, most notably in foreign portfolio equity investment and commercial lending.

The increase in private foreign capital flows to the infrastructure sector in developing countries also began in the 1990s. The electricity sector, which is one of the most important sectors concerning the GHG emissions, was no exception. This trend was significantly related to the energy sector reform and restructuring trend (deregulation and restructuring of energy markets in developed countries and privatization of energy sectors in developing countries) since the 1980s. The principle driving forces behind the reform movement of the electricity sector are: 1) poor performance of state-run electricity utilities in terms of costs, expansion of access to services, and/or supply reliability; 2) financial inability to make essential new investments and/or maintenance; 3) needs to remove subsidies in order to release the resources for other more pressing public expenditure needs; and 4) desire of the governments to raise immediate revenue through the sales from the sector (Bacon and Besant-Jones 2001). The electricity reform movements have increased market access and interests by multinational corporations, which have increasingly engaged in corporate mergers and acquisitions (M&A) and have grown by converging both electricity and non electricity-energy business and by expanding to rapidly growing developing countries that urgently need energy services, and have augmented the capital flows and investments but increased the emphasis on short-term financial returns (Sagar and Holdren 2002).

In terms of mode of foreign investments, although 100% subsidiaries have been a dominant mode, joint ventures have been increasing since the 1980s due to host government requirements, volatile local business environments, and internationalization of business to reduce costs (Datta 1988). Other types of external business arrangements such as licensing and franchising have also increased greatly since the beginning of the 1980s (Helleiner 1989).

The increase in international capital flows and the internationalized patterns of business management in technology, investment and sourcing by multinational corporations are considered as a part of the phenomena of intensified globalization. There is another clear global trend: the intensified globalization of governance and the increasing role of international organizations. In the field of policy making and implementation, globalization is taking a form of policy harmonization in areas such as trade and technology quality standards through the creation of the World Trade Organization (WTO) and the International Standards Organization (ISO). On the other hand, while the intensified role of the UN systems and the Conventions that deal with growing environmental problems and challenges beyond national borders is a part of such harmonization efforts emerged in the area of environmental governance, these international mechanisms and nation states have been having difficulty in understanding their role and the way to use their capacity effectively to deal with new demands of environmental governance posed on them.

Another important change for private business has happened in the nature of competition. According to Porter (1990), the world has shifted to so-called "new and dynamic competitiveness paradigm based on innovation" since the 1980s, where competitiveness at the industry level may well be achieved not only through higher productivity or lower prices but also by ability to provide different and better quality products due to technological innovations. Hence, technological innovations are the motor of competitiveness (Porter 1990; Porter and van der Linde 1995).

Thus, the environments surrounding private sector business activities and cross-border transactions have changed greatly since the beginning fo the 1980s and are still chaing rapidlly.

North-South Divide of Climate Change Technology Transfer

The privatization efforts and the process of globalization since 1980 have led the increase in capacity and capability of private sector in international investment and technology development, while transforming the role of public sector into the one inducing the private sector to contribute to public welfare creation. Under such circumstances, public and private partnerships are a requirement to advance the climate change mitigation efforts, and the incentive creation for robust private sector participation is an essential part of this process. Despite this growing capacity and capability of private sector and the recognition of the importance of cross-border technology transfer, however, technology transfer remains the most conflicted aspect of climate change negotiations between developed and developing countries. Divergent views regarding the treatment of technology as well as the roles of government and private sector have contributed to the conflict.

The global climate change regime such as the UNFCCC has treated climate change mitigation technologies as public information, because they are the means of creating public goods and reducing negative environmental externalities. General perception of the climate change mitigation efforts in developing countries is that implementing the Convention commitments and restricting the GHG emissions could mean limiting their economic growth. This view is reflected in Article 4.7 of the UNFCCC, which states "the extent to which developing country parties will effectively implement their commitments under the Convention will depend on the effective implementation by developed country parties of their commitment under the

Convention related to financial resources and transfer of technology, and will take fully into account that economic and social development and poverty eradication are the first and overriding priorities of the developing country parties" (UNFCCC 1992). An augment made by developing countries on this ground is that the technologies should be transferred to them on favorable terms under the mandates of multinational environmental agreements to meet the efforts necessary for climate change mitigation, and the governments of developed countries should play a key role in creating conducive "enabling environments" that encourages and "push" transfer of their technologies to developing countries (Forsyth 1998; UNFCCC 2003).

However, a controversy arises from the fact that it is private sector which owns most of such climate change mitigation technologies. Under the process of globalization supported by a notion of free market supremacy, developed countries argue that the governments of technology providing countries should play a minimum role in transfer of technologies owned by private sector, because transferring technologies on favorable terms pushed by public sector will undermine the commercial basis and industrial competitiveness of private sector players who develop and own such technologies. In this view, transfer of climate change mitigation technologies will happen once developing countries create macroeconomic, political, technical, institutional and social "enabling environments" conducive to technology transfer and there are many rooms for the governments of technology receiving countries to facilitate such environments through removal of generic market and institutional barriers and to "pull" spontaneous technology transfer (Forsyth 1998; UNFCCC 1998; UNFCCC 2003).

Those generic barriers emphasized by developed countries are lack of macroeconomic environment, institutional inertia, non-transparent legal system, capital constraints, absence of accounting for negative environmental externalities, etc. International Panel on Climate Change (IPCC) identified ten dimensions of "enabling environments" that foster adequate implementation on technology transfer and that create conducive national conditions in both developed and developing countries as follows (IPCC 2001; IPCC Working Group III 2000; UNFCCC 1998):

1) National Systems of Innovation (networks of institutions that initiate, modify, import and diffuse new technologies);
2) Social Infrastructure and Participatory Approaches;
3) Human and Intuitional Capacities;
4) Macroeconomic Policy Frameworks (access and availability of capital, banking sector development, inflation or interest rates, stability of tax and tariff policy, subsidized or average-cost price of energy, high import duties, investment risks, risks of expropriation);
5) Sustainable Markets (functioning domestic markets promote replicable, on-going technology development and diffusion);
6) National Legal Institutions (IPR regime, contract/property/regulatory risks, governance, corruption);
7) Codes, Standards, and Certifications;
8) Equity Considerations (distribution of costs and benefits);
9) Rights to Productive Resources (land, natural resources, factories, and other productive resources); and
10) Research and Technology Development.

The governments have responsibilities to provide a variety of policy tools for creating enabling environments. Although most technology transfer case studies point out the importance of removal of technology and sector-specific, i.e., micro-level environmental barriers, empirical evidences on the impact of macro-level environments on environmentally sound technologies are reportedly mixed (UNFCCC 2003).

Immediate Technology Transfer Needs and Long-term Process of Sustainable Development

Another important gap in the current climate change mitigation regime is found between the needs for immediate technology transfer and the long-term process necessary to achieve sustainable development goals.

The UNFCCC and its associated bodies such as IPCC have kept encouraging an approach that emphasizes immediate transfer of technology to rapidly industrializing developing countries to reduce the GHG emissions as soon as and as much as possible. On the other hand, the sustainable development criteria required in the CDM often entail a rather long-term process of education and technological capacity and capability building for technology receivers to achieve the goal, as technology providers are expected to bring more than mere relocation of products and technology receivers are demanded to master technological knowledge.

Many empirical studies on technology transfer conducted during the last two decades also defy any simple notion of technology transfer for successful economic growth, as transfer of technology is a complex socio-economic learning process. Thus, in order to successfully attain both the immediate technology transfer and the long-term sustainable development goals, the process exposes technology providers to high transfer costs, long-term commitments, risks of leaking proprietary knowledge and intellectual property rights, and potential loss of industrial competitiveness, while requiring technology receivers to build indigenous capability and often industrial competitiveness for relatively short term before technology agreements expire, in order to keep up with constantly advancing technology frontier.

Thus, there is an obvious inconsistency between the pressure of immediate technology transfer and the requirement of long-term sustainable development.

Unsolved Deep Chasms

The Kyoto Protocol developed the CDM that many hope spurring cross-border technology transfer, and the subsequent negotiations have been making great progresses in clarifying conceptual and administrative issues surrounding the CDM and offering some international supports for developing countries to build institutional and human capacity and capability to formulate and implement projects under the CDM. However, the deep chasms between developed and developing countries described above and the inconsistency between the immediate technology transfer and the long-term sustainable development goals have been left unsolved, and so far, the progress in cross-border technology transfer for climate change mitigation in the real world has been slow, compared to the speed of globalization.

Section 1.4: Research Significance and Focus of Research

1.4.1 Theoretical and Practical Relevance of Research and Scholarly Contribution

Considering the above theoretical and practical backgrounds, this research aims to contribute to the sustainable development and climate change mitigation fields in several ways.

Applications of General International Technology Transfer Theories on Climate Change Mitigation Technology Transfer

The primary theoretical contribution of this research is the cross-application of general theory and empirical evidences of international technology transfer to a case of climate change mitigation technology transfer. Analyzing the transfer of wind energy technology within the framework of conventional international technology transfer may produce insights for future climate change mitigation technology transfer. Most importantly, the research applies different theoretical frameworks on the case study findings to examine the explanatory power of the existing theories.

Applications of Accumulation and Assimilation Theories on Climate Change Mitigation Technology Development and Diffusion

Another theoretical contribution of this research is the examination of climate change mitigation technology development and diffusion to developing country through the perspectives of both accumulation and assimilation theories of economic growth and technological change. The research applies both theoretical frameworks on the research findings to consider their potentials to explain the case of wind energy technology transfer and development.

Additional Contribution to Literature

Another contribution of this research to literature is to generate some sector and technology specific factors and processes that can be additional knowledge to general international technology transfer theory as well as important evidence to the future formation of climate change mitigation technology transfer theory. Although this case study alone cannot generate a large volume of evidences that make the formation of theory on climate change mitigation technology transfer, it is important to build the knowledge specific to the climate change mitigation as well as sustainable development fields, both of which have important crossover between traditional economic development discipline and environmental discipline.

Practical Relevance of Research

This research also has significant practical relevance. First, although private sector technology transfer has been a great practical concern for the global climate change mitigation efforts, only limited progresses have been made so far in reality. This research examines the causal factors and dynamic processes behind the difficulty of private-sector climate change mitigation technology transfer under the rapidly changing business environments, by directly studying a long-term history of one case of international development and diffusion of climate change mitigation technology.

Second, by examining the historical development, this research attempts to find out the policy focus areas for the future climate change mitigation regime, in particular for distributed power generation technologies such as wind and solar. Various efforts are already underway to remove political and institutional barriers in order to create so-called “enabling environments,” especially in developing countries, to spur private-sector actions under the Kyoto Protocol, the CDM and beyond. However, the question remains whether or not such efforts targeting developing country environments alone can effectively solve the issues of industrial competitiveness management and control between technology providers and receivers in technology transfer and the issues of attaining both immediate technology transfer and long-term sustainable development. The research tries to consider the role of enabling environments and policy supports in light of intensifying firm competitiveness management, by examining the case findings against the on-going current climate change mitigation efforts for technology transfer as much as possible.

1.4.2 Research Focus

This research has the following conceptual focuses.

Role and Effects of Policy and Institutional Settings

The research places special emphasis on the role and effects of government policy and institutional settings.

First, as mentioned already, the intensifying forces of globalization have been rapidly transforming the nature of global and local businesses at every corner of the world since 1980, while the policy harmonization efforts are in progress in many fields including global environmental governance. Exploring the role of policy and institutional settings is important in this context, as it has been transformed from commanding and restricting private business behaviors to creating the environments that support their value creation activities through competition and as the role and effects of policy and nation states in global environmental and business governance are often uncertain.

The other very important reason is because development of climate change mitigation technologies and their market and industry is strongly policy-driven as neither negative socio-environmental externalities caused by our current mode of economic development nor positive externalities created by the climate change mitigation efforts is incorporated into the present market mechanism. Many factors in the macro-environments influence the processes of international development and diffusion of climate change mitigation technologies, including:

- Market demand and its characteristics;
- Characteristics and state of technology;
- Industry characteristics and firm-level competitiveness management and; and,
- Availability of resources (physical and human resources, including infrastructure).

Because government policy plays important roles in defining the impacts of the above factors, this research highlights the role of policy as the main driver of international development and diffusion of climate change mitigation technologies. The examination includes the role and effects of industrial policy, which have been controversial in developmental economics and they can be more controversial in the field of sustainable development and climate change because of the ambiguity in their role and effects on technological changes.

Co-evolution of Policy, Market, Industry and Technology on Both Technology Provider and Receiver Sides

While the role and effects of policy and institutional settings are the main focus of this research, policy alone cannot create the necessary dynamics of technology development and diffusion. Virtuous interactions among the factors mentioned above are essential. With this reason, the research pays strong attention to the co-evolutionary processes of policy, market, industry, and technology by following one case of long-term process of technology development and diffusion and engaging in more comprehensive and systemic assessment. By doing so, the research aims to providing insights on the effects of dynamically changing factors and their transformation processes on technology transfer results beyond the factors that influence the mode of transfer, which is the primary focus of general international technology transfer theory, as very few attempts have been made to follow such long-term process of cross-border development and diffusion of one climate change mitigation technology in detail so far.

This focus on process is also connected to the concept of replicable technology transfer; because technologies always advance and transform themselves, recurring transfer of upgraded technologies is very important to maximize the long-term developmental and climate change mitigation effects. By examining the factors necessary for replicable technology transfer, this research naturally concerns the process of dynamic changes of such factors.

This research also examines such co-evolutionary processes on both technology provider side and technology receiver side, because the interactions between them influence technology transfer outcomes greatly. In particular, the focus on the industry and firm evolution and their interactions with policy, market, and technology in both technology provider and receiver countries and the examination of their effects on technology transfer outcomes are considered unique to this research, because private firms and industry are the conduit of technology diffusion but comprehensive examination of the effects of their evolution on technology transfer has been rather rare. This inclusion of industry evolutionary perspective in international technology development and diffusion is also connected greatly to the next focus of this research, the role and effects of industrial competitiveness management.

Role and Effects of Industrial Competitiveness Management

The next focus of the research is the struggle between technology providers and receivers caused by cross-border technology transfer in terms of enhancement and management of industrial competitiveness. As already mentioned, developed countries argue that transfer of climate change mitigation technologies will happen once developing countries create "enabling environments" i.e., macroeconomic, political, technical, institutional and social environments conducive to technology transfer. However, even with such environments, the issues of industrial competitiveness control by technology providers will very likely remain, possibly hindering the process of immediate transfer of best available technologies and/or technologies most suitable to local conditions.

With this reason, this research focuses on the factors and processes that influence firm-level industrial competitiveness management from the perspectives of technology providers and receivers in the context of co-evolution of policy, market, industry and technology over time, as they change through the interactions with rapidly changing business environments. In international technology transfer literature, the factors that influence firm competitiveness management are analyzed as one of the decisive factors that determine the mode of transfer. However, competitiveness management continuously evolves after the mode of transfer is set. Therefore, this research follows the evolution of competitiveness management strategies in long-term process and examines their effects on technology transfer outcome.

Taking the industrial competitiveness issues into account, the research gives a consideration to what kinds of policy mechanisms, including carbon finance mechanism through the CDM, can be effective to create technology transfer that both technology providers and receivers can enhance industrial competitiveness together through collaborations. The power of private sector cannot be fully utilized in international development and diffusion of climate change mitigation technologies without addressing this subject.

1.4.3 Wind Energy as Case Technology

This research takes wind energy technology, in particular wind power generation technology, as case technology. As case study material, the research focuses on the development of the Indian wind energy sector and its interactions with the Danish and German wind energy sector. There are several reasons for this selection.

First, power generation technology plays the most important role for climate change mitigation, as the system and process of energy extraction, transformation, delivery, and usage in human activities are the primarily cause of the GHG emissions and global warming. In particular, wind energy is a distributed power generation technology, which has been becoming to play a significant role in electricity infrastructure. Wind energy technology, therefore, is a superb case material for future distributed power generation technology development and diffusion.

Second, wind energy technology is one of the most successfully developed and diffused new energy technologies since the Energy Crisis in the 1970s, and its history provides an opportunity to follow the co-evolutionary development paths of policy, market, industry, and technology, which has been most evident in Europe, especially in Denmark and Germany.

Third, the sector has a record of international private sector partnerships between European companies and Indian companies. This provides excellent case study materials. Stories from the Indian side will highlight some of successful policies as well as unsuccessful attempts to gain technological and institutional capabilities within the dynamic context of contemporary wind energy technology development. Stories from the European side will highlight policies that encourage private firms to advance technology frontier and expand cross-border technology transfer to India as a part of their global business strategies.

Lastly, the sector has the histories of public-private sector collaborations in all the three countries. Such histories will provide materials to examine the role and effects of public policy on both domestic and international technology development and diffusion as well as interactions among collaborators from different institutional backgrounds.

Thus, wind energy technology provides lots of important materials and potentials for transferable lessons and is considered as a good case technology for this research. There have been many studies done for wind energy sector development in individual countries, including Denmark, Germany and India. However, very little analysis has been made for the interaction between these countries, in particular from the perspective of technology transfer from developed countries to developing countries throughout the period of dynamic transformation occurred in the market, industry, and technology of wind energy under the intensifying globalization. This research, therefore, provides an interesting case material for the future of sustainable development as well.

Section 1.5: Dissertation Outline

This dissertation composes of seven chapters as follows.

Chapter 1:	The chapter discusses the motivation and significance of research, provides the theoretical and practical context, and describes the focus of research.
Chapter 2:	The chapter presents the research questions, the timeframe of the research, and the methodologies used for the analysis.
Chapter 3:	The chapter describes the basics of wind energy technology system, its value chain/system, and wind power generation economics.
Chapter 4:	The chapter briefly looks at the evolution of wind energy sector of the three research countries before 1990.
Chapter 5:	The chapter examines the evolution and the basic profiles of wind energy policy, market, industry, and technology in Denmark, Germany and India from 1990 through 2005, and the results of technology transfer between Denmark/Germany and India.
Chapter 6:	The chapter examines the co-evolution of policy, market, industry and technology that spurred technology development and diffusion at the technology frontier of Denmark and Germany and in India and explores the causal factors and processes that created technology gaps between the two sides.
Chapter 7:	The chapter summaries the findings of the research, examines the explanatory power of different theoretical frameworks introduced in Chapter 1 regarding the case findings, and explores practical implications of the research findings on the current and future climate change mitigation technology transfer and the role of government policy.

Chapter 2:
Research Questions and Methodology

Chapter 1 introduced the theoretical and practical backgrounds and foundations of this research. This chapter presents the research questions and the methodological approaches that this research takes. The first section discusses the core and specific questions of the research. The second section descries the research methodology and steps taken to address the research questions. The third section explains methodological rationale and data validity and reliability.

Section 2.1: Research Questions

The goal of this research is to provide some answers to the following questions.

2.1.1 Core Questions

As introduced in Chapter 1, the core questions that motivate this research are:

> *Why is it so difficult to transfer more advanced climate change mitigation technologies from developed countries to developing countries? How can we stimulate private sector involvement further in cross-border transfer of such technologies in order to advance not only global climate change mitigation but also sustainable development?*

The fundamental concern of the research is the factors and processes, hence the evolving mechanisms, which promote replicable transfer of climate change mitigation technologies by private sector from developed countries to developing countries.

2.1.2 Specific Questions

In order to gain some insights for the core questions, the research asks the following specific questions:

- *What are the factors and processes that influenced domestic and international development and diffusion of wind energy technology?*
- *How do those factors and processes evolve and how the mechanism of co-evolution of those factors differ in technology provider (developed) versus technology receiver (developing) country context?*
- *What are the role and effects of policy and institutional settings in technology development and diffusion, in particular cross-border transfer, of wind energy technology by private sector?*
- *What is and how important is the role of industrial competitiveness management in the outcomes of cross-border transfer of wind energy technology?*

Section 2.2: Research Methodology and Procedures

This research basically follows the historical footsteps of wind energy sector of the three research countries (Denmark, Germany and India) in order to analyze the factors and processes of technology development and diffusion. The research mainly focuses on the timeframe after 1990 and takes the following five steps.

2.2.1 Timeframe of Research

The primary timeframe of this research is between 1990 and 2005. This is because private sector development in India and Germany as well as Indo-European wind energy private sector partnerships mostly started during the 1990s. However, the development before 1990 has also impacts on the later development, and they will be briefly examined in Step 2 (Chapter 4) and also introduced as backgrounds as necessary.

2.2.2 Step 1: Wind Energy Technology and Economics Profile Development

The purpose of this first step is to lay out general technical backgrounds for the research by illustrating specific attributes of wind energy technology, its value chain and system, and economics. The analysis is based on literature review. This step consists of Chapter 3 and its three main tasks are:

Task 1) Describe the basics of wind energy technology system, focusing mainly on horizontal axis wind turbines and technologies that support the grid-connection

Task 2) Examine wind energy technology along its value chain/system

Task 3) Review the basics of common wind power generation economics

2.2.3 Step 2: Profile Development of Wind Energy Sector before 1990

The objective of this second step is to examine the evolution of wind energy policy, market, industry, and technology before 1990. The step is important because the historical paths before 1990 had important implications on the later development in all of the three research countries. The analysis is based on both literature review and the data gathered by personal interviews as well as the government and industry statistics. This step comprises Chapter 4 and its three main tasks include:

Task 1) Describe general wind energy sector development in Denmark, Germany and India before 1990

Task 2) Present technology development during the 1970s and 1980s, in relation to the government Research, Development & Demonstration (R&DD) programs and the success factors behind the Danish technology

Task 3) Portray industry development and structure before 1990

2.2.4 Step 3: Profile Development of Wind Energy Policy, Market Technology and Industry in Denmark, Germany and India

The purpose of the third step is to develop the basic country profiles of wind energy policy, market, industry, and technology in Denmark, Germany and India from 1990 to 2005, and the results of technology transfer between Denmark/Germany and India. The profiles are constructed through both literature review and the data gathered by personal interviews as well as the government and industry statistics. This step consists of Chapter 5 and the following six main tasks are involved:

Task 1) Present general institutional settings surrounding wind energy sector in the three countries, in terms of the following: 1) political and institutional settings surrounding the wind energy sector; 2) public organizations that concern wind energy development and their primary roles; and 3) electricity sector profiles in light of the sector reforms and restructuring

Task 2) Review wind energy policy of the three countries, in terms of the following: 1) technology investment and development policy and programs; 2) market investment and development policy and programs; 3) industry investment and development policy and programs; 4) cross-border transaction related policy and programs; and 5) the EU-wide technology support programs

Task 3) Portray development of wind energy market of the three countries along with global market development by examining the following: 1) market size (annual and cumulative installed capacity); and 2) share of wind energy generated electricity in total electricity generation or consumption

Task 4) Build general profiles and development of wind energy industry of the three countries and the global industry, by examining the following: 1) industry expansion (domestic, export, and total turnovers/sales in terms of installed capacity) and their growth rates; 2) the number of industry employment; 3) profiles of main manufacturers; and 4) industry structure (market share by manufacturer)

Task 5) Establish profiles of technology commercialization and introduction to the markets at Denmark and Germany

Stage 1: Analyze technology characteristics and their development history based on: 1) technology depreciation rate (average capacity/size of annually installed turbines over the years, size of available models over the years in terms of rated capacity, rotor diameter, and hub height); 2) specification of commercialized turbine models (model size in rated capacity, rotor diameter, hub height, years of introduction in Europe and withdrawal, rotor power regulation types, rotor speed control types, generator types, drive mechanisms, blade materials, SCADA, etc); and 3) commercialized technological innovation and their characteristics (engineering/science disciplines of innovation and required technological capability, and location of innovation in value chain/system and technology system)

Stage 2: Examine general technology trends from 1990 to 2005 by manufacturer and by component/technology system/value activity based on the analysis of Stage 1

Stage 3: Analyze characteristics of technology innovations and their transformation based on system integration, pacing technologies, cost composition, and technological complexity by synthesizing the analyses of Stage 1 and Stage 2

Task 6) Present technology evolution profiles of India as a result of technology transfer from the frontier and construct technology gap profiles with the frontier by comparing similarities and differences between the two sides

Stage 1: Examine general technology trends based on: 1) turbine capacity/size; 2) technology depreciation rate (average capacity/size of annually installed turbines over the years and size of available models over the years in terms of rated capacity, rotor diameter, and hub height)

Stage 2: Build product (wind turbine) technology transfer history based on: 1) transferred models and their technological characteristics (model size in rated capacity and rotor diameter, years of introduction in Europe and India, rotor power regulation types, rotor speed control types and drive mechanisms, generator types, and the mode/pathway of transfer); and 2) non-transferred technology and their technological characteristics

Stage 3: Construct turbine/component production technology transfer and capability development/indigenization history at manufacturer level

Stage 4: Build project execution technology transfer and capacity development/ indigenization history

Stage 5: Investigate innovation technology development by both R&D institutions and manufacturer in-house R&D

Stage 6: Analyze development of technology gaps between the frontier and India in product (technology depreciation rates, turbine capacity/size, and productivity in annual electricity production per installed turbine unit) and capability (production and innovation)

2.2.5 Step 4: Comparative Analysis of Causal Factors and Processes of Technology Development and Diffusion

The objectives of Step 4 is to conduct comparative analysis of the three countries, examine the causal factors and processes that have influenced technology development and diffusion, and explore the mechanisms, including cross-border technology transfer, which created the similarities and differences on technology provider and receiver sides, based on the constructed profiles of Step 3. The analysis involves both qualitative and quantitative examinations. The data used in Step 4 derive from both literature review and the data gathered by personal interviews, the government and industry statistics, and the figures and information published by manufacturers. This step comprises Chapter 6 and its eight main tasks are:

Task 1) Analyze market size and location, investment mechanisms, and characteristics of market demands of Denmark and Germany, and examine their effects and the role of policy on technology development and diffusion at the frontier

Stage 1: Establish the data regarding market characteristics based on: 1) market size and location and regional market-industry interaction; and 2) investment mechanism/ investor profile (funding sources, equity-debt ratio, investor characteristics, ownership structure and characteristics of wind projects).

Stage 2: Examine the interactions between market demands and technology development by comparing: 1) types of technology driving market demands and their sources (policy requirements, environmental and resource-related pressures, technical management demands, etc); and 2) technology development as a result of various market demands (model size in rated capacity, power control types, rotor speed operation types, generator types, drive mechanisms, blade materials, SCADA, etc)

Stage 3: Synthesize the above analyses and identify the role and effects of demand-pull and technology-push policy as well as institutional settings on market growth and demand-induced technology development

Task 2) Investigate the effects of changing technological characteristics on industry structure and competitiveness management strategies at the frontier and explore the role of policy in technology-push aspects

Stage 1: Establish the date regarding technology and cost management demands and examine their relationships with technology development costs and their growth rates at manufacturer level (annual manufacturer R&D costs)

Stage 2: Build the data regarding industry structure and manufacturer competitiveness strategy evolution in terms of the following: 1) industry structure in general (the number of companies, entry and exit, horizontal and vertical M&A); 2) business entry strategy; 3) organizational growth strategy; 4) domestic and international industry collaboration system (public and private sector collaboration frameworks, and their role as the sources of innovations and the relationship with specific technology development and value activities); 5) market expansion strategy (export and import share in total turnover or installed capacity, export/import destination, global expansion level with the number of foreign sales offices/subsidiaries/partnerships); 6) geographical management of value chain/system and production and innovation capacity/capability (locations of production and R&D facilities, geographical extension of backward and forward linkages and sub-supplier locations); and 7) sourcing strategy (choice of in-house sourcing, outsourcing, and mixed sourcing according to components/value activities)

Stage 3: Explore characteristics of competitive management strategy transformation in terms of: 1) industry stability (degree of change in the above strategies, change adjustment level, and level of diversification of each player); and 2) transformation of entry/business growth barriers and their characteristics (institutional and technical cost of building and keeping business, capital requirement for business entry, specialist knowledge/technical know-how and easiness of learning, existence of requirement by government, access to resources/technology/information, and cumulativeness of the above factors), and examine their relationships with required costs and management needs for technology development

Stage 4: Synthesize the above analyses and identify the role and effects of policy and institutional settings on industry structure, competitiveness management, and supply-push technology development and diffusion at the frontier

Task 3) Establish relationships between new turbine introduction and capacity (market) development in India quantitatively, utilizing time-series econometric analysis

Stage 1: Observe relationship between annually installed capacity as market indicator and new turbine introduction as technology transfer/diffusion indicator

Stage 2: Establish structural relationships between the two indicators by generating and testing possible time-series regression models

Task 4) Investigate the causal factors and processes behind the relationship between cross-border technology transfer and market development in India from the perspective of market development by utilizing both quantitative and qualitative analysis

Stage 1: Examine the Indian market characteristics based on: 1) market size and location and regional market-industry interaction; and 2) investment mechanism/ investor profile (funding sources, equity-debt ratio, investor characteristics, ownership structure and characteristics of wind projects)

Stage 2: Conduct quantitative analysis of the Indian wind energy investment and identify the causal factors of market development by the following methods: 1) econometric analysis of direct relationships between various policy incentive indicators (years of tax holiday, tax depreciation rate, interest rate of IREDA finance, import tariffs on raw materials/intermediate components/wind turbine complete sets, national average state feed-in tariffs, MNES wind budget as R&DD indicator) and market development (installed capacity); 2) profitability analysis by establishing the Indian wind energy cash flow models and calculating expected national average IRR and first-year tax saving between the 1992-93 year and the 2004-05 year; 3) econometric analysis of relationship between market development indicator (installed capacity) and profitability indicator (expected national average IRR); and 4) econometric analysis of relationship between market development indicator (installed capacity) and first-year tax saving

<u>Stage 3:</u> Conduct qualitative analysis of the causal factors of market development by following historical events, especially focusing on both national and state policy and institutional environments and market growth

<u>Stage 4:</u> Examine the interactions between market demands and technology development and transfer in India by comparing: 1) technology driving market demands (policy requirements, environmental and resource-related pressures, technical management demands, etc); and 2) technology development and transfer as a result of various market demands (model size in rated capacity, power control types, rotor speed operation types, generator types, drive mechanisms, blade materials, SCADA, etc).

<u>Stage 5:</u> Synthesize the above analyses and identify the role and effects of policy and institutional settings on market growth and demand-pull technology transfer

Task 5) Investigate the effects of changing technological characteristics and industry structure/competitiveness management at the frontier and India on cross-border technology transfer and the growth of technology gaps in India

<u>Stage 1:</u> Establish the data regarding the Indian industry formation and structural modification (manufacturer entry and exit and their foreign collaboration history)

<u>Stage 2:</u> Examine the effects of Indian policy as well as competitive strategy and industry modification at the frontier on the Indian industry by: 1) comparing industry structural modifications at the frontier and in India; 2) analyzing the direct role and effects of policy on the industry formation and structural modification in India; and 3) contrasting industry transformation with the structural break in capacity-turbine introduction relationship established in Task 4

<u>Stage 3:</u> Establish the data regarding technology transfer and development in India by manufacturer to: 1) examine the effects of technology control by technology providers (type of technology agreements/technology ownership) on the technology transfer results by comparing the two; and 2) investigate the strategic role of Indian partners/manufacturers in geographical capacity and capability management of their technology providers and sourcing by examining the export activities from the Indian side

<u>Stage 4:</u> Examine the effects of transformed technological characteristics at the frontier on the technology transfer results by investigating: 1) easiness of cross-border transfer according to technology system and components; and 2) cost change potentials by cross-border technology transfer

<u>Stage 5:</u> Analyze the effects of the Indian manufacturing incentives (import duty and exercise duty) on cost reduction and technological capability building by tracking their evolution and manufacturing capability building

Stage 6: Synthesize the above analyses and identify 1) the effects of technology and competitiveness management transformations at the frontier on technology development and diffusion in India; and 2) the role and effects of policy and institutional settings on supply-push technology transfer

Task 6) Explore appropriateness and suitability of the European technology to the Indian specific conditions and their effects on cross-border technology transfer

Stage 1: Establish the data regarding the Indian specific conditions (wind resources, electricity grid system and quality, and transportation infrastructure) and examine their difference from the frontier

Stage 2: Examine suitability of the frontier technology to the above Indian specific conditions and its effects on technology transfer by: 1) examining suitability and availability of the ready-available European technologies to the Indian conditions; 2) examining the R&D efforts for technology adjustment and development of the Indian-specific solutions; and 3) investigating the nature of infrastructure deficiency (transportation and electricity grid) and identify its effects on upgraded wind turbine introduction

Stage 3: Synthesize the above analyses and identify the role and effects of policy and institutional settings for technology adjustment and transfer

Task 7) Examine the effects of characteristics of different technology partnerships on the cross-border technology transfer. Establish detailed histories and profiles of six Indo-European partnerships (Vestas RRB Ltd., NEPC Micon Ltd., BHEL-Nordex, Pioneer Asia Group, Enercon India Ltd., and Suzlon Energy Group) and their technology transfer outcomes in product, project execution, and innovation technology through case study method

Task 8) Synthesize the findings of the analyses from Task 1 to Task 7, using value chain policy analysis and causal loop diagram analysis

Stage 1: Establish the frameworks of value chain policy analysis and causal loop diagrams

Stage 2: Conduct value chain policy analysis and construct causal loop diagrams on technology development and diffusion mechanisms of the frontier and India, and compare the causal loop structures between the frontier and India and evaluate the role and effects of policy measures in creating the mechanisms and their differences

2.2.6 Step 5: Application of General Theories on the Research Findings and Future Implication of the Research

The purposes of Step 5 are to summary the key research findings and draw some implications for the future. This step consists of Chapter 7.

Task 1) Review the key research findings according to the conceptual focus and theoretical and practical context of the research introduced in Chapter 1, which are: 1) the direct role and effects of government policy and institutional settings on technology development and diffusion; 2) the co-evolution of policy, market, industry and technology development mechanisms; 3) application of general theories of technological change on wind energy technology development; 4) application of general theories of international technology transfer on wind energy technology transfer case from Denmark/Germany to India; 5) the role and effects of industrial competitiveness management on technology transfer outcomes; 6) sector specific aspects of wind energy technology transfer; and 7) examination of enabling environments in the wind energy technology transfer case.

Task 2) Draw practical implications for the future climate change mitigation technology transfer based on the research findings, in terms of: 1) specific implications for the Indian wind energy sector; 2) the roles of government and firm in building enabling environments in light of intensifying competitiveness management; 3) the role of government for further business involvement; 4) potentials of the CDM for technology transfer; and 5) suggestions for future distributed power generation technology transfer.

Section 2.3: Rationale, Validity, and Reliability of Research

2.3.1 Methodological Rationale

While international technology transfer has been studied by numerous researchers, scholarly products that followed the long-term process of one climate change mitigation technology still remain limited. Most of the studies for climate change mitigation technology transfer have been the assemblage of short-term technology transfer case studies of different types of technologies. Because this research concerns not only the immediate needs of transfer of climate change mitigation technologies but also the long-term sustainable development prompted by the transfer of such technologies, the analysis of long-term processes and technology transfer outcomes is very important. The limited availability of scholarly products prompted this research to take in-depth case study approach, which also enabled this study to examine the role and effects of policy within the entire mechanisms of market, industry and technology development and interactions.

Case-study approach has been proven as an effective research method for investigating questions of 'how' and 'why' and when the researcher has no control over events and is not able to manipulate the relevant behaviors. However, there are also disadvantages. The most significant shortcoming is the indeterminacy of causal mechanisms. In order to overcome this disadvantage, this research took several measures. First, the research included a number of observations within the 15-year timeframe to analyze chronological change. Second, the research addressed comparability of cases by focusing on technologies in one field (wind energy sector) and on technology transfer from one strongly-tied geographical region (Denmark and Germany) to another (India). Lastly, process tracking procedure, which is a method to identify causal mechanisms by investigating the process of how various initial conditions cause the observed outcomes (George and McKeown 1985), was used in individual analysis.

2.3.2 Data Validity and Reliability

Used Variables

This research used variables that have been identified and accepted as effective market, industry, and technology indicators in the existing wind energy literatures, in order to improve the research validity. Multiple indicators were used to increase the comprehensiveness of the analysis, which is one of the important objectives of the research that aims to examine the relationships in the entire policy, market, industry, and technology development mechanisms.

Data Materials and Data Collection

In order to maximize the reliability of the research, a wide range of materials are used from both primary and secondary sources. Data were collected from both the first-hand interviews and documentation in the three countries and the second-hand data.

Primary Data Sources

The primary data collection mainly relied upon both policy documents and personal interviews in the three countries. Industry professionals as well as public sector actors including government officials, researchers at national laboratories and research organizations, and officials at professional and industry associations in the three countries were interviewed to gather necessary data. The first round of field research/data collection was conducted in summer 2002 in India. The second round of field research/data collection was carried out in November 2005 in Denmark and Germany. Then, the contacts made during the trip were followed up afterward for further data collection and verification.

One weakness of the primary data comes from the unavailability of personal contacts with the Danish and German wind turbine manufacturers, which denied interview access in order to protect their proprietary information. This weakness, therefore, was covered with the data attained from other industry insiders such as consultants and industry association officials as well as from the secondary sources.

Secondary Data Sources

There have been numerous literatures published regarding the Danish, German, and Indian wind energy sector developments as well as wind energy technology in general. The dissertation utilizes these journal articles, books, reports and analyses from international organizations, the governments, and other sources. In addition, all the three countries have detailed statistical data, gathered and published by the governments and industry associations as well as private wind energy consulting firms. In particular, the research makes the use of complied statistical as well as raw installation data from the Danish Wind Industry Association (DWIA), the Danish Energy Authority (DEA), Deutshce Wind Energie Institut (DEWI), Bundesverband Windenergie (BWE, German Wind Energy Association), BTM Consults ApS, and Consolidated Energy Consultants Ltd., all of which are considered authoritative as wind energy data materials.

Chapter 3:
Wind Energy Technology and Economics Profile

This chapter depicts basic characteristics of wind energy technology[9] and economics. The purpose of this chapter is to lay out general technical backgrounds for the analysis of the later chapters by illustrating specific attributes of wind energy technology and economics, because characteristics of technology are an important factor that influences the pattern and speed of development and diffusion of the technology.

Almost all contemporary industrial technologies are system technology that consists of various subsystem components. In a system technology, both system-wide and component-specific perspectives are important to understand the characteristics of technology, industry, and economics. The larger the system, the greater the roles of component producers, and the effective incorporations of better components into a system often require significant R&D work by system assemblers (Nelson and Rosenberg 1993). Complexity and extent of technology system has significant impacts on the extent and composition of value chain/system and business strategies to manage the value chain/system, industry structure and competition, and economics of innovation, production, and project execution.

The first section of this chapter describes the basics of wind energy technology system, focusing mainly on horizontal axis wind turbines and technologies that support their grid-connection, as they are the main focus of this research. The second section describes wind energy technology along value chain/system. The third section summaries the basics of wind power generation economics.

Section 3.1: Basics of Wind Energy Technology

3.1.1 Fundamentals of Wind Power Generation

Basic Physics

The basic concept of wind power is straightforward: converting wind's kinetic energy into mechanical-rotational energy of turbine blades, which is then converted to electrical energy by a generator (Figure 3-1).

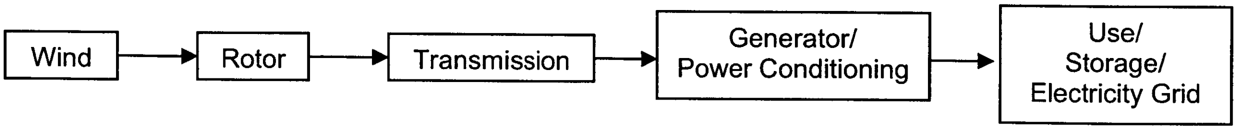

Figure 3-1: Block Diagram of Wind Energy System

Source: (Deutch and Lester 2004)

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[9] Although wind energy can generate mechanical power to pump water or to grind grain, this research only focuses on the technology used for electrical power generation. Therefore, the term "wind energy technology" used in this research is synonymous to wind electrical power generation technology.

Power is energy per unit time, and energy is power available over a given period of time. The power output of a wind turbine is estimated by the kinetic energy in a flow of air through a unit area of the blades perpendicular to the wind direction. The Power, P, delivered is given by:

$$\text{Power, } P = 1/2 \rho A V^3,$$

where ρ is the density of air (kg/m^3), A is the area swept by the rotor blades, V is the wind speed (m/s), and P is the power (watts or joules/second).[10]

The important point is that the amount of power produced by a wind turbine depends on both the speed of the wind and the size of turbine blades.[11] As a general characteristic, turbines with larger rotor generate more power at low wind speeds.

Rated Power of Wind Turbine

Performance of power generation technology is important because the economics depends on it. As an indicator of performance, turbine rating in kilo- or megawatts or rated power is usually used. Rated power is maximum continuous power output at the electrical connection point.[12]

3.1.2 Wind Energy Technology Basic Sub-systems and Components

While wind energy technology is fundamentally based on mechanical and electrical engineering, numerous other engineering and scientific disciplines are employed to compose contemporary wind energy technology system.

Power generation technology has both modular aspect (related to power generation aspect) and system aspect (related to grid-connection, transmission and distribution infrastructure), unless it is stand-alone. Although transmission and distribution (T&D) of electricity produced by wind is important parts of wind energy system technology, they concern the entire power industry and beyond the boundary of this research. This research focuses mainly on power generation and grid connection functions of wind energy technology, i.e., wind turbine technology.

Wind turbine consists of the following subsystems and components: rotor (rotor blades and hub); transmission system (gearbox and rotor braking); electrical power generation system (generator); yaw system; tower; control and monitoring system (controller); foundation; and transformer. Transmission system and electrical power generation system are contained within a nacelle (Figure 3-2).

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[10] The volume of air ΔV delivered in time period Δt is given by: $\Delta V = vA\Delta t$, where v is the incoming wind speed. The kinetic energy of a moving body is proportional to its mass. The kinetic energy in a parcel of air of unit volume traveling at speed $v = (\rho v^2/2)$. Thus, the kinetic energy delivered in time period $\Delta t = (\rho v^3/2)A\Delta t$. Therefore, the Power, $P = 1/2\rho AV^3$.

[11] The power P is proportional to V^3 and the area A swept by rotor blades, that is, $P \propto D^2$ where D is the rotor diameter.

[12] However, it is important to keep in mind that the ratings are only crude indicator of how much electricity the turbine can produce. Unlike conventional power plants such as fossil fuel and nuclear power plants, where the operator controls the fuels, wind turbines rarely operate for long periods at their rated power because the operator has no control over availability of fuel.

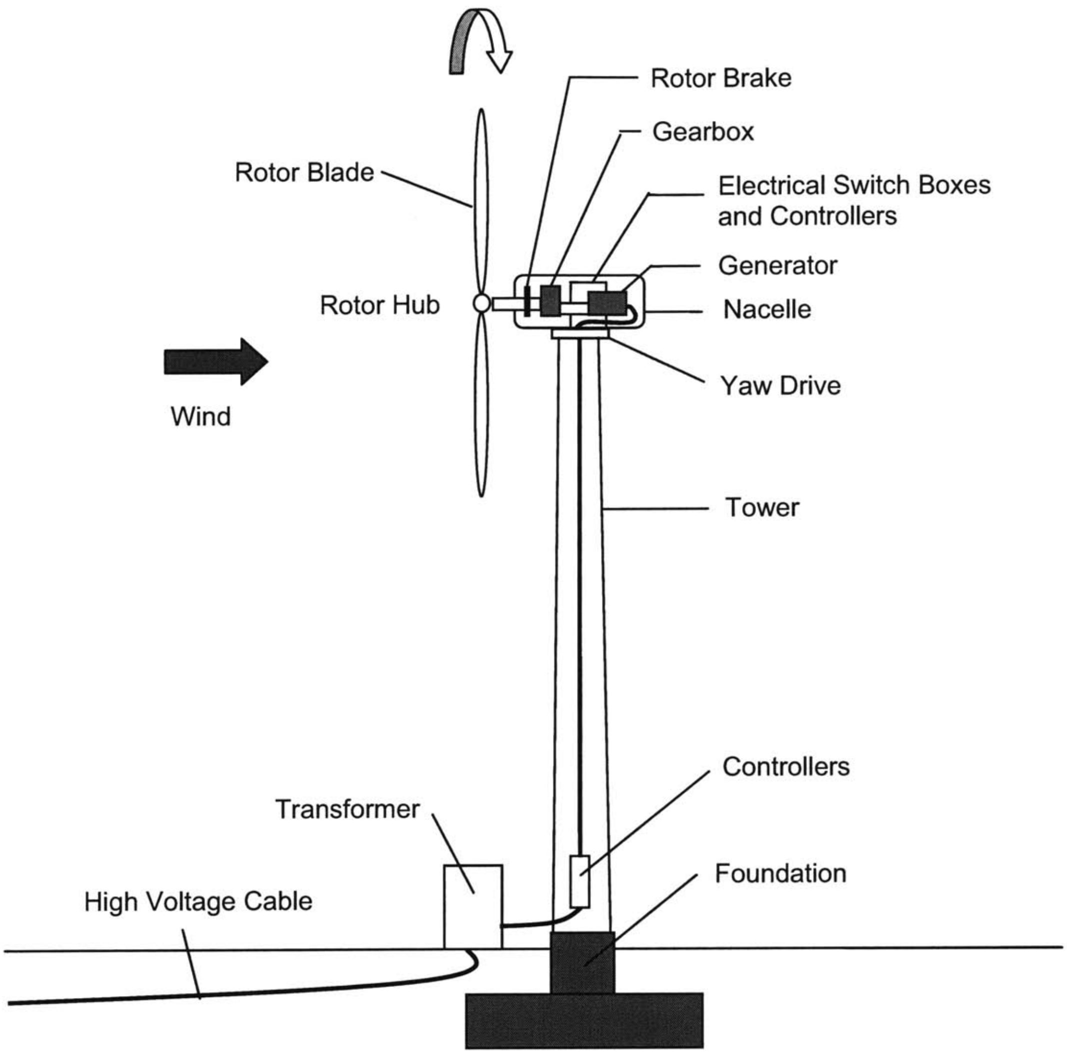

Figure 3-2: Cross-section of a Typical Grid-connected Horizontal Axis Wind Turbine
Drawn by the author based on (Redlinger, Dannemand Andersen, and Morthorst 2002; Walker and Jenkins 1997)

Rotor

Rotor continuously extracts kinetic energy from wind and transforms it into useful mechanical power in the rotor shaft. A rotor includes blades and a hub. The blades are attached to the hub, which connects them to the main shaft. Blade-pitch mechanisms (hydraulic, mechanical or electrical equipment to drive the pitch setting of the blades or emergency aerodynamics brakes) are often mounted in the hub. The number of design and engineering options available for rotor is quite large. In order to increase performance and productivity, a suitable concept in each of the following items is selected, considering wind characteristics and costs as well as their combination effects and trade-off:

- **Rotor Axis**: there are two options for wind turbine rotor axis; vertical and horizontal.[13]
- **Number of Rotor Blades**: Wind turbine rotor can be designed with one, two, or three blades.
- **Rotor Orientation**: Rotor orientation has two options; upwind or downwind. Rotors of upwind machines face wind and must have a yaw mechanism to do so.
- **Rotor Power Regulation**: Rotor power regulation systems limit and condition the rotor output power at high wind speeds aerodynamically in order to avoid very high drive train powers and torques. Without the control, these occasional high powers dominate the design and drive up the costs of turbine. Rotor power can be controlled by: blade pitch regulation, stall regulation, and active stall regulation.
- **Rotational Speed**: Wind turbines can be operated at fixed speeds or at variable speeds. The options are predominated by the electrical power generation system. While larger turbines with longer blades rotate slowly, small turbines with shorter blades have quicker rotations.
- **Rotor Blade Materials**: Blade materials can change rotor weight and rotor cost significantly.[14] Lighter and more flexible blades materials reduce blade loads, avoid strain, and reduce rotor weight and cost. Current choices[15] include: glass-fiber reinforced plastic, (GFRP); glass-fiber reinforced epoxy (GFRE); carbon-fiber reinforced plastic (CFRP); and wood epoxy.
- **Rotor Blade Profile/Configuration**: A typical structural architecture of wind turbine blades has spar cap that is a relatively thick laminate with primarily unidirectional fibers to carry the flap-wise bending loads. However, proportional relationships vary greatly and the number of design options available for blade profile is countless.

(Danish Wind Industry Association 2003; Redlinger, Dannemand Andersen, and Morthorst 2002)

Transmission System –Drivetrain, Gearbox, and Rotor Braking

Mechanical power generated by the rotor blades is transmitted to a generator through the rotor hub and by a transmission system placed in nacelle. The major components of transmission system are a gearbox, sometimes a clutch, and a braking system, and they are fixed inside nacelle that is mounted on the tower and can rotate or yaw according to wind direction.

The arrangement of shaft, gearbox, and generator, and other components of transmission and electrical systems within the nacelle is called mechanical drivetrain. Many different drivetrain layouts are developed by different manufacturers. The basic concept is divided into two:

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[13] The descriptions of technology in this research are about horizontal-axis upwind turbines, unless otherwise noted.

[14] Material parameters that influence these two factors are the specific strength (defined as the ratio of admissible tensile strength and density) and the specific manufacturing costs (the cost per kg of materials used). The weight of the rotor blade is inversely proportional to the specific strength, while the cost will be proportional to the quotient of the specific manufacturing cost factor and the specific strength (Harrison, Hau, and Snel. 2000).

[15] Wood, aluminum, steel have been used in the past. However, they all have problems as blade materials for medium- and large-sized wind turbines in terms of strength and cost, and no longer materials of choice.

- **Geared Drivetrain**: a gearbox is used to increase the speed of rotor from typically 20 to 50 revolutions per minute (rpm) to 1000 to 1500 rpm that is required for driving most types of generators.
- **Direct (Gearless) Drivetrain**: low speed generators are coupled directly to the rotor shaft, avoiding the need of a gearbox.

Mechanical barking system is fitted to the main transmission shaft in order to bring the rotor to rest in emergency and when not in operation. Fail safe mechanisms[16] are critical for safe operation of wind turbine. Aerodynamic braking systems are used as the primary braking system by all modern turbines, and mechanical brake systems are usually employed as the secondary system (Gipe 1995; Walker and Jenkins 1997).

Electrical Power Generation System – Generator

A generator is a coil of wire spinning in a magnetic field and converts the torque of spinning rotor into electricity. Generator of wind turbine converts mechanical power of the rotor transmitted by the transmission system into electrical power and transfers this to the power grid.

Non-rotating parts of generator are called the stator; the stator consists of a three-part winding on a laminated iron core, which produces a magnetic field rotating at a constant speed. The moving parts of generator are called the rotor. Wind turbines use two main classes of generators, induction and synchronous, and their differences come from the rotors while their stators are quite similar:

- **Induction Generators**: In induction generators, the rotor is not connected electrically. However, once placed in the middle of the stator, the rotor currents are induced by the relative motion of the rotor against the rotating magnetic field produced by the stator. Induction generators operate at a slightly higher frequency than the grid frequency, and the speed difference between the rotor and the rotating field created by the stator induces the rotor currents. They need to be connected to the power grid because starting them requires the stator to be magnetized from the grid at the grid frequency. Two types of induction generators have been used in wind turbines.

    - *Squirrel Cage Induction Generator (SCIG):* This type of induction generators uses so-called a squirrel cage rotor, which consists of aluminum ring at each end of the armature with a number of copper or aluminum bars connecting the rings running the length of the rotor.
    - *Wound Rotor Induction Generator (WRIG)*: An alternate design is to use a wound rotor, which is used for variable speed operation. Wound rotor has the same number of poles as the stator and the windings are made of wire, connected to slip rings on the shaft. The slip rings are connected by carbon brushes to an external controller such as a variable resistor that allows changing the motor's slip rate. Wound rotors are more expensive than squirrel cage rotors and require maintenance of slip rings and brushes.

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[16] Regulations of many countries require redundancy in the form of two independent systems.

- **Synchronous Generators**: In synchronous generators, the rotor has a so-called field winding. As direct current (DC) passes the rotor field winding, it magnetized the rotor and creates a constant magnetic field that locks into the stator rotating field and always rotates at a constant speed in synchronous with the stator field and the grid frequency. In other words, synchronous generators operate at exactly the same frequency with the power grid they are connected. Synchronous generators are connected to the grid indirectly through electronic device that adjust the rotor current to match the grid current. The sources of magnetic field determine the sub-categories of synchronous generators.

    - *Wound Rotor Synchronous Generator (WRSG)*: This type of synchronous generators uses electromagnets (poles) in the coil winding of wound rotor to create magnetic field. The rotor electromagnetic poles are fed by DC, which is fed by slip rings or other means on the rotor. Turbines convert alternate current (AC) of the power grid to DC before feeding it to the poles.
    - *Permanent Magnet Synchronous Generator (PMSG)*: This type of generators does do not require to be connected to the grid because they have a small permanent exciter connected to the rotor that produces the magnetic field for the stator.

(Danish Wind Industry Association 2003; Walker and Jenkins 1997)

Yaw System

Wind direction must be perpendicular to the swept rotor area during normal operation of turbines. A yaw system turns the nacelle of a horizontal-axis wind turbine to the actual wind direction, using a rotary actuator engaging on a gear ring at the top of the tower. A wind vane senses the relative wind direction and the wind turbine controller operates the yaw drives, which are controlled by a closed loop control system. Almost all horizontal axis turbines use active yawing, which is activated by an electronic controller that has a sensor to monitor wind direction (Danish Wind Industry Association 2003; Walker and Jenkins 1997).

Tower

Tower elevates the main components of wind turbine up into the air; it supports them and needs to withstand both gravity loads and wind loads. At minimum, tower of horizontal axis turbine needs to be high enough to keep the blade tip from touching the ground, but tower height is usually set much higher than the minimum because wind is usually stronger and less turbulent as elevation increases. The height is commonly one to one-and-a half the rotor diameter and it needs to be decided based on economic trade-off of increased energy capture and increased cost of materials, construction, and maintenance. Tower must be designed so that either its resonant frequencies do not coincide with induced frequencies for the rotor or they can be damped out.

The choices of construction materials of towers are limited to steel and concrete in practical terms. Steel is more common. Concrete tower is much heavier than steel tower. In terms of design, either lattice or tubular or cylindrical design is used. Lattice tower requires much less material and foundation costs than tubular towers, and more common in earlier machines. Tubular towers allow access from inside the tower to the nacelle during bad weather conditions (Danish Wind Industry Association 2003; Walker and Jenkins 1997).

Control and Monitoring System

A control system is required for contemporary wind turbine to monitor various parameters to ensure automatic and safe operation and protection of the turbine, control turbine behaviors, and enable communication between turbines and the operator. Electronic wind turbine controllers are used to control a large number of switches, hydraulic pumps, valves, and motors within the turbines. The main functions of the control system are as follows:

- **Supervisory Controllers of Individual Turbine**: Supervisory controllers perform functions such as sequencing control for start-up and shutdown, monitoring of wind and faults conditions, and providing inputs to the turbine dynamic controllers.
    - *Monitoring Controller*: Monitoring controller monitors or sets parameter values for the following items:
        - Checking rotational speeds of rotor/generators, and its voltage and current;
        - Registering lightening strikes and their charges; and
        - Measuring outside air temperature, oil temperature in the gearbox, temperatures in the electronic cabinets/of the generator windings/in the gearbox bearings, hydraulic pressure, pitch angle of each rotor blade, yaw angle, the number of power cable twists, wind direction, wind speed from the anemometer, size and frequency of vibrations in the nacelle and the rotor blades, thickness of the brake linings, and whether the tower door is open or closed (Danish Wind Industry Association 2003).
    - *Power Quality Controller:* This type of controller looks after power quality of the current generated by the turbine to ensure not to degrade power quality of local utility system:
        - *Soft-start Grid Connection*: a power semiconductor ensures gradual connection and disconnection of turbines to the grid to prevent sudden power surge from them to the grid; and
        - *Reactive Power Control*: A processor calculates the stability of grid frequency and active and reactive power of the turbine, and orders a dynamic component controller to switch on or off electrical capacitors to adjust reactive power (consumption of power from the grid to create a magnetic field inside induction generator at low loading stage) if necessary.

- **Dynamic Component Controllers within Each Turbine**: These controllers make continuous adjustment to turbine actuators and components according to the input provided by the supervisory controller. One dynamic controller manages only one specific system. Separate dynamic controllers perform functions such as slow closed-loop control of the yaw system, and fast closed-loop control of pitch mechanism for pitch regulated turbines.
- **Wind Farm Controller**: It coordinates and controls all turbines within a farm and communicates with the supervisory controllers of each turbine.
- **Communication Controllers**: They enable communication between turbines and their owner and/or operator outside, e.g., sending requests of services, through telephone or radio link. A PC unit in one turbine is used to communicate the rest of the turbines in a wind farm, and fiber optics communication units are usually used for internal communication between the controllers within a turbine.

(Danish Wind Industry Association 2003; McGowan and Connors 2000; Walker and Jenkins 1997)

Foundation

For onshore applications of wind turbines, the foundation is typically made of concrete poured into the ground and supports the tower that is bolted to it. The offshore wind turbines require specially engineered foundations according to economic and environmental requirements. The options are still developing, including: mono-piles, multi-piles (tripod), concrete gravity base, steel gravity base, mono-suction caisson, multiple suction caisson, and floating base (European Wind Energy Association 2003).

Transformer

Transformer steppes up low level voltage electricity output from wind turbines to high voltage electricity that fit to the grid level. A high voltage cable or overhead line feeds the transformed electricity to the main power grid (Danish Wind Industry Association 2003).

Section 3.2: Basics of Wind Energy Value Chain

The concept of value chain and value system (Porter 1985) is used as one of the analytical tools in this research. The research tries to expand the concept and modifies the original method to analyze policy and regulations as well as evolutionary relationship between development of technology and industry, utilizing the ability of value chain/system that easily captures the complex nature of policy, technology, and industry, as each value activity in the chain/ system embodies technology and knowledge that support the specific activity as well as the entire technology system and industry.

The original value chain analysis of sources of cost and technological competitive advantages as intended by Porter will be expanded to explain the evolutionary relationship between technological characteristics and industry competitiveness management; the research follows technological and managerial characteristics along value chain activities to reveal the evolution of technology holders and geographical and strategic management decisions made by firms in the industry, as value chain/system helps clarify different scientific and engineering disciplines involved in development and management of technology. Also, the method will be used to analyze various technology transfer decisions made by firms by illuminating the governance of specific value chain activities and division of labor that are shifting within the value chain (Memedovic 2004) and highlighting the nature and determinants of technological capabilities.

A new way of value chain analysis will be attempted for policy and regulation analysis; various policy instruments will be categorized along value chain/system in order to make policy targets and their resulting effects clear.

3.2.1 Functions of Wind Energy Project Value Chain

As all other industries, wind energy industry has specific value chain and system. Although where the boundary of the industry can be debatable, this research uses a broad boundary that includes sub-industries and activities of wind electricity generation and delivery. Figure 3-3 describes broad functions of wind energy project value chain in general.

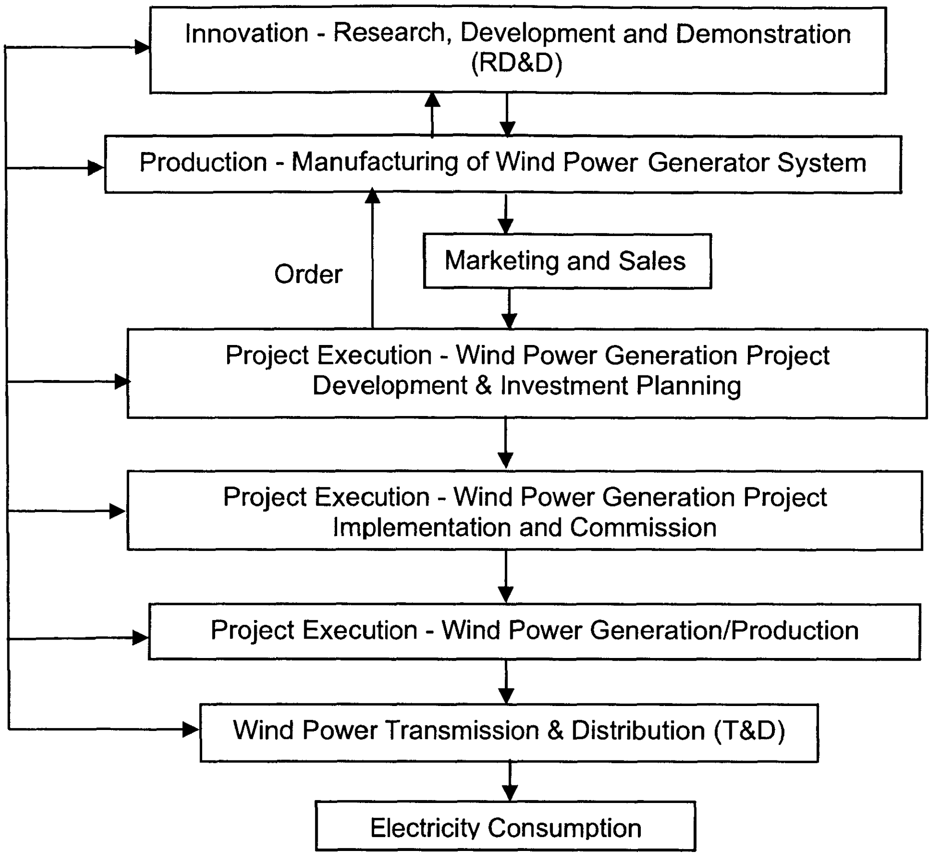

Figure 3-3: Wind Energy Project Value Chain (Broad Functions)

3.2.2 Value Activities in Each Function

The following identifies different value activities performed in each function:

- Innovation - Research, Development & Demonstration (RD&D):
  - Pure basic research[17]
  - Use-inspired basic research/purely applied research and development[18] for various components and systems
  - Product design and development
  - Demonstration

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[17] Stokes (1997) created a quadrant model of scientific research for the analysis of R&D. He defines pure basic research as basic research that is guided solely by the quest for understanding without thought of practical use, and named this group Bohr's quadrant. See (Stokes, 1997).

[18] On the other hand, use-inspired basic research as basic research seeks to extend the frontiers of understanding but is also inspired by consideration of use, and purely applied research and development is defined as research that is guided solely by applied goals without seeking a more general understanding of the phenomena of a scientific field. The former is named as Pasteur's quadrant and the latter Edison's quadrant by Stokes (1997).

- Production - Manufacturing of Wind Power Generation System (Wind Turbine):
    - Manufacturing of components:
        - rotor blades (materials science, aerodynamics, structural engineering)
        - nacelle (mechanical engineering, structural engineering)
        - drivetrain/gear/transmission (mechanical engineering)
        - generator (electrical engineering)
        - tower (materials science, structural engineering)
        - electronics control system (electronics, computer science and engineering)
        - software for power control/simulation/wind data analysis/grid management (computer science and engineering)
    - Assembly of the above components

- Marketing and Sales:

- Project Execution - Wind Power Generation Project Development & Investment Planning:
    - Pre-development (site selection):
        - data gathering (ownership and land lease agreement, search for potential investors, available policy incentives, geographical conditions, ground conditions, wind conditions, grid accessibility, infrastructure accessibility, opinions of planning authority and surrounding communities, commercially available turbine models)
    - Technical and economic risk analysis:
        - data analysis and evaluation
        - turbine selection and micrositing
        - project economic analysis (cost estimates, financial planning and analysis, and confirmation of economic viability)
        - legal check
    - Planning and project permission:
        - grid connection, infrastructure and cabling planning and confirmation
        - preparation of environmental impact report and other export reports
        - confirmation of power purchase agreement and delivery
        - specifications for tenders
        - contract with investors and insurers
        - application and attainment of planning permission

- Project Execution - Wind Power Generation Project Implementation and Commission:
    - Logistical coordination in turbine transportation
    - Infrastructure building
    - Civil works (ground works and foundations)

  - Turbine erection
  - Electrical works (grid connection)

- Project Execution - Electricity Generation:

  - Operation and maintenance
  - Repair services
  - Power control for T& D

- Electricity Transmission & Distribution (T&D):

  - Grid load management

- Electricity Consumption

Section 3.3: Basics of Wind Energy Economics

3.3.1 Wind Energy Cost

Cost of electricity generated from wind and the economics of wind energy are the functions of many factors. A wind project incurs the following three major costs.

- Wind Turbine Cost: cost of wind power generator equipment
- Installation Costs: costs for site preparation, foundations, grid connection, turbine erection and commissioning, and other miscellaneous costs (expenses for financing, planning and engineering, permission, and transport)
- O&M Costs: costs for regular operation/maintenance/repairs as well as insurance and management of wind farms

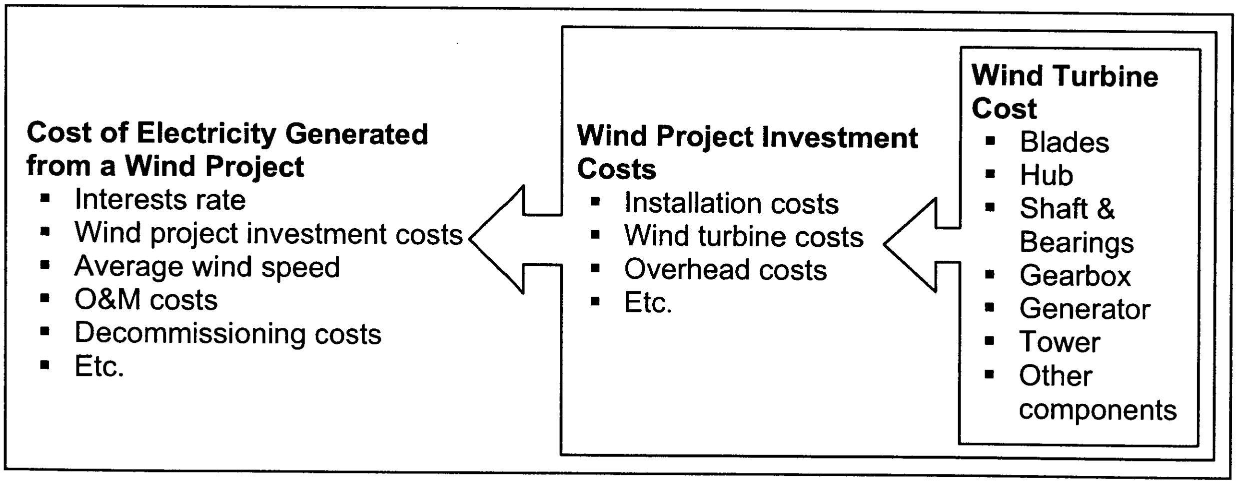

Figure 3-4: System Boundaries for Wind Energy Cost Economics
adapted from wind energy learning systems described
in (Junginger, Faaij, and Turkenburg 2005)

Figure 3-4 shows system boundaries of wind energy technology cost economics. Wind turbine costs are a subsystem of wind project investment costs, which are a subsystem of costs of electricity generated from a wind project.

3.3.2 Revenue from Electricity generated from a Wind Power Project

The following is typical revenue sources for private wind power projects:

- **Feed-in Electricity Tariffs (Purchase Price of Electricity):** the price paid by local utility for wind power delivered to the grid and the most important revenue source for the owner of the project.
- **Capacity Credit:** a certain amount per year paid to wind project owner as the project contributes to peak demands of a power system and it postpones the need to install other new generation capacities for the utility.
- **Environmental Credit or Premium:** an additional revenue source, sometimes given to wind energy either by the governments or utilities for the use of renewable energy on top of normal rates paid for electricity delivered to the grid.

The revenue can be reduced by:

- **Utility Charges:** charges posed by the utilities, e.g., charges for connection and maintenance and reactive power charge in case that the turbines cannot compensate the reactive power in accordance with the utility specification.

3.3.3 Project Finance and Investment Economics of Grid-connected Wind Power Generation

Project Finance and Debt Finance

Many public infrastructure projects and typical wind power projects use project financing method. Project finance is defined as an investment structure in which lenders look to cash flows from a project as the source of funds to service their loans and provide the return on their equity invested in the project. Lenders look to the assets of the project as the underlying security (collateral) for the loan. Typical financing structure of project finance is a mixture of debt and equity, but debt is the primary funding source. Equity commitments are used to attract debt. The method requires high degree of commitment from project sponsors, who must subordinate to lenders.

With project financing, it becomes easier for project owner or sponsor to finance the project with loans. Debt financing can make the project more profitable. Although Net Present Value (NPV) of the project remains the same, the investor puts less of his or her capital to the project and can realize a higher Internal Rate of Return (IRR). Also, it requires less time period to make the project profitable as the NPV of the project to turn positive in shorter time. Although the investor is exposed to greater risks by taking debt, most of wind power projects are financed with debt financing method.

Investment Economics

As any other power plant projects, a typical wind power project has three phases. Typical cash flow (different expenses and revenues occur in each phase) is as follows:

- Pre-construction: expenses for feasibility studies, planning, permits, specifications, and project development contract, e.g., contracts for input and output, financing;
- Construction: expenses for paying contractors and equipment providers, interest and dividends in case of delay; and
- Post-construction: revenue from the output, expenses for paying O&M, debt service, taxes, and depreciation

Typical system lifetime of wind power project is 20 years. As any other investment assessments, a wind power plant uses discounted cash flow analysis, which discounts all costs and revenues in the future to a fixed starting date (usually the beginning of the investment) to derive a single present value of the project, using an interests rate or discount rate. Figure 3-5 illustrates a typical wind project cash flow.

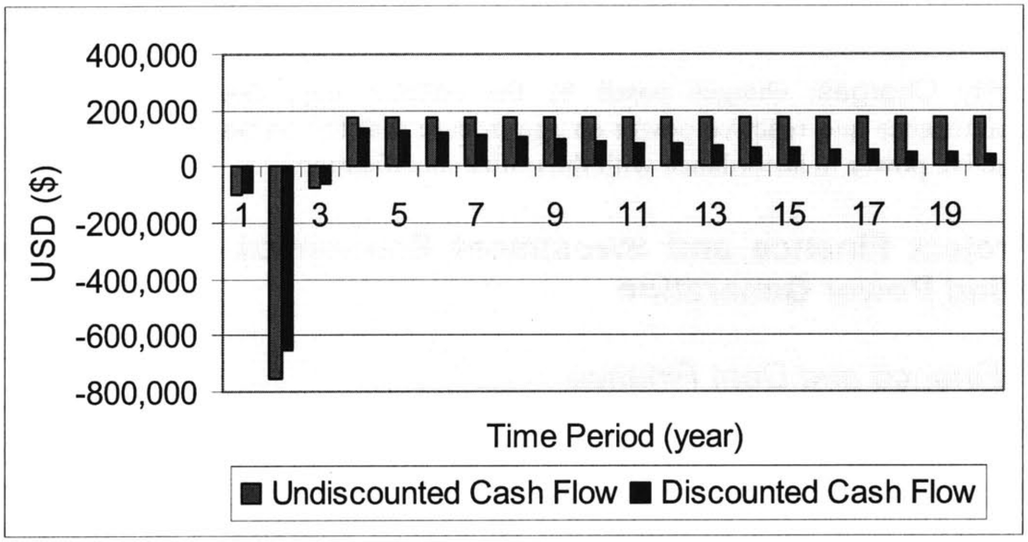

Figure 3-5: Undiscounted and Discounted Net Cash Flow for a typical Wind Power Project (1MW, r = 7%)

Sensitivity Factors of Project Investment Mechanism

Various sensitivity factors governing wind project investment economics can be divided into policy/institutional sensitivity factors and technology-related sensitivity factors.

Policy/Institutional Sensitivity Factors

The following sensitivity factors are related to policy and institutional settings.

- Revenue Sources: electricity tariffs, capacity credits, and environmental credits

- **Fiscal Measures**: measures that influence costs and revenue such as:
    - **capital subsidies**: reduced capital costs;
    - **tax credits**: increases the revenue flow; and
    - **tax depreciation schedule**: accelerated depreciation schedule that reduces costs
- **Cost of Financing**:
    - **discount or interests rate**: influenced by general trend of interest rate, financing term for the project, and risk perception
    - **project period**: different from technical lifetime, but still longer is favorable
- **Purchase Agreements**: longer agreement, along with secure transmission and market access, is favorable

Technology Related Sensitivity Factors

The following sensitivity factors are technology-related.

- **Investment Costs**: wind turbine cost and installation costs
- **O&M Costs**
- **Amount of Electricity Generated and Sold**: wind capture influenced by wind speed, location, hub height, micro-siting of turbines, and turbine configuration in the project
- **Technical System Lifetime**: longer system lifetime is favorable
- **Size Effects of Wind Project/Farm**: larger projects are favorable as transaction costs and O&M costs per unit can be spread and the efficiency of management increases due to economies of scale

Chapter 4:
Wind Energy Sector before 1990

Chapter 3 presented the basic profiles of wind energy technology and economics. This chapter examines the evolution of wind energy policy, market, industry, and technology before 1990 in the three research countries.

This chapter consists of three parts. The first section describes wind energy sector development in Denmark, Germany and India in general before 1990. The second section presents technology development during the 1970s and 1980s. The third section presents industry development before 1990.

Section 4.1: Wind Energy Sector in Denmark, Germany and India before 1990[19]

Wind energy is an ancient technology, which has been utilized for more than 3,000 years. For the most of its history, however, it was only used to provide mechanical power to pump water or mill grains. It was Charles Bruch, one of the founders of the American electrical industry, who developed the first automatically operating wind turbine for electricity generation during the winter of 1887-88. His turbine was 17m high and had a 12kW generator and 144 cedar-wood rotor blades. In 1891, a Dane named Poul la Cour discovered that fast-rotating wind turbines with a few rotor blades are more efficient for electricity generation than slow-moving wind turbines (Ackermann and Sober 2000; Danish Wind Industry Association 2003). The Danish engineers continuously improved the technology during World War I and II to overcome energy shortage. After World War II, however, the interests in large-scale electricity generation by wind declined despite the innovative designs by another Dane Johannes Juul in the 1950s and a German Ulrich Hütter in the early 1960s, because fossil-fuel fired electricity generation technologies could provide more consistent power than intermittent wind energy resources did. This situation began to change rapidly in the early 1970s.

4.1.1 The Energy Crisis, Opposition against Nuclear Power, and Environmental Concerns

It was the first Energy Crisis of 1973 that reinitiated the interests in wind energy as large-scale electricity generation resource; the government supports for wind energy technology became available in many countries. During the 1980s several national and international studies evoked the attentions to rapidly changing global climate for the first time. Local and regional environmental problems caused by conventional energy sources were mounting throughout all these years too. In some European countries, concerns over further nuclear energy development were growing as well, even before the 1986 nuclear reactor accident in Chernobyl. They all together pushed public opinions further toward renewable energy development.

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[19] This section only follows historical development of government supports and market development during the 1970s and 1980s. More detailed description of the government supports will be provided in Section 5.2.

Most of the supports during the 1970s and 1980s were oriented toward technology development through government sponsored R&D programs. Germany, Sweden, Canada, the United Kingdom, and the United States were among those which tried to develop large MW-class wind turbines. However, the most significant commercial technology development during the 1970s and 1980s emerged not from any of these countries but from Denmark.

4.1.2 Denmark

Denmark experienced a massive wave of industrialization from the end of the 1950s, particularly in construction, chemical, electronics and pharmaceutical industries as well as oil refineries and power stations. Besides local pollution problems caused by the rapid industrialization, energy was a big concern during the 1970s; electricity in Denmark was mainly generated by oil throughout this industrialization period, and the first oil shock of 1973 hit the country very hard as it did other industrialized countries. While the Danish power sector successfully reduced its oil consumption by 40% within two years of the first crisis by switching fuel to coal, it also explicitly expressed a strong desire to increase nuclear power generation in the future. This generated intense public debates regarding nuclear power generation.

Government Programs during the 1970s and 1980s

The government responded to the public debates for and against nuclear power generation by creating two scenarios for long-term future: one with nuclear power generation and the other for alternative energy future without nuclear. Ideas to push renewable energy, including wind energy, were developed under these circumstances: the environmental concerns on one hand and the reaction to nuclear power generation on the other. A comprehensive energy plan called the Alternative Energy Plan of 76 was published in 1976 with the main objectives to make Denmark less dependent on foreign oil.

The 1976 plan had several different support mechanisms for wind energy. The R&DD supports for large wind turbine development and demonstration started in 1976. In 1978, Wind Energy Department was created at the RISØ National Laboratory. The capital subsidy incentive was introduced to provide 30% of investment costs of wind turbine in 1979 and lasted until 1989. The wind turbine type approval scheme to issue a safety certification also began in 1979 to provide eligibility for the government capital subsidy and to protect buyers of wind turbines with strict safety regulations including the requirements for dual breaking systems.

During the late 1980s environmental concerns began increasing its importance again with the surge of regional acid rain controversy and global issues of sustainable development. The Danish energy policy began taking a very tight coupling with environmental policy, and taxes began gaining its importance in environmental policy. Electricity taxes on power generated by fossil fuel were introduced first in spring of 1986 for non-business sectors. Taxes on emissions from SO_2 and NOx were adopted in March 1989.

Grassroots Activities and Wind Cooperatives (Wind Guilds)

Strong grassroots activities and wind cooperatives (cooperative private owners of windmills, developed based on the concept of agricultural cooperatives) have played significant roles in the Danish wind development.

In 1975 it was not utilities or government researchers but a former carpenter Christian Riisager who succeeded in connecting a wind turbine to the utility power grid for the first time, although it was done without any utility permission. The success of the Riisager turbine connection to the grid triggered many business interests in wind. While he continued to build additional 50 turbines with 30kW capacity between 1976 and 1978 (Van Est 1999), the Organization for Renewable Energy established in 1975 began supplementing the formal government R&D programs with grassroots activities, which enabled many amateurs and professionals to meet each other and discuss ideas and experiences in construction of wind turbines. A network of Energy Offices was also set up, in order to disseminate the information and advice about how to use renewable energy systems across the country.

The growing interests in wind energy created a necessity of setting up the rules for grid connection, and this led to the Association of Danish Electric Utilities to publish its provisional guidelines and recommendation to buy surplus electricity production for the costs avoided by utilities in August 1976. However, the utilities did not pay wind turbine owners for the electricity they delivered to the grid, and this led to the establishment of the Danish Wind Turbine Owners Association (DWTOA) and the Danish Wind Turbine Manufacturers Association (DWTMA) in 1978; they worked together to bring this issue to political arena. By the end of 1979, the Ministry of Environment ordered the utilities to connect system-approved wind turbines to their grid and to pay fair rates for electricity fed into the grid in addition to 30% of grid connection costs. The Association of Danish Electric Utilities published new rules and accepted private projects by both individuals and cooperatively-owned wind turbines, but not the 30% grid connection cost payment.

Local Ownership Regulations and the First 100MW Agreement

The conflicts between the utilities and the wind energy supporters continued throughout the 1980s. Although the utilities accepted the grid connection term of wind turbines by the 1979 rules, they perceived private owners as self-suppliers and began forcing wind cooperatives to adjust their electricity production to their joint consumption. This resulted in the establishment of the so-called 3km rule, which required the member owners of cooperatives to live within 3km of the site. In 1984, this first ownership rule was modified after the five years of negotiations between DWTOA and the utilities; the utilities finally agreed: 1) to pay 35% of grid connection costs; 2) to replace the 3km rule with the demand that wind turbines should be sited within the supply area of the utility company that serves the turbine owners; 3) to place no limitation on maximum installed capacity; and 4) to purchase all surplus power from cooperative wind turbines at a rate of 85% of consumer price.

During the domestic market boom during 1984 and 1985, however, wind investments became profitable for institutions and local municipalities as well. The utilities complained this threatened the planning of electricity system, and negotiated with the government without involving DWTOA and DWTMA. In 1985, the negotiations resulted in another modification of the ownership rules, which required the owners to live within 10km of the project site and to limit the share of any individual owner to less than 6,000kWh per year or 135% of the person's electricity consumption. In return, however, the Ministry of Energy forced two utility companies Elsam and Elkraft to install 55MW and 45MW of wind power capacity, respectively, between 1986 and 1990, in order to secure a stable domestic market (the first 100MW agreement).

California Boom and Export

In November 1978 the United States Congress passed the Public Utility Regulatory Policies Act (PURPA), which aimed at decreasing the dependence on foreign oil by increasing domestic energy conservation and efficiency. By 1980 PURPA created a huge wind energy boom, especially in California, where both the federal and state energy and investment tax credits for renewable energy accumulated close to 50%. This California boom had tremendous impacts on the Danish wind turbine technology and industry development.

In the early 1980s the Danish wind turbine industry was searching for ways to increase its turnover. Their eyes were caught by the growing market in California. The export immediately took off with the delivery of some 40 wind turbines by the end of 1982. Between 1984 and 1987, the Danish wind turbine exports to oversea exceeded the delivery to the domestic market (Table 4-1). Most of them went to California. The Danish models were popular, simply because they were more reliable than the American counterparts. About 1,600 turbines were sold in California in 1984, and the profit rate in the United States was twice as much as that in Denmark. The peak came in 1985, when the export of almost 3,500 wind turbines created an export value of more than DKK two billion (Van Est 1999).

However, this boom did not last long. At the end of 1985 the California tax credits were expired. Around the same time, oil prices in the United States plummeted and the competitiveness of wind energy was diminished. The California market crashed. Although the US demand was not completely wiped out, the number of exported turbines from Denmark was reduced by almost a half and the dollar exchange rate also fell. Seven turbine manufacturers filed bankruptcy between 1986 and 1989 as a result. One of the lessons of this crash was the importance of diversification of market, which led to the market expansion of the Danish manufacturers to other countries from the 1990s.

Table 4-1: Danish Manufacturer Sales in MW 1983-1989

	1983	1984	1985	1986	1987	1988	1989
Domestic Market	20.6	7.2	23.1	31.7	33.0	82.0	65.7
Oversea Market	20.0	110.0	220.0	180.0	55.0	20.0	70.0
Total	40.6	117.2	243.1	211.7	88.0	102.0	135.7
The statistics do not include component kits with a value below 1/3 of the value of a complete wind turbine.							

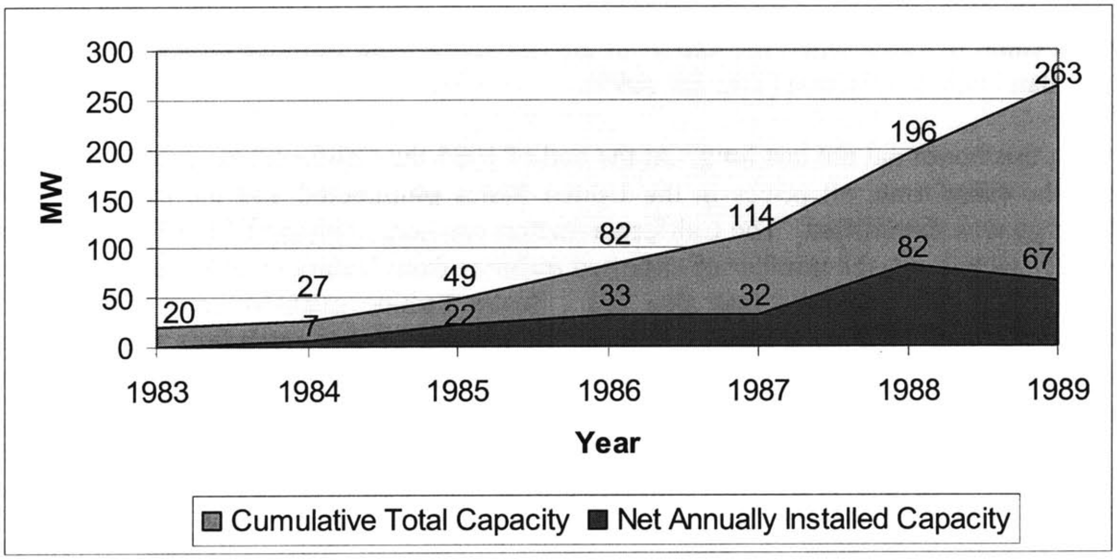
Source: (Danish Wind Industry Association 2006)

Export Support

Although there were no direct export policy, Denmark initiated several schemes that resulted in supporting the export of Danish turbines during the mid 1980s. One was a policy that the Danish investors in the US wind projects could receive tax benefits, which the Danish government started in 1986 and lasted until 1989. A Danish firm TIFCO helped the tax arrangement for the Danish investors. This policy contributed to the continuous export to the United States after the California market crash. Around the same time, the Wind Turbine Guarantee Company was set up to guarantee long-term financing of large export projects (Madsen 2005; Van Est 1999). In addition, the Danish International Development Assistance (DANIDA) began supporting wind demonstration projects in developing countries, resulting in the export of Danish products and technologies to those countries.

Danish Market and Export during the 1980s

With several strong demand-pull government incentives and the grassroots support for wind energy development, Denmark successfully established the wind market early on. At the same time, the California boom created strong export demand that helped the Danish industry expand. Table 4-1 and Figure 4-1 show that annually installed capacity within the country match domestic sales by the Danish manufacturers; the domestic manufacturers had 100% of domestic market share and this has never changed until this day.



Source: (Danish Wind Industry Association 2006)

Figure 4-1: Wind Energy Installed Capacity in Denmark in MW 1983-1989

4.1.3 Germany

The first Energy Crises of 1973 led to refocus on renewable energy in Germany, as it did in Denmark and many other countries. At first, the country emphasized on hard coal and nuclear development to avoid the dependence on foreign oil. However, nuclear power became rapidly controversial with the public by the end of the decade, as the similar situation happened in Denmark. In 1981, the Federal Ministry of Research and Technology (BMFT) commissioned a five-year study about the energy future of the country, which was published in 1986, around the Chernobyl accident. The conclusion was that the only choice that would be compatible with the basic value of a free society was renewables and energy efficiency (Meyer-Abich and Schefold, 1986, cited in Jacobsson and Lauber 2006).

Federal Program for Energy Research and Development

The Federal R&D program for renewable energy started in 1974. As for wind energy, a large amount of spending went to development of large MW-class turbines. The most notable project was the Growian project.[20] At the same time, the German R&D funding was large enough to fund most projects applied for: about 46 R&D projects and as many as 19 industrial firms and a range of academic organizations were granted the funding for testing or development of small- to medium-capacity turbines between 1977 and 1991 (Windheim, 2000b, cited in Johnson and Jacobsson 2000).

Demonstration Programs and Development of Small Market

During the 1980s the R&D program began including demonstration projects, which were subsidized by several programs (Hemmelskamp, 1998, cited in Jacobsson and Lauber 2006). At least 14 German turbine manufacturers received the funding for demonstration of 124 turbines[21] between 1983 and 1991 (Windheim, 2000, cited in Jacobsson and Lauber 2006). These government-led demonstration programs created small but very important domestic market in Germany during the 1980s. Despite the niche market created by environmentally concerned farmers and green demands from some utilities, however, total installed capacity in Germany by the end of 1989 was just under 20MW (Schult and Barger, 2000, Tacke, 2000, Reeker, 1999, Durstewitz, 2000, all cited in Jacobsson and Lauber 2006).

Table 4-2: German Market between 1982 and 1989 (capacity in MW)

	1982	1983	1984	1985	1986	1987	1988	1989
# of New Turbines	1	1	4	12	15	44	61	87
Accumulated # of Turbines	1	2	6	18	33	77	138	225
Newly Installed Capacity	0.02	0.06	0.10	0.24	0.52	1.94	4.99	11.8
Accumulated Installed Capacity	0.02	0.08	0.18	0.42	0.94	2.88	7.87	19.67

Source: (Durstewitz, 2000, cited in Johnson and Jacobsson 2000)

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[20] See the description under *German Attempts* in the part 4.1.5.

[21] Jacobsson and Lauber (2006) notes Hemmelskamp (1998) mentioned the number was 214 turbines.

4.1.4 India

India also began taking renewable energy seriously during the 1970s. The Ministry of Agricultural and Rural Development began administering biogas and cook stove programs, while the Department of Science and Technology started overseeing implementation of solar and wind programs.

Department of Non-conventional Energy Sources (DNES)

More focused and intensive programs on renewable energy started with the formation of the Department of Non-conventional Energy Sources (DNES) in 1982, which concentrated on coordination, development and promotion of a wide range of renewable energy programs and technologies.[22] For wind energy sector, the main focus of DNES was the development of large-scale government-own demonstration projects and the wind resource assessment program.

Demonstration Project and International Collaborations

The program for wind farm demonstration started in 1985 by DNES. In 1982, a separate provision and a technical committee were created for wind energy R&D within DNES. However, in order to start large-scale demonstration projects, DNES needed helps from foreign technology providers. The limited liberalization in industrial policy happened during the 1980s,[23] which began allowing the import of state-of-art foreign technology that was not available indigenously, helped technology collaborations from abroad.

In December 1986 DNES requested DANIDA to help DNES, the Tamil Nadu Electricity Board (TNEB) and the Gujarat Energy Development Agency (GEDA) to develop three demonstration wind farms with total capacity of 20MW. The purpose of the collaboration was to build up the capacity of utilities to integrate wind power projects into their grid system. One year later, after DANIDA created the appraisal for the projects, the Danish assistance retained an experienced Danish wind energy consulting firm (T. Bak-Jensen/PA Consulting Group) to plan, design, and oversee the implementation of three wind farms and contracted with two well-established Danish wind turbine manufacturers (Micon and Vestas) to supply and install wind turbines. All three Danish firms were required to work closely with local partners to develop indigenous technical capability and share responsibilities. While all turbine components and 90% of towers were imported from Denmark and the Indian partners assembled them on site, the Danish firms not only instructed construction and replacement of wind turbines and central monitoring systems but also offered training in planning, implementation, operation, and maintenance. The

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[22] DNES was then located within the Ministry of Energy, and was hierarchically organized by specific technology. Every division looked after one technology such as solar PV, wind, or improved cook stoves, which were promoted through design and development support and through the establishment of large-scale demonstration programs.

[23] Before 1991, the Indian business was heavily regulated, and the industrial licensing, the complex import licensing procedures, and the high tariffs severely restricted foreign investment and created inefficiencies in many sectors. India suffered from a lack of technological progress, the excessive governmental spending on largely inefficient public companies and the extreme bureaucratic control. Prompted by this situation, the Government of India (GOI) began a liberalization process during the 1980s to attract foreign equity capital, however, on the very limited bases. The government considered foreign investments on a case-by-case basis and placed a ceiling of 40% of total equity investment on the amount of control that a foreign interest could have in a project. Imported technology was allowed only if it was state-of-art and not available indigenously (Bath, 1998).

reminders of towers were manufactured in India (Kozloff 1995). This collaboration eventually produced two joint venture firms in India, NEPC-Micon and Vestas RRB in 1987.

Meanwhile, DNES also began exploring a possibility to develop fully indigenous wind turbines; it assigned the state-own enterprise, Bharat Heavy Electricals Ltd. (BHEL) for the R&D project. This project successfully produced 20kW and 50kW models, which had reasonably good domestic market in demonstration projects. By 1992 the BHEL R&D division developed 200kW models (BHEL 2002).

These early demonstration projects by the governments were the only market available in India throughout the 1980s. However, they prompted building the initial manufacturing base with help from foreign technology collaborators and supported the governments and the infant industry to understand important technical and project execution issues (TERI 2001).

National Wind Resource Assessment Program

Another important programs initiated by DNES during the 1980s was the National Wind Resource Assessment Program started in 1983. The network of meteorological laboratories gathered information and analyzed data on wind availability. The first Wind Energy Data book was published in 1983[24] (Consolidated Energy Consultants Ltd. 2002).

Section 4.2: Technology Development before 1990

Wind energy technology development during the 1970s and 1980s took two very different paths: one was radical innovation approach taken by many developed countries to build large-capacity turbines under massive government R&D programs; and the other was incremental innovation approach taken by the Danes with their grassroots and craftsmanship tradition that gradually upgraded small-capacity turbine technologies.

4.2.1. Large Turbine Development under Government R&D Programs

The majority of the government supports for wind energy started after the first Energy Crisis of 1973 was financial supports for R&D. Countries such as Germany, the Netherlands, the United Kingdom, and Sweden, Canada, and the United States took this approach, aiming to develop MW-class wind turbines. In Germany and the United States alone, between 1975 and 1988, total R&D expenditure for wind reached USD 103.3 million and USD 427.4 million, respectively (Heymann 1998). At the end, however, all the prototype turbines developed under these government R&D programs did not perform well, became extremely expensive, and hence did not succeed commercially.

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[24] This data served as preliminary date source of the early initiatives in India during the Seventh Five Year Plan (1985-1990). See (MNES. 1997a).

United States Modification (MOD) Program

In the United States, the development of MW-class turbines was managed by the National Aeronautics and Space Administration (NASA) and coordinated by the NASA Lewis Research Center, which hired subcontractors, mainly large companies in the aerospace industry such as Boeing, McDonnell Douglas, Lockheed, Grumman Aerospace, General Electric (GE) Space Division, Kaman, and Westinghouse. During the mid 1970s, those subcontractors started to develop large-capacity turbines under the NASA modification (MOD) program.

MOD supported the development of five turbines: MOD-0 (100kW, field test 1975-78, 450 operations hours), MOD-0A (200kW, field test 1977-82, 13,045 operation hours), MOD-1 (2MW, field test 1979-83), MOD-2 (2.5MW, field test 1982-88, 8,658 operation hours), and MOD-5B (3.2MW, field test 1987-92, 20,561 operation hours). Despite the intensive efforts of the top aerospace companies, all of them failed with severe problems and short operation hours. Although MOD-5B lasted more than 20,000 hours of operation, it was shut down due to chronic malfunction and poor economic performance (Gipe 1995; Heymann 1998). The US R&D program during the 1970s and 1980s produced no commercial outcome of large-capacity turbines.

German Attempts

The German R&D program also focused on the development of large-capacity turbines. The program was mainly shaped by Ulrich Hütter who successfully developed two-bladed 100kW turbine in the early 1960s. BMFT sponsored the construction of the world largest wind turbine, Growian, which had 3MW capacity with 100m rotor diameter and 100m tower height. Although the construction took four years from 1979 to 1983, the turbine failed with severe fatigue problems, faulty bearing and brakes, and frost damage from the beginning. After only 420 hours of operation in four years, it was dismantled in 1988 (Heymann 1998).

The second German project was to build one-bladed 10MW Growian II turbine through the funding from the European Community and BMFT. After an aviation and aircraft company Messerschmidt-Bölkow-Blohm (MBB) spent more than ten years for the development, the firm could only develop economically unprofitable 640kW models, production of which was stopped in the early 1990s. A machinery company Voith also developed a 270kW model, which also failed with severe stability problems. The German R&D program too left very little commercial impact, and the major German companies in the government-sponsored R&D program left wind turbine development business by the early 1990s (Heymann 1998).

Danish Wind Power Program

The first large-scale wind power R&D program by the Danish government was the restoration of the Gedser turbine built by Johannes Juul in 1956 and put it into test operation from 1977 to 1979. With the Gedser's positive test operation results, a Danish utility Elsam constructed two 630kW turbines, one with stall regulation and another with pitch regulation in order to compare one with the other. These so-called Nibe twins were three-bladed, upwind turbines with 40m rotor diameter. Nibe B with pitch regulation outperformed Nibe A with stall regulation in more than 18,000-hour test operation by the fall of 1988. However, both the turbines never performed better than much smaller commercially manufactured turbines throughout their operation period.

During the 1980s the Danish wind R&D program continued to develop large-capacity turbines. Although the Danish attempts aimed much smaller-capacity turbines compared to the US and German programs, they also suffer numerous malfunctions and did not produce commercially successful turbines at the end.

4.2.2 Danish Innovations and Successful Commercialization

While all the government-sponsored R&D programs took strong top-down, radical approaches for development of wind turbines, the Danes were simultaneously taking another very different approach. The most successful Danish innovations and commercialization happened independent of the government program; the Danish grassroots tradition and craftsman approach were the driving force behind the successfully technology development and commercialization, whichcurrent wind turbines are based on.

Danish Classical Concept

While many wind turbines design concepts developed under the government-sponsored R&D programs in various countries failed, Danish designers succeeded to develop commercially viable turbines by combining certain types of components and design concepts, which is called the "Danish Classical Concept." The name is applied to wind turbines with the following technical features:

- three-bladed upwind rotor;
- stall power control regulation;
- constant (fixed) rotor speed;
- induction AC generator, coupled directly to the grid; and
- two independent, fail-safe brake systems

The 200kW turbine developed by Johannes Juul in 1956 in Gedser was the first wind turbine to combine three of the Danish concept (three-bladed upwind rotor, induction AC generator with direct grid connection, and stall regulation) (Danish Wind Industry Association 2003). Electromechanical yawing was also first used in this turbine. Between 1956 and 1967 the Gedser turbine generated about 2.2 million kWh of electricity (Ackermann and Sober 2000) and became the model of present wind turbines.

During the 1970s Danish technicians began incorporating many other engineering methods and components used in later commercial turbines. Smaller versions of the Gedser turbines, rated from 5kW to 11kW developed by amateur technicians, began using hydraulics for transmission systems. The 1975 Riisager turbine with 22kW capacity, which was also based on the Gedser model, used glassfiber blade. The HVK turbine developed in 1979 incorporated the blades with cantilever glassfiber arms reinforced with revolving tip brakes and galvanized steel towers that replaced galvanized lattice tower (NEG Micon 2002). Thus, the Danes gradually developed prototype technology of current wind turbines during the 1970s. By 1979, all principle Danish wind turbine manufacturers were using the "Danish Classical Concept."

Turbine Upscaling

Although Danish designers also tested other concepts, they kept using the Classical Concept due to its simplicity and reliability. Soon they began focusing on turbine upscaling in order to increase energy capture and efficiency. The target of turbine upscaling was to develop larger and more economically efficient turbines due to decreasing number of sites with good wind resources in California and a pursuit of economies of scale in installation and O&M costs in general (Van Est 1999).

The largest capacity of commercialized Danish turbines was around 20-30kW in the late 1970s. This, however, quickly changed. In 1978 55kW turbines was developed by Vestas (Vestas V16/15-55kW) and Windmatic (VVM715-S). They were the new generation of wind turbines, and other Danish manufacturers such as Bonus, Micon, and Nordtank, also promptly commercialized 55kW-class turbines. Series productions of these 55kW turbines started in 1980 and 1981. Together with the development of the European Wind Atlas Methods by the RISØ National Laboratory, they succeeded in reducing cost per kWh around 50% (Danish Wind Industry Association 2003).

The Danish turbines were continuously upscaled during the 1980s; turbine rating increased from 55kW to 65kW, 75kW, 95kW, 100kW, 120kW, 150kW, 225kW, 250kW, 400kW, 450kW, to 500kW. The installation record in Denmark shows the following introduction of turbines: 65kW turbines (Nordtank 85-208) in 1981; 75kW turbines (Vestas V17-75) in 1982; 90kW turbines (Vestas V19-90) and 95kW turbines (Bonus 95kW) in 1984; 150kW turbines (Bonus 150kW) in 1985; 130kW turbines (Nordtank NTK-99/130, Vind-syssel VS-130) and 250kW turbines (Micon M530-250/50) in 1986; 160kW turbines (Wind World W2320), 200kW turbines (Dencon 200/50, Vestas V25-200), 225kW turbines (Nordtank N27/250), and 250kW turbines (Micon M250) in 1987; 300kW turbines (Nordtank NTK300) and 400kW turbines (Windane 34) in 1988; and 450kW turbines (Bonus 450kW) in 1989 (interpolated from Danish Energy Authority 2006). Table 4-3 shows that the average rating sold by the Danish manufacturers increased six-fold between 1983 and 1989.

The Danish turbine upscaling was also evident in the US market. The Bonus installation record shows that the firm began installing its 65kW turbines in 1982, 120kW turbines in 1985 and 150kW turbines in 1987 in the United States (Bonus Energy A/S 2004a).

The extent of turbine upscaling was greater during the late 1980s than during the early and mid 1980s, despite the collapse of the California market in 1986. The tax benefits to the Danish investors to the US wind projects between 1986 and 1989 supported the Danish manufacturers to push turbine upscaling for the US market to the level which had never been seen before (Madsen 2005). The upscaling demand also emerged in the home market. After the first 100MW agreement was formed in 1985, the utilities demanded the manufacturers to develop larger and more cost effective wind turbines to fulfill the agreement within five years.

Table 4-3: Average Turbine Size sold by Danish Manufacturers in kW 1983-1989

	1983	1984	1985	1986	1987	1988	1989
Domestic Market	22	57	71	89	106	179	140
Oversea Market	56	70	63	95	121	143	246
Total	31	69	64	94	115	171	180

Source: (Danish Wind Industry Association 2006)

Major Danish Innovations and Commercialization

Electronics Main Processing Unit Controller

Main processing unit of wind turbine checks the power output of turbine and if it became too high, the controller sends an order to pitch rotor blades slightly out of the wind. It is done by electronics.

Electronics controller was already used in many industries in the 1980s. Using electronics to control mechanical components, however, was a new idea. The Danish wind turbine manufacturers were the first to use electronics for mechanical controlling purpose. Computer chips and other necessary electronics components were readily available in Denmark, as the country had all manufacturers of those components. By the mid to late 1980s, all the Danish manufacturers were using micro-processor and integrated circuits for turbine control. It was very high-tech technology at the time, but technology development was not driven by the wind turbine industry which was just clever enough to use it for wind turbines. Vestas was the first company to export the machines with main processing unit to the United States (Madsen 2005).

Drivetrain

Drivetrain also advanced during the 1980s. The Danish manufacturers developed a metal frame or bed plat, to which they mounted the main shaft, transmission, generator and other components, rather than integrating the drivetrain. The Danes chose modular drivetrain, instead of integrated ones, in order to allow the components to be replaced readily without the removal of rotor. Nacelle became enclosed during the 1980s in order to reduce noise too (Gipe 1995).

Turbine Safety and Reliability

During the 1970s and 1980s, the safety and reliability of wind turbines increased greatly. The important contributing factors were the demands and requirements for dual breaking systems made by DWTOA and by the safety regulations under the Danish type approval scheme. As a result, aerodynamic methods became used to limit rotor speed when the brake failed (Gipe 1995).

SCADA (Supervisory, Control and Data Acquisition) Technology

SCADA (Supervisory, Control and Data Acquisition) system is a monitoring system that allows a remote operator to log in and control wind turbines and wind farm with great precision. SCADA is a Danish innovation; its development was forced by the Danish utilities who became the buyers of wind turbines as a result of the 100MW agreement in 1985. In return to accept the agreement, the utilities demanded the wind industry to develop wind turbines that can talk to their grid system. As a result, the SCADA protocol was developed by the collaboration of all industry players (Madsen 2005).

SCADA manages overall transmission of information between wind turbines and the grid system. Parameters include: energy yield, faults, component temperatures, wind speeds and directions, and detailed log of all maintenance tasks and spare parts. Each Danish manufacturer has developed its own, unique SCADA system based on the protocol. However, the protocol made all information exchangeable from one company's SCADA to another company's SCADA. The system is used now worldwide and has greatly advanced since its innovation.

Wind Power Meteorology - European Wind Atlas and WAsP (Wind Atlas Analysis and Application Program) Model

Early on, the Danes also realized the importance of precise wind resource estimation data for wind turbine siting and for increasing energy capture through more accurate estimation.

From 1976 the RISØ National Laboratory began creating wind atlas of Denmark, then Europe. The efforts resulted in the European Wind Atlas. In order to create the atlas, RISØ developed a topographical wind flow model called Wind Atlas Analysis and Application Program (WAsP) in 1987. WAsP is a model of wind flow over topography and roughness change. WAsP was used for the Atlas development to remove local roughness and topographic effects from measurements in order to make them representative of the broader background wind resource (Windlab Systems 2005).

Project Execution Technology - WindPRO

Another important innovation by the Danes was the development of wind power project execution software WindPRO, used for project design and planning of wind turbines and wind farms. The first main frame tools for wind energy calculations and wind turbine construction were developed in 1986. Since then, the software has been continuously updated and has been used worldwide.

The development of WindPRO was rather accidental; it was not targeted to help the wind energy industry originally. The project was initiated by the Danish Ministry of Communication, which wanted to market communication resources. This was before the Internet era, and the Ministry was the only organization in Denmark in the 1980s to permit communication rights. The Ministry first formed several different industry groups and gathered consultants, utilities, manufacturers and research institutions and universities, which can work on the communication project. Within these groups, the wind energy sector was selected to test the communication system project by coincident. The Ministry of Communication was running the project first, and the period between 1980 and 1983 was the trial phase. After this period was over, the Ministry found the project has been successful and wanted to continue. Per Nielsen was selected to continue the project, as he had the knowledge in both wind power technology and data communication skills at the same time. The project was classified as a university research project for two years between 1984 and 1985. In 1986 an independent institution Energi-og-Miljødata (EMD) was founded and the project became commercial, but it has received public funding during the first years[25] (Nielsen 2005).

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[25] A proposal was made during the year 1986 for the system. Then a three-year funding was granted for the proposal in 1987 and became four-person projects. Since then, it has gradually converted into commercial activities (Nielsen, 2005).

The first main frame tools for wind energy calculations and wind turbine construction developed in 1986 included Basis, Atlas (wind atlas calculation), Park (wind farm energy calculation) and Decibel (noise calculation). Noise calculation was important from the very beginning and the module came even before the first noise regulation in 1991 in Denmark. These first modules were closely followed by the incorporation of the WAsP module. In 1988, the Basis, Atlas, Park, Decibel and WAsP became the DOS version for the first time (Nielsen 2005).

Other Commercial Technology Developments Incorporated into Danish Turbines

There were many other important technological innovations during the 1970s and 1980s. Although the following technologies were not necessary innovated first by the Danish designers and engineers, they were successfully incorporated by the Danes into their commercial turbines.

Blade Materials – Composite and Fiberglass

During the early 1980s many issues concerning blade materials were investigated. On the course of events, steel and aluminum were rejected as rotor blade material due to heavy self-weight and uncertain fatigue endurance, respectively. As any blades made of a single material turned out to be inadequate, "composite" became a key word for blade materials construction. Among several materials choice, it was glass fiber reinforced plastic (GFRP) construction that became commercially dominant during the 1980s. GFRP consists of glass fibers and polyester resin. Although it was very labor intensive technology, GFRP is strong and relatively inexpensive and suitable for variety of design and manufacturing processes while having good fatigue strength. The material has originally evolved from boat building and became the industry standard as most Danish turbines during the 1980s had become using it.

Full-span Pitch Regulation

Pitch regulation method captures energy more effectively than stall regulation does. Full-scale pitch regulation uses the blades to regulate the power delivered by the rotor by pitching them to reduce the lifting forces generated by blade aerofoil sections. Their pitch only varies after they reach the rated power to dump the excess power.

The technology was first developed by US Windpower during the late 1970s, and used widely by small American manufacturers during the 1980s. The first Danish pitch regulated turbines were developed by Vestas for its V25 series in 1985. Pitch regulation was too expensive to justify the cost for turbines less than 25m rotor diameter (Gipe 1995), and this also made more American turbines used the technology in the beginning as they were larger than the Danish counterparts.

Dual Generators and Two Fixed-speed Operation

Generators often operate at partial loads, but the efficiency drops rapidly when generators are operated at less than one-third of its rated power during periods of low winds (Gipe 1995). To avoid this efficiency loss, dual generators were begun used to make wind turbines operate at two fixed-speeds during the 1980s. Turbines with dual generators have one large main generator for periods of high winds and one small generator (one-fifth to one-third that capacity of the main generator) for periods of low winds. The use of dual generators allows turbines to operate at two speeds and enable the rotor to be driven at a higher aerodynamic efficiency over a wide range of wind speeds. In Denmark, the manufacturers, Bonus, Micon, and Nordtank, began using dual generators during the mid 1980s.

Soft Start Electronics

In order to avoid sudden connection of wind turbines to the power grid that causes a large voltage fluctuation, soft start method is necessary to connect turbines with induction generator to the grid gradually (1/10 of a second). Soft start electronics was innovated in the beginning of the 1980s (Hjuler Jensen 2005). Thyristors was the earliest device and most commonly used. The Danish manufacturers begin using soft start electronics in their commercial turbines during the early 1980s.

4.2.3 Danish Success in Technology Development and Diffusion

As examined above, the Danes succeeded in innovating many commercially and technically viable technologies that became the basis of the further development of wind energy technology in the 1990s and beyond. Several reasons were pointed out for this Danish success.

Continuous Market Pressure for Technology Development

The most important reason was the continuous market demand that the industry had throughout the 1980s. The Danish market was developed earlier than any other countries as a result of the government investment subsidies introduced in 1979. This home market base made the Danish manufacturers to produce a relatively large number of turbines from the beginning. The investment subsides also required the manufacturers produce wind turbines good enough to pass the turbine approval scheme.

In the early 1980s when the domestic demand decreased, the California boom started. The US market was also constantly demanding larger and cost effective turbines. When the California market crashed at the end of 1985, the domestic market gained the strength again. This time the Danish utilities demanded turbine upscaling. The Wind Turbine Guarantee Company set up to guarantee long-term financing of large export projects in the late 1980s also forced the manufacturers to improve their turbines, because the financing required the turbines pass a new and more demanding approval scheme (Hvidtfelt Nielsen 2001, cited in Kamp, Smits, and Andriesse 2004).

Grassroots Networks

Strong grassroots networks formed by manufacturers, turbine owners, government officials, and researchers were also behind the successful turbine development by the Danish manufacturers, by providing valuable feedbacks to technology development in the process.

Wind cooperatives and DWTOA have played significant roles in technology development in many ways. The most notable contribution was providing a list of all turbines and regular reports of their performance and technical problems in the DWTOA monthly membership magazine, Naturlig Energi. In this way, any technical problems were quickly worked upon and the manufacturers were constantly under the pressure to improve their turbine performance. This helped establishing credibility and eliminating myths of unreliability and high costs of wind power. It also helped create the insurance market and free-standing firms to supply insurance.

In Denmark, even the RISØ National Laboratory was a part of the networks rather than the symbol of ivory tower. When its Wind Energy Department was conceived in 1978, the original finance was only for three years. This made the lab assist the immediate needs of the manufacturers rather than engaging in long-term R&D projects. The future of the department depended on the manufacturers' evaluation after the three years. The department survived and has continuously thrived as the role of RISØ changed into more formal ones, as the manufacturers needed to meet technical demands from the utilities and the export market during the late 1980s (Dennemand Anderson, 1993, cited in Kamp, Smits, and Andriesse 2004).

The grassroots collaborations were also evident in the development of WindPRO. From the beginning, small group of wind energy industry people and supporters, i.e., manufacturers, turbine owners, and students, gathered together for informal meetings, once or twice a year. Green organizations usually arrange these meetings, and they have been an important feedback source until this day (Nielsen 2005).

Triumph of Craftsman Tradition

The other important reason was a bottom-up, incremental innovation approach taken by the Danes. Karnøe (1993) points out that the success of the Danish wind technology development was due to the absence of handicap that could be posed by sophisticated knowledge of aerodynamics. The failures of the large-scale wind R&D programs by the United States and other countries showed that technical challenges posed by wind turbine design were badly misjudged by academic engineers engaged in those government programs; aerodynamics around wind turbine blades is far more complicated than that around aircraft wings. The sophisticated aeronautical models could not substitute the knowledge stemmed from long-term field experiences. On the other hand, with empirical and hand-on knowledge that had its root in agricultural machinery manufacturing, the Danish turbine manufacturers relied upon simple and pragmatic principles, did not try understanding the theory of complex force fields around wind turbine, and simply took well-known measures to increase structural stability and security.[26] They built robust machines that worked sufficiently and kept on refining them in response to market demand. In this way, they avoided time-consuming R&D in building up necessary knowledge (BTM Consult ApS 2005b; Heymann 1998; Karnøe 1993).

Although the designs proposed by academic engineers under the large government R&D programs did not produce commercially viable turbines, they also made some contributions to the advancement of wind turbine technology. Technologies such as pitch regulation method, the use of composite blade materials, and the design principles such as optimization of aerodynamic efficiency and light weight construction were all originated from aerospace engineering, which was the main business area of companies participated in the US and the German R&D programs (Heymann 1998). The sophisticated engineering knowledge such as these could not be possibly come out of the Danish craftsmen.

However, it was then the Danish manufacturers who incorporated these technologies and crafted them into successful commercial products at the end. There was a virtuous cycle of knowledge accumulation; the Danish manufacturers gained empirical knowledge from their commercial

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[26] In general, the Danish turbines in the 1980s were much more massive in weight than their American larger counterparts because Danish designers simply put more weight to increase structural stability (Heymann, 1998).

experiences in the markets in California and Denmark, combined it with new engineering solutions from the research programs only after they showed satisfactory test operation results, and tried them out again in the commercial markets. This process helped the Danish manufacturers synthesize the results from R&D, learning-by-doing, learning-by-using, and learning-by-interacting (Kamp, Smits, and Andriesse 2004) into a new layer of practical knowledge.

Section 4.3: Industry Development before 1990

The wind turbine industry structure changed a great deal during the 1980s. In the countries that engaged in the strong national R&D programs during the late 1970s and 1980s, large firms with power generator or aerospace industry backgrounds entered into wind turbine business and focused on MW-class turbine development. On the other hand, many small firms also entered into wind turbine development business in European countries and the United States during the same time period. They were either entrepreneur start-ups or diversification from mechanical engineering firms, and focused on development of small turbines.

BTM Consult ApS (2005b) listed total 66 of wind turbine manufacturers, which sold more than one wind turbines to the market by the end of 1989. The list includes 16 American, 15 Danish, ten West German, nine British, six Dutch, three Swedish, two Japanese, one Belgian, one Irish, one Swiss, one Spanish, and one Austrian firms. The American and Danish manufacturers occupied the top ten company list (Table 4-4).

Table 4-4: Top Ten Manufacturers in terms of Total Number of Sales by the end of 1989

Manufacturer	# of Turbines Sold	Total Capacity Sold (MW)	Domestic	Export	Nationality
US Windpower	3,272	327.2	3,272	0	USA
Vestas	2,672	227.73	526	2,146	Denmark
Micon	1,587	144.157	44	1,543	Denmark
Fayette	1,370	137.27	1,370	0	USA
Bonus	1,190	119.652	317	873	Denmark
Nordtank	1,097	95.959	235	862	Denmark
Jacobs	630	11.705	630	0	USA
Flowind	511	94.715	511	0	USA
Enertech	485	20.51	485	0	USA
Windmatics	368	29.126	135	233	Denmark

Source: (BTM Consult ApS 2005b)

4.3.1 Danish Industry

Establishment of Wind Turbine Industry

By 1978 about ten small wind turbine companies were established in Denmark (Kamp, Smits, and Andriesse 2004). These small entrants during the 1970s were private carpenters and craftsmen who were enthusiastic about renewable energy development. Around 1980 this situation changed; the industry became professionalized as enterprises began taking over the turbine development role. During the late 1970s and the early 1980s, enterprise manufacturers continuously entered into the business; they included some manufacturers that formed the core of the industry later: Vestas and Nordtank in 1979; Danregn Vindkraft (later Bonus) in 1981; Micon in 1983; and Nordex in 1985. The number of entrants exceeded 20 during the 1980s.

Many entrants had the backgrounds in building agricultural equipments. Equipment builders, not theoretical engineers, were engaging in developing wind turbines based on their experiences in agricultural and irrigational machinery development. There were also no legal and political entry barriers in Denmark at the time that restricted the business entry of any kinds of firms to the industry.[27] Thus, both technical and legal entry barriers to the wind turbine industry were relatively low.

Danish Industry Competition and Consolidation during the 1980s

The Danish manufacturers enjoyed the domestic market development supported by the government investment subsidies from the beginning. When the Danish market demand was reduced in the beginning of the 1980s, the California boom began. However, this industry expansion mode supported by both the Danish and US markets changed around 1986. The nature of competition and the logic to control the industry structure did rapidly change during the mid 1980s, along with technological and financial entry and growth barriers.

The exports started in 1982 to the United States changed the logic governing the industry structure with business entry and exit. In the beginning, the Danish turbines were competing with their American counterparts for market share. However, once the Danish turbines proved their superior reliability and outperformed the American competitors, they began competing with each other in the California market. Turbine upscaling competition began. This competition of domestic manufacturers oversea made the innovation process so fast that many models disappeared from the market within one year, replaced with newer and larger models, and made the obsolete models need to be sold with discounted prices. Although the exponentially increasing demands made the production to be moved from batch to series quickly, cost reduction by series production was insufficient to compensate the price reduction as a result of new product introduction. By 1985, a quarter of the industry turnover involved a loss, and seven out of 12 Danish firms reported negative trade results. By this time, approximately 50% of generating capacity in California came from European-made wind turbines, especially Danish ones (Van Est 1999).

As the California market reduced, 11 out of 12 Danish firms suffered from negative running costs in 1986 (Kjær, 1988, cited in van Est, 1999), and all of production facilities of the Danish manufacturers in the United States were closed (JETRO Copenhagen Office 2003). Many manufacturers filed bankruptcy and exited the business after 1986. However, some of the bankrupted companies simply reestablished again due to the Danish legal system that allowed such reinstatement (Heymann 1998).

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[27] There was only one exception. In the early 1980s, the Ministry of Energy could have the ownership of firms that are environmentally important, and the Ministry was one of the shareholders of Danish Wind Technology (DWT) under this rule. However, the complications for the national government to support one firm while others not receiving such support in a competitive sector cancelled the rule in 1986 (Madsen, 2005).

Even after this crash, however, the pressure on turbine upscaling continued. The still-existed weak US market and the 1986-1989 Danish tax incentive policy for the Danish investors in the US wind projects let the technological competition continue. Between 1986 and 1989, almost all small manufacturers exited the business because they could not afford turbine upscaling. At the point of 1990, only seven Danish manufacturers, Vestas, Nordex, Bonus, Micon, Nordtank, Wincon West Wind, and Wind World, remained in the business (Madsen 2005).

Changing Strategies of the Danish Manufacturers

The experiences in California have influenced greatly competitive business strategies of the Danish manufacturers from the late 1980s.

The forced upscaling of turbines in California and the hasty serial production caused many problems with gearboxes, generators, oil-cooling, and blades for the exported, unproven turbine designs by the Danish manufacturers. In addition, although the wind and weather regime of California is very different from the one in Denmark, the manufacturers lacked the advantages of geographical proximity to fix them quickly. Technology was not easily transferred. The California boom showed the lack of managerial skills and technological and organizational capability. In addition, most companies were small and undercapitalized, and lacked financial resources to offer project security. Wind power projects in California were financed by shared financing, the shares of which were sold to the Danish institutional investors. However, this method of financing could not live up with the expectations from the investors (Van Est 1999).

Lessons from the California experiences were reflected to the domestic market though the change of business strategies and a new method of finance. First, the manufacturers began reducing business risks by: 1) diversifying their marketing efforts over several political markets; 2) hedging against exchange rate risks; and 3) having at least two reliable suppliers in order to ensure stable supply of components (Van Est 1999). These changes were exercised in new European markets from the 1990s, especially Germany and Spain, which showed string resemblance with the Danish domestic market. Second, in order to find investors, there were the necessities of controlled development of new turbines, certification of a uniform turbine quality, and guarantee of project performance and insurance. A private Wind Turbine Guarantee Company was established with a state guarantee of DKK 750 million in order to warrant long-term finance of large projects with Danish wind turbines outside Denmark (Van Est 1999).

4.3.2 German Industry

Like the United States, there were two types of firms engaged in wind turbine development business in Germany early on: one was large firms such as MBB entered into the business on the basis of government contracts to develop MW-class turbines; and the other was small idealistic developers that focused on development of smaller turbines. While the former mostly left the business by the late 1980s due to the non-feasibility of their MW-class machines, the latter faced huge obstacles with very small domestic market. Total of 14 small German firms sold turbines during the 1980s, and 11 out of those 14 firms still existed in 1989 (Durstewits, 2000, cited in Johnson and Jacobsson 2000). They survived with the government funding for small- to medium-capacity turbine R&DD projects. Some manufacturers also exported their turbines to the United States and other European markets except Denmark. However, their presence in the global scene was very limited.

4.3.3 Indian Industry

As mentioned, there was no market demand for wind turbines in India except the government demonstration projects during the 1980s. The Indian industry was also largely cut out from the development made in developed countries except Denmark, which was the main technology provider at the time. However, the country succeeded in establishing three pioneer companies. The wind farm demonstration program in 1986 resulted in the establishment of two joint venture companies, NEPC-Micon and Vestas RRB, while BHEL succeeded in developing the first Indian turbine prototypes on its own with the government R&D support.

4.3.4 Other Country Industry

American Industry

The US market boom during the early to mid 1980s nurtured not only the Danish industry but also the American industry. There were many entrants which were not supported by the government R&D program but tried smaller turbine development on their own.

These small commercial American manufacturers in the 1980s used two- or three-bladed, downwind rotor turbines with pitch or semi-pitch regulations. Due to the lack of sufficient financial resources, however, they needed to develop turbines quickly and did not have time to test them in operation. Although their combined market share during the mid 1980s in California was larger than that of the Danish manufacturers, their turbines installed without proper testing were doomed to fail. Almost all designs along with their creators did not survive by the late 1980s. By 1990 only one major commercial manufacturer, US Windpower survived (Heymann 1998).

US Windpower became the world market leader by the end of 1980s (Table 4-4). This firm was the only wind turbine manufacture, seriously competing with the Danish manufacturers. US Windpower engaged in all activities of wind business value chain: production, development, finance, and operation or of wind turbines and projects. This was a distinctively different strategy from the one taken by Vestas that was the other largest firm on the market. Several hundred employees involved in manufacturing and maintaining wind turbines, and the maintenance and financing fees provided cash flow for technology and project development (U.S. Department of Energy 2003). However, US Windpower could not compete against The Danish manufacturers, because it had never faced a competition within the United States and did not move fast enough to compete against the turbine upscaling by the Danes. The firm spent USD 30 millions to the project of upscaling of turbines from 100kW to 300kW class. When the project was close to the completion, several European manufacturers were already making 500kW turbines. This caused a serious financial trouble to the firm, which was subsequently taken over by Kenetech in 1994 (Madsen 2005).

Other European Manufacturers

Several manufacturers survived the 1980s. In particular, a Belgian manufacturer HMZ and a Dutch manufacturer Lagerwey were the notable examples. HMZ showed strong export performance, while Lagerwey and other Dutch manufacturers relied upon the domestic market.

4.3.5 Industry Consolidation Logic of the 1980s

As seen, the industry gradually consolidated by the end of the 1980s. Two different logics were working on the consolidation trend simultaneously for different kinds of manufacturers during the 1980s.

One was for the firms who engaged in the government programs to develop large MW-class turbines. They exited from wind business during the 1980s or by the early 1990s because they could not produce commercially viable turbines. The other was smaller manufacturers that started with small-capacity turbines. They were facing a different industry consolidation logic during the 1980s; the incremental but rapid turbine upscaling and technological improvement pressure occurred in California and Denmark to increase economic efficiency. The pressure raised both technical and financial requirements for manufacturers and resulted in the rapid industry consolidation.

Chapter 5: Wind Energy Policy, Market, Industry, and Technology Profile 1990-2005

Chapter 4 presented the wind energy sector development before 1990. This chapter examines the evolution and the basic profiles of wind energy policy, market, industry, and technology in Denmark, Germany and India since 1990, and the results of technology transfer between Denmark/Germany and India.

This chapter consists of six sections. The first section presents the institutional settings surrounding wind energy sector in the three countries. The second section summaries wind energy policy of the three countries. The third section presents the development of wind energy market of the three countries and the global market. The fourth section describes the general profiles and development of wind energy industry of the three countries and the global industry. The fifth section summaries the technology profile and evolution at technology frontier of Denmark and Germany. The sixth section presents the technology profile and evolution of India by focusing on technology transfer from Europe and explores technology gaps with the frontier.

Section 5.1: Institutional Setting surrounding Wind Energy in Denmark, Germany and India

North (1994) defines institutions as humanly devised constraints that structure human interaction. They include both formal and informal constraints such as laws, regulations, market and organizational norms. Institutional evolution is determined by the interaction between institutions that are the rule of the game and organizations such as group of individuals and players (North 1994).

This section describes the formal side of institutional settings regarding the electricity and wind energy sector of Denmark, Germany and India. The section also briefly portrays the structure of their electricity sector and government organizations that concern wind energy policy and institutions. At first, the European Union (EU) electricity liberalization will be explained, as it has had a large impact on the Danish and German electricity sector structures and institutional settings as well as wind energy policy in recent years.

5.1.1 EU Electricity Liberalization

The European Commission (EC) initiated a single and competitive energy market policy for the region in 1990 by harmonizing the existing rules and identifying complementary measures to unify 15 separate markets. After the Treaty of Maastricht and the establishment of the EU in 1992, the integration of energy policy among its member states accelerated. Directives 96/92/EEC and 98/30/EEC were introduced in 1996 and 1998, respectively, which required its member states to: 1) dismantle their electricity monopolies to separate them into electricity generation, transmission and distribution, except System Operators; 2) fully liberalize and create an open and competitive electricity market that allows electricity trading, and incorporate domestic necessary regulatory changes by February 20, 1999; and 3) incorporate the EU provisions into domestic legislation by August 2000. While these directives were to seek to abolish exclusive rights, the member states are allowed to include extra costs for environmental requirements and other national strategic requirements such as security of supply. This allowance is called Public Service Obligation (PSO), which is not governed by free market competition.

One June 26, 2003, a new Directive was adopted by the European Parliament and the Council. The Directive aims at: 1) achieving complete opening of the EU electricity market by July 2007; 2) reducing risks of market dominance and predatory behaviors; 3) ensuring non-discriminatory transmission and distribution tariffs and network access; 4) establishing the provisions for unbundling of transmission and distribution operators; and 5) establishing labeling requirements for electricity suppliers regarding CO_2 emissions and radioactive waste for electricity generation as well as for the contribution of energy mix of each energy source in the supplier's fuel mix.

5.1.2 Denmark

General Institutional Setting surrounding Wind Energy

Denmark has a unicameral system. While both the national government and the regional/local governments exercise administrative power, 13 counties and 271 local municipalities have a high degree of regional autonomy and many of the administrative powers are delegated to them.

In terms of energy policy, until the first Energy Crisis of 1973, Denmark had no economic regulation of the energy sector. The first of such regulations were Electricity Supply Act of 1976, which governed the development and structure of the electricity sector, and the Danish Energy Plan of 1976, which decided the national objectives regarding security of supply, energy savings, and most importantly reduction of dependence on imported oil.

As a result of the 1976 plan, Denmark reduced its oil dependency by switching oil to coal for electricity generation. While the fuel switching was done in extraordinary speed,[28] it increased the emissions of noxious pollutants and GHGs. The Energy Plan of 1981 updated the Energy Plan of 1976 and stipulated to switch large power plants from oil to gas and install more renewables and Combined Heat and Power (CHP) plants. In 1990, Energy 2000 was passed to add a goal of sustainability to energy policy, set targets for CO_2, SO_2 and NOx emission reductions, and place a plan for R&D, energy savings and the increased use of CHP and cleaner fuels. The next major policy statement was Energy 21 of 1996, which tightened the targets for the CO_2 reductions for 2005[29], set a target for 2030, and promoted further introduction of CHP and renewable energy to cover 12-14% of primary energy by renewable energy by 2005 and 35% by 2030. Wind energy is given a primary role in these plans with targets for installed capacity of 1,500MW by 2005 and 5,500MW by 2030, covering 10% and up to 50% of electricity consumption of the country, respectively.

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[28] From 1973 to 1979, the percentage of electricity generated from oil declined from 64% to 37%, and then to 5% in 1983 (OECD/IEA. 2000).

[29] Reduce CO_2 emissions from 1988 levels by 20% by 2005.

In 1996 the Electricity Supply Act was amended to change the structure and economic regulations of the electricity sector in order to promote environmentally benign utilization of energy. The Act came into force in January 1998. In 1999 the Electricity Reform Act was adopted to introduce competition into electricity production and trade while maintaining the objectives of the 1996 Act. The 1999 Act also introduced the quota for annual CO_2 emission for Danish utilities as well as a special green market for trade of green certificates in combination with consumer quota for green electricity.[30] Also the 1999 Act mandated the Danish electricity market to become fully open for all the EU consumers in January 2003.

Public Organizations that concern Wind Energy Sector

Key public organizations related to wind energy are as follows, although various ministries (Ministry of Trade, Ministry of the Environment, and Ministry of Economics and Business Affairs, etc) directly and indirectly concerned wind-energy-related policy and projects.

Danish Energy Authority (DEA)

The Danish Energy Authority (DEA), established in 1976, is the key government organization concerning wind energy technology development.[31] DEA is responsible for: 1) administering the Danish energy legislations and conducting analyses and assessments of the development in the field of energy, nationally and internationally, as well as implementing policy through agreements with utilities; 2) administering the Electricity Supply Act and the legislation concerning CO_2 quotas for electricity production and the reform of energy structure from monopoly to competition; 3) administering subsidies for environmentally friendly electricity production as well as key R&D grants/subsidies/programs in the area of cleaner and more energy efficient technologies; and 4) promoting the export of energy technology and know-how possessed by Danish enterprises and participating in systems export projects, conducting export promotion activities, and creating a platform for Danish industry and know-how and developing the link between bilateral support and export, in cooperation with industry (Danish Energy Authority 2005a).

Spatial Planning Department under Ministry of the Environment

Spatial Planning Department under the Ministry of the Environment coordinates spatial planning concerning the location of wind turbines at local and municipal, regional, and national levels.

RISØ National Laboratory

Wind Energy Department at the RISØ National Laboratory was created in 1978. The department has dealt with type approval under the turbine certificate program from 1979. Its responsibilities in R&D became more formalized and increased during the 1980s (Dannermand Anderson, 1993, cited in Kamp, Smits, and Andriesse, 2004). From the 1990s both Wind Energy and Atmospheric Physics Departments are mainly working on basic research on aero-elastics, i.e., the interaction between aerodynamics and structural dynamics, on wind turbine technology, and on wind resource assessment.

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[30] Trading of quota with the American and German utilities has started in 2001.

[31] DEA was under the Ministry of Environment and Energy, and then under the Ministry of Economic and Business Affairs, until it became an agency under the Ministry of Transport and Energy on February 18, 2005.

Danish International Development Assistance (DANIDA)

The Danish International Development Assistance (DANIDA) is a grant program under the Ministry for Foreign Affairs, starting its operation in 1963. The grant is for both bilateral and multilateral development assistances, and it must constitute 1% of Denmark's GNP according to the 1963 parliamentary decision. DANIDA focus on a selected number of developing countries (program countries). The agency helped a number of wind demonstration projects during the 1980s and the 1990s (Ministry of Foreign Affairs of Denmark 2006).

Industrialization Fund for Developing Countries (IFU)

IFU was established in 1967 under the Government of Denmark to promote economic activity in developing countries by promoting investments with Danish enterprises. Although the Minister for Development Cooperation appoints the Supervisory Board and the Managing Director, it is an independent, self-governing entity, participating as a partner in joint ventures in developing countries through committing equity capital and/or loans and through board membership. The Fund's revenues consist of interest, dividends and profits from sale of shares (Industrialization Fund for Developing Countries 2006).

Danish Electricity Sector

Denmark has developed two separate electricity grid after WWII: one grid covers the Jutland and Funen area and runs synchronous with the European continental system; and the other covers Sealand and Lolland-Falster and runs synchronous with the Scandinavian grid. Regional power companies under these two grids established two power pools in the mid 1950s: one was Elsam that dominated the western Denmark, and the other was Elkraft[32] that dominated the eastern Denmark. These two associations had played various roles of utilities, i.e., planning/design/ construction of new power plants, load dispatching, fuel purchases, and operation of transmission grid, etc., in the country. Elsam had six generation companies under its control and Elkraft had two; however, the control over the eight generation companies was centralized to the two associations, which have been the strategic players of the country's electricity sector.

With the introduction of the EU directives for electricity liberalization, Denmark prepared for market liberalization. The Electricity Supply Act of 1999 introduced competition into electricity generation and trade; final consumers could become choose their electricity supplier[33] and electricity supply activities were unbundled so that each of electricity generation, ownership of the transmission grid, operation of the grid, distribution, and electricity supply must be organized in separate legal entities. The transmission system operators became responsible to ensure the function of the 400kV transmission network of the country and proper support for producers of environmentally-friendly electricity. As a result, Eltra was founded to take over Elsam's activities regarding the transmission networks in Jutland and Funen from January 1998. Elsam remained as a generation utility. Elkraft System that was responsible for system operation of Zealand was established as a unit of Elkraft with separate accounts and information system from

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[32] Elkraft was called as Kraftimport until 1978.

[33] The liberalization was done step by step. At first, final customers of 10 GWh or more per year have been eligible to choose their electricity supplier in the free market from April 2000. On January 2001, the threshold was lowered to 1 GWh, and on January 2003, all final consumers became eligible as the Danish electricity market was opened for all EU consumers.

those of the remainder of Elkraft. This changed in 2004 when the Act on Energinet Danmark was passed; from January 2005 the Danish state took over and merged Elkraft System, Elkraft Transmission, Eltra and Gastra into Energinet.dk, an independent public corporation owned by the Danish state under the Ministry of Transport and Energy and with its own Supervisory Board. Energinet.dk became responsible for the electricity and natural gas systems in Denmark.

Another important feature of the Danish electricity structure is that the western Denmark has been a part of the Nordic Power Exchange (NordPool), which is a series of markets for the trading of electricity, incorporating Norway, Sweden, Finland (since 1997) and the western part of Denmark (since 1999). Trading companies trade electricity on a purely commercial basis.

5.1.3 Germany

General Institutional Setting surrounding Wind Energy

Germany is a federal republic comprised of 16 sovereign states (Länder). While the federal government decides general legislative framework through the constitution as well as national laws and acts, the states have their own state constitution, legislatures, and governments, which can pass laws on all matters. The federal government has the exclusive right for defense, foreign affairs, and finance, while education, local law enforcement, culture, and environmental protection are controlled by the state. Both the federal government and the state governments exercise their original legislative power over renewable energy.

In terms of economic regulations on the electricity market, the German electricity sector was structured based on the Energy Industry Act of 1935 prior to the market liberalization of 1998. While power generation, transmission, distribution and supply were monopolized and the sector was under the state control under the Act of 1935, private laws dictated contracts for concessions, territorial boundaries, supply to special customers, technical conditions for feeding surplus electricity to the grid, and reserve deliveries. The situation changed when the Act on the Supply of Gas and Electricity liberalized the German gas and electricity markets in April 1998.

There have been several important legislations for renewable energy. The first legislation, the Electricity Feed Law (EFL) that guaranteed feed-in tariffs available to electricity generated from renewable energy sources, came into force in January 1991. After it was amended in 1998, the act was updated into Renewable Energy Sources Act (EEG) in October 2000, which was amended in July 2004. In 1998 the country also set the national targets to double the share of renewable energy sources excluding large hydro in the primary energy consumption to 4% by 2010 and to further increase the share to 25% by 2030 and to 50% by 2050.

Public Organizations that concern Wind Energy

Unlike DEA of Denmark, Germany does not have a single federal energy agency, responsible for formulation and administration of energy policy and legislations. The ministerial responsibilities over energy related issues spread across several different ministries. Currently both the Federal Ministry of Economics and Technology (BMWi) and the Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) share the overall responsibility for energy policy within the government, but BMU has the responsibility for renewable energy from autumn of 2002.

Federal Ministry of Economics and Technology (BMWi)

BMWi and its predecessor the Federal Ministry of Economics and Labor have been responsible for economic efficiency, supply safeguards, and environmental sustaibility aspects of the German energy policy, carrying out the market liberalization and the introduction of competition (BMWi 2006).

Federal Environmental Agency (UBA) under Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

The Federal Environmental Ministry has played significant roles in environmental aspects of energy policy making and legislation. Currently the Federal Environmental Agency (UBA) under BMU is responsible for environmental aspect of energy. BMU holds the overall responsibilities of the German government to satisfy its international responsibilities and fulfill the targets that it has set itself for climate change (BMU 2006).

R&D Organizations

In Germany, the federal agencies sponsor the majority of non-university based R&D, and several Ministries (Research, Economics, Environment, Building, and Agriculture) are held responsible for research in respect of energy and the climate. In addition, the individual states have established their own specialized institutes. Before 1994 the R&D programs were carried out by the Federal Ministry of Research and Technology (BMFT). After BMFT was reformulated into the Federal Ministry of Education, Science, Research and Technology (BMBF), BMBF and BMWi have carried out the R&D programs for wind energy. BMBF coordinates all federal R&D activities and supports most of energy related R&D projects. Public research infrastructure of Germany is large and decentralized; the country does not have a centralized single R&D organization for wind energy, but the federal programs frequently meet the state governments to coordinate the industry and the research community.

Kreditanstalt für Wiederaufbau (KfW) Development Bank/Deutche Ausgleichsbank (DtA)

KfW Development Bank finances investments in developing countries and consulting services related to the investments. It works on behalf of the Federal Ministry for Economic Cooperation and Development through its Financial Cooperation (KfW 2006). Meanwhile, Deutche Ausgleichsbank (DtA) has financed economic measures for commercial middleclass and free occupations as well as measures for environmental protection since the mid 1980s.[34] DtA was under the Federal Ministry of Finance and the Federal Ministry of Economics but was absorbed by KfW Mittelstandsbank (a part of KfW Group), which continues the works of DtA since July 2003.

German Agency for Technical Cooperation (GTZ)

The German Agency for Technical Cooperation (GTZ), established in 1975, is a closed limited company in private sector, owned by the German Federal Government[35] as an international cooperation enterprise for sustainable development. The agency mainly works for the German Federal Government, especially the Federal Ministry for Economic Cooperation and

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[34] It was originally created to support people suffered from WWII such as refugees in 1950.

[35] The GTZ Supervisory Board has representatives of four Federal Ministries: BMZ, Federal Foreign Office, Federal Ministry of Finance, and Federal Ministry of Economics and Technology.

Development, and implements development projects and programmes in developing countries. The main focus is technical cooperation: technical knowledge transfer and capability building of people and organizations to form a basis of stable development. In renewable energy sector, it provides technical and advisory support of renewable energy projects in developing countries and shares annual funds with KfW for this purpose (GTZ 2006).

German Electricity Sector

The reunification of East and West Germany in 1990 brought a major task to the country to merge the radically different energy sectors of the two sides. West Germany had mainly privately owned energy supply with high level of energy efficiency and environmental protection. In contrast, East Germany had highly centralized and state-owned utilities with low energy efficiency and environmental standards. Much progress has been made to privatize the former East Germany energy sector and improve its environmental performance.

Before the market liberalization of 1998, about 1,000 utilities provided monopolies in power generation, transmission and distribution in Germany. Eight were involved in large-scale power generation and high-voltage transmission, about 80 engaged in regional distribution with some generation, and local distribution was carried out by more than 900 utilities. The large utilities were mostly privately owned, while the local utilities were often owned by the communities. In April 1998 the German gas and electricity markets were liberalized according to the Act on the Supply of Gas and Electricity. Due to intense price competition and erosion of profit margins that followed the liberalization, a great number of M&A occurred in a few years and the number of large utilities reduced into four (RWE AG, E.On, Vattenfall Europe, and EnBW).[36] These four utilities also merged and acquired local and regional utilities as well as horizontally diversified by acquiring gas companies. Many new entrants did not survive (Wustenhagen and Bilharz 2006).

Germany has the largest electricity market in Europe. Nearly 100% of electricity demands in Germany are met domestically, but the country imports electricity due to transmission loss and the proximity to foreign sources. According to Statistisches Bundesamt, about 80% of electricity is generated from coal and lignite (48.9%) and nuclear (27.5%), followed by natural gas (10.2%), hydro (4.5%) and non-hydro-renewables (7.3% - 4.1% by wind) in 2004.

5.1.4 India

General Institutional Setting surrounding Wind Energy

India is also a federal republic, constitutes 25 states and seven union territories. The Constitution of India divides the power of the Government of India (GOI) and the state governments into three lists: the Union List, the State List, and the Concurrent List. The Union List consists of any matter that the Parliament has exclusive power to make laws such as defense, foreign affairs, currency, income tax, excise duty, railways, shipping, posts and telegraphs, etc. The State List is made of items over which the relevant state has responsibility and power to make laws such as

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[36] They are known as "supra-regional companies." The four companies operate in the following regions: RWE in western Germany; E.On in central Germany; Vattenfall Europe in New Länder and Berlin; and EnBW in south-western Germany.

public order, police, public health, communications, agriculture, taxes on entertainment and wealth, and sales tax, etc. Both the central and state governments can enforce their power over the items listed in the Concurrent List, which the national legislation prevails in the case of any conflict between the legislations passed by the central and the state governments, including newspapers, criminal law, marriage and divorce, stamp duties, trade unions, price controls, etc. Supply of electric power is on the Concurrent List.

As a Concurrent subject, the Indian electricity sector possesses a federal structure; GOI formulates the national power policy through several ministries and agencies but the extend of implementation of the national policy is determined by decisions of individual states, because the final decision to approve any private sector projects, levels of tariffs and related issues as well as all commercial aspects, including power purchase agreements, are within the jurisdiction of the state governments. The electricity market is also segregated by state border; the power generated in one state is not transmitted or wheeled to another state in general.

Until 2003, there were three acts that provided the statuary framework for regulation of electricity in India, and the state level legislations also existed in several states. The Electricity Act of 1910 provided the basic framework of the electricity sector. The Electricity (Supply) Act of 1948 established State Electricity Boards (SEBs) as vertically-integrated, monopoly utilities. In 1991 both the Acts were amended to restructure the electricity sector. In 1998 the Electricity Regulatory Act was introduced to mandate the creation of the Central Electricity Regulatory Commission (CERC) at the central level and the State Electricity Regulatory Commission (SERC) at the state level to facilitate the power sector reform further. In June 2003, the Electricity Act of 2003 was enacted to replace the above three acts.

Public Organizations that concern Wind Energy

India has developed various unique support organizations for renewable energy over the years.

Ministry of Non-conventional Energy Sources (MNES)

GOI upgraded DNES to the status of a full-fledged Ministry of Non-conventional Energy Sources (MNES) in 1993 with renewed emphasis on policy, planning, and institutional linkages and gave it more autonomy and stronger decision-making and resource allocation power. MNES is responsible for all matters related to non-conventional/renewable energy, which include: policy making and planning; promotion and coordination of functions related to all aspects of renewable energy, including fiscal and financial incentives; creation of industrial capacity; promotion of demonstration and commercial programs; R&D and technology development; intellectual property protection; human resource development; and international relation.

Indian Renewable Energy Development Agency (IREDA)

Indian Renewable Energy Development Agency Limited (IREDA) was established in March 1987, as a public limited government company to promote and develop renewable energy and energy efficiency/conservation projects by providing short-term financial assistance in the forms of soft loans through the operation of revolving fund. The revolving fund has been created by the funds received through various international institutions as assistance, including the World Bank and GEF, the Asian Development Bank, DANIDA, KFW, etc (Table 5-1).

Table 5-1: Cumulative International Assistance Received for Revolving Fund by IREDA as of December 2005

Institutions	Cumulative Assistance
World Bank/GEF/SDC	145 million USD
World Bank line of credit	130 million USD
GEF Grant	5million USD
Asian Development Bank line of credit	100 million USD
DANIDA mixed credit	15 million USD
KFW Germany	120 million DM
Government of the Netherlands	18 Million Dutch Guilders
JBIC Japan (Pipeline)	85 million USD
US EXIM Bank (Pipeline)	100 million USD

Sources: (IREDA 2001 and 2006)

State Nodal Agencies (SNAs)

State Nodal Agencies (SNAs) were created since the 1980s in order to implement demonstration projects and channel devices, loans and subsidies to consumers as well as to take care of after-sales services and consumer support for renewable energy projects. In the 1990s SNAs began formulating state specific renewable energy policy and programs and implementing them through providing necessary clearances, allotment of land, power purchase agreements, etc. Although SNAs receive financial support from GOI (DNES and later MNES), they are administratively under the control of their respective state governments. The organizational setting of SNAs varies among states.[37]

Center for Wind Energy Technology (C-WET)

The Center for Wind Energy Technology (C-WET) was established by MNES in Chennai in 1999 as an autonomous institution of GOI to serve as the technical focal point for wind power development, with technical and financial support from DANIDA. C-WET aims to assist all players in the field by providing value-added services on all scientific and technical fronts as well as to support the promotion of exports of products and services to other countries. The Center has a comprehensive program with five units: Research and Development unit; Wind Resource Assessment unit; Wind Turbine Testing unit; Standards and Certification unit; and Information Training and Commercial Services unit (MNES 2000a).

State Electricity Boards (SEBs) and State Electricity Regulatory Boards (SERCs)

The Electricity (Supply) Act of 1948 established State Electricity Boards (SEBs) as vertically-integrated monopoly power generation and distribution agencies owned by the state governments. SEBs held responsibilities of actual development works within the framework of national policy, but the Electricity Regulatory Act of 1998 introduced unbundling of their electricity generation, transmission and distribution activities into separate legal entities and took the authority to decide tariffs from SEBs and handed it to State Electricity Regulatory Boards (SERCs). Some of SEBs have acted as SNAs.

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[37] While many states have SNAs as independent agency, some undertake the role as SNA without any specifically assigned department or by designating Department of Electricity or Power as SNAs. In the case of Tamil Nadu, the programs for non-grid connected renewable energy projects are carried out by Tamil Nadu Energy development Agency (TNEDA) and all gird-connected projects are under the responsibility of Tamil Nadu Electricity Board (TNEB). (TNEB, 2002.)

Indian Electricity Sector

The Indian power grid system is divided into four subsystems, which are only interconnected through DC links and are not operated synchronously. The southern Indian grid includes Tamil Nadu, Kerala, Karnataka, and Andhra Pradesh. The western grid has Gujarat, Maharastra, and Madhya Pradesh. GOI has exclusive responsibility for high-voltage interstate transmission.

Until 1991, the power sector of India was under the direct control of the government. Various state and central sector utilities owned 98% of generation and 95% of distribution (Prayas 2001). Power generation, distribution, and transmission within states were in hands of SEBs. In 1991 GOI was facing urgent necessity of a profound reform of its power sector because of the ever-widening demand and supply gap,[38] poor technical and financial performance of SEBs, and the incapacity of GOI and the state governments to finance power generation expansion. The Indian Electricity Act of 1910 and the Electricity Supply Act of 1948 were amended in October 1991, in order to allow private sector, including foreign investments, to establish power generation or undertake distribution as licensees. To induce private participation, GOI offered various concessions.[39] The reforms have also relaxed the requirements of Central Electricity Authority (CEA) for project approval. This amendment also enabled set-up of non-conventional energy-based power projects by private sector (Bath 1998; Prayas 2001)

Despite the reforms since 1991, the financial situations of SEBs were not improved due to the huge accumulated financial deficits caused by large transmission and distribution (T&D) losses and highly cross-subsidized tariff structures from industry/commerce/railways to agricultural and residential consumers. The problem of under-pricing worsened progressively throughout the early 1990s and the average retail price of electricity represented approximately 75% of real average costs in the mid 1990s (IEA 2002b). Also out of total electricity generated, only 55% was billed and 41% was regularly paid (GOI 2001, cited in IEA2002b). T&D losses due to the inadequacy of the system vary between 20% and 45% but the average T&D losses increased during the 1990s (IEA 2002b) All of these factors had deterred the involvement of Independent Power Producers (IPPs) and the private market power sector development.

In order to address these issues, GOI enacted the Electricity Regulatory Act in 1998 to create CERC and SERCs to rationalize tariffs among different sets of consumers, remove cross-subsidies, and bring efficiency to the sector. CERC has a mandate to introduce competition and efficiency in the electricity-supply industry at both the central and interstate levels and to set

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[38] Final consumption of electricity has increased by average of 7% per year since the independence of 1947. However, electricity supply has been less than demand for many years, and the duration and the number of blackouts were beyond acceptable limits (IEA. 2002b).

[39] Concessions such as 100% equity participation by foreign private investors and long-term purchase agreement were offered. It also allowed a required minimum of 11% of the total outlay for promoter's contribution and a required minimum of 60% of the total project cost from sources other than Indian public financial institutions. Fiscal incentives were also provided to private sector investors to assure profits: a five-year tax holiday on profits and gains of new projects for generation or generation and distribution of power; faster depreciation on assets; and reduction in customs and excise duty on equipment. Other incentives included the two-part tariff with guaranteed 16% return on equity for a minimum 68.5% plant load factor (Sinha, C. S. , and P. Venkata Ramana. 1995). Non-competitive contracts with SEBs were also allowed for independent power producers (IPPs) between 1991 and 1994, although GOI enforced competitive bidding after 1995.

tariffs and conditions of supply and services for interstate exchange and multi-state generation. SERCs have a mandate to promote competition, efficiency and economy in the electricity industry and to rationalize and regulate wholesale (from producers to dispatchers), bulk (from dispatchers to distributors) and grid tariffs (transmission) and retail prices at state level. This Act started unbundling and restructuring of SEBs in some states (CERC 2002; Indianelectricity 2002).

In June 2003 the Electricity Act of 2003 came into force to replace all of the three previous acts. The objectives of the Act are to advance the reform efforts since 1991 and to show a clear direction toward a market-based regime by providing measures to promote competition, rationalize tariffs, protect consumer interests, not the interests of SEBs, and promote environmentally-friendly electricity policies.

This Act changed some fundamental aspects of the electricity sector of India, including the following: 1) completely de-licensing power generation, except interstate hydro projects, and give free entry to power generation business; 2) freely permitting captive generation by removing all licensing and permissions; 3) providing any power generation plants open access to the transmission grid as well as rights to build transmission lines at a fee in order to wheel power for self-usage or for third-party sales; 4) obligating all state governments to separate transmission activity from SEBs and establish state-owned State Transmission Utilities as well as SERCs, while providing the state governments freedom to decide sequence and phases of restructuring; 5) ordering SERCs to determine tariffs based on commercial principles and gradually eliminating cross-subsides; 6) permitting consumers to freely enter direct commercial relationships with generating company or trader after open access is allowed; 7) introducing power trading;[40] and 8) obligating GOI to formulate National Electricity Plan and CEA to prepare the National Electricity Plan (Prayas 2003).

As for renewable energy, the Act of 2003 limits the role of state governments to only formulate policies related to: 1) providing the government lands at nominal cost for renewable energy projects; 2) providing subsidy to the cost of infrastructure development; and 3) providing the cost of electricity purchase by licensees from renewable energy plants. Tariffs and charges now are decided not by the state governments or SEBs but by SERCs. The predominant roles of SERCs are: 1) to determine tariffs for generation, supply, transmission, and wheeling of electricity within the state as well as surcharges for open access to consume power from a source other than a licensee; 2) to regulate electricity purchase and procurement process of distribution; 3) to facilitate wheeling of electricity within the state; and 4) to promote electricity generation from renewable energy sources by providing suitable measures for grid connection and power sales to any person and measures that specify a percentage of total consumption of electricity in the area of distribution licensees for purchase of electricity from such sources (Consolidated Energy Consultants Ltd. 2005).

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[40] Power trading needs to be authorized by the Regulatory Commissions. Although distribution companies and the state governments do not need licensing for power trading, State Transmission Utilities cannot engage in power trading.

Section 5.2 Wind Energy Policy Instruments of Denmark, Germany, and India

This section follows wind energy policy development of the three countries. Although politics behind the policy development is important, the section tried to contain political aspects at minimum as they are not the primary focus of this research.

5.2.1 Denmark

Denmark has provided both technology-push policies and demand-pull incentives from the beginning. The main policy instruments to promote wind energy in Denmark have been feed-in-tariff system, political obligations, investment and production subsidies, tax refunds, R&D programs, along with ownership and investment regulations and technical certification requirements.

Research, Development and Demonstration (R&DD) (1977 - Present)

The government-supported wind energy R&DD program started in 1977 as a part of the Energy Plan of 1976, which was financed by the Ministry of Trade. Two major wind energy R&DD programs since then are: Energy Research Program (EEP), which was created under the Energy Plan of 1981; and Development Program for Renewable Energy (UVE), established in 1982 by the Danish Industry and Trade Agency. Both the programs were transferred to DEA later. EEP continues today, but UVE ended in 2002. Table 5-2 shows other R&DD programs as well. Recent R&DD focus has been the development of offshore and system operation technology.

An important difference in wind energy R&DD between Denmark and other countries is that the Danish support has primarily been directed towards basic research, whereas other governments tend to support wind turbine development. The difference is also remarkable when looking at the Ministry of Energy funding of energy research. More budgets in other energy technology research tend to be allocated to product development phase than in the case for wind energy. The other important feature of the Danish budgets is that the country has been spending a high amount of the budget (average 16.0% of total energy R&D and average 47.8% of renewable energy R&D) to wind energy technology development since the late 1970s. Although there are some yearly fluctuations, the importance of wind energy in energy R&DD increased from the 1980s and the support was fairly constant during the 1990s (Appendix A-1).

Besides the government R&D programs, transmission system operators have PSO-subsidized R&D programs for non-commercial projects, concerning new and environmentally-friendly energy technologies. The PSO programs are financed by electricity consumers, but their final approval rests with DEA and the responsible minister determines the budgets. Total 31 wind projects were funded with a total support of DKK 91 million since 1998 (Table 5-3) (IEA 2004; IEA 2005).

Table 5-2: Government Wind Energy R&DD Programs in Denmark

Programs	Program Contents
Energy Research Program (EEP, 1976 - present)	First wind energy R&D projects (1977-1979) ▪ Two Nibe turbines ▪ Establishment of the RISØ test station (1978) EEP under Energy Plan of 1981 ▪ Creation of large turbine program and small turbine program to pursued wind turbines of all sizes to be developed for electricity generation. Merger of the two programs in 1989 EEP by DEA (1980s – Present) ▪ Focus on technological possibilities for practical implementation of the national energy policy, reinforcement of exports of Danish technologies and expertise, and international standardization ▪ All project initiated through the annual call for proposal and almost all of them have several partners, industrial participation and co-financing is encouraged. DEA typically finance 50% to 85% of total cost
Development Program for Renewable Energy (UVE, 1982 – 2002)	Programs renew every three year, focusing on the following: ▪ R&DD for new, improved technology ▪ Optimum utilization of the available sites ▪ Removing barriers for sustainable utilization of wind energy ▪ Enhance Danish contribution to international cooperation ▪ Stimulate Danish industry and export Operation of the test station at RISØ from 1982 to 2002 ▪ Secretariat for Danish type-approval and certification scheme ▪ Spot check of type-approved turbines ▪ Inspection of major breakdown ▪ International standardization ▪ Development of test methods for turbines and blades ▪ International cooperation with other test stations for turbines
New Energy Technologies Program (1980-1990)	Stimulate commercial manufacturing of new energy technology, focusing on industrial development project. Between 1980 and 1990, the Danish wind turbine industries received DKK 42 million.
Individual Energy Projects (1982-1989)	Establishment of series of demonstration wind farms
Contract between DEA and RISØ (2003- present)	Administration of type approval scheme
Renewable Energy R&D (2003 – 2005)	DKK 100 million support for three years for renewable energy research projects, administered by the Danish Research Agency

Sources: (Dannemand Andersen 1999; IEA 2004; IEA 2005)

Table 5-3: Non-Government Wind Energy R&DD Programs in Denmark

Programs	Program Contents
EU Public Service Obligation (PSO) subsidized R&D Program (1998 -)	R&DD for non-commercial projects concerning clean energy technologies. Focus is efficiency, costs, reliability of turbines, regulation and forecasting of production, environmental impact, maintenance, and interaction between wind turbines and the power system (e.g., wind plants' abilities to contribute to grid regulation and stability), and environmental offshore demonstration study.

Source: (European Commission 1999; IEA 2005; Krohn 2003b)

Turbine Type Approval and Certification (1979 - Present)

Wind turbine type certification confirms that the particular type of wind turbines in terms of size, form, and use are designed, documented, and manufactured in conformity with design assumptions, specific standards, and other technical requirements. It also demonstrates that it is possible to install, operate, and maintain the turbines in accordance with the design assumptions at a site appropriate for the type. Type certification is applied to a series of wind turbines of the same type, and required for the verification of design for their serial production. It has expiration. Wind turbine manufacturers obtain the certifications in order to demonstrate that a specific wind turbine system or installation (facility) meets the specified standards for key elements such as identification and labeling, design, power performance, noise emissions, and structural integrity.

Table 5-4: Danish Turbine Approval and Certification Scheme

Programs	Contents of the Scheme
Type Approval and System Certificate Program (1979-1990)	▪ Require general design review ▪ Require review of load and strength calculations
Type Approval and Turbine Certificate Program (1991 – December 2004)	For all turbines installed in Denmark after July 1, 1992, and all turbines exported from Denmark in order to obtain export guarantee from the Danish Wind Turbine Guarantee A/S. ▪ Require documentation of basic text results for all design criteria of: load cases and loads; fatigue evaluation; safely level; power curves; and noise emissions ▪ Provide production and installation certification o quality procedures for manufacturing, transportation, installation and subsequent servicing of wind turbines o require manufacturers to have a fully introduced and certified quality assurance system according to ISO 9000 quality system
Type Approval Scheme (December 2004 – present)	Scheme for design, manufacture and installation of both on-shore and off-shore wind turbines, based on IEC system. There are two main elements: ▪ Require type certification (including component certification) based on the following elements: design evaluation; type testing; manufacturing evaluation; foundation design evaluation; type characteristic measurements; final evaluation report; and type certificate ▪ Require project certification based on the following elements: site assessment; foundation design evaluation; installation evaluation; project certificate; and operational and maintenance (O&M) surveillance

Sources: (Danish Energy Authority 2005b; Dannemand Andersen 1999; IEA 1997)

The Danish type approval of wind turbine became the obligation for eligibility for the government investment subsidy in 1979 and for connection to the power grid, and has been performed at the RISØ Test Station since 1978. After the repeal of the investment subsidy in 1989, the turbine certification became a requirement for connection to the grid. The 1991 turbine approval scheme required all installed turbines in Denmark and exported turbines to be certified. The most recent type approval is based on the International Electrotechnical Commission (IEC)[41] 61400 series of standards for wind turbines, which is the mutual basis of

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[41] IEC is the international standards and conformity assessment body for all fields of electrotechnology.

international recognition of certification and type testing performed at national level; as a result, the Danish type approval scheme now has a higher degree of international recognition of certificates from all over the world and provides easier access for all manufacturers to sell their products internationally (Table 5-4).

The Danish type approval schemes define three approval classes: A-type approval is issued for turbine types that obtained a production and installation certificate and documented loads and strength/service life; B-type approval is issued for turbine types that obtained the same certification and documentation as A-type approval plus documentation of items judged to have no essential influence on primary safety could be listed as outstanding items; and C-type approval is used for test and demonstration wind turbines in connection with development of new turbine type and for renovation of old turbines in connection with tests (Danish Energy Authority 2005b; Dannemand Andersen 1999). DEA has been responsible for administration of all the schemes and RISØ manages the approval and certification system as secretariat.[42]

Turbine Ownership Regulations with Criteria for Electricity Consumption (1976-2000)

Denmark placed ownership regulations from the beginning to ensure that local inhabitants were the beneficiary of wind turbines and to remove environmental oppositions and encourage wide acceptance from the neighbors.

Table 5-5: Turbine Ownership Regulations in Denmark

Time Period	Contents of the Regulations
1979 Rule	Allow turbine ownership by wind cooperative but require geographical area of residency of the member owners to live within 3km of the site
1984 Rule	Replace the 3km rule with the demand that wind turbines should be sited within the supply area of the utility company that serves their owners with no limitation to the maximum installed capacity
1985 Rule	Expand the geographical area of residency of wind turbine owners to 10km of the site but limit the share of any individual owner to less than 6,000kWh/year or 135% of the person's electricity consumption
1993- Wind Mill Law	Expand the required geographical area of residency to the neighboring community and the ownership share to 150% of their own yearly consumption Abolish the capacity limit of 150kW
1994 - 1995	Not all the members of a wind cooperative to be required to live near the wind plant, just half of them to allow the utilities and townspeople to participate in a wind project. Expand the size of a cooperative member's share in a wind plant to 20,000 kWh/year, equivalent to an average household's total energy consumption
1996- Transmission Rules	Expand the cooperative ownership of up to 30,000kWh/year by any person who lives or worked in the community or who owns a house or real estate Expand turbine ownership to individuals, including farmers, but require to install turbines on the land owned by the owner
May 21, 2000	Lift all its geographical and quantitative restrictions on wind turbine ownership

Sources: (Guey-Lee 1998; JETRO Copenhagen Office 2003; Moore and Ihle 1999; Van Est 1999)

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[42] The process evolved into a commercial activity for RISØ, by manufacturers paying the full cost of testing and certification fee. Over the years, the government extended the authority to other organizations such as Norske Veritas and Germanischer Lloyd.

The local ownership of turbines was a central part of national policy for the subsidized wind power development during the 1970s and 1980s. During the 1980s the criteria for electricity consumption began being coupled with the ownership regulations, in order to prevent anyone making enormous amount of profit by abusing the government incentives. The ownership rules were continuously updated until May 21, 2000, when all of such regulations were lifted to open up the market for investment by any citizen of the EU in any amount of wind power capacity, as the Danish electricity market was fully liberalized (Table 5-5).

Investment Incentives (1976 – Present)

The Danish government used investment incentives in the form of both direct subsidy and tax reduction from the beginning. In 1979 a direct subsidy was introduced by the Ministry of Trade with the collaboration with the Department of Housing as the first concrete support measure for wind energy.[43] The subsidy was gradually reduced during the following years and repealed in August 1989 after Danish wind turbines steadily increased their reliability and cost-effectiveness.[44] Tax incentives to support investment for private wind turbine installations were also employed from the beginning (Table 5-6).

Table 5-6: Investment Incentives on Domestic Wind Investment in Denmark

Programs	Contents
Investment Subsidy (1976 – 1989)	Subsidy covers certain % of investment cost of wind turbine 30% (1976-1979), 20% (1980-1981), 30% (1982), 25% (1983-1984), 20% (1985-1986), 15% (1987-1988), Repealed in 1989
Full Tax Deduction (1976 – 1996)	Investment in wind turbines and income from wind investment were fully tax deductible
Reduced Tax Incentives (1997 – Present)	Income from wind investment became fully taxable For owners of individually-owned or company-owned turbines ▪ Full tax on the income but tax deductions for 30% annual depreciation of the investment and expenditures on O&M costs For Shareholders in private cooperative ▪ The first DKK 3,000 income from selling electricity from wind plants is tax free and the 60% of the rest is taxed with the usual marginal income tax percentage[45]

Source: (BTM Consult ApS 1998b; Dannemand Andersen 1999; Guey-Lee 1998; Matsuoka 2004; Moore and Ihle 1999), and Kanøe (1991) cited in BTM Consult ApS 1998b)

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[43] The goal was to create opportunities for the Danish industry to make series production capacity. The Energy Plan of 81 shifted the R&D efforts toward smaller turbines as this subsidy stemmed from employment policy.

[44] Cumulative amount of the support for total of 2,567 turbines installed under this subsidy program was about DKK 275 million (Dannemand Andersen, 1999).

[45] Since an individual can own up to 20,000 kWh/year-worth of shares in the cooperatives, this creates a preferable tax condition for cooperative owners who own fewer turbine shares, and used to spread the ownership to as many citizens as possible.

Production Incentives before 2000

The Danish government used production subsidy and feed-in tariff mechanism, which guarantees the long-term minimum price for wind-generated electricity, in order to stimulate wind power production.

The Danish production incentives are closely related to the environmental tax system, as tax began increasing its importance in environmental policy and taking a very tight coupling with energy policy during the late 1980s. Among the three environment-related taxes, energy tax and CO_2 tax directly concern wind energy development.[46] The first production subsidy started in 1981 and gradually increased; it was set at DKK 0.23/kWh in late 1986. This rate was a refund of energy tax on electricity produced by fossil fuels outside the business sector. It was reduced to DKK 0.17/kW in December 1991 but reinforced by the CO_2 tax refund of DKK 0.10/kWh[47] at the same time, which made the total production subsidy DKK 0.27/kWh.

Since 1979, the payment for wind power fed into the power grid and the grid connection costs depended on case-by-case negotiations between the utilities and the wind turbine owners. In 1984 DEA, DWTOA, and DWTMA reached a voluntary agreement on the payment for wind power to be equal to 85% of the retail electricity price and a set of rules for grid connection cost calculation and reinforcement of the distribution grid. The Wind Mill Law of 1992 made this condition mandate, ordering the utilities to pay 85% of the electricity price for household customers to the wind turbine owners who feed wind-generated electricity to the power grid.

These production incentives were cumulative. The Wind Mill Law and direct production subsidy ended on December 31, 1999 as the new mechanism was introduced from January 2000, but the CO_2 tax refund continues.

Table 5-7: Production Incentives before 2000 in Denmark

Programs	Program Contents
Direct Production Subsidy (1981-1999)	To private turbine owners DKK 0.23/kWh (1987-1991) and DKK 0.17/kWh (1992-1999)
CO_2 Tax Refund (1992 – Present)	Refund of CO_2 tax of DKK 0.10/kWh Utilities became eligible for the refund from 1996
Wind Mill Law (1992 – 1999)	Mandate Danish utilities to pay 85% of the electricity price for household customers, excluding charges (electricity tax, CO_2 tax and SO_2 tax from 1996 and VAT and administrative costs) for the wind energy purchased from co-operative and privately owned wind turbines

Sources: (Dannemand Andersen 1999; Guey-Lee 1998; Moore and Ihle 1999)

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[46] The other is the SNOX-law, which aims to reduce SO_2 and NOx emissions by 2005, 60 and 50%, respectively from 1985 levels, was adopted in March 1989.

[47] Utilities that generate wind power only received DKK 0.10/kWh reimbursement of the general CO_2 tax on electricity from 1996.

Transitional Tariff Rules for Green Electricity and Certificate (2000 - Present)

Considering the strong trend of the EU favoring a market-based model, Denmark passed the Danish Electricity Reform Act in June 1999 to change the renewable energy support mechanism upon an assumption that the feed-in tariff mechanism that uses fixed-price instruments does not conform the market principles and the liberalization pursued by the EU; the country decided to shift to a competitive system for wind energy, using the green certificates traded in a special green market in combination with consumer quota for green electricity specified by the government from January 2003, as the Danish electricity market was to open to all EU consumers.

Denmark decided the introduction of the certificate to avoid a conflict between the old feed-in mechanism and the new liberalized competitive market system of Europe. The new mechanism is considered as not a state support in legal terms because the premium is financed as an addition to electricity price per kWh and shared equally among all electricity consumers in relation to their electricity use and the excess cost of renewable energy has been internalized in the electricity price. The scheme was confirmed by the EU in September 2000. Meanwhile the Danish government introduced transitional rules from January 2000 for the introduction of the certificate.

However, the situation did not turned out as the country expected. The EU approval of the continuation of the German feed-in tariff mechanism in 2002 under the liberalized market and the halt of new domestic onshore projects since 2000 under the transitional rules prompted the government to change the rules frequently and the introduction of green certificate has been postponed several times.

The interim tariff schemes were elaborate ones, combining the timing of turbine commission, the age of turbines, and the number of load hours. In general, the interim scheme reduced the purchase tariffs about 28% (DKK 0.60/kWh of rate at the end of 1999 to DKK 0.43/kWh from January 2000) for turbines installed on and after January 1, 2000. Upon the establishment of the green certificate market in 2003, the government was planning to replace the 0.43/kWh of tariffs with the market price of the certificate (Appendix A-2).

With the poor market responses to the new mechanism, however, the Danish government concluded that the scheme was impracticable for the time being, and the introduction of the certificates have been temporarily replaced by a premium of DKK 0.10/kWh in 2003. The scheme up on the DEA web site as of May 30, 2005 states total of the market price and the subsidy as the tariff (Appendix A-3). The market price for electricity is defined as the spot market price at NordPool in the area that the turbine is connected.

Turbine Repowering Schemes

Denmark has placed the incentives to reduce the number of smaller-capacity turbines while increasing the country's wind generation capacity by replacing older and less efficient turbines with newer and more cost effective models (Table 5-8).

Table 5-8: Danish Turbine Repowering Scheme

Programs	Contents
First Replacement Program (1994-1997)[48]	Direct subsidy to replace old small turbines (55kW) with new large ones (600-750kW) and remove the first generation turbines placed before planning and zoning requirements to avoid noise and visual pollution
Danish Electricity Reform Act of 1999 (Spring 2001 - December 2003)	Set aside up to DKK 10 million ($1.5 million) annually. Measures were: ▪ Lower the price for electricity produced by turbines older than ten years ▪ Issue scrap guarantees for machines taken off line between March 1999 and December 2003. For a scrapped turbine of 100kW or less, an owner can receive a guaranteed payment of DKK 0.60/kWh for 12,000 full load hours from a machine with three times the capacity. For turbines of 100 to 150kW investment under the same conditions can be made in a turbine of twice the old unit's capacity. ▪ In addition to their guaranteed ten year base payment, turbines built from 2000-2002 receive at least DKK 0.10/kWh from sales of green credits to consumers or utilities. They will not receive the DKK 0.17/kWh production subsidy.
Replacement Program (late 2004-2009)	Turbines connected to the grid between 4/1/2000 and 1/1/2004. ▪ An extra premium of DKK 0.17/kWh for 12,000 full load hours for the production covered by a removing certificate from a 150 kW or less turbine decommissioned between 3/3/1999 and 12/31/2003. Turbines on land connected to the grid between 1/1/2005 and 12.31/2009 ▪ An extra premium up to DKK 0.12/kWh for 12,000 full load hours for production covered by a removing certificate from a 450 kW or less turbine decommissioned between 12/15/2004 and 12/15/2009. The premium is regulated in relation to the market price as the total of premiums and market price must not exceed DKK 0.48/kWh.

Sources, DEA (www.end.dk) (Dannemand Andersen 1999)

Spatial Planning Regulations

Denmark has three levels of spatial planning: 1) location of turbines, how to be located (individuals, clusters, parks), tower types, color, and distance to roads and dwellings, which are decided at municipality level; 2) issuance of zoning and installation permit and guidelines, which are decide at regional planning at county level; and 3) national planning, which is coordinated by the Ministry of Environment and Energy. There was no consistent planning or siting procedure for wind turbine installation until 1995. Spatial planning regulations began implemented from the mid 1990s to balance wind energy interests against other interests (Table 5-9).

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[48] The scheme was not attractive enough; only 36 turbines were replaced with 31 new turbines (Dannemand Andersen, 1999).

Table 5-9: Spatial Planning Regulations in Denmark

Regulations	Contents
Municipality Planning (1995 – Present)	All Danish municipalities to have planning for siting of reasonable number of wind turbines within their districts as of July 1, 1995
Building Legislation	Installation of wind turbines does not presuppose permission in terms of building codes but type approval
Environmental Protection Act	Wind turbine proximity guidelines decide distance between: turbines and coastlines (300m); lakes and streams (150m); forests (300m), ancient monuments (100m); and churches (300m)

Source: (Dannemand Andersen 1999)

Noise Regulations (1991 – Present)

Noise has been a strong concern over wind energy development from the beginning. The first special legislation on wind turbine noise emission was introduced in May 1991. The Ministry of Environment and Energy Executive Order no. 304 regulates that noise must not exceed 45dB outdoors at the nearest habitation in rural areas and 40dB in residential areas and other noise sensitive areas planned for institutions, non-permanent dwellings or allotment-gardens, or for recreation. In case of complaints, emission measurements are performed according to the legislation, i.e., on a plate on the ground at a distance of 1-2 times the hub height of the turbine. Noise imission at the dwelling of the complainant is then calculated (Dannemand Andersen 1999).

Grid Connection and Reinforcement Policy

In 1979 the Ministry of Environment ordered the utilities to provide system-approved wind turbines to the power grid and to pay fair rates for electricity fed into the grid. In 1984, the utilities began paying 35% of the grid connection costs.

The Executive Order on Grid Connection of Wind Turbines was issued in 1996, and then the Danish Electricity Reform Act of 1999 formalized the areas of existing practice with regard to the grid connection. According to the Order and the regulations, local power distribution companies are obliged to provide grid connection facilities at any site that municipal planning designated for wind turbine installation. In other cases, power companies are obliged to allow wind projects grid access to the local gird, but the extension to the grid is to be paid by the owner up to the point of connection. Necessary reinforcement of the gird must be paid by the power companies, but the wind turbine owners must pay for transformer and rental fee of electricity meter. Reactive power consumption is not charged.

Agreement with Utilities

The Danish government has forced the utilities to participate in wind development by forming agreements that obligate them to install wind power projects from 1985. The agreements were replaced with new ones over years, as the targets of the old ones were met (Table 5-10).

Table 5-10: Utility Agreements in Denmark

Agreements	Contents
First 100MW agreement (1985)	Mandated to be fulfilled within five years. Fully implemented in 1992, including Vindeby Offshore Wind Farm (1991)
Second 100MW Agreement (Energy 2000, 1990-1995)	Mandated to be fulfilled by the end of 1993. Fully implemented in 1996, including Tunø Knob Offshore Wind Farm (1995)
Third 200MW Agreement (1996)	Mandate to fulfill by the end of 1999
Energy Plan of 1996	Reaching a target of 1500MW owned by private sector and utilities by 2005. Targeted to be reached by the end of 2000
First 750MW Offshore Agreement (1997)	Five large offshore farms to fulfill 750MW installation between 2001 and 2008

Offshore Policy and Regulations

Denmark started exploring the opportunities for offshore wind farm from 1977. The effort accelerated during the 1980s, as the first 100MW agreement between the utilities and the government in 1985 soon encountered the difficulties of securing land and gaining permission to site large scale wind farms on land. The Ministry of Energy set up a Committee for Offshore Wind Farms in November 1987 and began searching for suitable sites and technology. Two studies (1987, 1995) were conducted to explore regulatory condition for offshore development and to create a mapping of potential sites.

After two demonstration farms were constructed as a part of the government-utility installation agreement during the 1990s, the Danish Electricity Reform Act of 1999 formalized the following regarding the future offshore wind farm development: 1) the right to exploit energy from water and wind within the territorial waters and the economical zone (up to 200 miles nautical miles) around Denmark belongs to the Danish Government; 2) procedure for the approval of electricity production from water and wind and pre-investigation of such within the national territorial waters and within the economical zone belong to Denmark; and 3) establishment of a central tender procedure as well as an alternative procedure.

The establishment of offshore wind farm requires a permit and license for operation after submitting Environmental Impact Assessment and going through public hearings. The six offshore wind farms built since 1991 have demonstration status, which obligates the comprehensive environmental measurement and monitoring; in particular, investigation of the effects of the marine environment has been conducted in these farms, along with evaluation of economic and technical aspects (IEA 2003).

Export Assistance/Development Assistance Programs

Both DANIDA and RISØ have been actively involved wind energy technology transfer and development in developing countries since the early 1980s. In terms of export policy, a couple of export assistances have been provided for the Danish companies to seek opportunities oversea, in order to strengthen the Danish industry position in the world. However, the support has been indirect; there have never been official direct export policy or financial schemes to support export of Danish turbines (Krohn 1998).

Tax benefits on oversea wind project investment was provided to increase Danish investments in the United States between 1986 and 1989, which helped the Danish manufacturers continue to export their turbines to the US market after the California market crash of 1986. In this scheme, the Danish investors in the US wind projects received tax benefits and a Danish firm TIFCO helped the tax arrangement for those Danish investors (Madsen 2005).

Table 5-11: Danish Export/Development Assistance Programs

Schemes	Contents
Wind Turbine Guarantee Company (late 1980s -)	The private company warrants long-term finance of large projects with Danish wind turbines outside Denmark, in order to guarantee project performance and insurance to find willing investors to oversea projects.
DANIDA Development Aid program	Providing bilateral grants and project development loans to qualified importing developing countries in order to strengthen the Danish industry position. The grants are typically tied aids that require using Danish technologies; 50% of contract value must be of Danish origin, and the grants are provided to form joint ventures that pave a way for future development using soft loans tied to the purchase of Danish equipment directly or setting up a licensing agreement with Danish firms to manufacture locally. Such loans have lower interest rates and longer payback periods than market loans, but the exact terms are determined by importing country government.
RISØ WindConsult (1980-)	RISØ help international wind energy projects and engage in direct technology transfer activities. The services include: ▪ engage in design and supply of equipment for technology centres and in building type approval and certification schemes ▪ offer wind turbine tests and measurements ▪ offer consulting services and technical assistance in all technical phases of wind farm development and implementation in close collaboration with recipients on contract with DANIDA, UNDP, the World Bank, and EU-programmes, as well as private investors, industry, power companies, banks and others ▪ study the feasibility of various types of wind power projects ▪ provide dedicated training based on training needs assessment for capacity building at RISØ or on location

Sources: (Guey-Lee 1998; Van Est 1999), http://www.risoe.dk/windconsult/

5.2.2 Germany

The main wind energy policy instruments in Germany have been feed-in-tariff system, investment subsidies, R&D supports, the 100MW/250MW programs, and investment assistances through loan programs. There had been also tax benefits through linear depreciation as well as promotion policies by several states.

Research, Development and Demonstration (R&DD) (1977 - Present)

Wind energy R&DD program in Germany started in 1974. R&DD programs were the only substantial measure in Germany to push renewable energy during the 1970s and 1980s.

The failure of the Growian projects led the government to concentrate on smaller-scale turbine development from 1986 to 1989. Demonstration projects became a part of the R&D program in the 1980s, and several of them subsidized the investments in wind turbines (Hemmelskamp, 1998 cited in Jacobsson and Lauber 2006). During the 1990s, the federal R&D program became co-financed by the industry and the supports for diverse types of projects continue until today (Appendix A-4), but in general, the German renewable energy R&DD has shifted its focus from R&D to demonstration.

Wind energy R&DD is a part of Energy Research and Energy Technology Program by the federal government. The fourth phase of the program has been administered by BMBF since 1996 and by BMWi since December, 1998. In addition, BMWi initiated Investment Program for the Future (ZIP) from 2001, and BMU published a new R&D strategy for renewable energy in November 2004 (Table 5-12).

Total R&DD budget goes to wind energy in Germany is larger than that of Denmark. However, the ratio of wind energy R&DD to the total budget is much smaller (average 3.5% of total energy R&DD and average 18.6% of renewable energy), as Germany has much larger total budget for energy R&DD in general than Denmark. The annual growth rate of wind energy R&DD is 4.1%, compared to 16.5% of Denmark. The large budget was allocated to wind in the early 1980s when the total energy R&DD increased, but the amount decreased in the late 1980s. The importance of wind energy in energy R&DD definitely increased in the 1990s again; the ratio of wind energy budget in total energy R&DD increased gradually from 1993 and the fourth phase of Energy Research and Energy Technology Program from 1996 pushed the budget to over USD 30 million, while the total energy R&DD budget was reduced. In recent years the wind energy R&DD budget has been decreased, compared to that of 1990s (Appendix A-5).

Table 5-12: Government Wind Energy R&DD Programs in Germany

Programs	Program Contents
R&DD in the 1970s and 1980s	3MW Growian I (1979 -1988) funded by BMFT 10MW Growian II funded by BMFT and the European Community 46 projects for turbine development in various scale (1977 – 1991) Demonstration programs from the 1980s
Energy Research and Energy Technology Program	Aim of the 4th Phase (1996 -) - Support of basic research for: ▪ Improvement of performance and reliability of existing techniques; ▪ Development and demonstration of technological concepts for the future 250MW Wind Program El Dorado (see Oversea Development Assistance program) Scientific Measurement and Evaluation Program (WMEP) (1991- 2006) ▪ Data measurement of turbines installed under the 100MW/250MW Wind Program through the contract with ISET. Phase IV (July 2000-) covers operation of turbines that were not installed by the 250MW Program
Investment Program for the Future - ZIP (2001-)	Support for R&D projects of environment-saving energy technologies during a limited period of three years by annual budgets of EUR 41 million. Offshore Measuring Platform Program ▪ 3-4 Platforms in the North and Baltic Sea to collect offshore data for the certification of offshore wind systems and operators o Part A - technical and meteorological measurement o Part B - biological investigations
New R&D Measures by BMU (November 2004 – Present)	Main goals for wind are as follows: ▪ Reduce the costs and to increase the yield of electricity from wind energy by: improving adjustment and monitoring technology; using new materials; optimizing offshore foundations; reducing mass of wind turbines; reducing mechanical loads on wind turbine structures/ foundations; upgrading automation in the production process of wind turbines; and improving measuring and testing technologies ▪ Integrate large amounts of electrical energy produced from wind: o conceptions for grid integration of offshore wind farms o technologies for power management in the grid o improvement of yield prognosis o specific aspects of energy storage with respect to wind energy ▪ Conduct ecological research along with offshore wind energy deployment

Sources: (IEA 2001; IEA 2002a; IEA 2003; IEA 2004; IEA 2005)

Federal Combination Program - 100MW/250MW Wind Program (1989 – 1996 for subsidy and data analysis, the latter continues until 2006)

The technology-push only policy for wind energy changed in 1989; the federal government began providing the first combination program of market stimulation and scientific program. The 100MW Wind Program was created to stimulate technology development and the manufacturing industry building and to acquire statistical data on the operation of wind turbines simultaneously. The target of the program was upgraded in 1991 to 250MW and their statistical measurement was operated until 2006.

The program provided the investment subsidy grants for installation and operation of wind turbines at suitable sites, but only for private investors, not for utilities. In addition to a guaranteed production subsidy per kWh (DM 0.06-0.08/kWh), the subsidies up to 25% of the investment costs with a maximum ceiling[49] were available to private investors. The last grants were approved in 1996 for the turbines to be connected to the grid by the mid 1998.

The projects were selected in order to encourage a wide range of experiments from different applicants for various types of turbines. All turbines installed under the program by receiving the financial support were required to be monitored and analyzed for ten years under the Scientific Measurement and Evaluation Program (WMEP) (Table 5-12).

Production Incentives (1991 – Present)

The Law on Feeding Electricity from Renewable Sources into the Public Network (Electricity Feed-in Law, EFL) came into effects on January 1, 1991, in order to increase the share of electricity produced by renewable energy sources. The law mandated the utilities to accept electricity produced by independent wind turbines and to pay a fixed rate to it, equal to 90% of the retail residential price.[50] The payment was put on top of the 100/250MW program subsidy as well as various state program benefits. The Amendment of the EFL came into force in April 1998; it did not influence the tariff structure but specified financial charges by different utilities and set a date for reconsideration. The EFL was effect until March 31, 2000.

Although the EFL was a very effective measure to start and flourish the German wind energy market, the law had a few difficulties: 1) the tariffs were not financed from taxes but from revenues of the utilities, which distorted the competition among the utilities; 2) the premiums were applied only to the non-utility sector and the utilities were not eligible; and 3) because the tariffs were based on the utility revenues, they went down when electricity prices, hence the revenues, went down, and this was especially evident after the market liberalization of 1998. There features of the EFL caused prolonged oppositions from the utilities and some regional rate payers.

A new law, the Renewable Energy Source Act (EEG) replaced this original feed-in law and became operational on April 1, 2000. The EEG continues and strengthens the basic principles from the EFL, while aiming to double the share of renewable energy in total energy consumption by 2010, committing strongly toward climate change mitigation, addressing the liberalization of the EU electricity market, and easing the problems of the EFL mentioned above. The biggest controversy was whether or not the feed-in mechanism is in conflict with the EU State Aid rules or with the rules of the Single Market. In March 2001, the EU Court confirmed that the feed-in mechanisms are not in conflict with either rules and the feed-in schemes are being preserved in both Germany and Spain.

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[49] The amount of ceiling changed over the years.

[50] Tariffs for biomass, hydro, sewage and landfill gas installation under 0.5MW are 80% of retail residential prices, and tariffs for hydro, sewage and landfill gas installation between 0.5 and 5MW are 65% of retail residential prices.

Table 5-13: Production Incentives in Germany

Programs	Program Contents
Electricity Feed-in Law (EFL, 1991- 3/2000)	Mandated German utilities to accept electricity produced by independent wind turbines and to pay a fixed rate, equal to 90% of the retail residential price, for electricity from wind and solar power, putting on top of the 100/250MW program subsidy as well as various state program benefits. The regulatory authority fixed tariffs for one-year period based on the value of the average utility revenue per kWh sold, drawn from an official statistics.
1998 EFL Amendment (1998- 3/2000)	Not influence the tariff structure but specified the financial charges of different utilities and set a date for reconsideration. 5% cap on electricity generated by renewable resources
Renewable Energy Source Act (EEG, 4/2000 - Present)	Require grid operators, not utilities, to pay the feed-in tariffs, but the utilities still have obligations to take the electricity produced from renewable energy sources. The payment is put on top of the 100/250MW program subsidy as well as various state program benefits. Wind energy premium tariffs are EUR 0.091/kWh (DM 0.178/kWh) for five years (nine years for offshore wind farms commissioned before 2007) from the date of commissioning, and the possible extension above five years will be decided by an algorism.[51] From January 1, 2002, the tariffs will be reduced by 1.5% annually for new installations commissioned between 2002 and 2004, and reduced 2% annually for new installation after 2005.[52] The expiration date of the tariffs is 20 years from the installation.
2004 EEG Amendment (7/21/2004 - Present)	Make it compulsory for grid operators to give priority to feeding electricity from renewable energies into the grid and to pay fixed prices Reduction of onshore wind premium, but improvement of offshore premium tariffs from nine years to 12 years for projects commissioned before 2010

Sources: (Lauber and Mez 2004; Wustenhagen and Bilharz 2006)

The EEG has the following important features: 1) the tariffs are not dependent on the market price of energy but are defined by the law for the period of 20 years; 2) the grid operators whose grid is closest to the renewable energy installation pay the tariffs and their costs are covered by an additional fee aided by all consumers, although the utilities still have obligations to take the electricity produced by renewable energy sources; 3) the same premium tariffs are applied to both utilities and private investors; and 4) the tariffs are different for different renewable energy sources, and are decreased over the years in order to take technological learning curves into account.

The EEG was amended on July 21, 2004 to differentiate and develop the framework for electricity from renewable energies further. The Amendament grants priority to renewable energy sources and makes it compulsory for the grid operators to give a priority and pay the fixed prices to electricity fed by renewable energies into the grid.

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[51] The algorism favors sites with less wind resources in relation to a reference site (mean wind speed of 5.5m/s at 30m above ground, a logarithmic wind shear profile and a roughness length of 0.1m for each site.

[52] The tariffs are only paid to the generators within the territorial scope of the Act, or within Germany's exclusive economic zone, and cover both on-shore and off-shore projects.

Table 5-14: Feed-in Tariff Rates for Wind under EFL (DM/kWh)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Rate	0.1661	0.1653	0.1657	0.1693	0.1728	0.1721	0.1715	0.1679	0.1652	0.1613

Source: (Lauber and Mez 2004)

Table 5-15: Feed-in Tariff Rates for Wind under EEG (EUR cents/kWh)

		2000-01	2002	2003	2004 EEG Amend.	Annual Reduction	
						From 2002	From 2005
Onshore	< 5 yrs	9.1*	9.0	8.87	8.7	1.5%	2%
	> 5 yrs	6.19	6.1	6.01	5.5		
Offshore	< 9 yrs	9.1	9.0	8.87	9.1**		
	> 9 yrs	6.19	6.1	6.01	6.19***		

* 9.1 EUR cents = 0.178 DM/kWh

** applied for 12 years to offshore projects commissioned before 2010.

*** applied to all other offshore projects.

Source: (Wustenhagen and Bilharz 2006)

Investment Assistance – Federal Loan Programs for Renewable Energy Projects (1990 - Present)

Investment assistance, providing low interest loans for renewable energy projects, has been also available to address capital market failure.

Table 5-16: Low Interests Loans by National Banks in Germany

Loan Programs	Contents
Environment and Energy Saving Program of the European Recovery Program (ERP, 1990 -)	Available for up to 50% of the cost of a wind project, provided to the project undertaken by small companies with an annual turnover up to EUR 250 million, self employed people or public-private partnerships. Private households can apply up to 100% of qualifying costs up to 20 years. Interest is 0% for the first two years, increasing by 1% each year thereafter.[53]
Environmental Fund by DtA and KfW (1990 -)	Available over ten, 15, and 20 years at interest rates 1-2% lower than market rates for up to 75% of the capital investment, or 100% for small and medium-capacity companies.

Sources: (Lauber and Mez 2004; Moore and Ihle 1999; Wind Power Monthly 2002a)

Two federal loans have been administered by the state-owned Deutch Ausgleichsbank (DtA) (Table 5-16). One is the environment and energy saving program of the European Recovery Program (ERP), which taps into the funds created under the Marshall Plan. The other is the environmental program under DtA and KfW. Small farmers and cooperatives are encouraged to use the latter. Between 1990 and 1995, more than 1,500 wind projects were granted the ERP loan and the Kfw and DtA loan, and about 80% of all turbines installed by 1998 were supported by these loan programs (Krohn 1998). In addition, the agricultural financing institutes offer low

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[53] In western Germany, up to ten year loans are available (15 years for construction projects) with up to two years of grace on repayments. Loans in the east are for 15 and 20 years, respectively, with up to five years grace before repayment. The loan limit is EUR 0.5 million in western Germany and EUR 1 million in the east. The limits can be exceeded for environmental projects (Wind Power Monthly. 2002a).

interest loans for wind turbine investment by farmers. Up to 90% of the investment can be financed by the loan.

Fiscal Incentives

Fiscal incentives for wind project investments were also provided in a form of tax benefits. However, the government reduced the benefits over the years in order to shift the source of an investor's earning from tax savings to power generation (Table 5-17).

Table 5-17: Tax Incentives for Wind Projects in Germany

Regulations	Contents
Depreciation	Reduce investor taxable income by about 10% of the turnkey cost per year with a linear depreciation ▪ Until the end of June 1997: linear depreciation of ten years ▪ From July 1997: linear depreciation of 12 years ▪ From January 2000: linear depreciation of 16 years
Taxable Income Deduction	▪ Projects applied before March 5, 1999: No limits on the amount of income tax deduction (All losses could be subtracted) ▪ Projects applied after March 5, 1999: o A DM 200,000 cap on total deduction in all investments (wind investment losses can be fully offset against gains in other investment earning). Beyond the cap, only 50% of wind investment losses can be tax deductible. o Special tax write-off rules allowing artificially high accounting losses, applicable only in eastern Germany, have been abolished. o Wind project financing companies are no longer allowed to actively advertise wind investment as tax write-off.

Sources: (Guey-Lee 1998; IEA 2001; Wind Power Monthly 1999a)

Eco-tax (1999 - Present)

The eco-tax reform, passed in April, 1999, introduced a tax on consumption of electricity except that from renewable energy sources and raised the exiting mineral oil taxes on petrol, diesel, natural gas and various mineral oils. DM 0.02/kWh of the tax was added to the overall prices of electricity, but did not raise the wind feed-in tariffs. Tax levels increased in five steps by 2003, and a part of the revenues is used for promotion of renewable energy (Lauber and Mez 2004).

Spatial Planning Regulations (1994 – Present)

Before 1994 there was no ways for communities to stop turbine siting, as most of wind installations were built under the utility privilege permitted to the facilities for public electricity generation or the farm-related buildings built freely by farmers. In 1994, the first spatial planning restrictions and regulations were introduced in order to create ease for large wind projects in terms of land development as well as encourage harmonious development with their neighbors. In the same year, a court order blocked installation of single turbine over 100kW in non-built up areas, denying the wind turbine privilege. However, the 1997 Building Statue Book Amendment restored the wind turbines privilege, made it easier to gain building permission, and forced every local community to create wind turbine zoning.

Table 5-18: Spatial Regulations in Germany

Regulations	Contents
1994 Court Restriction	Block the installation of single turbine over 100kW in non-built up areas. Single turbines with rated capacities higher than around 80 kW can only be installed after a building plan or area usage plan has been drawn up and passed by local government.
1997 Amendment to Building Statue Book	Reintroduction of privileged status to single wind turbines in open countryside by giving single wind turbines the same status in planning law as farm building, radio masts and nuclear power stations, making it easier to gain building permission from the beginning of 1997. Local authorities are given the greatest decision making power, and every local community is mandated to present zoning plan appropriate for wind turbines. Without wind turbine zoning, privilege is given to wind turbine.
Licensing Procedure (2001 – present)	Require wind installations of three or more turbines to be approved under the Protection against Emissions Act. Projects under five turbines undergo a simplified procedure, while stations of 6 to 19 machines must undergo the full procedure. Projects of 20 or more turbines must always have an EIA. Individual or a pair of turbines needs to be licensed under the old building law system.

Sources: (Wind Power Monthly 1996g; Wind Power Monthly 2001d)

Grid Connection and Reinforcement Policy

The turbine owners in Germany must pay for any costs incurred by grid reinforcement or extension caused by wind turbine installation. A new rule from January 2000 decided that power stations including wind plants will not have to pay the grid use charges like other electricity market players. In addition, the grid users have become to pay a single, all inclusive annual charge, and the distance dependent components, where extra charges were levied for transmission over longer distance, were dropped.

Noise Regulation

The Federal Clean Air Act of 1974 forms the legal base for noise pollution in Germany.

Table 5-19: Noise Regulations in Germany

Area	Day	Night
Industrial Area (Industrial/business & commercial)	70 dB / 65 dB	70 dB / 50 dB
Mixed residential area and Industry or Residential areas mixed with industry	60 dB	45 dB
Purely residential areas with no commercial developments (General Residential/Pure Residential)	55 dB/ 50 dB	40 dB/ 35 dB
Areas with hospitals, health resorts, etc.	45 dB	35 dB
Note: Calculation of sound propagation is done according to DIN ISO 9613-2. All calculations have to be done with a reference wind speed of 10m/s at 10m heights.		

Sources: (Pedersen and Halmstad 2003)

Environmental Regulation on Blade Materials (1995 –Present)

From January 1995, styrol emissions during the production of rotor blades using polyester have to be 20 parts per million (ppm) or below.

Turbine Certification and Approval (1992 – Present)

The turbine certification is governed not by the federal laws but by the state laws in Germany. However, there are a common set of regulations for loads, towers, and foundations, as there is general consensus among the states on requirements for building structures and loads even though the building laws are not a federal law. On the other hand, the rules for safety systems and requirements on machinery and electrics may vary among states. A type approval granted in one state is valid in other states. The German Institute for Civil Engineering is responsible for development of new regulations.

The German type approval has two components: examination of loads and machinery that is carried out only by the testing bodies approved in accordance with legal regulation such as CIWI/ECN, Germanischer Lloyd, RISØ, and TÜV; and approval of tower and foundations that can only be carried out by the authorities. Electrical systems are not checked by a third party. There is no commonly agreed set of rules and standards on examination of machinery. In 1993 the standards requiring power curves to be determined by the qualified organization were adopted, and the grid compatibility testing was added in the mid 1990s (Sawin 2001). Many designs were approved with reference to Germanischer Lloyd's Regulations (Nath et al. 1999).

Table 5-20: An Example of Approval and Certification Service in Germany

Policy	Contents
Certification and Approval of the Design	Verification of the fatigue and extreme loads ▪ Assessment of the safety and control system ▪ Safety configuration and operational assumptions ▪ Design assessment by thorough recalculation for: rotor blades and machinery components; tower and foundations; electrical components and control system Power curve measurement Grid compatibility testing Review of the operating and maintenance instructions
Approval of Tower and Foundation	Evaluation of the structural components includes investigation of strength and of the service life of these key components
Product certification and manufacturing inspections	▪ Inspection and approval of materials and components ▪ Review of material and quality assurance records ▪ Production supervision for blades, machine components, tower and foundations

Source: (TUV Industrie Service GmbH)

Federal and State Industrial Policy

After the reunification of 1990, the federal government offered subsidies for industries in the former East Germany to build up production plants, in order to stimulate industrial development there (Michaelowa 2004). At state level, some states also had explicit and implicit industrial policy to protect the German wind turbine manufacturers and suppliers and created a temporary quasi-protected market from foreign manufacturers for the German manufacturers to increase domestic supply. At the end of the 1980s, for example, the state of North Rhein-Westfalia created a program that only the Tacke turbines were eligible for 50% of the investment subsidy (Tacke 2000, cited in Johnson and Jacobsson, 2000). Enercon was also benefited from the state policy; it helped to sell its turbines to the local utilities (Johnson and Jacobsson 2000), and the strong local bias helped Husumer Schiffswerft (HSW) as supplier of turbines to its local market as well (Johnson and Jacobsson 2000).

State Support Policies for Market Development

Many state governments have provided wind energy promotion policy through investment subsidies, tax incentives and soft loans. For the period of 1991-97, total support at state level (EUR 218 million) actually exceeded than those at federal level (EUR 148 million) (Neij et al. 2003). In general, those policies were consistent over the years or gradually reduced, but not increased. Six states (Bremen, Mecklenburg – Vorpommern, Neidersachsen, Rheinland-Pfalz, Scheleswig-Holstein) withdrew their support policy by 1997. With the great success with the federal feed-in tariff mechanism, most of the states stopped their support programs for wind after 2000, while some inland states continued direct funding supports, e.g., Nordreihn-Westfalia.

Table 5-21: Summary of State Support Policy in Germany until 1999

State	Promotion Scheme Contents	
Baden-Württemberg	1996 1997 -1998	Investment Subsidy (25%) Soft loans with 3% lower than market rate for 15 years with ceiling
Bayern	1993 -1999	Investment subsidies (30% of cost, reduced to 10% from 1996) with a ceiling
Bremen	1993 - 1995	Promotion according to nacelle height, rotor diameter, location and investment cost with a ceiling of 33% of investment cost
Brandenburg	1993 - 1999	Investment subsidies (rates varied between 20% to 30% of cost) with a changing ceiling
Hamburg	1993 - 1997 1994 - 1998	Investment subsidies (30% of cost, reduced gradually to 5% in 1997) Production incentives of 0.10 DM/kWh for ten years
Hessen	1993 - 1999	Investment subsidies (rates were gradually reduced from 50% of cost to 20% in 1996) Maximum ceiling applied from 1997 according to plant size
Mecklenburg - Vorpommern	1993 - 1997	Investment subsidy (rates were gradually reduced from 20% of cost to 10% in 1997)
Neidersachsen	1993 - 1994	Subsidy for turbine cost
Nordrhein Westfalia	1993 - 1998 1996 - 1999	Investment subsidies with various methods of determining ceiling (percentage of investment cost in 1993, subsidy per rotor diameter combined with noise level from 1994 to 1998) Soft loans with 3.5% to 4% lower than market rate for ten to 11 years
Rheinland-Pfalz	1993 - 1997	Investment subsidies (20% to 25% of cost) with a ceiling
Saarland	1993 - 1999	Investment subsidy (20% of cost) with a ceiling
Sachsen-Anhalt	1993 -1999	Subsidy for 30% of installation and commissioning cost with max 3,000 DM /kW
Scheleswig-Holstein	1993 - 1996	Subsidy for turbine cost (up to 17% of cost from 1994)
Thüringen	1993 - 1999	Investment subsidies with a ceiling

Sources: Interpolated from (BWE 1993; BWE 1994; BWE 1996; BWE 1997; BWE 1998; BWE1999)

Offshore Policy (2000 – Present)

The German offshore policy started with the EEG, which created the framework for offshore wind development (Table 5-22). In 2001 offshore wind development was begun discussed by the representatives of research institutes, associations that concern wind energy, and the ministries intensively. BMU published a report in June 2001, which set the future development targets (500MW by 2007 2,000 to 3,000MW by 2010, and 25,000MW by 2030).

ZIP initiated offshore measurement platform projects in 2001, and the first offshore measuring platform FINO 1 was built in 2003. With these intensive efforts since 2000, the German government formulated the Strategy of the German Government on the Use of Offshore Wind Energy. A stricter permission procedure is required for offshore projects (IEA 2005).

Table 5-22: Offshore Development Policy in Germany

Policy	Contents
EEG (2000 and 2004)	Provide the tariff system for offshore plants (Table 5-15). Define offshore plants as the ones in German territorial waters and the German zone outside of the 12 nautical miles zone, or the German exclusive economic zone.
Offshore Measurement Platform under ZIP (2001 - Present)	Hydrological, meteorological, oceanographic, environmental and physical data collection for the construction of offshore wind plants in the North Sea
Strategy of the German Government on the Use of Offshore Wind Energy	Sets the target to install 2,000 MW by 2010. Default conditions are: ▪ Natural, environmental and economic viability ▪ Step-by-step approach implementation taking into consideration technical, economic, and legal uncertainties ▪ Clarification of the legal situation within the 12-nautical miles zone and in the Exclusive ▪ Set up of Economic Zone (EEZ) (environment/ nature protection, investment security) and the resulting revision of the Federal Nature Conservation Act and Offshore Installations Ordinance ▪ Expansion of technical and ecological research ▪ Identification of suitable areas, considering competing forms of use in the EEZ areas such as fisheries, extraction of mineral resources, navigation, military uses, and environment protection.

Sources: (IEA 2002a; IEA 2003; IEA 2005)

Oversea Development Assistance Programs (1991 – Present)

Germany has had three oversea aid programs: El Dorado Program, Technical Expertise for Renewable Energy Application (TERNA), and Public-Private Partnership Program (Table 5-23).

El Dorado Program is an export assistant program for the German manufacturers and offered financial supports for those which embarked on export to developing countries in other climate zones.

Meanwhile, GTZ started the third-world development and technical assistance in wind energy (TERNA) in the late 1980s by focusing on stand-alone installation of 50-70 kW capacity turbines. GTZ shifted its focus to grid-connected wind development then. Unlike the DANIDA support, TERNA does not have the purpose of stimulating the use of German turbine technology but providing neutral and objective advice to the third world; it has been very successful.

Another GTZ program, Public-Private Partnership Program, started in 2003, offers project investment support for the oversea projects.

Table 5-23: Oversea Development Aid Programs by German Government

Programs	Contents
El Dorado (1991 – 1999)	Export assistance program to give wind turbine manufacturers a chance to test and demonstrate their machines in other climate zones and strengthening the German industry position in those countries. Administered by BMFT until 1998 and then by BMWi ▪ Grants up to 70% of the purchase price of the technology and the cost of its international transport ▪ Support amounted to about 50% of the total cost of each venture
Technical Expertise for Renewable Energy Application (TERNA) I & II (1995 - Present)	Provide neutral and objective advice to the third world on potential wind projects. Administered by GTZ ▪ TERNA helps: searching for funding (TERNA itself does not provide finance); wind resource finding and measuring; building cooperative relationship with the developing country agency; and assisting pre-feasibility study ▪ Project initiation by developers for TERNA support by pushing the local utility to receive government backing for its TERNA application. No application for relevant government involved required.
Public-Private Partnership Program (2003 – Present)	Encourage private investors to undertake wind energy projects in developing countries. Administered by GTZ Sustainable Energy System's department. ▪ GTZ providing technical and advisory support ▪ GTZ offering a limited guarantee to participate in the program; if the results of a feasibility study for wind station do not look promising, the developer can claim back 33% of the costs of the study, or 50% if tit has commissioned another company to carry out the work. The upper limit for reimbursement is EUR 100,000.

Sources: (Abramowski and Posprski 2000; Guey-Lee 1998; IEA 2001; Wind Power Monthly 1996h; Wind Power Monthly 2003a)

5.2.3 EU-Wide Initiatives for MW-class Wind Turbine Development

In addition to the R&DD supported by national governments, multinational European R&D collaborations started during the mid 1980s.

The EU programs continuously supported the development of large-scale wind turbines, even after the attempts by many national governments failed and they withdrew their programs during the 1980s. The EU programs turned their focus from developing radical new concepts to upscaling successful turbine designs in the 1990s. The main objective was to develop large turbines suitable for the incorporation into the utility grid.

JOULE Program – WEGA and THERMIE

The EC has been the center of such collaborations. The EC support was provided through a R&D program called JOULE (energy R&DD program by the EU). Within JOULE, wind specific R&D for development of large turbines is called WEGA Program.[54] WEGA was extended into two phases: WEGA I during the 1980s and WEGA II during the 1990s.

WEGA I started in 1984 and built three MW-class experimental turbines by 1986: Tjaereborg 2MW in Denmark built by a Danish utility subsidiary; AWEC-60 1.2MW in Spain built by a Spanish and German consortium; and Richborough 1MW in the United Kingdom by a Scottish engineering firm and a former UK utility. A common feature of the three WEGA I turbines was that they were based on strong academic principles although they were built by very different groups of companies. They also had similarities in their three bladed configuration and size. However, they all suffered from major problems in the first year of operation. The evaluation of design and operation of the three machines did not provide the foundation for commercially viable large-scale wind turbine technology due to their extreme weight and high manufacturing cost (Harrison, Hau, and Snel 2000).

Meanwhile, the EC also paid attention to smaller turbines in order to take commercial viability into the future development. Based on the result of the three WEGA I turbines and the successful commercial experiences of the manufacturers of small and medium-capacity turbines, WEGA II was launched in order to develop MW-class turbines with significantly lighter weight than the WEGA I machines. The strong focus of WEGA II was the commercialization of such turbines and the involvement of the most successful industrial companies such as Bonus, Enercon, Nordex, Nordtank, Micon, Tacke, and Vestas. Between 1993 and 1995, a variety of completely new prototypes of horizontal-axis MW-class turbines were developed by the participating manufacturers through the support from WEGA II. The WEGA II machines were erected and fully evaluated between 1994 and 1996 and the developers of those machines were obligated to perform full measurement and evaluation during the test phase (Harrison, Hau, and Snel 2000).

The other EU program is the THERMIE Program, which is the demonstration phase within JOULE. The aim was to demonstrate commercial potential of machines used in unusual locations and conditions. A number of wind turbines with rated capacity between 700kW and 3MW were supported. Some turbines were supported in conjunction of WEGA II and THERME.

JOULE also covers a wide range of wind R&D outside of WEGA. The focus of such R&D efforts, for example, includes generic research of crucial technical areas (verification of aerodynamic tools, issues related to lightening, electromagnetic interference, and grid connection), highly innovative turbines for cost reduction, turbines for alternative sites, certification and standardization, and stand alone and desalinization system.

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[54] WEGA stands for Wind Energie Groß Anlagen in German.

5.2.4 India

The main policy instruments to promote wind energy in India from 1990 have been investment assistance through soft loans, tax benefits on wind energy investment income, state feed-in-tariff system, R&DD and resource assessment, and offering direct third party sales, banking and wheeling benefits to wind power producers. In particular, policies implemented after 1991 have had significant impacts on wind energy development.

Research, Development and Demonstration (R&DD) (1984 - Present)

The government-led R&DD programs were two of the main components of wind energy support started in the 1980s. The focus of R&DD efforts changed over the years.

Table 5-24: Government Wind Energy R&DD Programs in India

Programs	Program Contents
R&D in the 1980s	Focus on indigenous turbine prototype development in collaboration with BHEL (produced 20kW/50kWw/200kW turbines)
Demonstration Program (1985- Present)	Demonstrate new types of wind turbines or opening up new potential areas or locations up to 10MW of commercial project potentials ▪ Need to be initiated and implemented by the state governments, SEBs or SNAs ▪ Demonstration sizes need to be between 2MW and 6MW ▪ 60% of equipment costs are available
Market focus of R&D efforts (1992 – Present)	R&D focus more on commercialization through: expansion of the market; cost reduction; efficiency and capacity increase; and overcoming Indian-specific technical conditions (low wind, grid connection, and the field testing of newly designed machines and components) Demonstration focus on technological and economic viability of technologies and applications and on opening up the new areas for commercial projects to attract financial resources
Industry Collaboration Focus of R&D (1997 to Present)	R&D focus more on providing generic information/knowledge to innovate components/sub-systems suitable for the Indian specific conditions Three R&D models involving the industry, research institutions and laboratories,[55] academic institutions and end-users. ▪ Industry in-house R&D model: 50:50 cost share between the industry and MNES ▪ Consortium model: Consortium members to share at least 50% of the project cost with MNES ▪ Industry and MNES joint entrustment of R&D project to an institution or research laboratory: funding to the institution ▪ In all models, the industry/institution contributing 50% of cost has the right on commercialization of the obtained technical know-how. Custom duty exemption for goods for R&D projects undertaken by any company with in-house R&D unit approved by GOI
Five Generic Areas of R&D Focus (2003 –Present)	Indigenous design/manufacturer of all types of turbines by 2012 Technology support to become net foreign exchange earner by 2012 Performance improvement of existing turbines (CUF from 17% to 25% by 2012) Human resource development Research support for wind resource assessment and micro-siting

Sources: (MNES 1997a; MNES 2002/2004/2006; MNES 2004)

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[55] Besides the C-WET, Electronics Research and Development Centre, National Aerospace Laboratories, and Corporate Research and Development Division of BHEL, are the R&D institutions for wind energy.

During the 1980s, the Indian wind R&DD was focusing on development of indigenous turbine prototypes. The demonstration program started in 1985. The direction of the wind energy R&DD in India changed its priority in 1992 to a more market-driven approach. Focusing only on the indigenous turbine development became impractical, considering the rapid technology advancement and the large capital requirements for wind turbine R&D at technology frontier from the late 1980s as well as the R&D budget restriction posed by GOI. Since 1997, the R&D efforts became focus more on government-industry collaboration by encouraging in-house R&D effort by supporting the industry's R&D proposals on cost-sharing basis as well as by trying to strengthen the connection among R&D institutions by the establishment of the R&D Unit in C-WET.

The actual R&DD expenditure of MNES to wind energy over the years is not available. However, a comparison of the expenditure among various energy ministries indicates the tight budget situation of MNES; it has only received less than 4% of total energy-related-government expenditure since the inception of DNES. This small budget has been then divided into several divisions that support different non-conventional energy technologies (Appendix A-6).

National Wind Resource Assessment Program (1983 – Present)

The wind resource assessment program started in 1983, in order to assess the overall wind potential in India by using the collected data and to identify suitable sites for wind energy projects. The network of meteorological laboratories gathered information and analyzed data on wind availability through wind monitoring, wind mapping and complex terrain projects. The first Wind Energy Data book was published in 1983. MNES also uses several private organizations in India and abroad to conduct comprehensive wind resource assessment by using the state-of-art technique (MNES 1997a). Since 1999 C-WET has taken over the wind resource assessment task. The resource assessment also continues on-going basis after the projects are commissioned, as the project monitoring recommended since 1995 became a mandate in 1999. Total of 540 monitoring stations were built by March 2005 (Consolidated Energy Consultants Ltd. 2005). The data gathered by the program has significantly influenced state wind energy policy formation.

The data collected from 1983 had some problems, as it was collected through the methods and sites that were based on aviation and meteorological purpose (Winrock International India 2003). During the 1996-97 year, MNES upgraded the wind power potential estimate based on new and larger turbine sizes. As a result, the initial numbers of around 20,000 MW were upgraded into the gross potential of 30,000 MW. MNES again upgraded the potential to 45,000 MW in 1999, assuming 1% of land availability for wind projects in the potential areas (MNES 1999a). Technical potential, which indicates the resources that can be practically exploited with the current infrastructure, is currently estimated at 13,390 MW, assuming 20% grid penetration, which can increase with the augmentation of grid capacity. In total, only 30% of gross potential can be extracted in technically feasible ways and the gross-technical potential ratio varies considerably among states (MNES 2005).

Economic Reforms of 1991 and New Policy Direction for Wind Energy

By the beginning of the 1990s, India had amassed an unsustainable level of public debt and faced an unprecedented level of economic crisis. As a result of industrial policy with heavy regulations and restrictions controlled by bureaucrats since the Independence of 1947, the Indian business suffered from the lack of transparency of business environment, stagnant private and foreign investments, heavy government spending on inefficient public enterprises, and the lack of technological progress. The country suffered from inflation, high budgetary deficit, and foreign debt, increasing government duties and taxes, and low GDP per capita. The limited liberalization attempts taken during the 1980s were insufficient to overcome those economic problems. The fiscal imbalance diverted household savings to public consumption and reduced the amount of resources available for private investment. Due to the restrictions on foreign investment and trade, India faced a balance of payments crisis in early 1991 and its foreign exchange reserves reached the all-time low. GOI attempted a series of short-term policies to finance imports and meet its immediate debt service obligations, which included using its gold stock to obtain foreign exchange, utilizing special facilities of the IMF, and gaining emergency assistance from Germany and Japan. Eventually, however, GOI had no choice but to embark on a program of more fundamental economic reforms and reduce the role of the government in economic development (Bajpai 2002; Bath 1998).

The reforms have covered a wide range of sectors, including the power sector. As a part of the reforms, on July 25, 1991, India announced new Industrial Policy, aiming at a shift from resource-based manufacturing to technology-intensive manufacturing and services and allowing both domestic and foreign private investments. The policy was the first substantial step taken by GOI to liberalize the excessive restrictions on foreign investment, industrial licensing, trade practices, foreign technology, and the private sector, thereby to create greater transparency and competition and to establish market-oriented economic system (Bajpai 2002). This general industrial policy direction also became the direction of wind energy sector industrial policy. New R&D/investment/fiscal/trade policies as well as financial incentives for demand creation have been introduced to the sector since 1993.

In line with the general economic reforms, MNES created the Strategy and Action Plan of 1993 that set the following new direction for renewable energy development: 1) focusing the government's limited budgetary resources on demonstration projects; 2) extending the institutional finance from IREDA and other financial institutions for commercially viable projects with private sector participation and attracting external assistance from international and bilateral agencies; and 3) promoting private investments through fiscal and financial incentives as well as through facilities for wheeling, banking of power for the grid and the appropriate pricing for wind power provided to the grid. These three elements became the core concept of new policy for the wind energy sector, and MNES began focusing on the commercialization-focused programs (Gupta 1995; MNES 2002b; TERI 2001).

Investment Assistance – IREDA Soft Loan (1989 - Present)

IREDA started soft loans to the wind turbine manufacturers, SNAs and SEBs in 1989. It was only after 1991 that IREDA expanded its loans to project finance by private investors. As mentioned already, the soft loans have been funded by various multilateral and bilateral international assistances and operated as a revolving fund.

Three basic schemes have been available for the wind energy sector since 1991 (Table 5-25).[56] The interest rates are slightly lower than market rates. The payment has one year moratorium. Until June 1997, the borrowers needed to fund a minimum of 40% of the cost themselves. Since then the amount was reduced to 20% to 30% of the cost. At the same time, the payback period was extended from eight to ten years (Wind Power Monthly 1997d).

Table 5-25: Three Basic IREDA Wind Energy Soft Loan Schemes in India

Schemes	Contents
Wind Farm Project Financing Scheme	For private developers to finance wind farms ▪ six to ten years of repayment periods ▪ one year moratorium ▪ require minimum 25% to 30% contribution from promoter ▪ lending up to 70 to 80% of total project cost and/or 100% equipment cost for farms on lease basis
Equipment Financing Scheme	Available to finance equipment (wind turbine, tower, control panel, transformer, reactive power) and compensator necessary to build wind farms ▪ eight to ten years of repayment period ▪ one year moratorium ▪ require minimum 20% to 25% contribution from promoter ▪ lending up to 75 to 80% of total project cost
Manufacturing Equipment Financing Scheme	Available for wind turbine manufacturers to finance wind farms developments and market assistance ▪ one year moratorium ▪ require minimum 25% to 30% contribution from promoter ▪ Lending up to 75% of total project cost for development and up to 70% of last three years average or expected expenditure on market assistance promotional efforts (including export promotion)

Sources:(IREDA 2002a; IREDA 2002b and 2006; IREDA 2002c; Jagadeesh 2000; MNES 2002/2004/2006)

The IREDA interest rates have changed over the years in accordance with the lending institutions' term and the market conditions. In the 1992-93 year, the rates were 12%, but they were raised between 14% and 16% in the mid 1990s. The rates were further increased to 18 - 21% (18% for project financing and 19% for equipment financing) in 1996 and the high rates continued until May 1997. In June 1997 the interests for project financing was cut to 15.5%. The rates were 14-16% during the late 1990s, but fell to 11.5-14.5% in the early 2000s. From 2003 the rates were lowered to 9.5%-11.5%, with repayment periods between seven and ten years (Gupta 1995; IREDA 2002b and 2006; Jagadeesh 2000; Sasi and Basu 2002; Wind Power Monthly 1997b; Wind Power Monthly 1997d; Wind Power Monthly 2000b; Wind Power Monthly 2004).

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[56] In addition, IREDA also offers loans for grid interconnection and T&D facility building: Grid Interconnection Facility Scheme is offered to the eligible SEB/Utility, and Financing Guidelines for Renewable Energy Users is offered to finance building T&D facility.

Investment Incentives (1989 – Present)

Fiscal policy and incentives specific to wind projects was first introduced in 1989. Then the 1993 Income Tax Rules began placing very lucrative incentives.

In late 1996, as a new administration took the office, GOI reduced the levels of incentives and changed the tax planning procedure; by lowering tax rate and imposing Minimum Alternative Tax (MAT), GOI reduced the immediate tax benefits to the investors and encouraged the developers to actually operate to make real profits on their investments (Rajsekhar, Van Hulle, and Jansen 1999; Singh and Bretz 1999).[57] In general, the corporate tax on domestic companies, including those which engaging in wind energy business, was reduced to a uniform 46% for both closely- and widely-held companies. The domestic corporate tax was further reduced in April 1997 to 35%, then to 30% in April 1998, meaning a parallel decrease in the size of tax exemption (Aitken 1994; Bath 1998).

The tax breaks for wind turbines are more lucrative for projects built in the first half of the Indian financial year, which runs from April to March next year. If turbines are installed before September, the investor is entitled to the 100% tax depreciation for that year and can write off total cost of the turbines against tax. However, if turbines are installed between October and the end of March next year, only 50% of the depreciation is allowed for the current financial year and another 50% must be taken in the next year.

Table 5-26: Fiscal Policy and Incentives for Wind Energy in India

Schemes	Contents
1989 Tax Scheme on Wind Power Project	Tax breaks to deduct the entire cost of equipment in the first year from pre-tax profits
1993 Income Tax Rules	Five-year 100% tax holiday on income from sales of wind electricity 100% depreciation on investment in capital equipment related to wind power plants in the first year Zero-Tax planning (possible to avoid paying corporate tax on incomes of their registered companies and corporations) by combining various tax rebates and exemption and 100% accelerated depreciation
1997 Tax Rules	Introduction of Minimum Alternate Tax (MAT) on wind project ▪ 12.9% MAT on book-value profits (return on equity) imposed on the companies that chose the 'zero-tax' planning, while 100% first-year depreciation continued. Lowering tax rate for the companies with higher book-value profits than investments on wind power projects ▪ Reduced marginal corporate tax rate (from 46% to 35% in April 1997, further to 30% in 1998)
April 1999 Tax Rules	11.4% MAT Rate
April 2000 Tax Rules	8.4% MAT Rate
April 2001 Tax Rules	Ten-year tax holiday on income from sales of wind electricity
2003 Tax Revision	80% of first year depreciation on and after 4/1/2003

Sources: (Consolidated Energy Consultants Ltd. 2005; MNES 1995a; Rajsekhar, Van Hulle, and Jansen 1999)

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[57] IREDA also increased interest rates for loans to set up wind farms during this period.

Foreign Direct Investment (FDI) Policy (1991 – Present)

Foreign Direct Investment (FDI) policy was one of the most significant changes made by the economic reforms of 1991. The door to foreign investments was substantially widen in 1991, when GOI permitted financial collaborations, joint ventures and technical collaborations, capital market via EUR issues and private placements or preferential allotments for the 35 high-priority, capital intensive and hi-technology sectors, including the power sector and renewable energy facilities.[58] The Ministry of Industry also began streamlined its approval process for foreign investment projects. The automatic approval route for FDI was created in 1991 to permit foreign equity participation up to 51% in the 35 high-priority sectors (Bajpai and Sachs 2000).

Import Duty (1993 – Present)

Another important policy change of 1991 was a new trade policy, in particular the changes in custom duty. The Foreign Trade (Development & Regulation) Act of 1992, which repealed the Import and Export (Control) Act of 1947, changed the attitudes toward trade entirely from prohibiting or controlling to regulating and facilitating imports and exports from India. Tariff mechanisms have become the measure to regulate trade. The licensing restrictions and discretionary control regarding trade were abolished.

Between 1991 and 1994, GOI trimmed the upper level of import duties from 400% to 65%, and made the rupee fully convertible on trade and current accounts. Tariff rates on imported power equipment, including wind turbine sets, were reduced to 20%, and the duty on capital equipment fell into 25% (Bath 1998).

The import duty for wind turbines has been changed frequently since then. No import duty was posed on up to ten components of wind turbines between 1993 and 1995. However, the duty on raw materials of rotor blades was 80%. In 1997 GOI raised the duty for components but eliminated the 80% duty on rotor blade materials. The import duty rate on components was lowered in 1998. From 2002 the import duty became uniform 5%. However, the duty on four turbine components (sensors, flexible coupling, brake hydraulics, and brake calipers) was increased from 5% to 25% in 2003. This policy was removed in July 2004, and the import duty has become uniform 5% on all components (Table 5-27).

In the 2000-01 year, GOI permitted MNES to issue the Duty Exemption Certification, which can wave the necessity of declaration on critical components required for wind turbine erection and for spare parts.

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[58] Industries that have been liberalized for foreign investments are 35 high-priority industries: export/trading/star trading houses; hotels & tourism industry; 100% EOUs and units related industry; sick industries; mining; telecommunications; power; medical clinics/hospitals/shipping/oil exploitation/deep sea fishing/with licenses; industries reserved for small-scale industries; housing/real estate/business centers & infrastructure facilities/portfolio investment; government securities; units in UTI; public sector mutual funds; and private sector mutual funds (Bajpai and Sachs. 2000).

Table 5-27: Import Duty on Wind Turbine Sets and Components in India

Items	Import Duty Rates					
	1993-3/1997	4/1997-3/1998***	4/1998-3/2002	4/2002-3/2003	4/2003-6/2004	7/2004-Present
Generators up to 30kW	25%	37.86%	29%	5%	5%	5%
Wind Turbine Parts/ Components* **Special bearing** **Gearbox** **Yaw components**	0%**	22%	9%			
Turbine controllers **Sensors** **Brake hydraulics** **Flexible coupling** **Brake calipers**					25%	
Rotor blades*		12%	9%		5%	
Rotor blade parts*		0%	9%			
Raw materials for rotor blades	80%	0%	N/A			

Duties are total effective duties that combine basic duty and special duty.

* For both manufacture and maintenance purpose

** Import duty exemption was up to ten components

*** A prerequisite to clearing imports will be a requirement for the importer to furnish a certificate to the customs authorities from an officer of the rank of deputy secretary and above at MNES. MNES clearance required for each and every shipment, the whole procedure could be time consuming and arduous.

Sources: (IWTMA 2002; Khanna 1998; MNES 2002/2004/2006; Wind Power Monthly 1996c; Wind Power Monthly 1997c; Wind Power Monthly 2003c)

Manufacturing Incentives (1993 – Present)

In addition to import duty, the 1993 tax rule set wind turbines to be exempt from excise duty and sales tax. In 1998, the exercise duty system was changed; while the first parts of wind turbines and rotor blades have no exercise duty, the spare parts need to pay both exercise duty and sales tax in order to encourage high quality production and assemble of the first parts to avoid the replacement (IWTMA 2002).

Industrial Clearance (1991 – Present)

Industrial clearances were eased to encourage private investment in the power sector after 1991. No clearance is required from CEA for power generation projects up to INR 1,000 million as well as for setting up of any renewable energy projects.[59] For wind projects, the forest clearance and environment are the most important requirements in terms of environmental clearance. Land availability from the state government and financing from CEA and financial institutions such as IREDA are also required as non-statuary clearance (MNES 2001b).

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[59] Beyond this limits, statuary clearance is required for the projects to submit cost estimates as well as techno-economic clearance such as greatest possible economic output of electric power, transmission lines and systems and site location to CEA.

Wind Energy Estate

In 1994 MNES and IREDA jointly introduced "Wind Energy Estates," the joint sector companies that can be formed by a private developer, state government or its Boards or Corporations, and MNES/IREDA. Their equity capital participation is set to 51%, 25% and 24%, respectively (Jagan 1995).

Wind Energy Estates set up wind farms in windy areas where fully developed plots that would be provided for installation of wind turbines by individual investors. The joint sector companies acquire and lease the land, develop infrastructure and grid facilities, obtain the necessary clearances, and install/operate/maintain wind turbines on behalf of the investors. The objectives of the formation of the Estates are to encourage the ownership of a small number (one or two) of turbines and diversify the market base, reduce the project gestation period, provide infrastructure facilities, and reduce the cost for investors.[60]

Export Market Development

MNES has been very active to cultivate potential foreign markets through its financial and consultancy services to other developing countries. Need-based consultancy services and expertise are provided by SNAs, technical institutions, autonomous organizations and freelance experts in India. MNES has been a contact point to coordinate such international cooperation.[61] IREDA also provides the export promotion through its market development assistance loan.

Technology Upgradation Fund (TUF) by Ministry of Textile (April 1999 – February 2005)

Technology Upgradation Fund (TUF) by the Ministry of Textile offered a 5% reimbursement on the interest actually charged by financial institutions on the sanctioned textiles projects that include wind energy equipment for captive power generation by textile business entities. The scheme was available from April 1, 1999 to February 22, 2005.

Quality Standards (1995 – Present)

In 1995 MNES issued the first guidelines for wind power projects, which required all turbines have the turbine approval and certification from the recognized foreign agencies, submit the Detailed Project Reports (DPR), and perform measurements after the project commissions, in order to reduce any abuse of the government incentives and address geographical inconsistency of wind policies across the states. The recommendations on the guidelines have been revised several times and they became mandate in May 1999 (Table 5-28).

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[60] The first joint company was set up in the State of Madhya Pradesh in 1995. This company has performed well and declared dividends of 20% in both years of operation, 1995-96 and 1996-97. The second company was set in Kerala. Andra Pradesh, Maharashtra, and Karnataka, in particular, have been requested by MNES to promote this concept in order to benefit small investors (MNES. 1997a).

[61] As of March 2001, the MNES provided the consultancy services to 12 countries (Cuba, Morocco, Tunisia, Philippines, Sri Lanka, Bangladesh, Bhutan, Mali, Nepal, Senegal, Namibia, and Uganda) (MNES. 2001a).

Table 5-28: Quality Standards by MNES Guidelines

Revisions	Contents
Guidelines for Wind Power Projects (July 1995)	▪ Mandate wind power producers to submit wind power project reports to SNA/SEB ▪ Advise developers to site wind projects on locations approved by MNES based on National Wind Resource Assessment ▪ Require turbine approval from recognized foreign agencies and manufacturing surveillance by third party for the project approval as well as for the eligibility for the IREDA loans ▪ Require performance estimates, physical verification of the project at the time of commissioning by MNES and SNAs, monthly performance reports, and proper maintenance
Revised Guidelines for Wind Power Projects (June 1996 Revision)	▪ Mandate wind power producers to obtain clearance in the form of No Objection Certificates (NOC)[62] ▪ For projects up to 1MW capacity, require detailed project report (DPR)/ application that cover: site selection and micro-siting; selection of equipment; capital cost/means of financing; annual energy output; cost of generation; captive generation or sale; planned operation and maintenance systems; and quality aspects
Turbine Approval and Certification (February 1997 Revision)	▪ Require all wind turbines to be subject of third-party testing and quality assurance evaluation and subsequent certification only by recognized foreign agencies. ▪ Certification to be based on: design evaluation; evaluation of manuals; and type testing for power performance including power curve test and safety/function test ▪ Prohibit any use of second-hand wind turbines imported abroad ▪ The quality aspects of the require project report covers: certification of wind turbines; grid parameters at minimum monthly power factor of 0.85; quality system adopted; minimum monthly average power factor; O&M contract; spare-parts stock; supplier manufacturing base and installation support infrastructure; and a detailed monthly performance monitoring[63]
Turbine Approval and Certification (May 1999 Revision)	Removal of "foreign agencies only" requirement for certification and allow the manufacturers to perform self-certification, with penalty if the turbines fail to perform the their own certification standards
Turbine Approval and Certification (October 2000 Revision)	▪ Category-I: C-WET to validate turbine certification issued by designated foreign agencies and certified them with TAPS-2000 requirements ▪ Category-II: C-WET to verify modifications by the Provisional Type Test/Measurements based on TAPS-2000 requirements for turbines with foreign certified turbines with minor modifications ▪ Category-III: C-WET to evaluate new types of turbines by the Provisional Type Test/Measurements based on TAPS-2000 requirements.

Sources: (MNES 1995b; MNES 1996b; MNES 1997b; MNES 1999b; MNES 2000b)

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[62] No Objection Certificates are the approval and clearance given by the State Authorities to the developers in order to proceed a proposed project. Tamil Nadu was the first state to issue NOC to wind power project from 1986 (TNEB, 2002).

[63] If the projects fail to achieve the minimum monthly average power factor of 0.85 at the metering point, the guidelines gave the authority to SEBs to impose a penalty (MNES. 1996b).

After the establishment of testing facility at C-WET in 1999, the first Indian own turbine certification scheme, the Turbine Approval Provisional Scheme (TAPS) 2000, was created to issue turbine certification based on the Indian wind and grid conditions in 2000. Before 2000, most of the turbines supplied in India had the certifications based on the European sites and grid conditions from the internationally accredited certification bodies. TAPS-2000 categorizes wind turbines 225kW and above into three groups. C-WET was designated to perform TAPS-2000 in October 2000, but the self-certification by manufacturers was also permitted until March 31, 2004 (Table 5-28).

1993 MNES Guidelines for State Policy (1993 –Present)

In September 1993, MNES issued the guidelines to all states, regarding promotional and fiscal incentives for wind project development for the first time, in order to guarantee no restriction on generation capacity or supply of electricity to the grid from non-conventional energy sources and set up the general rules for: operation period; producer eligibility; grid interfacing; facilities by SEBs and other incentives; application and clearances; and guidelines for fixing purchase process. The most important part of the guidelines was the facilities by SEBs, which stated wheeling, banking, and purchase of power for grid-connected wind power projects, and other incentives to stimulate the private sector investment (Gupta 1995; MNES 1995b). The original guidelines (Table 5-29) and the subsequent revisions became mandatory in May 1999.

Table 5-29: 1993 MNES Guidelines for State Incentives

Main Contents of 1993 MNES Guidelines
▪ Facilities by SEBs
o Wheeling: Direct SEBs to make the state gird available to wind energy producers for captive use or the third party within the state, at a uniform wheeling charge of 2% of the tariff-value of electricity wheeled along the grid
o Banking: Direct SEBs to permit to bank the electricity generated for up to one year
o Feed-in Tariffs: Direct SEBs: 1) to purchase wind electricity from the producer at a minimum rate of INR 2.25/kWh with 5% annual escalation; 2) pose no restriction on the time or quantum of electricity; and 3) offer options of captive usage and third party sales within the state for the producer.
o Electricity duty exemption for captive consumption
o Exemption of energy tax on consumption of electricity by wind power producer
o Exemption from power cut to the extent of 30% of the installed capacity of the producer
▪ Grid Interfacing
o Producers to install a current limiting devices such as thyristors and capacitors that maintain power factor always above 0.80
▪ Infrastructure development policy
o Producers to bear the entire cost of interfacing and maintenance including transformers, metering, and grid extension
o Other infrastructure facilities (approach roads, water supply, crane, power during construction periods) to be covered by the line of industrial estates
▪ Other Incentives
o Sales tax benefits to power producer, tax incentives/concessions and subsidy available for new industrial unit and unit in backward areas[64]

Sources: (Gupta 1995; MNES 1995b)

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[64] See details on (Gupta, 1995; MNES, 1995b).

State Policy – Production and Investment Incentives

State policies play the significant roles in India due to the institutional setting of the power sector; each state government determines its own wind policy, regarding wheeling (feeding wind electricity to the nearby grid while the power producer using the same amount of electricity at distant location), banking (feeding wind electricity to the grid and using the same amount later), third party sale (selling wind electricity directly to other power users via the grid), feed-in tariffs paid to the producer by SEBs, and all other incentives.

The 1993 MNES guidelines encouraged many states to start their own wind energy policy. However, wind support policy in each state started in different times and there has been little consistency among the states. In some states, the support policy has changed significantly over the years. The responsibilities to formulate feed-in tariffs and other charges have been transferred from SEB/SNA to SERC of each state after the enactment of the 1998 Electricity Regulatory Act. Many states started new wind policy in recent years; however, the charges on wheeling and banking are set high, reflecting poor financial health of SEBs and their efforts to compensate the significant T&D losses. The 2003 Electricity Act allows third-party sales in all states. However, this is still subject to the SERC decision of each state.

The tables below illustrate the development of wind energy policy in six important states (See Appendix A-7 for policy by other states).

Tamil Nadu

Tamil Nadu was the first state that placed support policy for wind energy, long before the MNES 1993 guidelines was issued. Tamil Nadu strongly promoted demonstration projects from the 1980s, and reflected the accumulated experiences on their early state policy (Table 5-30).

Gujarat

Gujarat was another state that started the demonstration projects in the 1980s that helped to formulate its state support policy. Gujarat completely withdrew state policy in March 1998, following a slight policy modification in 1997. In June 2002, the state announced a new policy (Table 5-31).

Table 5-30: Support Policy in Tamil Nadu

Time Period	Wheeling Charge	Banking	Feed-in Tariffs	Third-Party Sales
Pre 1993 – 3/1996*	2% of power generated	One year 2% charge	INR 2.00/kWh in 1994-95 INR 2.75/kWh in 1995-96	Allowed with 15% wheeling charge (1994-95)
4/1996 – 3/2001*		One Month 2% charge	INR 2.25/kWh in 1996-97 5% annual escalation based on 1996-96 tariff ***	Not allowed
4/2001 – Present **	5% of power generated	One financial year 5% charge	INR 2.70/kWh*** No escalation for five year	

* In addition, capital subsidy of 10% of project cost with a ceiling of INR 15 lakhs was available until 1996-97 fiscal year. Exemption of generation tax was available until 2000-01 fiscal year. Penalties for reactive power charge of INR 0.1/KVARH (quantum of reactive power) started from June 1995. The charge was increased to INR 0.30/KVARH in June 1999, and again to INR 1/KVARH in April 2000.

** Infrastructure charges of INR 28.75/MW and application/processing fee of INR 11,000/application are applied. In addition, from May 2002, reactive power charge of INR 0.30/KVARH if the ratio of reactive power drawn to kWh exported is 10% or less and INR 1/KVARH for more than 10%.

*** TNEB has been too financially strapped to keep 5% annual increase between 1996 and March 2001 and the tariff of INR. 2.70/kWh after April 2001. Only INR 2.25/kWh has been paid in reality. TNEB claims the balance will be paid as and when the utility's financial health improves.

Sources: (Consolidated Energy Consultants Ltd. 2005; MNES 1995a; MNES 1996a; MNES 1997a; MNES 1998; MNES 1999a; MNES 2000a; MNES 2001a; MNES 2002a; MNES 2003; MNES 2004; MNES 2005; Winrock International India 2003)

Table 5-31: Support Policy in Gujarat

Time Period	Wheeling Charge	Banking	Feed-in Tariffs	Third-Party Sales
1994 – 1997*	2% of power generated	6 months	INR1.75/kWh No escalation	Not allowed
1997 – 3/1998**				
6/2002 – Present***	4% of power generated		INR 2.60/kWh INR 0.05 annual escalation based on 2002-03 tariff for ten years	

* Land was leased on the 15-year term, and sale tax and electricity duty were exempted.

** Sales tax exemption and deferment were available up to 50% of investment.

*** Reactive power charge INR 0.1 per consumed power and application/processing fee of INR 50,000/MW are applied. Electricity duty exemption and exemption from power cut are available to the extent of 30%.

Sources: (Consolidated Energy Consultants Ltd. 2005; MNES 1995a; MNES 1996a; MNES 1997a; MNES 1998; MNES 1999a; MNES 2000a; MNES 2001a; MNES 2002a; MNES 2003; MNES 2004; MNES 2005)

Maharashtra

Maharashtra first placed its support policy in 1995. The state began implementing a new policy with the strong fiscal and financial incentives in December 1999, which ended in March 2002. The newest policy began in November 2003 (Table 5-32).

Andhra Pradesh, Karnataka and Rajasthan

The states of Andhra Pradesh, Karnataka and Rajasthan have offered the following policy (Table 5-33).

Table 5-32: Support Policy in Maharashtra

Time Period	Wheeling Charge	Banking	Feed-in Tariffs	Third-Party Sales
1995 – 12/1999	Allowed	Allowed* up to 20% of energy generated	INR 2.25/Kwh 5% annual escalation based on 1994-95 tariff	Allowed
12/1999 - 3/2002**	2% of power generated	One Year	INR 2.25.KWh 5% annual escalation based on 1997-98 tariff	
11/2003-Present ***	2% of power generated for wheeling plus 5% for T&D loss	One Year	INR 2.25.KWh 5% annual escalation based on 1994-95 tariff for Group1 and 2**** INR 3.50/kWh with INR 0.15/kWh annual increase for Group 3*****	

* Banking was for three month in 1996-97 fiscal year and became one year after 1997.

** Although this policy itself was created in 1998, the state did not implement it until December 1999 when the new administration took the office at the state. In addition to the above, capital subsidy of 30% of project cost subject to maximum INR 20 lakh, and sale tax exemption up to 100% of investment were available.

*** Reactive power charge INR 0.25 per consumed power and application/processing fee of INR 50,000/MW. No electricity duty for five years for captive use and Green energy fund are available for 100% of cost of approach road and for 50% of power evacuation arrangement cost as subsidy. No interest loan is available for 50% of power evacuation arrangement cost.

**** 5% tariff escalation is set differently for the following three groups:

Group 1 (projects commissioned before 12/27/1999): annual increase of compound basis for the first ten years, no increase for the next three years, and then 5% increase for the next seven years.

Group 2 (project commissioned between 12/27/1999 and 3/31/2003): annual increase of for eight years. Then the producer needs to sell power in the open market. Increase to be simple rate.

*****Group 3 (project commissioned between 4/1/2003 and 3/31/2007): INR 3.50/kWh for the first year with INR 0.15/kWh annual increase for a period of 13 years

Sources: (Consolidated Energy Consultants Ltd. 2005; MEDA 2001a; MEDA 2001b; MEDA 2002; MNES 1995a; MNES 1996a; MNES 1997a; MNES 1998; MNES 1999a; MNES 2000a; MNES 2001a; MNES 2002a; MNES 2003; MNES 2004; MNES 2005)

Table 5-33: Support Policy in Andhra Pradesh, Karnataka and Rajasthan

<table>
<tr><th>State</th><th>Time Period</th><th>Wheeling Charge</th><th>Banking</th><th>Feed-in Tariffs</th><th>Third-Party Sales</th></tr>
<tr><td rowspan="4">Andhra Pradesh</td><td>1994 – 3/1997*</td><td rowspan="3">2% of power generated</td><td>One Year 2% charge*</td><td>INR 2.25/Kwh</td><td rowspan="2">Allowed</td></tr>
<tr><td>4/1997 – 3/2000**</td><td rowspan="2">One Year</td><td rowspan="2">INR 2.25/Kwh 5% annual escalation based on 1997-98 tariffs (until 3/2000) and 1994-95 tariffs (from 4/2000)
INR 3.48/kWh in 2003-04</td></tr>
<tr><td>4/2000 - 3/2004***</td><td rowspan="2">Not allowed</td></tr>
<tr><td>4/2004 – Present ****</td><td>Vary between INR 46/kWh and 60/kWh</td><td>N/A</td><td>INR 3.37/kWh
No escalation</td></tr>
<tr><td colspan="6">* 8 months banking was allowed from August to March. Capital subsidy of 20% of project cost subject to max. INR 25 lakh and 20-year long land lease with free rent for the first five years.
** Capital subsidy of 20% of project cost subject to maximum INR 25 lakh.
*** Reactive power charge of INR 0.1 per consumed power.
****Reactive power charge of INR 0.1 per consumed power, infrastructure development charge of INR 10 lakh/MW, and application/processing fee of INR 5,000/MW are applied.</td></tr>
<tr><td rowspan="5">Karnataka</td><td rowspan="2">1994 – 3/1997*</td><td rowspan="3">2% of power generated</td><td rowspan="2">One year (July – June)*</td><td>INR 1.75/kWh in 1994-95</td><td rowspan="5">Allowed</td></tr>
<tr><td rowspan="3">INR 2.25/kWh
5% annual escalation base on 1994-95 tariffs</td></tr>
<tr><td>4/1997 – 3/2000**</td><td>One year</td></tr>
<tr><td>4/2000 – 12/2004***</td><td>20% of power generated</td><td>2% per month for one year</td></tr>
<tr><td>1/2005 – Present****</td><td>5% of power generated</td><td>2% charge</td><td>INR 3.40/kWh
No escalation for ten years</td></tr>
<tr><td colspan="6">* Banking had one month grace period. Land-lease for a period of 50 years, capital subsidy same for other industries, and exemption of electricity duty for five years were available.
** Exemption of electricity duty for five years was available.
*** Capital subsidy of max INR 25 lakh, electricity duty exemption for five years, and reactive power charge of INR. 0.4 per consumed power were applicable. Feed-in-tariffs were INR 3.25/kWh and INR 3.10/kWh for projects commissioned before 8/31/2003 and from 9/1/2003 to 12/31/2004, respectively.
**** Application/processing fee of INR. 30,000/MW and electricity duty exemption for five years.</td></tr>
<tr><td rowspan="2">Rajasthan</td><td>4/1999 – 10/2004*</td><td>2% of power generated</td><td>One year</td><td>INR 2.75/kWh in 1999-01
INR 2.89/kWh in 2001-04
5% annual escalation base on 1999-00 tariffs</td><td rowspan="2">Allowed</td></tr>
<tr><td>10/2004 – Present**</td><td>10% of power generated</td><td>One calendar year</td><td>INR 2.91/kWh for the first year, then INR 0.05/kWh annual escalation until 10th year, then INR. 3.36/ kWh until 20th year</td></tr>
<tr><td colspan="6">* Exemption of electricity duty for five years was available.
** 50% exemption of electricity duty for seven years is available. Reactive power charge of INR 0.25 per consumed power and application/processing fee of INR. 50,000/MW are applied.</td></tr>
</table>

Sources: (Consolidated Energy Consultants Ltd. 2005; MNES 1995a; MNES 1996a; MNES 1997a; MNES 1998; MNES 1999a; MNES 2000a; MNES 2001a; MNES 2002a; MNES 2003; MNES 2004; MNES 2005)

Section 5.3: Wind Energy Market 1990-2005

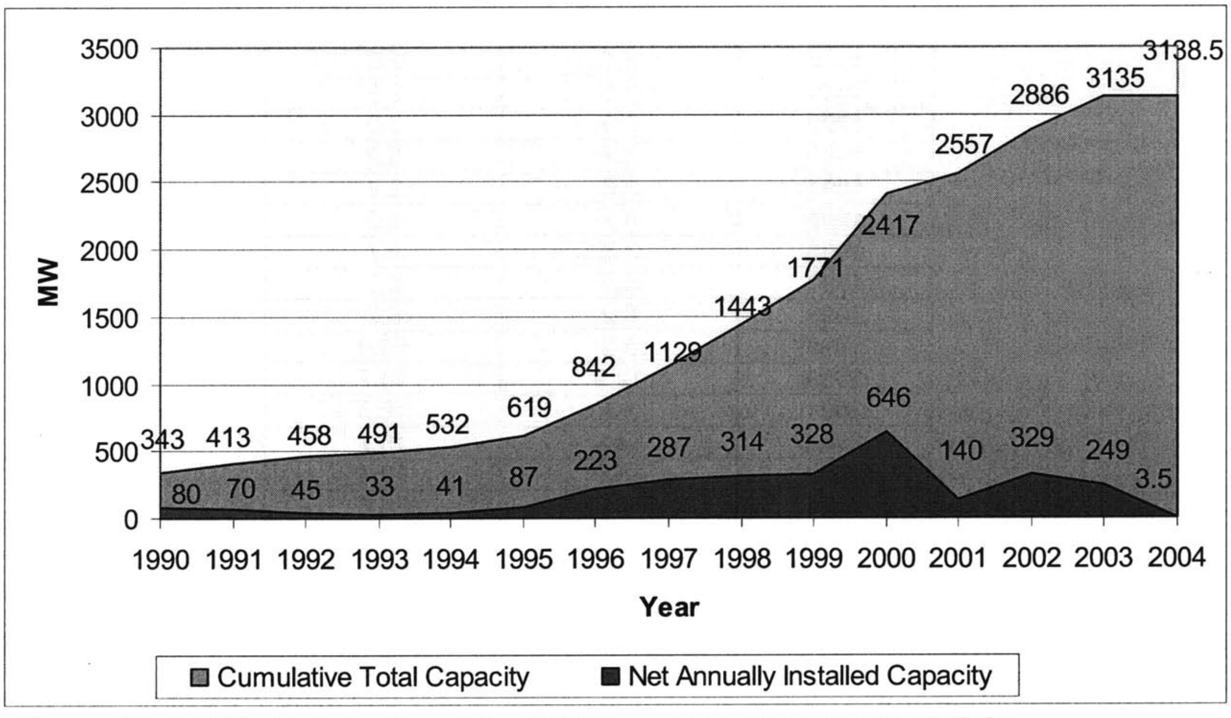
The wind energy market grew tremendously since 1990. The market growth is closely related to the policy schemes of each country.

5.3.1 Wind Energy Market in Denmark, Germany and India

Market Development in Denmark

Figure 5-1 shows the Danish wind energy market development by installed capacity. The Danish wind market grew steadily during the 1990s. The cumulative installed capacity reached over 400MW in 1991 and exceeded 500MW in 1994. Then, it was doubled every three years; achieving 1,129MW in 1997 and 2,417MW in 2000. As of the end of 2004, the country had total 3,138.5MW of wind capacity.

The market fluctuated time to time. Although the Danish market slowed down during 1992 and 1994, it marked the record installation every year from 1995 to 2000. In 2001, the new installation suddenly reduced. The installation recovered in the next two years, but in 2004 only 3.5MW of capacity was installed domestically in Denmark.



Source: (Danish Wind Industry Association 2006) based on power company statistics

Figure 5-1: Installed Capacity in MW in Denmark

Denmark was the first country that engaged in offshore wind energy development. The world-first offshore wind farm was built at Vindeby (4.95MW with 11 of Bonus 450kW turbines) in 1991, followed by the second farm at Tunø Knob (5MW with ten Vestas 500kW machines) that became operational from 1995. Both were small demonstration programs, built as a part of the government-utility wind installation agreements. The Middelgrunden project (40MW with 20 of

Bonus 2MW turbines) followed in 2001 with the 50-50 wind cooperative-utility ownership. The installed capacity of offshore projects has increased, as MW-class offshore turbines became available. In the early 2000s, by the government orders, the utilities constructed Horns Rev (160MW with 80 of Vestas 2MW turbines, operational in 2002) and Nysted farm (165.6MW with 72 of Bonus 2.3MW turbines, operational in 2003). Samsø offshore farm (23MW with ten of Bonus 2.3MW turbines) was also inaugurated in early 2003.

Although the installed capacity in Denmark is not as large as those of Germany, Spain and the Unites States, a more impressive achievement can be demonstrated by the share of wind energy in electricity consumption (Table 5-34). During the 1980s, the normalized share of wind in total power consumption was less than 1% of electricity consumption of the country. However, the share increased steadily during the 1990s. Especially the growth in recent years is tremendous; the 10% mark was exceeded in 1999 and the share reached to 20% in 2004. Also the installed capacity per capita in Denmark was 579.4kW as of 2003, far more than any other countries (BWE 2005b). In Denmark, wind power has become one of the main stream power generation sources.

Table 5-34: Share of Wind Energy in Danish Electricity Consumption

Year	Actual (%)	Normalized (%)*
1990	2.1	1.9
1991	2.5	2.5
1992	3.0	3.0
1993	3.4	3.2
1994	3.6	3.4
1995	3.7	4.0
1996	3.8	4.7
1997	6.0	6.6
1998	8.2	8.2
1999	9.3	10.9
2000	12.9	13.7
2001	13	16.3
2002	14.8	15.7
2003	15.9	19.4
2004	18.8	20.8

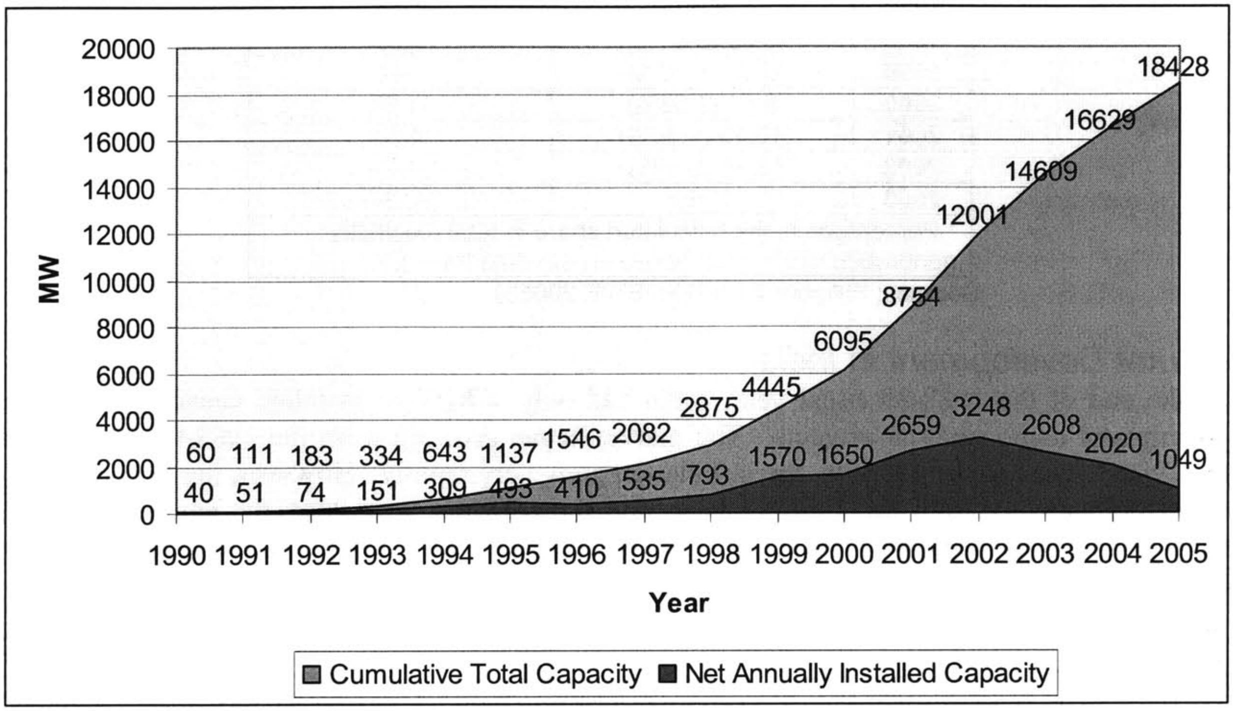
* The normalized figures show the share of wind power recalculated as in a normal wind year.

Sources: Power company statistics, Naturlig Energi and (Danish Wind Industry Association 2006)

As for the contribution of wind power generation into the power grid, only 2.1% of the generated electricity was consumed by the turbine owners themselves and the rest (98%) were fed into the power grid at the point of 1994 (Wind Power Monthly 1994c). Although the more recent statistics was not obtained, it is assumed the ratio of self consumption of wind power in Denmark is still very low as any sign of changes have not been reported.

Market Development in Germany

At the end of 1989, the German market only had 20MW of installed capacity. Figure 5-2, however, shows the enormous market expansion during the 1990s. Since 1990 the market grows steadily except the slight slowdown between 1996 and 1998. After the stagnation, however, the market was quickly rebound and marked GW level record installation every year since 1999. The annual installation has been decreased for onshore development after it reached its peak in 2002 with 3,248MW and dropped to 1,049MW in 2005.



Sources: (DEWI 2002a; DEWI 2003a; DEWI 2004a; DEWI 2005; DEWI 2006; DEWI 1993; DEWI 1994; DEWI 1995; DEWI 1996; DEWI 1997a; DEWI 1998a; DEWI 1999a; DEWI 2000a; DEWI 2001a)

Figure 5-2: Installed Capacity in MW in Germany

As for the cumulative installed capacity, it exceeded 300MW in 1993. After reaching over 1,000MW in 1995, it almost doubled every two years, reaching 2,082MW in 1997, 4,445MW in 1999, and 8,754MW in 2001. The cumulative capacity at the end of 2005 was 18,428MW. The average growth rate of cumulative capacity between 1992 and 2005 was 44%. The size of the German market is far exceeding than that of any other countries. As for offshore development, the first offshore wind turbine (one Nordex N90/2500) was installed in February 2006, 500m off the quay wall of the Rostock international port.

In terms of the share of wind generated electricity in the German power requirements, 14,609MW of installed capacity at the end of 2003 is estimated to cover nearly 6% of the country's net annual electricity consumption, and the installed capacity of wind energy per capita in Germany was 177.2kW as of 2003 (BWE 2005b). Table 5-35 shows the rapid expansion of electricity generated from wind in recent years.

Table 5-35: Electricity Production by Wind Energy in Germany

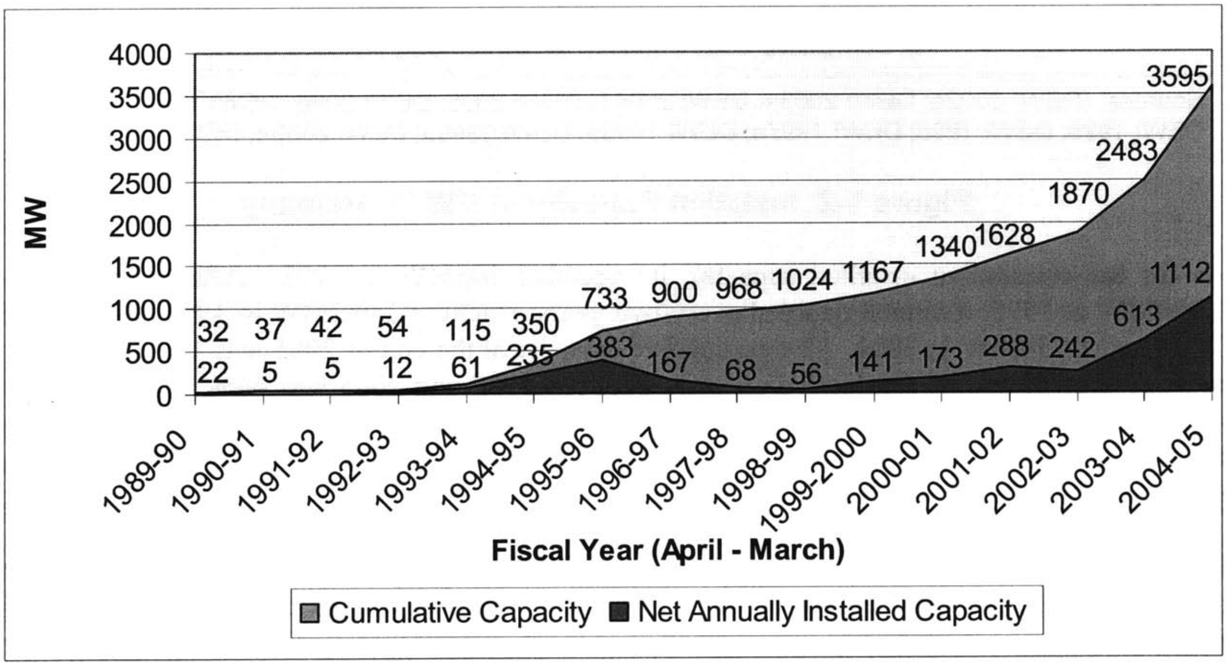
Year	Actual (TWh) *	Potential (TWh)
1991	0.14	0.20
1992	0.23	0.33
1993	0.67	0.75
1994	0.94	1.16
1995	1.80 (0.34%)	2.06
1996	2.20	2.80
1997	3.00	3.77
1998	4.49 (0.81%)	5.20
1999	5.53 (1.00%)	8.04
2000	9.51 (1.68%)	11.03
2001	10.46 (1.80%)	15.84
2002	15.86 (2.74%)	21.72
2003	18.63	22.37

* Percentage is the calculated share in total electricity generation of the year based on the data from IEA.

Sources: IEA; ISET cited in (BWE 2005b)

Market Development in India

At the end of the 1988-89 fiscal year, India had only 10MW of installed capacity, all by the government demonstration projects. The market began growing from the 1989-90 year. From the 1994-95 year to the 1995-96, the installation grew very rapidly. However, the market slowed down dramatically from the 1996-97 year, and the recovery was slow: the annually installed capacity only exceeded the 1994-95 level in the 2001-02 year. The 2003-04 and 2004-05 years saw the strong installation in record numbers (Figure 5-3).



Source: MNES cited in (Consolidated Energy Consultants Ltd. 2005)

Figure 5-3: Installed Capacity in MW in India

The cumulative installed capacity exceeded 100MW in the 1993-94 year, quickly reached 350MW next year, and then it was more than doubled to 733MW in the 1995-96 year. However, it took the next six years to double the number, reaching over 1,500MW only in the 2001-02 year. The cumulative capacity at March 2005 was 3,595MW (Figure 5-3). The average growth rate of cumulative capacity between the 1992-93 year and the 2004-05 year was 41%.

The electricity generation from wind has increased as the installed capacity increases (Table 5-36). As of the end of March 2005, the ratio of installed capacity in total power generation capacity is estimated around 3% (Consolidated Energy Consultants Ltd. 2005). However, the percentage of wind in total electricity generation is below 1%, as shown in Table 5-36, and the contribution of wind is still very low.

Table 5-36: Total Electricity Generation and Generation by Wind in India

Year	Actual Generation by Wind (GWh)	Total Gross Generated Electricity (GWh)	Percentage of Wind in Total Generation
1992-93	88	332713	0.03%
1993-94	95	356335	0.03%
1994-95	191	385557	0.05%
1995-96	496	418043	0.12%
1996-97	878	436730	0.20%
1997-98	988	465825	0.21%
1998-99	1073	496914	0.22%
1999-2000	1446	536452	0.27%
2000-01	1577	560842	0.28%
2001-02	1971	579120	0.34%
2002-03	2448	596543	0.41%
2003-04	2811	633275	0.44%

Sources: (Central Electricity Authority 2005) and MNES and SNAs cited in (Consolidated Energy Consultants Ltd. 2005)

5.3.2 Global Wind Energy Market

The total installed capacity of the world wind energy was 59,322MW as of the end of 2005. Germany was the largest wind market in the world with total installed capacity of 18,428MW, followed by Spain (10,027MW) and the United States (9,149MW). In 2005, India, with total of 4,430MW installed capacity, surpassed Denmark that became the fifth largest market with 3,122MW of installed capacity (Global Wind Energy Council 2006).

World Market Growth

Table 5-37 shows the development of the world wind energy market since 1990.[65] The world wind market between 1990 and 2005 grew tremendously with the average annual growth rates of 29% for annually installed capacity and 25% for cumulative installed capacity. The impressive growth started from 1993, which corresponds to the start of strong market growth in Germany and India. Since 1995, the world market experienced GW level of annually installed capacity, and the number has progressively increased. The installations increased every year except 1996 and 2004; in both years the German market experienced relative slowdowns. 11,407 MW of

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[65] The cumulative installed capacity as of the end of 2005 in Table 5-37 by BTM Consult ApS is slightly different from the figures provided by Global Wind Energy Council due to the differences in data sources.

newly installed capacity in 2005 was the highest ever in a single year, and showed the highest annual percentage growth since 2001. The average annual growth rate since 2001 was 20.5% (BTM Consult APS 2006).

Total power generated from wind also increased steadily, as shown in Table 5-38. Between 1996 and 2004, the electricity generated from wind increased a 7.8-fold. 40,504MW (68.3%) out of 59,322MW of the world cumulative installation at the end of 2005 has been installed within the EU countries; in an average wind year, the EU can produce some 83TWh of wind electricity, equal to 2.8% of the entire EU electricity consumption in 2004 (European Wind Energy Association 2006).

Table 5-37: World Market Development 1990-2005 in MW

	Annually Installed	Increase in %	Cumulative	Increase in %
1990	250	-	1985	-
1991	317	27%	2302	16%
1992	231	-27%	2533	10%
1993	480	108%	3010	19%
1994	730	52%	3725	24%
1995	1290	77%	4778	28%
1996	1292	0%	6070	27%
1997	1568	21%	7636	26%
1998	2597	66%	10153	33%
1999	3922	51%	13932	37%
2000	4495	15%	18449	32%
2001	6824	52%	24927	35%
2002	7227	6%	32037	29%
2003	8344	15%	40301	26%
2004	8154	-2%	47912	19%
2005	11407	40%	59264	24%
Average		29%		25%

Source: (BTM Consult ApS 2005b; BTM Consult APS 2006)

Table 5-38: World Power Generation from Wind in TWh

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004
TWh	12.23	15.39	21.25	23.18	37.30	50.27	64.81	82.24	95.50

Source: (BTM Consult ApS 2005b)

Market Locations

Geographically, the market locations have been concentrated in Europe, North America, India, and China. Table 5-39 shows that the 14 markets have been in the top ten between 1995 and 2004. It is clear that the global market has definitely become more diverse; while the top ten markets of 1995 occupied 98.7% of the total market, the ratio has been reduced steadily to 84.5% in 2004. Although the world market has expanded, the wind market is very much policy-driven; the geographical market locations and boundaries are largely defined by national and institutional boundaries and the market growth pattern greatly depends on national policy.

The market leader during the 1980s was the United States, more specifically California. This changed in the early 1990s; Germany, Denmark, and India became the leading markets. From the mid to late 1990s, Germany, Spain, and the United States became the growth factor. However, the US market greatly fluctuates, as political uncertainty is extremely strong for its support incentives based on tax credits. For example, while the United States installed only 389MW in 2004, it had the largest installation with 2,431MW and became the market leader in 2005. Germany had been the very strong and consistent market leader since the mid 1990s to 2003. Spain began placing its wind policy support schemes from 1995, and in 2004 the country became the market leader surpassing Germany for the first time in annual installed capacity. With Germany, Spain, Denmark, and several other countries, the EU has a robust regional market with average growth rate of approximately 35% between 1995 and 2004. The growth of the European market in 2005 accounted for about a half of total new capacity, while other regions also show strong growth trends.

In terms of annually installed capacity in 2005, the United States (2,431 MW) was followed by Germany (1,808 MW), Spain (1,764 MW), India (1,430 MW), Portugal (500 MW) and China (498 MW) (Global Wind Energy Council 2006). However, Europe is still leading the market with total of 40,504MW of installed capacity and showing continuing growth.

Table 5-39: Annual Installation by Country 1995-2004

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Top Five										
Germany	**500**	**420**	**533**	**793**	**1568**	**1665**	**2627**	**3247**	**2674**	**2054**
Spain	58	116	262	**368**	**932**	**1024**	**1050**	**1493**	**1377**	**2064**
USA	53	12	29	**577**	**477**	165	**1635**	**429**	**1687**	**389**
India	**375**	244	120	82	43	169	236	220	**423**	**875**
Denmark	98	200	285	**310**	**325**	**603**	115	**530**	218	
Other Europe										
Austria									285	
Greece					103	116	84	104		
Italy	11	38	33	94	80	147	276	106	116	**357**
Netherlands	95	50	44	50	54			219	233	199
Portugal										274
Sweden	29	34	19	54	44					
UK	40	73	55			63	107		195	253
North America and Asia										
Canada				57	43					
Australia								119		
Japan						74	217	129	275	230
China	14	35	67	54		84	75			198
Total	1273	1222	1447	2439	3669	4110	6422	6595	7483	6893
% of Top ten in the world market	98.7 %	94.6 %	92.3 %	93.9 %	93.6 %	91.4 %	94.1 %	91.3 %	89.7 %	84.5 %

Source: (BTM Consult ApS 2005b)

Section 5.4: Wind Energy Industry 1990-2005

This section describes the evolution of wind energy industry since 1990, in particular focusing on industry basic characteristics and manufacturer profiles in Denmark, Germany, and India. The wind industry is one of the fastest growing industries, and the average growth rate of the world wind industry was more than 40% during the second half of the 1990s.

5.4.1. Wind Industry Components

Wind energy industry can be subdivided into wind turbine manufacturing industry, wind project development industry, wind project operation/management/service industry, and wind electricity grid management industry, along its value chain. In addition, all these subdivided industries can be further grouped into sub-suppliers of product components and services (Figure 5-4). The term "wind energy industry" is frequently used to describe the wind turbine manufacturing industry only; however, the boundary of the term is often not clear in many literatures and statistical data.

Turnkey provision means that one company performs all or most of the above value chain functions and activities. Turnkey is prevailing today, as the total system and quality management is one of the key elements for cost reduction in any geographic regions. Many turbine manufacturers are also project developers themselves. Because of this, many statistical data do not clearly draw lines between the numbers in the subdivided industries, as it is often very difficult to do so.

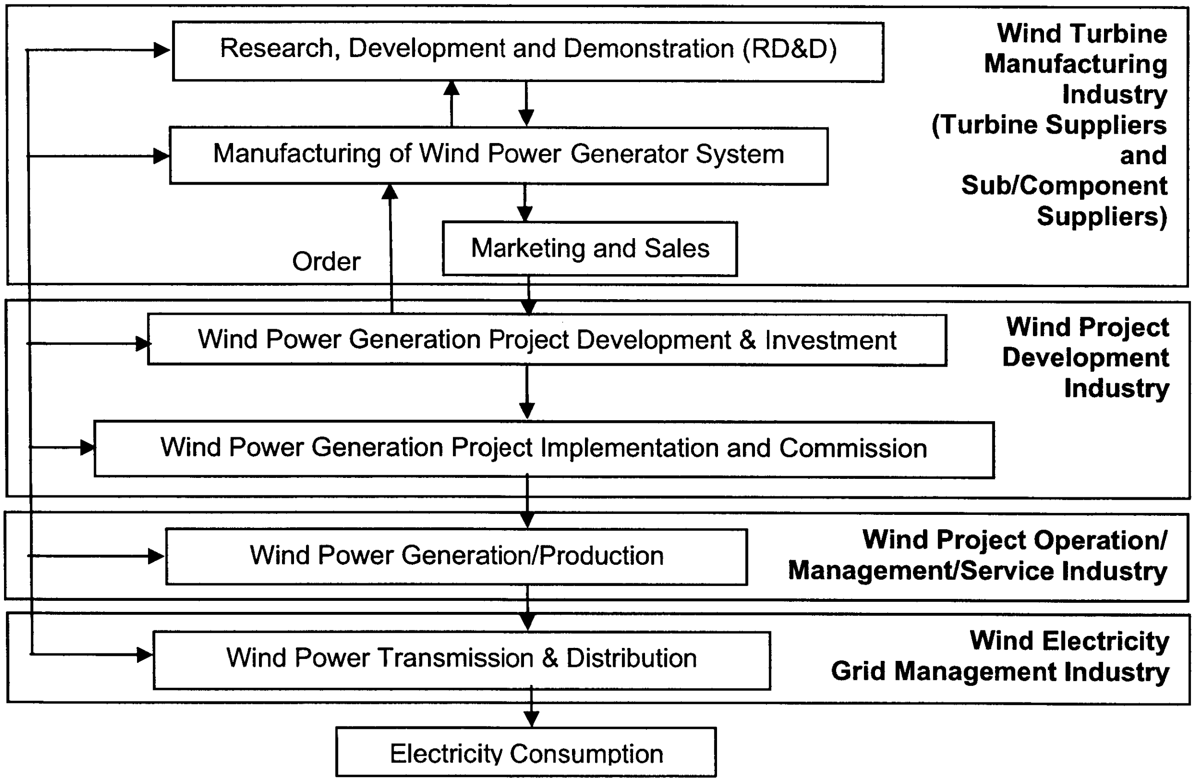


Figure 5-4: Wind Energy Project Value Chain (Broad Functions) and Wind Energy Industry Subdivision

5.4.2 Wind Industry Profile of Denmark, Germany, and India

The wind energy industry structure and characteristics have changed greatly since 1990, and both the Danish and German industries have played critical roles in this development.

Danish Industry Basic Profile

The Danish wind industry was dominant in the world scene already in the 1980s. Although the California bust in 1986 bankrupted many Danish turbine manufacturers, some of them reestablished quickly within a year or so and began growing again as the European market expended from the early 1990s.

Industry Expansion

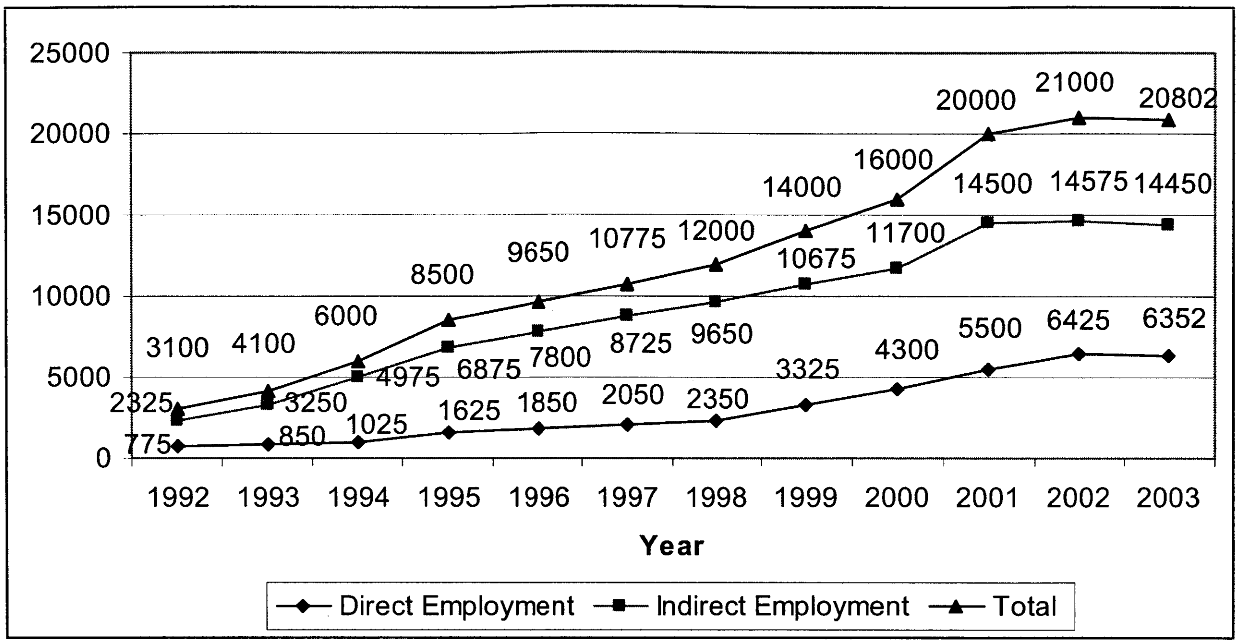
The Danish wind industry expanded tremendously since 1990; the sales turnover increased almost 23-fold from DKK 925 million in 1990 to DKK 21,049 million in 2004, and its average annual growth rate was 23% in sales turnover during the same period. The sales in capacity also show the similar growth (18-fold increase in manufactured capacity and the average annual growth rate of 25% between 1992 and 2004, Table 5-40). The industry employment also grew greatly. Between 1992 and 2003, the direct employment showed an 8-fold increase and the total employment including indirect employment grew 6.7-fold (Figure 5-5) (Danish Wind Industry Association 2006).

Table 5-40: Danish Manufacturer Sales 1990-2004

	Sales in Capacity (MW) and Share (%) in Total					Growth Rate in Sales in Capacity		
	Domestic		Oversea		Total	Domestic	Oversea	Total
1990	81.0	--	N/A	--	N/A	--	--	--
1991	72.6	44%	93.7	56%	166.3	-10%	--	--
1992	44.4	27%	121.0	73%	165.4	-39%	29%	-1%
1993	29.1	14%	181.2	86%	210.2	-34%	50%	27%
1994	51.9	14%	316.4	86%	368.2	78%	75%	75%
1995	98.1	17%	476.3	83%	574.4	89%	51%	56%
1996	221.2	30%	504.8	70%	726.1	125%	6%	26%
1997	286.1	30%	681.4	70%	967.5	29%	35%	33%
1998	316.8	26%	899.1	74%	1215.9	11%	32%	26%
1999	387.7	17%	1853.6	83%	2241.2	22%	106%	84%
2000	565.9	26%	1574.5	74%	2140.4	46%	-15%	-4%
2001	117.1	3%	3335.0	97%	3452.1	-79%	112%	61%
2002	525.9	15%	3088.3	85%	3614.2	349%	-7%	5%
2003	207.6	7%	2875.4	93%	3083.0	-61%	-7%	-15%
2004	3.0	0%	3033.9	100%	3036.9	-99%	6%	-1%
Average		19%	--	81%	--	-21%	31%	25%

1. Nordex no longer manufactures wind turbines in Denmark and is no longer included in the statistics since 2003. This explains the decline in 2003, although the turnover of the remaining Danish manufacturers increased by 5%.
2. Danish suppliers of wind turbine components had an additional export to foreign manufacturers of approximately DKK 1-2 billion per year from 1995 to 2002.
3. The statistics do not include component kits with a value below 1/3 of the value of a complete wind turbine.
4. In addition to the registered complete units, there were substantial exports in 1995-96 of wind turbine components to be assembled in India.

Source: (Danish Wind Industry Association 2006)



Source:(Danish Wind Industry Association 2006) Employment figures are mid-year figures. Indirect employment figures in 1996, 1997 and 1999 were estimated numbers.

Figure 5-5: Employment in Danish Wind Industry 1992-2003

Table 5-40 also illustrates that the most important characteristic of the Danish wind industry is its strong dependence on export. The export dependency was already clear during the 1980s but got stronger since the 1990s. Although the share of domestic market in total sales had never exceeded 50%, the average share of oversea market was approximately 80% in sales in capacity between 1990 and 2004 and has increased over the years.[66] Wind turbines became the second most important export item of the country in 1998. The main export destination has been Germany throughout the 1990s and 2000s, and other important export destinations include the United States, Spain, Italy, and Japan.

Danish Wind Turbine Manufacturers

By the end of the 1980s, the Danish industry consolidated greatly as described in Chapter 4. This industry modification trend continued during the 1990s and 2000s. Among the seven surviving manufacturers by 1990, five major manufacturers have played significant roles in the industry development. For the past 15 years or so, there were only a very few new entries but the structure changed by horizontal M&A. The four Danish manufacturers were horizontally merged and acquired within the Danish border and converged into one company, Vestas A/S, while two companies, Nordex and Bonus, were acquired by German industrial giants.

- Nordtank Energy Group (NEG) A/S, Micon A/S, and NEG Micon A/S: Nordtank was founded in 1962 as a manufacturer of tankers. The Energy Crisis of the 1970s created the oil shortage, which made the firm to move into an alternative new product. Nordtank started wind turbine business in 1979. One of the notable innovations by Nordtank was the closed

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[66] This is also true in sales turnover (Danish Wind Industry Association. 2006).

tubular tower which became the industry standard by the end of the 1980s. Nordtank was floated on the Danish stock exchange in 1995; it was the first European wind turbine manufacturer to do so. Meanwhile, some employees who left Nordtank founded a new firm Micon A/S in 1983. On July 4, 1997, the two firms merged, forming a new company NEG Micon A/S. NEG was the dominant partner. The new NEG Micon then acquired WindWorld A/S (another small Danish manufacturer) in the same year.

- **Vestas Wind Systems A/S**: Vestas was established in 1945 as an agricultural machinery and industrial equipment manufacturer. The firm began its wind turbine business in 1979 in Lem, Denmark, and started the export to the United States in 1981. In October 1986, the firm filed a bankruptcy as a result of the crash of the California market. Although a large part of the company was sold off, within two months of period, a new firm Vestas Wind Systems A/S was established with 60 employees and a handful of shareholders, focusing only on wind turbines. Since the formation of NEG Micon, Vestas and NEG Micon were the largest and the second largest wind turbine manufacturers in the world. Vestas began the stock floatation on the Danish stock exchange in 1998. These two firms disclosed the merger plan in December, 2003, and the deal was finalized in 2004 with the EU approval (Vestas Wind Systems A/S 2004/2005).
- **Nordex A/S**: Nordex was founded in 1985. From the beginning, the firm focused on large, but not MW-class, turbine development. The firm established its German subsidiary, Nordex Energy GmbH, in 1992. In 1995, a German industrial giant BDAG (Balcke-Dürr, suppliers of components, systems and services for re-cooling and heat transfer technology) acquired 51% of the shares of Nordex Energy GmbH and increased the shares to 75% in 1997. In 1999 the firm was integrated into another German industrial group Babcock-Borsig AG. In 2000, all Nordex activities were integrated to a new German firm, Nordex AG. After the stock flotation in Germany in 2001, all Danish facilities were closed in 2002. Nordex is now a German firm.
- **Bonus Energy A/S and Siemens Wind Power A/S**: History of Bonus started in 1980 when an irrigation plant manufacturer Danregn A/S developed 5kW and 22kW wind turbines. In 1981, Danregn Vindkraft (the owner of Bonus Energy A/S) was founded and began manufacturing 55kW wind turbines. The export to the United States started in 1982. Bonus survived the crash of the California market, but stopped the export to the US market in 1987. Bonus Energy A/S survived the 1990s and the early 2000s as the last privately-owned and independent Danish wind turbine manufacturer, but it was acquired by the German electrical engineering and electronics giant Siemens AG on December 1, 2004. The new company Siemens Wind Power A/S is listed as a Danish company (Bonus Energy A/S 2004b).

Domestic Market Share

The share of domestic manufacturers in the Danish market has been always 100%; no foreign manufacturers ever erected wind turbines on the Danish land and sea. Table 5-41 shows that Vestas and NEG Micon had the majority of share in the Danish market over the years, while Bonus had lower but constant shares. The year 2003 was the exception; Bonus had a large share because the majority of the country's installation of the year was the company's offshore installment in Nysted and Samsø offshore wind farms as the onshore development sharply declined. Other firms have much smaller shares.

Table 5-41: Manufacturer Market Share (%) of Annually Installed Capacity in Denmark

	1996	1997	1998	2001	2002	2003
Vestas	**38.8**	31.7	28.4	**44.6**	**49.5**	**12.1**
Micon	**35.8**	**52.2**	**58.4**	**46.2**	**30.8**	5.7
NEG	6.9					
WindWorld	5.2	2.5	3.2			
Bonus	**12.1**	**10.6**	**9.0**	--	**13.7**	**80.8**
Nordex	1.2	0.2	0.6	9.2	5.9	1.5
Wincon	--	--	0.4	--	--	--
Total	100	97.2	100	100	100	100
The 2004 figure is not shown as the total Danish installed capacity was only 9MW.						

Sources: (BTM Consult ApS 1997; BTM Consult ApS 1998a; BTM Consult ApS 1999; BTM Consult ApS 2002; BTM Consult ApS 2003; BTM Consult ApS 2004; BTM Consult ApS 2005a)

German Industry Basic Profile

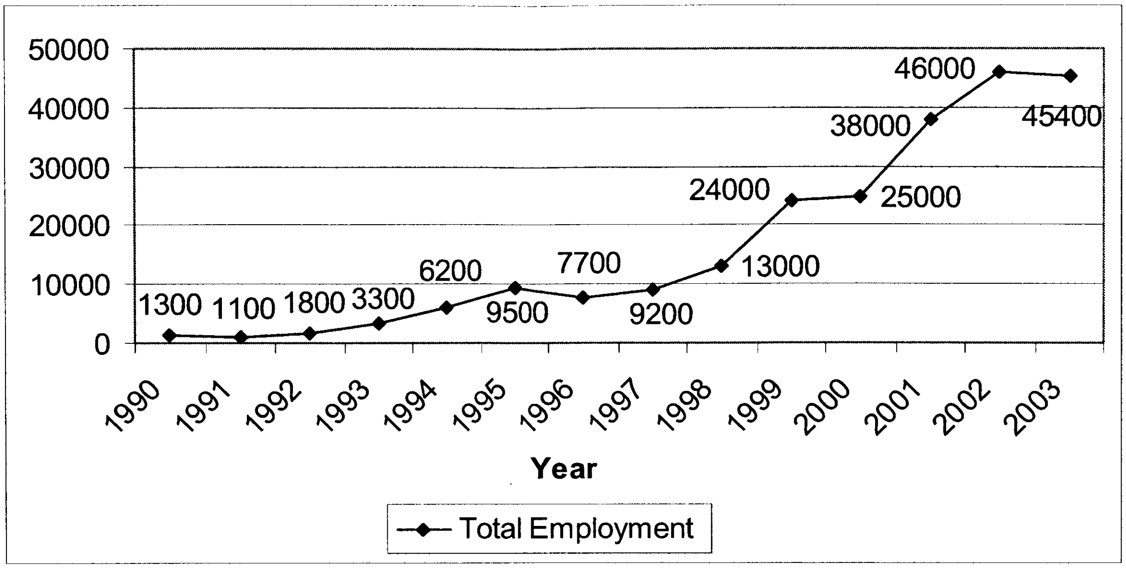
Industry Expansion

The growth of the German wind turbine manufacturing industry has been strongly supported by its large domestic market, as seen in Table 5-42. Between 1995 and 2003, the sales in capacity increased 6-fold and its average annual growth rate was 26%. During the same period, the average 87% of manufactured capacity was sold to the domestic market that grew at 23% of rate annually. The growth of employment also has been enormous. Between 1990 and 2003, total employment of the German wind industry grew 35-fold. In terms of the size of industry, the Danish and German industries became comparable by sales in capacity in recent years (Figure 5-6). The German industry has almost twice as many of employment. However, the direct comparison may be difficult as the geographical boundary of the industry and the methods of taking statistics are not certain.

Table 5-42: Growth Rate of German Manufacturer Sales 1995-2003

	Sales in Capacity (MW) and Share (%) in Total					Growth Rate in Sales in Capacity		
	Domestic		Oversea		Total	Domestic	Oversea	Total
1995	504	93%	36	7%	540	--	--	--
1996	428	84%	83	16%	510	-15%	130%	-5%
1997	534	91%	54	9%	588	25%	-35%	15%
1998	793	86%	126	14%	919	49%	134%	56%
1999	1568	90%	179	10%	1747	98%	42%	90%
2000	1665	88%	236	12%	1901	6%	32%	9%
2001	2659	84%	518	16%	3177	60%	119%	67%
2002	3240	86%	522	14%	3762	22%	1%	18%
2003	2638	78%	735	22%	3373	-19%	41%	-10%
Average	--	87%	--	13%	--	23%	46%	26%

Sources: (DEWI 2002a; DEWI 2003a; DEWI 2004a; DEWI 2005; DEWI 2006; DEWI 1993; DEWI 1994; DEWI 1995; DEWI 1996; DEWI 1997a; DEWI 1998a; DEWI 1999a; DEWI 2000a; DEWI 2001a)



Source: (BWE 2005b)

Figure 5-6: Employment in German Wind Industry 1990-2003

Compared to the Danish industry, the German industry has much weaker export performance; only the average 13% of total manufactured capacity went to the oversea markets between 1995 and 2003.

German Wind Turbine Manufacturers

The German manufacturers are generally smaller compared to the Danish wind giants such as Vestas and NEG Micon. After the aerospace giants such as MAN and MBB exited from the wind business in the late 1980s, the remained German players were small and local manufacturers. Among the survivors, two companies, Tacke Windtechnik GmbH and Enercon GmbH, emerged as strong actor. For the past 15 years, there were more new entries in Germany than in Denmark. Their exits have been always the acquisition by other players after bankruptcy or financial troubles. There have been no large-scale horizontal M&A of turbine manufacturers within the German border.

- **Enercon GmbH**: Enercon was established in 1984 by a young graduate engineer Aloys Wöbben. The firm has worked with energy converters and wind turbine development since. Total installation by the firm by the end of 1989 was only 35 turbines and 2MW, and all the installation was in Germany (BTM Consult ApS 2005b). The firm became the most significant player in the German industry since 1990, and Enercon has been the German market leader from the early 1990s until today. Enercon is the only company in the industry, which successfully introduced and commercialized a radical new concept with its direct-drive, variable speed turbines with multi-poled synchronous generator in 1992. The firm remains privately owned and its sole owner has been the founder Aloys Wöbben.
- **Tacke Windtechnik GmbH**: Franz Tacke, a grandson of the founder of F. Tacke KG that specialized in gears and industrial clutches, started to develop wind turbines in 1984. Tacke merged with a gearbox manufacturer, Renk KG Augsburg in 1987, forming Renk-Tacke. Renk was a subsidiary of MAN that was engaging in the Growian project and the merger was

done to increase their mutual lead in experience and know-how for wind turbine development. Renk-Tacke only installed 16 turbines and total 1.38MW capacity during the 1980s. Six of them were installed in Germany and the rest were exported (BTM Consult ApS 2005b). In 1990, following the MAN's departure from renewable-energy business, Franz Tacke bought out the wind division of Renk-Tacke and assumed the responsibility for all corporate activities associated with wind energy, establishing a new firm Tacke Windtechnik GmbH (Germania Windpark GmbH & Co. KG). Tacke grew to the Germany's second largest turbine manufacturer during the first half of the 1990s, supported by the strong German market growth. However, the market recession in 1996 caused a financial difficulty to the firm, which filed a bankruptcy in July 1997. Tacke Windtechnik was purchased by Enron Wind Corp, a subsidiary of the American energy giant Enron Corp, in October 1997. After Enron collapsed in 2001, its wind energy division was bought by General Electric (GE) and became GE Wind Energy in 2002. GE Wind Energy GmbH is listed as a German company. This research treats the firm as a German-US company.

There are several other small manufacturers in Germany:

- **Fuhrländer GmbH**: Fuhrländer started wind turbine manufacturing during the 1980s, diversifying from metal processing company established in the 1960s;
- **Jacobs Energie**: the firm was founded in 1992 and jointly making larger wind turbines with Fuhrländer;
- **DeWind AG**: DeWind was founded in 1995, but taken over by a British engineering group FKI, becoming a British company in 2003;
- **AN Windenergie**: AN has been the licensed maker of the Danish Bonus turbines in Germany from 1989;
- **REpower Systems AG**: the firm was founded in January 2001 through the merger of Jacobs Energie, BWU, and pro + pro Energiesysteme.
- **Südwind**: Südwind Windkraftanlagen was founded in the early 1990s but bankrupted and reformed into Sudwind Enmergiesysteme of Berlin in July 1996. In 1998, Südwind was taken over by BDAG, the parent company of Nordex that subsequently took over the firm and founded Südwind Energy GmbH in 1999. All the activities were integrated in new Nordex AG in 2000.

Domestic Market Share

The German industry concentrated on its domestic market, which has been too large even for the German industry to serve it entirely on its own. The share of domestic manufacturers in the German market has never been over 60%.

In 1992 the total market share of small manufacturers serving the German market was 30.2%. However, the share declined over the years and the largest drop occurred between 1992 and 1993. Enercon has been always the market leader since the early 1990s, and the firms' market shares have been very stable and usually have a large margin to the second; the average market share of Enercon between 1992 and 2005 was 32.1%, and the firm had more than 40% of the share in 2004 and 2005. Enercon has been always followed by Vestas except 1994, 1995, and 2000, when Tacke/Enron occupied the second place. The Tacke/Enron share declined for two years after the Tacke bankruptcy and the following takeover by Enron in 1997 and 1998, but was recovered in the late 1990s and early 2000s. Other German manufacturers (REpower/BWU/Jacobs, DeWind, and Fuhrländer) have not been the major players. The Danish manufacturers (Vestas, NEG Micon, Bonus, and Nordex) have enjoyed the comfortable shares in the German market over the years (Table 5-43).

Table 5-43: Manufacturer Market Share (%) of Annually Installed Capacity in Germany

	Enercon	Vestas	NEG Micon		AN Bonus	Nordex	Tacke/ Enron/ GE	RE Power/ Jacobs	DeWind	Fuhr-länder	Others
			Micon	Nordtank							
1992	28.4	13.3	5.6	7.5	7.7	2.6	4.7	---	---	---	30.2
1993	20.8	20.2	11.6	8.2	12.3	4.7	11.0	---	---	---	11.2
1994	32.6	13.9	7.5	5.7	9.7	3.9	19.4	---	---	---	7.3
1995	29.8	11.6	13.1	4.8	5.4	3.7	20.7	---	---	---	10.9
1996	31.2	14.5	7.3	5.5	10.0	6.3	17.3	2.3	---	---	5.6
1997	37.4	13.4	12.2		12.6	11.1	5.0	1.6	---	---	6.1
1998	33.1	12.3	8.1		9.4	15.2	9.4	---	2.8	---	9.7
1999	25.6	15.7	10.5		9.2	13.2	12.7	---	4.5	---	6.9
2000	27.4	13.2	11.1		11.2	8.7	14.9	2.5	5.6	1.9	3.5
2001	28.5	19.5	11.4		8.5	10.4	10.9	5.0	2.7	2.4	0.8
2002	34.0	17.8	8.3		7.0	8.7	13.1	6.8	2.4	1.4	0.2
2003	33.4	23.5	8.2		5.0	4.8	11.2	10.7	1.3	0.9	0.9
2004	41.8	30.0			4.0	4.4	7.7	9.2	0.5	1.3	1.0
2005	41.7	26.8			4.0	7.8	8.1	5.5	---	2.6	3.4

Sources: (DEWI 2002a; DEWI 2003a; DEWI 2004a; DEWI 2005; DEWI 2006; DEWI 1993; DEWI 1994; DEWI 1995; DEWI 1996; DEWI 1997a; DEWI 1998a; DEWI 1999a; DEWI 2000a; DEWI 2001a)

Indian Industry Basic Profile

The Indian government has had an objective to create a competitive domestic wind energy industry by building strong technological capabilities in wind turbine manufacturing and project engineering, aiming to export its technology in long run.

Industry Expansion and Indian Wind Turbine Manufacturers

There are no statistics available for the Indian industry regarding sales in capacity, employment or export. However, the industry greatly expanded since 1993.

The rapid market expansion from 1993 triggered the entry from the European and American manufacturers through joint ventures and license agreements with local companies. The picture of the wind turbine manufacturing industry in India was rapidly changing and chaotic. According to MNES, by March 1995, there were total of 21 Indian companies that tied up for joint venture or license agreement with foreign collaborators for turbine manufacturing. During the 1995-96 year, additional 13 joint venture companies were formed. By the end of the 1996-97 year, however, only a dozen out of more than 30 joint venture establishments were actively manufacturing wind turbines (MNES 1995a; MNES 1996a), and all other firms exited the business by 1998. The lists of manufacturers active in India issued by MNES and Indian Wind Turbine Manufacturers Associations (IWTMA) since 1998 have had only around ten manufacturers. Through this turbulent industry evolution, the following main players have emerged.

- **Bharat Heavy Electricals Ltd. (BHEL):** BHEL is a Public Sector Undertaking, with 66% of the government share. Out of its 13 divisions, the Ranipet division, established in 1982 in Tamil Nadu, has the wind turbine manufacturing operation. BHEL signed technology collaboration agreement with a Danish manufacturer Nordex in 1993, which expired in 2002 (BHEL 2002). A new agreement was formed between BHEL and Nordex in 2003.
- **NEPC Micon Ltd. and NEPC India Ltd.:** NEPC-Micon was created in 1987 as the first wind turbine joint venture firm in India. About 40% of the company share was owned by the Indian firm Non-conventional Energy Product Company (NEPC) and the rest was owned by Micon, a Danish wind turbine manufacture. The joint venture NEPC Micon was broken up in 1996. The Indian partner NEPC became an independent manufacturer, NEPC India Ltd.
- **NEG Micon India:** Following the NEPC-Micon break-up and the new company formation in Denmark, NEG-Micon started a 100% subsidiary in India in 1997.
- **Vestas RRB India Ltd:** Vestas RRB was also established in 1987 as a joint venture firm between Vestas Wind Systems A/S and an Indian engineering firm, RRB Consultants & Engineers Private Ltd (RRB). The initial share holding agreement was that RRB owned 51% and Vestas held 49% of the company. The company headquarter is located in New Delhi and the main manufacturing plant is located in Chennai, Tamil Nadu. Vestas RRB is the longest surviving joint venture firm in the Indian wind energy sector.
- **Enercon India Ltd:** The joint venture Enercon India Ltd. was formed in 1994 with the 56:44 venture shares between Enercon GmbH and the Mehra Group of India, and began manufacturing and installing wind turbines in India from 1995.
- **Pioneer Asia Wind Turbine Ltd:** Pioneer Asia is a South-Indian family-owned company, active in paper, textile, timber, and firework businesses for years. In 1998 Pioneer formed a joint venture Pioneer Wincon Ltd with a small Danish Manufacturer Wincon West Wind (26% of share), along with Industrialization Fund for Developing Countries (IFU) (24% of the share) (Pioneer Wincon Ltd. 2002). Pioneer Asia formed the second joint venture firm with Gamesa Ecólica of Spain in 2004.
- **Suzlon Energy Ltd:** The parent company of Suzlon was established in textile business in 1986 in Ahmedabad and soon expanded into international trade, hotels, and finance. The Group diversified into wind energy business by establishing Suzlon Energy Ltd, which formed a technical agreement with a German wind turbine manufacturer, Südwind, in 1995. After Südwind was bankrupted in July 1996, Suzlon restarted as an independent manufacturer in 1997. The company became the first Indian wind turbine manufacturer publicly listed in 2005.
- **GE Wind Energy:** After taking over Enron Wind, GE Wind Energy quickly established its subsidiary and assembly plant in India in 2002.

Export

While MNES has been very active to cultivate potential foreign markets through their financial and consultancy services to other developing countries and as a contact for international cooperation, the export orders for the Indian manufacturers were begun negotiated with the neighboring countries such as Sri Lanka and Indonesia during the 1996-97 year (MNES, 1997a). The export of wind turbine components and sets except towers from India has been increased, and the export of such products stood USD 9.2 -11.5 million annually between 2001 and 2004 according to IWTMA (Siliconindia.com 2005). This is not a large figure, however, considering the cost of 1MW project is approximately USD 1 million. India has not been a large export hub.

Domestic Market Share

Table 5-44 illustrates the marker share of the Indian market by installed capacity. The market share was spread over many manufacturers during the 1990s; this is especially evident in 1996 when the number of manufacturers reached its peak. However, with the exits of many firms, the share has gradually converged into several main players; since 2001, four major players (Enercon, NEG Micon, Suzlon, and Vestas RRB) have occupied more than 85% of the market.

The share of each manufacturer changes greatly year to year. In the early years, NEPC Micon was the very strong market leader, but its dominance decreased as other manufacturers entered to the market. Suzlon became a new market leader in the early 2000s. Vestas RRB, despite the solid world status by Vestas A/S, has not been a particularly strong player in India, although it has steady market share over the years.

Table 5-44: Manufacturer Market Share (%) of Annually Installed Capacity in India

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
ABAN-Kenetech	---	---	10.9	8.0	**29.2**	---	---	---	---	---	---	0.1
AMTL-WindWorld	2.3	12.5	10.1	9.1	1.8	---	0.9	1.5	---	---	---	---
BHEL-Nordex	---	3.5	8.3	5.4	1.8	---	4.9	---	---	---	---	---
Das Lagerwey	---	---	1.6	6.7	6.9	**23.1**	7.9	16.1	---	---	---	---
Enercon			0.2	4.6	6.4	14.3	11.2	11.6	34.7	26.6	16.1	**31.3**
NEPC Micon	**81.3**	**62.8**	**40.7**	**21.8**	21.0	12.6	1.7	---	---	---	---	---
NEG Micon	---	---	---	---	---	---	3.6	2.8	13.3	13.1	30.7	26.6
NEPC India	---	---	---	---	---	1.3	5.0	3.0	0.0	6.0	3.1	9.6
Pioneer Wincon	---	---	0.3	1.4	3.0	2.7	4.6	4.1	0.2	1.7	0.5	0.1
Suzlon	---	---	---	1.5	6.8	13.0	26.4	**50.7**	**39.9**	**42.3**	**39.3**	19.6
Vestas RRB	16.4	18.7	15.5	9.9	5.5	6.8	**28.4**	7.5	8.5	6.2	9.8	10.7
Others	0.0	2.5	12.4	31.6	17.6	26.2	5.4	2.7	3.4	4.1	0.5	2.0
Total	100	100	100	100	100	100	100	100	100	100	100	100

Bold letters show the market leader of the year.

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005).

5.4.3 Global Wind Industry Profile

As BTM Consults (2005b) pointed out, between 2000 and 2004, Vestas has been the global market leader and the competition was for the second place. Also the market share by top ten manufactures have been more than 90% since 1997 and increasing due to the intensified industry concentration in recent years. The largest manufacturers (Vestas, NEG Micon, Siemens/Bonus, Enercon, Gamesa, and Tacke/Enron/GE Wind) stay the same for the past ten years.

Table 5-45 illustrates the strength of the Danish industry in the global market, although its share has declined for the past ten years. The Danish industry share was 59.5% in 1996, 45.3% in

1998, 42.3% in 2002, and 38.7% in 2004 (not including Nordex). They have lost their share to the Spanish firms; while no Spanish firms were on the top-ten list in 1996, they had 12.8% of the world share in 1998, and 19.9% in 2004. The German industry has relatively steady shares, 24.4% in 1996, 30% in 1998, 36.3 % in 2002, and 31.3% in 2004 (including Tacke/Enron/GE). The Indian firms still have very small share of the world market. However, the market share does not tell the whole story; the absolute industry output for even the share-declining Danish industry has increased more than 4-fold, from 768MW in 1996 to 3,156MW in 2004, as the annual global output has increased more than 6-hold from 1,292MW in 1995 to 8,1541MW in 2004.

Overall, while the industry has grown tremendously, the market power has been concentrating in handful players. At the same time, the niche for non-top ten, small players still remain due to the increase of absolute output despite the increased concentration rate for top ten players.

Table 5-45: World Market Shares (%) 1996-2004

1996	1997	1998	1999	2000	2001	2002	2003	2004
Vestas (27.3)	NEG Micon (20.0)	NEG Micon (24.1)	NEG Micon (18.9)	Vestas (17.9)	Vestas (23.9)	Vestas (21.6)	Vestas (21.8)	Vestas (32.3)
Enercon (13.6)	Vestas (18.8)	Enron (16.8)	Vestas (16.2)	Gamesa (13.9)	Enercon (15.0)	Enercon (17.9)	GE Wind (18.0)	Gamesa (17.3)
Micon (11.9)	Enercon (14.5)	Vestas (15.3)	Gamesa (12.3)	Enercon (13.7)	NEG Micon (12.7)	NEG Micon (13.9)	Enercon (14.6)	Enercon (15.1)
Bonus (10.4)	Bonus (14.4)	Enercon (13.2)	Enercon (12.1)	NEG Micon (13.4)	Enron (12.6)	Gamesa (11.5)	Gamesa (11.5)	GE Wind (10.8)
Tacke (7.4)	Gamesa (6.09)	Gamesa (6.8)	Enron (8.9)	Bonus (11.5)	Gamesa (9.4)	GE Wind (8.6)	NEG Micon (10.3)	Bonus/ Siemens (6.0)
NEG (7.3)	MADE (4.9)	Bonus (5.9)	Bonus (8.4)	Nordex (8.3)	Bonus (8.6)	Bonus (6.8)	Bonus (6.6)	Suzlon (3.8)
Nordex (3.4)	Enron (4.4)	Nordex (5.2)	Nordex (7.6)	Enron (6.0)	Nordex (6.7)	Nordex (6.8)	REpo (3.5)	RE (3.2)
NEPC (3.2)	Nordex (4.4)	MADE (4.1)	MADE (5.4)	EC (3.9)	MADE (2.8)	MADE (3.36)	MADE (2.9)	MI (2.5)
NW (2.8)	DES (3.5)	EC (1.9)	EC (1.5)	Suzlon (2.3)	MI (2.6)	RE (3.0)	Nordex (2.9)	EC (2.5)
WW (2.6)	---	---	DeWind (1.4)	Dewind (2.1)	RE (1.9)	EC (1.6)	MI (2.6)	Nordex (2.2)
Top Ten Total								
89.9	90.9	93.7	92.7	93.0	96.3	95.0	94.7	96.1
Annually Installed Capacity in the World in MW								
1292	1568	2597	3922	4495	6824	7227	8344	8154
DES = Desarrolios (Spain), EC = Ecotecnia (Spain) MI = Mitsubishi (Japan), NEG = Nordtank, NW = NedWind (the Netherlands), RE = REPower, WW = WindWorld								

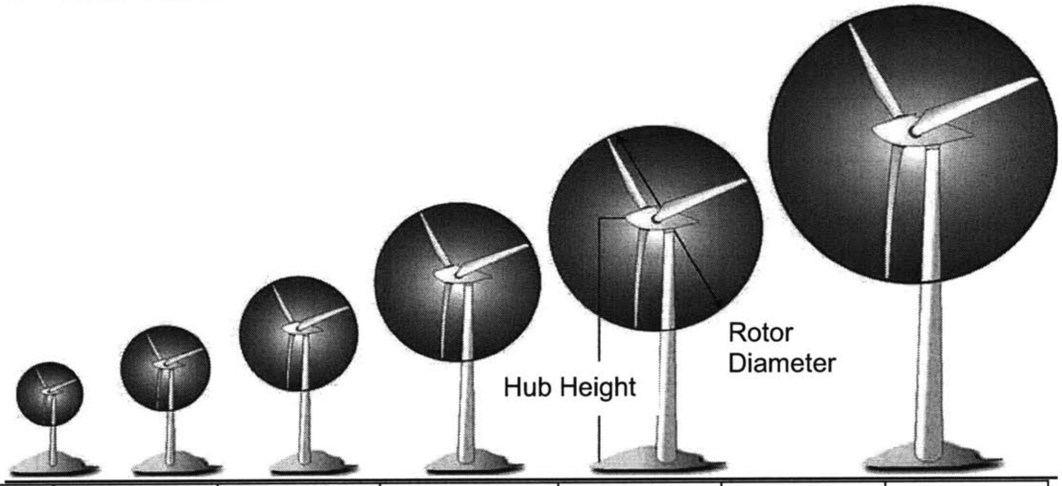
Sources: Market Share by (DEWI 2001b; DEWI 2002b; DEWI 2003b; DEWI 2004b; DEWI 1997b; DEWI 1998b; DEWI 1999b; DEWI 2000b). The World Installed capacity by (BTM Consult ApS 2005b)

Section 5.5: Wind Energy Technology Development at Frontier 1990-2005

This section examines the main characteristics of wind energy technology development at the technology frontier, especially in Denmark and Germany, since 1990. Technologies examined in this section are not exhaustive of all technologies innovated; this section only focuses on the well-commercialized technologies of three-bladed, horizontal-axis wind turbines with upwind rotor by the major manufacturers of the two countries, although some technologies developed and commercialized by other manufacturers may be introduced according to their importance.

5.5.1 Technology Development at Technology Frontier

Up-scaling of Wind Turbine



	1980	1985	1990	1995	2000	2005
Rated Power	30-55kW	80-100kW	250-450kW	500-600kW	1.5-2MW	5MW
Rotor Diameter	15 -20m	20m	30-40m	40-50m	65-80m	115-124m
Hub Height	25-30m	40m	40-50m	78m	80-100m	100-120m
Annual Energy Yield	35,000kWh (30kW)	95,000kWh (80kW)	400,000kWh (250kW)	1,250,000 kWh	3,500,000 kWh (1500kW)	Approx. 17,000,000 kWh

Sources: (BWE 2005; European Wind Energy Association 2003; McGowan and Connors 2000)

Figure 5-7: Representative Size of Wind Turbines on Frontier Market

The most important feature of wind energy technology development is the steady growth of size of turbine, rotor, and rated capacity. Technology depreciation rate of wind turbine is very high in terms of size. Figure 5-7, Tables 5-46 and 5-47 show the rapid increase of wind turbine size and commercialization at the technology frontier. Figure 5-7 illustrates that the size growth of the past 25 years is 90-fold and the energy yield has increased 485-fold. Table 5-46 shows that the average size increased more rapidly in Germany than in Denmark during the 1990s. This relationship reversed from 2002; the large offshore development in Denmark pushed up the average almost 1.7-fold from 2001, while the German market has begun showing the saturation of onshore sites for larger turbine installation. The other noticeable feature is that the average sizes of Denmark and Germany were close to that of the world average during the 1990s, while they have been far exceeding to that of the world average in recent years. The comparison between Table 5-46 and Table 5-47 show that the average turbine size matches the rated capacity of majority of installed turbine segments of Germany extremely well; most of the installed turbines in the German market have not deviated from the average sizes.

Table 5-46: Average Size of Annually Installed Wind Turbines

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Denmark	248	365	493	531	560	687	750	931	850	1443	1988	2225
Germany	255	371	473	530	623	783	919	1101	1281	1397	1650	1715
World	---	---	394	433	528	699	784	738	918	1092	1207	1246

Sources: (BTM Consult ApS 2005b; Danish Wind Industry Association 2006; DEWI 2002a; DEWI 2003a; DEWI 2004a; DEWI 2005; DEWI 2006; DEWI 1993; DEWI 1994; DEWI 1995; DEWI 1996; DEWI 1997a; DEWI 1998a; DEWI 1999a; DEWI 2000a; DEWI 2001a)

Table 5-47: Product Segment in German Market (% share)

	0kW≤	<200kW≤	<310kW≤	<400kW≤	<750kW≤	<1.5MW≤	<3.1MW≤
1993	18%	**82%**	---	---	---	---	---
1994	7%	**93%**			---	---	---
1995	3%	6%		**91%**	---	---	---
1996	-1%	2%		**99%**		---	---
1997	1%	1%		**72%**	26%	---	---
1998	---	**---**		49%	**51%**	---	---
1999	---	**---**		34%	**66%**	---	---
2000	---			19%	**82%**	---	---
2001	---			10%	**90%**		---
2002	---	7%			15%	**78%**	---
2003	---		2%		8%	**89%**	---
2004	---		1%		5%	**93%**	1%

Source: (DEWI 2002a; DEWI 2003a; DEWI 2004a; DEWI 2005; DEWI 1994; DEWI 1996; DEWI 1997a; DEWI 1998a; DEWI 1999a; DEWI 2000a; DEWI 2001a)

Convergence to Three-Bladed, Upwind, Horizontal Axis Structure

While wind turbines have continuously upscaled, most of diverse design concepts of basic wind turbine structure emerged during the 1970s and 1980s in terms of the number of blade, rotor orientation, and direction of axis gradually disappeared during the 1990s, by reaching either technical or commercial dead-end; the basic structure of wind turbines has mostly converged into three-bladed, upwind, horizontal axis design with steel tubular tower by the mid 1990s (Gasch and Twele 2002; Gipe 1995). There has been a strong preference of three-bladed rotors in the market due to several reasons: historical connection to the successful early Danish turbine designs and the associated needs for a dynamically simple rotor in stall regulation; visual preference over one- or two-bladed turbines; and low noise production.

On the other hand, both commercialized and emerging concepts remain diverse in the following areas of wind energy technology sub-systems.

Rotor Power Regulation through Rotor Blade Angle - Wind Power Capture Mechanism

Rotor power regulation systems limit and condition the rotor output power at high wind speeds aerodynamically, in order to avoid very high powers and torques on drivetrain. Three mechanisms are available today.

Stall Regulation

Stall regulation system fixes the blade pitch angle for all wind speeds. Without any change to the rotor geometry, the rotor aerofoil stall as wind speed and relative flow angle increase. In shorts, in stall-regulated turbines, power is regulated by the progressive loss of rotor efficiency as the stall extends over the rotor and no excessive power is produced because the rotor geometry does not change at high wind. Stall-regulated wind turbines require constant rotor speed for such stalling to take place, and this is usually achieved by induction generator connected to the power grid (European Commission 1999). Because of its simplicity due to no necessity of any blade control system, this regulation system has been used for small and medium-capacity Danish commercial turbines since the 1970s and the technology has been well-established in the 1980s.

Blade Pitch Regulation

Blade pitch regulation system increases the blade pitch angle at wind speed when it reaches higher than the rated speed, in order to ensure the power output from the rotor to be limited to the rated power of the generator while the angle is fitted up to the rated wind speed. Therefore, pitch-regulated turbines can have an almost optimum pitch angle at any wind speeds and a relatively low cut-in wind speed. An active blade pitch mechanism (usually fitted in the rotor hub) is required to sense the blade position, measure the output power and instruct the adjustment of blade pitch with the hydraulically-operated steel pull-bars. This regulation system has become increasingly controlled by microprocessor for continuous and optimal adjustment of blade angels during the 1990s, e.g., Vestas OptiTip® (1994).

- Collective Pitching System: pitch mechanisms of all three blades are mechanically interlinked and powered by a single actuator. It was common in the 1980s.
- Independent Pitching System: each blade has an independent pitch actuator and two independent rotor brakes. It became used from the mid 1990s.

Active Stall Regulation

Active stall regulation system uses a number of fixed pitch settings to optimize stall behavior at different wind speeds. The blades pitch along their axis like a propeller blade. Active stall regulation offers a better control than stall regulation and consumes less power than pitch regulation, because it does not regulate pitch angles as many as regular pitch regulation methods. The most notable example of active stall is Bonus CombiStall®, which came into the market in 1995 with the firm's first 1 MW turbine (54m rotor diameter); it maintains the fixed full-span stall regulation for normal operation but the blades are pitched back into stall for rotor braking and over-speed protection once wind speed reaches above the rated speed.

Rotor Speed Control and Electrical Power Generation System Configurations

Wind turbines can be operated at fixed (constant) speeds or at variable speeds. The options are predominated by the electrical system. There is an important connection between the choice of rotor power regulation and the choice of rotor speed control/electrical power generation system.

Fixed-Speed Configurations (Danish Classical Concept)

Fixed-speed configurations can use readily available induction generators[67] to produce the utility compatible electricity inexpensively without any sophisticated controls. The speed of induction generator is fixed by the frequency of the grid; there is no control of the speed. Fixed-speed configurations work with stall regulation well, as the stall requires constant speeds that can be done by the induction generator connected to the grid. The fixed-speed operation with stall power regulation is called the Danish Classical Concept. The electrical system of fixed-speed turbines contains a soft-starter for smoother grid connection and a capacitor bank for reduction of reactive power consumption (Figure 5-8) (BTM Consult ApS 2005b).

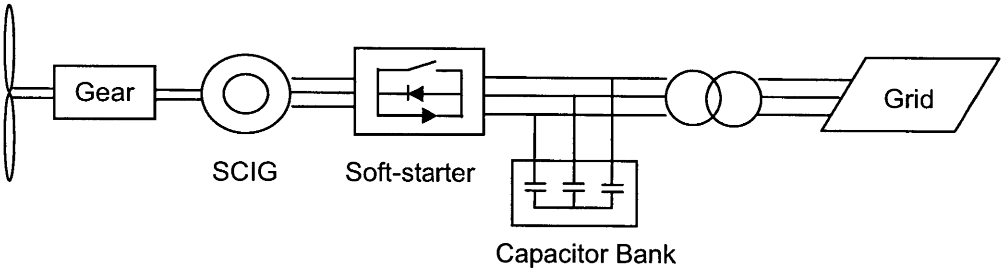


Figure 5-8: Fixed-Speed Configuration
Source: (BTM Consult ApS 2005b)

One-Speed Configurations

One-speed systems use one generator and it operates at one constant speed.

Two-Speed Configurations with Dual Generator or Single Generator with Dual Winding (Pole Switching)

Efficiency drops off rapidly when the generator is operated at less than one-third of its rated value. In order to prevent this from happening, fixed-speed turbines often use dual generators or dual windings, which permit the turbines to operate at two speeds:

- Dual Generators: use one main generator and a smaller generator, one-fifth to one-third the capacity of the main generator that operates at low to moderate wind. Two generators are connected by a belt drive.
- Dual Windings: use pole switching of one generator that operates on six poles during low winds and operates on four poles in higher winds. This operation can capture most of the

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[67] Induction generators are not common outside the wind energy industry, but became widely used in wind turbines because they can increase or decrease the speed slightly if the torque varies within the generator's slip (frequency difference between the rotational speeds at peak power and at idle, about 1%) and reduce wear and tear on the gearbox.

efficiency advantages of variable speed turbines, with only a small increase in cost for extra windings. This is more recent development than dual generators.

Two-speed configurations were already in use in the 1980s by the Danish manufacturers. The Danish two-speed turbines in the mid to late 1980s were dual generator turbines. Two-speed turbines in the mid 1990s more often used dual windings (Gipe 1995).

Variable Speed Configurations

The alternative to fixed-speed operations is variable speed configurations. In variable speed operations, rotor speed varies with wind speed, maintaining the relationship between rotor tip speed and wind speed and gaining the greater rotor efficiency.

Variable speed operations have several advantages over fixed-speed operations: 1) increase in aerodynamic efficiency and energy capture; 2) reduction of noise at low wind level; and 3) reduction of mechanical loads on drivetrain, which can reduce design requirement and the cost of gearbox or generator. To maximize the benefits of variable speed operations, a wide range of variable speeds is required (about the factor of 2.5 to 3 in speed variation) (European Commission 1999). To generate the utility-compatible electricity, however, the output from variable speed turbines must be conditioned, typically with synchronous power converter/ inverter and power electronics. There is trade-off between cost of power electronics and performance improvement through the increased speed range and energy capture.

Variable-speed idea was first employed by the Dutch Bergey Windpower during the 1970s and 1980s. Technological alternatives of variable speed operations depend on power electronics and its cost. The falling cost of power electronics due to the activities unrelated to the wind turbine industry has increased technology options and variable speed systems are increasing since 1990 (Gipe 1995). The followings are well-commercialized configurations.

Limited Variable Speed Configurations using Variable Rotor Resistance (OptiSlip®)

This type of configurations achieves a limited range of variable speed operations, allowing both the rotor and the generator to vary their speed by up to 10% during wind gusts. It uses a wound rotor induction generator (WRIG) that is directly connected to the grid.

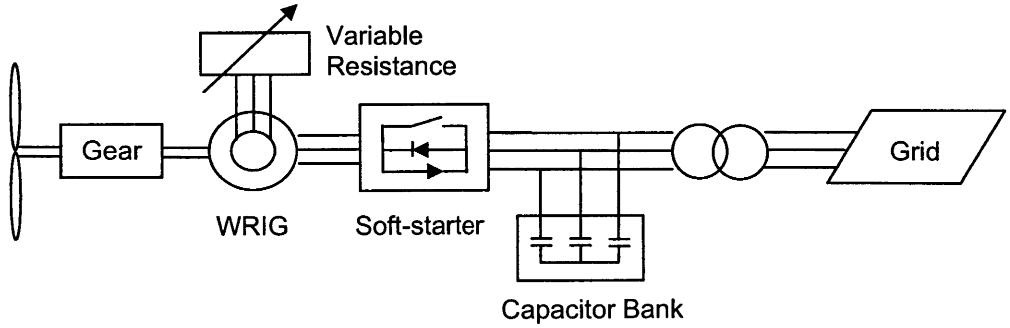

Figure 5-9: Variable Speed Configuration using Variable Rotor Resistance
Source: (BTM Consult ApS 2005b)

The rotor winding of the generator is connected in series with a controlled resistance, whose size defines the range of variable speed (0-10% above synchronous speed). The use of optical coupling to the rotor to control resistor switching for rotor resistance change eliminates the need of costly and unreliable slip ring and brushes. Reactive power compensation and a soft starter are required (Figure 5-9) (BTM Consult ApS 2005b; Carlin, Laxson, and Muljadi 2003). The technology was developed by Vestas; it was named as OptiSlip® and introduced to the market in 1995 with several turbine series with pitch regulation.

Limited Variable Speed Configurations with Doubly-Fed Induction Generator (DFIG)

This type of configurations achieves a narrower range of variable speed operations than full-range variable speed operations. It uses a partial-scale power converter (only 1/4 to 1/3 of size and cost of rated capacity of the generator), connected to the rotor of WRIG through slip rings and brushes, because only 25-30% of the power is fed through the converter. The stator winding of the generator is directly connected to the grid, while the rotor is fed at variable frequency through the converter. The power converter controls the rotor current, which is used to control active and reactive power through the stator. The size of power converter defines the speed range, which is more limited (approximately 1.5 to 2:1) than full-range variable speed range (2.5:1 or more). However, this is enough to have all the benefits of full-range variable speed operations while the partial-scale converter makes this type of configuration economical (Figure 5-10) (BTM Consult ApS 2005b; European Wind Energy Association 2003).

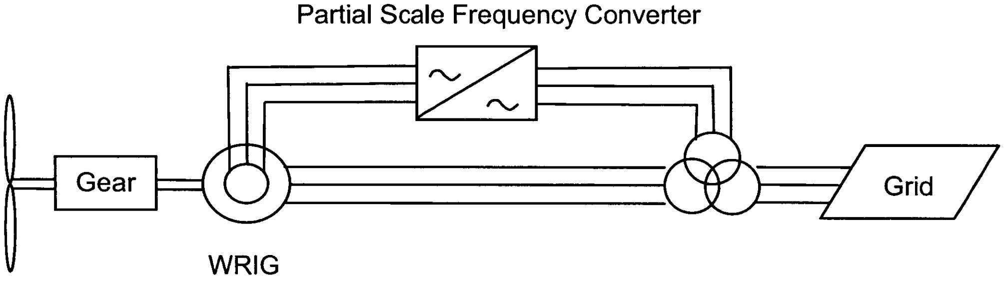

Figure 5-10: Variable Speed Configuration with DFIG
Source: (BTM Consult ApS 2005b)

This type of configurations allows extracting the maximum energy from low wind speeds by optimizing the turbine speed, while minimizing the mechanical stresses on the turbines during wind gusts. Another advantage is the power electronic converter that generates or absorbs reactive power, eliminating the need for installing capacitor banks. The converter also eliminates the need for smooth grid connection. The rotor power regulation for this type of configurations is mostly pitch. This type of configurations was first experimented in the Growian turbine during the 1980s. The first successful commercial application was made by Tacke in 1996. Many other Danish and German manufacturers have followed since. Tacke's original TW1.5 model used permanently excited induction generator. Vestas calls its DFIG technology as OptiSpeed®.

Full-range Variable Speed Configurations with Full-Scale Power Converter

This type of configurations achieves wide-range variable speed operations. It uses full-scale power converter with the same rating as the generator, which is commercially viable now, especially for offshore. The generator stator is connected to the grid through full-scale power converter, which gives reactive power compensation and smooth grid connection for the entire speed range. Incorporation of the power conditioning equipment also provides the power factor control to turbine operators/utilities (Figure 5-11) (BTM Consult ApS 2005b; European Wind Energy Association 2003). Rotor control for this type of configurations is pitch. Types of generators used define the subcategories.

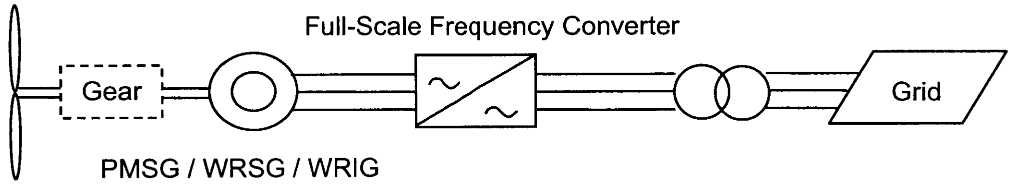

Figure 5-11: Variable Speed Configuration with Full-Scale Power Converter
Source: (BTM Consult ApS 2005b)

- Direct Drive System with Wound Rotor Synchronous Generator (WRSG): Variable speed concepts and direct drive concepts have existed for long time, but it was Enercon that put these two radial concepts together.[68] Enercon uses very large, multi-pole ring WRSGs, which run at very low rpm. Since 1993, all wind turbines by Enercon use the same configuration. A Dutch manufacturer Lagerwey also marketed two models with this configuration LW52 and LW58 during the 1990s.
- Direct Drive System with Permanent Magnet Synchronous Generator (PMSG): All other direct drive turbines on the market use PMSG, although the number is very limited due to the high cost of permanent magnet.
- Geared Drive System with WRIG/WRSG: Before shifting to the direct drive technology, Enercon was using geared-drive system with WRSG from 1985. Bonus began using this configuration from 2003 with WRIG.
- Multibrid® - Single Stage Geared Drive System with Medium Speed PMSG: This is the newest type of configuration. This configuration has a single stage gear (6:1) driving a medium-speed, permanently-magnetic, multi-pole synchronous generator, in order to avoid the complexity of multi-stage gearbox but to have a lower system mass with more efficient and compact nacelle arrangement than large direct drive generators (European Wind Energy Association 2003). The concept was first presented by a German engineering consultancy firm Aerodyn in 1998. In 2000, Pfleiderer Wind Energy (Germany) acquired the exclusive right from Aerodyn to use the Multibrid technology in application over 3MW, while WinWinD of Finland acquired the right in application up to 3MW. After Pfleiderer built a prototype 5MW Multibrid turbine (M5000) in 2003, the firm sold the technology to Prokon Nord Energiesysteme GmbH (Germany).

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[68] In general, this innovation is considered the only radical innovation that has achieved the commercial success in the contemporary wind turbine history, as all other innovations are incremental.

Transmission System Configuration

Geared Drive

Geared drive uses multi-stage gearbox for high speed generators. Gearboxes increase the speed of the main shaft up to a maximum of 6:1 per stage, in order to increase the speed of the slow running main shaft (rotor rpm) to match the mass-produced induction generator rpm. A two-stage transmission can increase rotor speed a total of 36:1. The number of stages influences the cost and efficiency of turbines. Medium- and large-capacity turbines typically use three stage gears. Two types of gear, parallel shafts and planetary gears, are used for wind turbine gearbox; planetary gears are more compact, lighter in weight, and less noisy. Typical three stage units today use planetary gear at the input stage and parallel shafts with helical gears at the two higher-speed stages. Small-capacity turbines in the 1980s used two-stage transmissions. Medium- and large-capacity turbines from the 1990s use mostly three stages (Gipe 1995).

Gearboxes have been the most problematic components in wind turbines and its failures have been a major cause of system non-availability from the beginning.[69] Historically the problems are equally divided with low speed (planetary) stage and high speed stages (European Wind Energy Association 2003).

Direct (Gearless) Drive

Direct (Gearless) drive concept uses a slow-speed generator, driven directly without transmission, as presented above. It can eliminate historically problematic gearboxes and their cost, although the cost of generators increases. Direct drive systems are in general best suited to variable speed operations. Their development depends on development and cost reduction of power conditioning systems

Multibrid® Concept (Single Stage Gearing):

This newest type of drive concept is considered as a hybrid between conventional geared drive with high-speed generators and direct drive with low speed generators (see above). Multibrid turbines have compact and highly integrated drivetrains.

Drivetrain Design

Drivetrain can be modular or integrated. Drivetrain design parameters are handling of wind thrust on the rotor, rotor weight, and torque that the rotor transmits to the transmission, all of which get bigger as turbines become larger (Gipe 1995).

Modular Drivetrain

As mentioned in Chapter 4, modular drivetrains have a metal frame or bed plate, where the main shaft, transmission, generator and other components within separate housings are mounted. The separate main shaft and its support bearings allowed the transmission to be replaced readily for repair and maintenance without requiring removal of the rotor. Modular drivetrain was the standard of the very first generation of the Danish Classical Concept during the late 1970s and early 1980s. Actual placements of components depend on manufacturer designs.

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[69] While gearboxes themselves are a med-tech component, the basic technology needs to be treated as high-tech technology and its safety requirements should be higher (Hjuler Jensen 2005).

Integrated Drivetrain

Integrated drivetrains use one of the drivetrain components, usually gearbox, as the primary component, to which all the other components are flanged. Integrated drivetrains, therefore, do not use a bed plate. Their assembly is simpler and they are more compact than modular designs, usually used for light-weight turbines, conserve materials, and reduce nacelle weight and space demands. However, sound insulation can be insufficient, replacement of defective parts often requires complete removal of the nacelle from the tower, and the gearbox can be an expensive special component. Various ways of integration have been developed by different manufacturers. Many manufacturers also use partially integrated drivetrain, which is a compromise between modular and integrated designs.

Rotor Blade Technology

The most important elements of rotor blade technology are materials development, aerodynamic design, and quality control in production process. Design of individual rotor blade is determined by aerofoil profile, external geometry, and materials. The required aerofoil quality determines materials and manufacturing methods for rotor blade (Gasch and Twele 2002).

Rotor Blade Aerofoil Design

Various families of aerofoil have been developed and the number of options available for blade profile is enormous.

Aircraft Aerofoil

Most small and medium-capacity wind turbine blades adapt aerofoil developed for aircraft, not optimized for wind turbine operation. They have two shortcomings: 1) they are never intended for stall regulation, and it shortens the lifespan of generators and transmissions if wind turbines with aircraft aerofoil blades reach excessive peaks before the aerofoil stalls; and 2) they are sensitive to roughness as well as dusts and dead insects in dry climate that increase the roughness and reduce the performance (Gipe 1995).

General aviation aerofoil series by the US National Advisory Committee on Aeronautics (NACA) such as NACA 63/NACA 64/NACA 65 series have been widely used for wind turbine blades. They can be used independently or in conjunction with special-purpose aerofoil design.

Special-purpose Aerofoil tailored for Wind Turbines

With years of experiences, it turned out that blade aerofoil design, both external geometry and profile, for wind turbines is extremely high-tech, because the working conditions of wind turbines are more complex due to lifting and turbulences than the working conditions of aircraft. In addition, the design objectives of rotor blade aerofoil for wind turbines have changed from maximizing blade efficiency during the 1990s to optimizing the cost of energy during the 2000s, and also turbine sizes increased tremendously. As a result, more slender profiles became required, as the chord sizes increase at much lower rate as the blades get longer (De Vries 2004a).

These conditions prompted many manufacturers began using tailored blade aerofoil designs developed specifically for wind turbines since the mid 1990s. Some of the most recent models have the aerofoil developed just for them. The significant advancement of IT software and hardware was the key for special-purpose blade aerofoil innovation and calculation of loads on blades and entire turbine. The innovation process requires extremely high-speed calculation for Computational Fluid Dynamics (CFD) simulation of wind system aerodynamics, which became only possible in recent years with the availability of super-computer (Hjuler Jensen 2005).

Naturally, such simulation and calculation can be mainly carried out by large research institutions or research consortiums with super-computer. Many of these research institutions are national research laboratories and they have developed ready-to-use, special-purpose aerofoil for wind turbines for commercial purpose, and this part of technology and knowledge is coded. The most representative series are: S8 series by the US National Renewable Energy Laboratory (NREL); FFA-W series by Department of Wind Energy under the Swedish Defense Research Agency (FOI); RISØ-A1 series/RISØ-B series/RISØ-P series by RISØ; and DU-XX-W series by Technical University of Delft in the Netherlands. Meanwhile, some manufacturers, Vestas, Enercon and Bonus/Siemens in particular, also develop the profiles by themselves, while Vestas buys some profiles from RISØ as well (Madsen 2005).

Blade Materials

Blade materials can change rotor weight and cost significantly. Lighter and more flexible blades materials reduce blade loads, avoid strain, and reduce rotor weight and cost. As mentioned in Chapters 3 and 4, the composite construction became dominant during the 1980s. Table 5-48 shows the most representative blade materials since the 1980s.

Table 5-48: Major Rotor Blade Materials for Wind Turbines

Materials	Features
Glass-fiber Reinforced Plastic (GFRP)	▪ A matrix of fiber glass mats are integrated with polyester, which is hardened after it has impregnated with the fiber glass. ▪ Fiberglass is strong and relatively inexpensive but has good fatigue strength, suitable for variety of design and manufacturing processes. ▪ The dominant materials during the 1980s and 1990s.
Glass-fiber Reinforced Epoxy (GFRE)	▪ Use of epoxy instead of polyester for glass fiber composite. ▪ GFRE is suitable for more slender and lightweight blades for larger machines to reduce loads and create more favorable blade mass. ▪ Easier quality control and lower variation in material properties than GFRP. ▪ The dominant materials since the mid 1990s.
Carbon-fiber Reinforced Plastic (CFRP)	▪ Carbon can substantially increase the stiffness and fatigue strength of blades without increasing the weight. Ideal for lightweight design. Carbon fiber can be used to form the whole or partial basic blade matrix, e.g., CFRP. ▪ CFRP is light weight but highly strong. But because it is very expensive, using CFRP only in the load carrying parts is a cost effective option. ▪ Evolved from aerospace applications. Smart production techniques developed by ATV Enterprise in France in the mid 1990s made it cost effective for wind turbines.
Wood Epoxy Laminates	▪ Wood-epoxy system was first developed by Gougeon Brothers in the United States and was already in use during the 1980s. The critical factor of using wood was the development of epoxy resin system that seals the wood laminates, preventing significant moisture change during lifetime of wind turbines. ▪ Wood-epoxy laminates have are light-weight and relative easy to dispose.

Sources: (European Commission 1999; European Wind Energy Association 2003; Gipe 1995)

Rotor Blade Manufacturing Technology

Rotor blade manufacturing is the extremely complex process and exclusive to each manufacturer. Competitiveness in blade technology derives from its manufacturing technology; copying blade is extremely difficult, and the production secret is what makes blade very exclusive. Materials science parts of blades are deeply integrated into production, which makes the entire blade technology very complex (Hjuler Jensen 2005). Table 5-49 shows several representative manufacturing methods of rotor blades.

Table 5-49: Rotor Blade Manufacturing Process

Process	Features
Hand Lay-up Wet Process of GFRP and GFRE Blade	▪ Hand lay-up of primarily fiberglass structure in open-mould wet processes. First, the layer-upon-layer of fiberglass cloths are hand-placed in half-shell moulds of a blade. Each additional layer cloth is coated by a polyester or epoxy resin. Once the shell is complete, the structural stiffeners and longitudinal spar running the length of the blade are added. Then, the two halves are glues together to form a blade. ▪ The most conventional manufacturing method of GFRP and GFRE blades for up to the 30m blades. Used widely by almost all manufacturers for small and medium-capacity turbine blades in Europe.
Pre-impregnated Process	▪ Fiber fabrics that are pre-impregnated with a resin that hardens when heated. ▪ Shortcomings are: fiber fabrics used in this process is more expensive than vacuum infusion process; the processing time is also longer; and the materials require being stored in cold storage and large machines to handle.
Vacuum Infusion Process for Resin	▪ Fiber already presented in the mould is impregnated with resin (epoxy or thermo-setting plastic such as polyester) that is drawn into the mould by means of a vacuum. ▪ The process allows for blades to be made in one cast, creating crystal clear laminate without air bubbles and microscopic pores. 100% quality control is possible. More environmentally friendly by not exposing surrounding to the resin, and provides considerable flexibility of choosing between materials and combinations than the pre-impregnated process. ▪ The process has been used since the late 1990s, e.g., LM Glasfiber, Aeropac, Enercon, GE, NEG Micon.
Monolithic (Single-shot Infusion) Process	▪ Uses a dry perform, not a wet open-mould; blades are pressed in a single mould, eliminating a seam and the need for bonding two separately manufactured blade halves. ▪ Used by Bonus (Siemens) since 2002 for their in-house GFRE blades.

Sources: (Enercon GmbH 2004b; Gipe 1995; LM Glassfiber 2005b).

Production Mould Innovation

Development of production moulds is an important part of manufacturing technology innovation. Production moulds made from composite materials, instead of fabricated steel of the past, have made lighter and more rigid moulds possible, providing the advantages from production engineering and process points of views (De Vries 2004a). Production moulds from composite materials are begun used in the 1980s, but have been patented since 1970s. They are continuously improved by manufacturers and remain as the production secret for them (Hjuler Jensen 2005).

Automation/Robotics Application

Robotic systems have been used for the last 25 years for blade production and are also the production secret for each blade manufacturer. In the past, it was used only for making the moulds, not blade itself. However, in recent years, more and more blades and other machine elements are made with robotic techniques in order to control quality and reduce wastes and risks of error. For example, robotic systems place glass fiber sheets very precisely at predetermined places in the moulds, while registering and documenting every step in the manufacturing process and transferred to the SCADA system. Another robotic process applies glue that bonds the two blade shells (De Vries 2004a; Hjuler Jensen 2005; LM Glasfiber A/S 2005c). Machine dependency depends on manufacturing methods and manufacturers, but it has been increasing since the mid to late 1990s.

Control, Conditioning and Monitoring System

Control, conditioning and monitoring functions and the strategies for optimizing wind turbine reliability and performance through various methods that the controller interacts with turbine components are the very important business secrets for wind turbine manufacturers. Improved control strategies have contributed to the increase of wind turbine productivity in recent years (Danish Wind Industry Association 2003). They vary greatly from one turbine to another as well. Both hardware and software play important roles.

Power Electronics/Power Semi-conductor - Hardware

Power electronics makes wind turbines friendly to the grid and the power utilities. Most wind turbines on the market since the 1980s have used power electronics for soft-starter and variable speed control systems. The development and availability of power electronics have influenced the choice of rotor speed control and electrical power generation system configurations greatly.

Thyristors

Thyristors is a solid-state semiconductor device that acts as a switch when their gate receives a current pulse. Modern thyristors can switch up to megawatts amounts of power. Thyristors is the earliest device used for wind turbine operation, mainly as soft-starter. The soft-starter application was developed in the beginning of the 1980s and thyristors was a part of this technology. It became common place during the 1980s and 1990s (Hjuler Jensen 2005).

Transistors

Transistors, such as insulated gate bipolar transistor (IGBT), bipolar junction transistor, and metal-oxide-semiconductor field-effect transistor, can regulate a large amount of power at one time. These devices as well as other circuit elements can be combined in a range of ways to control switching, current flow, resistance, and voltages. Transistors are old technology but have made dramatic advancement in power handling capability for the past 20 years, while the ten-time price reduction occurred during the last ten to 15 years (Carlin, Laxson, and Muljadi 2001; Hjuler Jensen 2005).

- **IGBT (Insulated Gate Bipolar Transistors)**: IGBT has become a choice for high-power inverters/converters and soft-start controllers for wind turbines in recent years. IGBT is a power electronics device invented during the 1980s and mainly used in switching power supplies and motor control applications. Although the first generation IGBT were relatively slow in switching and prone to failure, the second generation devices from the mid 1990 improved greatly and the current third generation withstands high-speed operations and has tolerance of overloads. In addition, higher performance avaiability and sharp cost reduction since the mid 1990s have increased the popularity of IGBT as adjustable speed power electronics drives for most of variable speed operations and soft-start controllers. Many pitch-regulated, variable speed turbines, regardless of their drive system, use IGBT as the adjustable-speed power electronics drives (partial- or full-scale power electronic converters as well as cost-effective torque-speed control for blades) (Gertmar 2003).

Supervisory Control and Data Acquisition (SCADA) - Hardware and Software

SCADA (Supervisory, Control and Data Acquisition) system is a monitoring system that allows a remote operator to log in and control wind turbines and wind farm with great precision. As explained in Chapter 4, the Danish industry created the SCADA protocol in the mid 1980s in order to manage the overall transmission of information between wind turbines and the grid system. The protocol made all the SCADA information to be exchangeable from one company's SCADA to other company's SCADA. Each manufacturer has developed its own, unique SCADA system based on the protocol since the late 1980s, and the manufacturers and their electronics system suppliers have continuously improved reliability and sophistication of SCADA and user-friendliness. New SCADA products are usually applied to newly introduced turbine models. Older models and already installed turbines can be retrofitted with new SCADA system, usually by request.

Remote Monitoring

The amount of data monitored by SCADA and their monitoring precision have increased. Remote monitoring technology has continuously upgraded for the past 20 years, and the 24-hour remote monitoring is a norm in the industry. Currently all manufacturers offer the SCADA remote monitoring of: 1) wind turbine data (wind speed, active and reactive power, yaw angle, etc. and command/operational/fault status); 2) electrical and mechanical data (three-phases and current voltage, power factor, frequency, rotational speeds of generator and rotor, and temperatures of gear oil/generator/nacelle, etc.); 3) turbine statistical data (availability, external errors hours, and calendar hours, etc.); 4) meteorological data (wind speed and direction, air pressure, temperature, mean wind speed, and any other project-specific data); and 5) grid data (three- phases and current voltage, active and reactive power, and any project-specific data).

The latest development is preventive monitoring, which uses vibration censors to identify any faults in very early stage. The products came around 2003, e.g., Vestas Condition Monitoring Systems (VCMS) and Nordex Condition Monitoring System (Nordex AG 2002b; Vestas Wind Systems A/S 2004).

Remote Reporting - Internet Information Portal

Internet information portal have been used to provide remotely and instantaneously the monitored data to anybody concerns the wind turbine performance, not only customers but also service contractors and technical management personnel. Such services become popular since the early the 2000s. They include Nordex Control 2 (2001, web-based), Vestas Online™

(2002, web-based), Enercon Service Information Portal (SIP, 2004),[70] and Siemens WebWPS SCADA (web-based). These most recent products convert the data into information, tailoring them into standardized and customized reports that can be easily exported to the standardized software product such as Excel (Enercon GmbH 2003b; Nordex AG 2002b; Vestas Wind Systems A/S 2002c).

Grid Interface Management

As the number of wind turbines connected to the electricity grid increases, the grid interface management has become a contentious issue for the grid stability. SCADA plays a vital role in supporting optimal interface between the turbine controller and the grid control center at the utility by measuring the grid conditions and controlling the turbine behaviors. Enercon Process Data Interface (PDI, 2003) and Vestas GridSupport™ (2003), both perform such a role even during the grid error by dealing with short-term voltage drop and preventing voltage collapse from occurring (Enercon GmbH 2003a; Vestas Wind Systems A/S 2004).

Remote Controlling and Wind Farm Controller

SCADA has also considerably advanced its remote controlling ability together with remote monitoring ability. The development during the early 2000s was the innovation of integrated remote controlling system of all previously stand-alone monitoring systems. This enabled wind farm controlling and optimization by registering all data concerning individual turbines in a wind farm, meteorological and management systems as well as the grid substations. Both Nordex Control 2 (2001) and Vestas Online™ (2002) are built for this purpose with the web-based data exchange system. Vestas Online™ was launched with V80/2.0MW for Horns Rev Offshore Wind Farm. Enercon PDI (2003) also targets wind farm integration (Enercon GmbH 2003b; Nordex AG 2002b; Vestas Wind Systems A/S 2002c).

Noise/Sound Reduction Technology

Advancement of noise reduction has been constant and significant. Sound emission levels of many new turbines tend to cluster around similar values; this indicates technological development in this area has well-incorporated into most of commercialized turbine designs (Danish Wind Industry Association 2003). There are two main noise sources for wind turbine: mechanical noise and aerodynamic noise.

Mechanical Noise Reduction

Mechanical noise arises from wind turbine internal components. In order to create an efficient transmission that reduces mechanical noise, spheroidal graphite iron casting with better acoustic damping characteristics than steel and elastometric gaskets became common by the mid 1990s (European Commission 1999). Variable speed turbines have also reduced the mechanical noise level in lower wind by lowering rotor speeds.

Aerodynamic Sound Reduction

Aerodynamic noise comes from the process that the rotor blades decelerate the wind when transferring the energy to the rotor. It can be reduced by the favorable shape and design of rotor blade profile. More efficient blade aerofoil can convert more wind energy into rotational energy,

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[70] Enercon SIP information supplys not only SCADA but also SAP, service scheduling, and the firm's field service system (Enercon GmbH. 2003b).

hence reduce aerodynamic noise. The development of smoother blade surface and suitable rotor tip design geometry has also contributed to reducing aerodynamic noise vastly. Although the aerodynamic noise from rotor blades has been vastly reduced (European Wind Energy Association 2003), it is still the technology frontier of R&D today because calculation of aerodynamic sound emission from blades can be done only by a few institutions with supercomputer (Hjuler Jensen 2005).

Tower Technology

The primary consideration for tower technology is overall tower stiffness. The other factors are the mode and cost of erection and aesthetics. Tubular designs become dominant at the frontier during the 1990s because of their aesthetic appearance, less labor intensiveness in construction, logistical advantages with easy transport, and reduction of the impacts on avian populations.

Stiff Tower and Soft Tower

Towers with higher fundamental natural frequency than blade passing frequency (rotor speed times the number of blades) are called stiff tower. They are relatively insensitive to the motions of the turbine itself but tend to be heavy and more expensive. On the other hand, towers with lower fundamental natural frequency than blade passing frequency are called soft tower. They are generally less expensive than stiff towers, since they are lighter, but it is important to make sure that no resonance are excited by any motions of the rest of the turbine by careful analysis of the entire system (McGowan and Connors 2000), which became increasingly possible by increased capability of computer sciences. The development of soft towers has been greatly advanced since the 1990s and they are preferred for larger turbines due to their light weight.

Offshore Wind Energy Technology Innovations and Adaptation

Since the mid 1990s the R&D focus on offshore wind energy technology has been the estimation of offshore wind resources and the methodology improvement of wind modeling, the design method development of dealing with the effects of combined wind and wave loading, the development of certificate rules, and the evaluation of pilot plants in shallow waters, along with the development of turbines specifically design for offshore environment.

Offshore-specific Turbines

There are many parameters required for turbines specific for offshore environment. Special paint for towers to prevent corrosion as well as temperature control and dehumidifiers for nacelle to prevent condensation are important. In addition, strong turbine control capabilities through remote control and monitoring are required for offshore wind farms that are increasingly treated as power plant by the utilities. Meanwhile, offshore turbines can operate at a higher rotational speed than onshore, because turbulence at offshore is less. The most important objective in designing cost effective offshore turbines, however, is to minimize the inspection and maintenance requirements due to the difficulty and high expense of turbine access in harsh offshore environments.

During the 1990s, the impacts of putting some additional marinisation features to offshore applications were not significant because many onshore turbines are originally specified for costal regions; dehumidifiers, small service cranes, special cooling system and special paint for towers were all introduced as additional features to onshore turbines in the Danish offshore wind farms developed during the 1990s.

Specifically designed offshore-specific wind turbines were begun commercialized from the early 2000s by various manufacturers, mainly modifying their onshore models by adjusting them to higher tip speeds and higher instrumentation specification and putting a larger generator, redundant electrical system components, and built-in handling equipment in the nacelle.

Offshore Foundation

Offshore wind projects require several different technical solutions from onshore turbines. The most distinguishably different part is the foundation. Onshore wind turbines usually use concrete bed plate as foundation, which was also used for Middelgrunden Offshore Wind farm. The following several offshore foundation concepts and techniques are developed (Table 5-50). Most of the existing offshore wind parks use gravitation foundations, and only concrete caisson and monopole foundations have been successfully installed as of the end of 2005.

Table 5-50: Offshore Foundation Technology

Concepts	Technology	Advantages/Disadvantages
Concrete Caisson Foundation	Can be built in dry dock near the site using reinforced concrete and be floated into the site before being filled with sand and gravel to achieve the necessary weight. Three offshore wind farms, Vindeby (1991), Tunø Knob (1995), and Nysted (2003) in Denmark used this method.	Simple technology. Concrete platform can be used in any soil conditions, but will become too heavy and expensive to install at water depths above 10m.
Steel Gravity Foundation	Use a cylindrical steel tube placed on a flat steel box on the sea bed. Then, the steel tube will be filled with olivine (very dense mineral), which gives the foundation sufficient weight to withstand waves and ice pressure.	Considerably lighter than concrete. Can be made onshore, may be used on all types of seabed, and can use in deeper water condition than concrete. However, it requires comprehensive erosion protection.
Mono-pile Foundation	Use a steel pile with a diameter of between 3.5m and 4.5m, which is driven some 10 to 20m into the seabed, depending on the type of underground. Mono pile foundation is effectively extending the turbine tower under water and into the seabed. Horns Rev Wind Farm in Denmark used this method in 2002.	Semi-standard in the mid 2000s. While requiring no preparations of the seabed in most soil conditions, the installation is expensive due to the need of heavy duty piling equipment. Not suitable for locations with many large boulders in the seabed.
Tripod or Multi-pole Foundation	Steel pile below the turbine tower emanates a steel frame that transfers the forces from the tower into three steel piles. The three piles are driven 10 to 20m into the seabed depending on soil conditions and ice loads.	While suitable for water depths above 30m and in most soil conditions with minimum site preparations, it is not suitable at water depths lower than 6-7m because the steel frame makes service vessels difficult to approach.
Suction Bucket Foundation	Place mono- or tripod-suction caisson on the sea bed and pump out the water, which creates pressure from the surrounding water to force it into the sea bed.	Easy installation and removal. An attempt by Enercon in 2005 failed due to mechanical deformation of the bucket during the installation.

Sources: (Danish Wind Industry Association 2003; De Vries 2005b; European Wind Energy Association 2003)

Wind Project Execution Technology

Wind Resource Estimation/Energy Prediction and Optimization Technology

The Danish National Laboratory RISØ has been making the standards on wind resource estimation, wind energy prediction, and optimization technologies.

Wind Atlas Analysis and Application Program (WAsP)

As mentioned in Chapter 4, RISØ developed a topographical wind flow model called Wind Atlas Analysis and Application Program (WAsP) in 1987. WAsP is a wind resource estimation model, which contains several physical models (flow model, roughness change model, model for sheltering obstacles, model for turbine wakes in wind farms) to describe wind flow over different topographies and roughness changes. WAsP is an implementation of the so-called wind atlas methodology, which can do the tasks described in Table 5-51. RISØ has continuously improved WAsP to increase its accuracy and user friendliness and has constantly introduced new tasks since the 1987 introduction. For example, the combination of the topographical and wake models by WAsP to optimize the layout came in the mid 1990s (European Commission 1999). As of February 2006, WAsP model has been used by more than 1600 users in over 100 countries and territories. It is the industry standard model for wind estimation (RISØ National Laboratory Wind Energy Department 2006a).

Table 5-51: WAsP Functions

Output Products	Tasks	Inputs
Observed Wind Climate (OWC) ▪ Wind Data Analysis	Analysis	Time-Series Analysis of Wind Speed and Direction
Regional Wind Climate (RWC) ▪ Wind Atlas Generation (wind atlas data sets)		Observed Wind Climate (OWC) + Site Description
Predicted Wind Climate (PWC) ▪ Wind Climate Estimation ▪ Wind Resource Mapping	Application	Regional Wind Climate (RWC) + Site Description
Annual Energy Production (AEP) of Wind Turbine		Predicted Wind Climate (PWC) + Power Curve
Micro Siting of Wind Turbine		Regional Wind Climate (RWC) + Digital Terrain Map
Wind Farm Wake Losses	Wind Farm Production	Predicted Wind Climates (PWC) + Wind Turbine Characteristics + Wind Farm Layout
Net Annual Energy Production of Entire Wind Farm		Annual Energy Productions + Wake Losses

Source: (RISØ National Laboratory Wind Energy Department 2006a)

WAsP Engineering

RISØ introduced another computer program called WAsP Engineering in 2001 to support the estimation of loads on wind turbines in complex terrain by estimating extreme speeds, wind shears, profiles, and turbulences. It designs and assumes 3D turbulence. Data from WAsP and WAsP engineering are used as input to the aerodynamic computer code and the load and safety analysis, which are used to design wind turbines (RISØ National Laboratory Wind Energy Department 2006b)

Project Design and Planning Software - WindPRO

WindPRO, a software product used for project design and planning of wind turbines and wind farms, is another Danish innovation of the 1980s, as mentioned in Chapter 4. The product has continuously improved (Table 5-52) and extended its customer base all over the world.

It is clear from Table 5-52 that the WindPRO development has happened around every aspect of wind power project execution. There are also two similar products (Windfarmer by Garrad Hassan and Windfarm by Resoft) competing on the market today.[71] All the three products include both energy and environment models, while WAsP by RISØ only calculates energy parts.[72] However, in terms of market share, the share of WindPRO is very high. Approximately 600 to 700 users have been licensed by the end of 2005. In Denmark and Germany, the market share has been 100%. Also all turbine manufacturers have WindPRO. In Spain, the market share of WindPRO is smaller, approximately 50%. Only in the United Kingdom, the shares by the other two products are larger (Nielsen 2005).

Table 5-52: Development History of WindPRO

Year	Module	Module Contents
1986	**Basis**	Project Administration, Map Handling, WTG Catalogue, Wind Data and on-screen digitalization of Height Contour Lines
	Atlas	Wind atlas calculation in non-complex terrain
	Park	Wind farm energy calculation
	Decibel	Noise calculation
1987	**WAsP**	Pre- and post-processing of data calculated with WAsP
1988		Basis, Atlas, Park, Decibel and WAsP became **DOS version**
1995	**Photomontage**	First visualization tool. Turbine rendering into landscape photo or artificial landscape. Added as Windows 3.1 tool
1996/97	**WindBank**	Economic analysis of wind projects
1997		Release of **the first Windows version** of WindPRO
1998	**Animation**	Animated presentation of photomontage
	Shadow Calculation	Calculation of shadow impact. Visualization module.
	ZVI	Calculation of Zones of Visual Influences (ZVI) for a specific area
1999	**Resource**	Calculation and presentation of wind resource maps
2000	**Energy Optimization**	Automatic optimization of layout for maximum energy output
2001	**Environmental Impact**	Environmental Impact Assessment report creation for each neighbor with separate report
	WindPLAN	Planning and/or site finding based on GIS data
2002	**3D Animator**	Visual reality presentation of wind turbines in an artificially rendered landscape
		First Internet auto update service began.
2005	**eGrid**	Calculation of power grid connections

Sources: (EMD 2005; Nielsen 2005)

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[71] Both the products are originated from the United Kingdom. These two products received the EU and British funding for their development (Nielsen, 2005).

[72] WindPRO also has three array loss models and more turbulence models to choose today, which has been demanded by users to compare the results by different models. Ibid.

Integrated Design and Optimization of Wind Turbine

The advancement of wind project execution technology is greatly interacted with the development of mathematical models for wind turbine components, wind turbines, wind farms, and wind resources. This resulted in the advancement of detailed modeling of wind turbine behaviors as analytical tools as well as the prediction of long-term wind resources at any site and wind turbine behaviors within a wind farm as design tools. This is an important technological contributing factor for the expansion of wind energy during the 1990s.

Computer Modeling for Integrated Design and Optimization of Wind Turbines

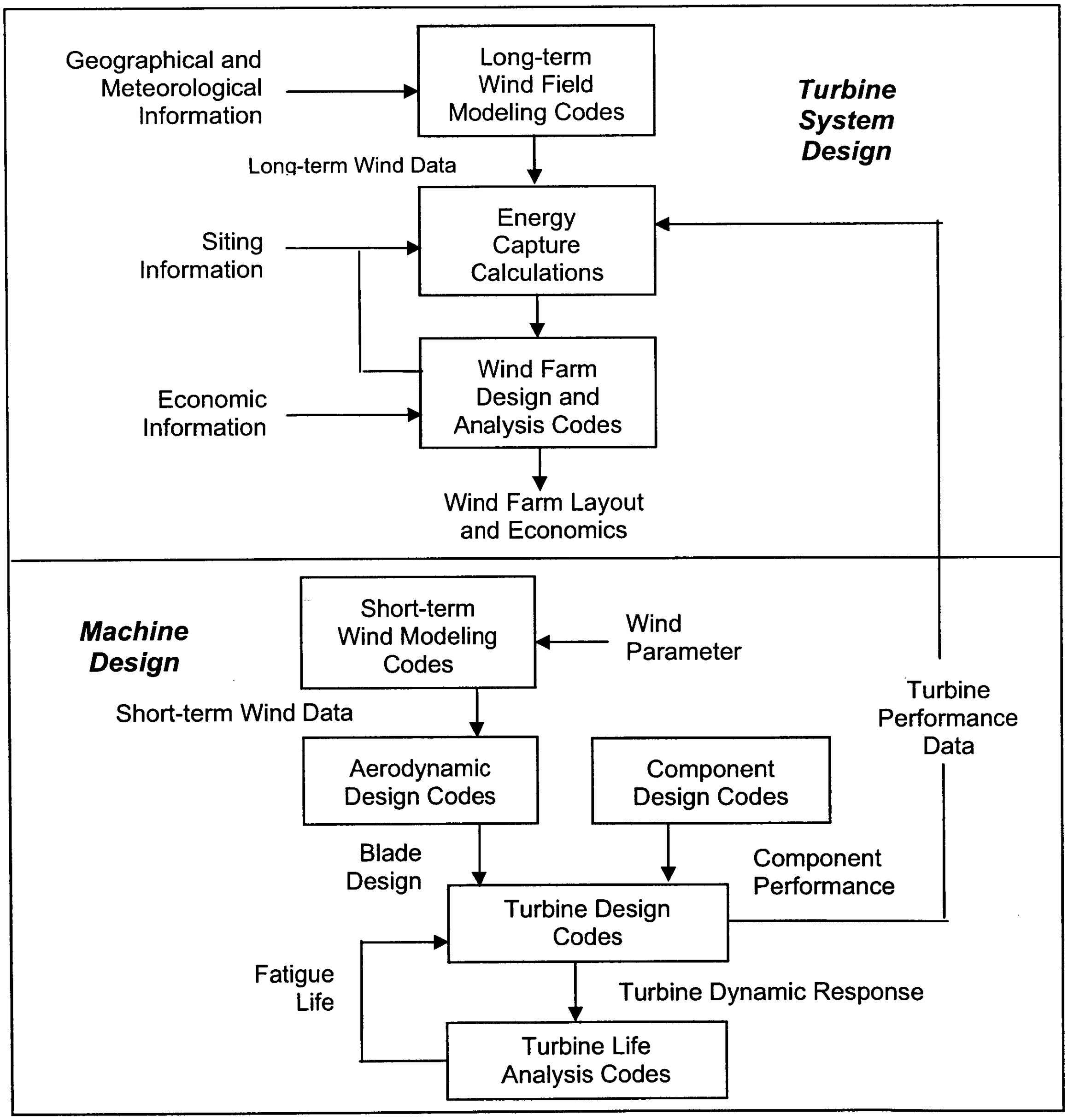


Figure 5-12: Relationships among Computer Modeling Codes
Source: (Manwell, J.G., and Rogers 1999) cited in (McGowan and Connors 2000)

Optimization of wind turbines does not solely depend on technology but on the combination of technology and economics, as the goal is to deliver electricity at the lowest possible cost per kWh of energy. The turbine optimization needs to be done as a system. For example, the relative size of generator and rotor and their fit to wind characteristics, e.g., small generator with small rotor for low speed wind, and large generator with large rotor for high speed wind, are important for optimization (Danish Wind Industry Association 2003; Garrad 1998).

As illustrated in Figure 5-12, in the computer modeling for integrated design and optimization of wind turbines, the results of component design codes and aerodynamic design codes are used for turbine design codes to determine the expected turbine performance under a specific wind climate. Then, this performance data is used with long-term wind projections and topographic data to optimize the wind turbine performance (McGowan and Connors 2000).

Turbine Transportation and Logistics Innovations

Innovations in turbine transportation and logistics have been constant. However, their importance has greatly increased with the introduction of MW-class turbines.

Small-capacity Turbines

A complete set of small-capacity wind turbine in the 1980s (100kW) could be packed inside a standard shipping container (12m-long, 70m^3 of space).

Medium-capacity Turbines

Logistics and installation are not a huge issue even for medium-capacity turbine (500-600kW), where road infrastructure is good and local site conditions are permitted.

- Around 1994, the standard container system showed its limits, when rotor blades began exceeding 12m for the first time. A system to open the doors of containers in order for the blades to stick out 2m was begun used (Wind Power Monthly 2002c).
- For medium-capacity turbines, the tower parts command the logistics. Towers are usually manufactured in 20 to 30 sections, and the limiting factors are the logistics on road and rail. Tubular tower has a logistical advantage over concrete and lattice towers, because nested tube towers are easily transported directly to the foundation for final assembly.

MW- and Multi-MW class Turbines

The size of MW-class turbines has brought new problems with logistics and installation. Transportation problems and costs increase as the sizes of rotor blades, hub, gearbox, and generator increase. MW-class components are far too big for normal transport solutions. For example, a 2MW turbine can fill 1500m^3, which is more than 20 times the space of the 100 kW turbines in simple comparison (Wind Power Monthly 2002c). All turbines manufacturers that produce MW-class turbines have devised unique solutions in collaborations with transportation equipment suppliers and freight forwarders. The followings are some example:

- General practice of stacking of the tower sections on a ship for oversea transportation (each manufacturer has a different way of stacking) (Wind Power Monthly 2002c).

- Special container unit for oversea shipping of long blades (Vestas 2000): linking three standard container units to transport up to three blades. Normal harbor cranes can be used (Vestas Wind Systems A/S 2001).
- Design of special transportation vehicle and system:
    - Special tailor for long rotor blade (NEG Micon, 2001): carry two blades instead of one (NEG Micon NR 6.2002).
    - Special trailer for large nacelle (Vestas, 2000): lower its base to the ground level and load and unload without the use of crane. The nacelle is manufactured directly on the base frame that is then attached to the trailer (Vestas Wind Systems A/S 2001).
    - Modular system for large tower (Vestas): modular tower system with wheels that can fix the tower sections to the trailer without using tools (self-loading and unloading). Adjustable for future larger and heavier tower transportation needs (Vestas Wind Systems A/S Date Unknown).
- Using an entire ship for exports (Vestas): nacelles in the hull area and blades on the deck.

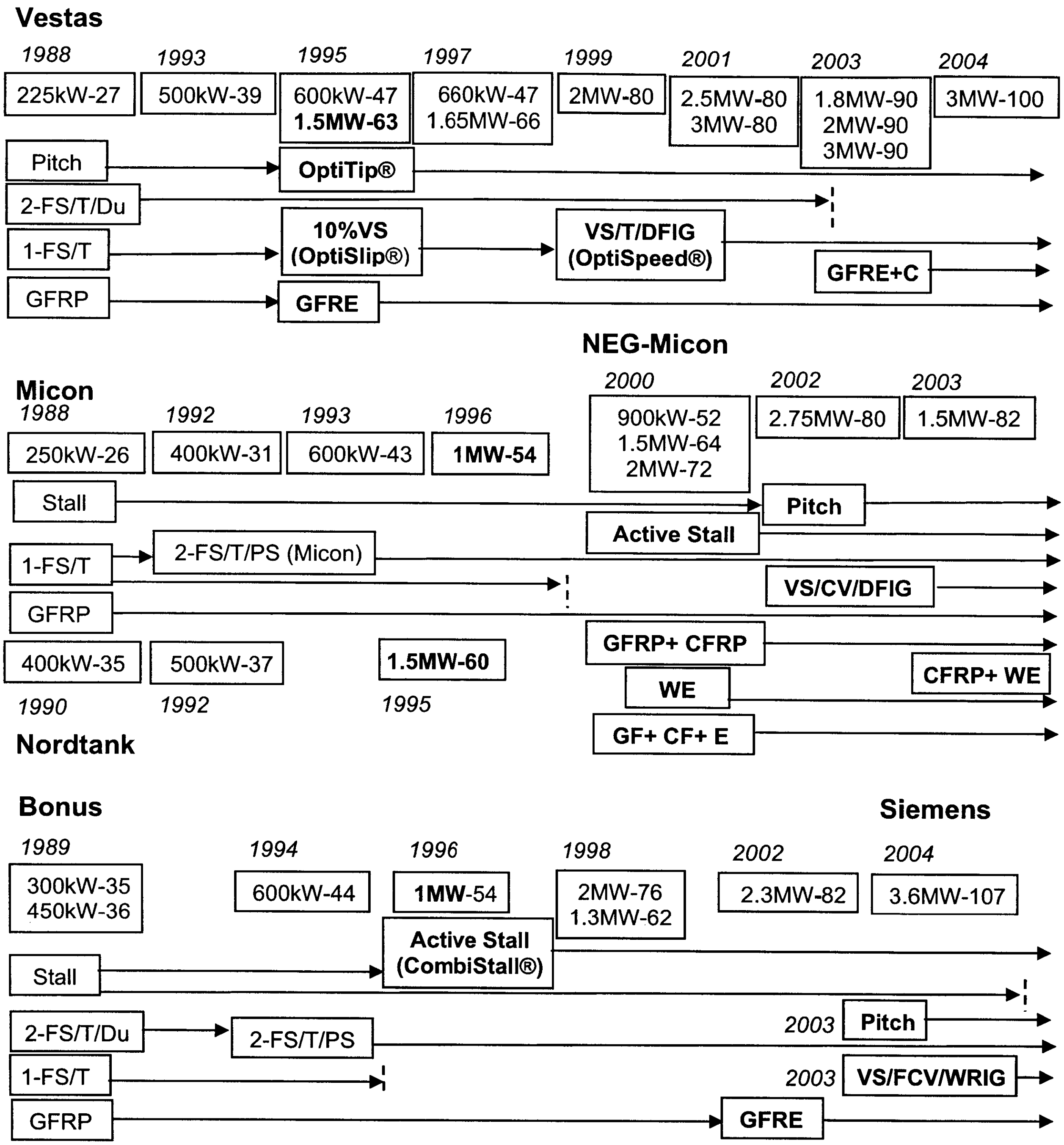
Participation of New Sub-suppliers (Freight Forwarders/Transportation Equipment Manufacturers)

The new logistical requirements and challenges have created a niche market for new sub-suppliers. The innovations in the logistics of oversea projects are done in collaboration between freight forwarders and wind turbine manufacturers, and the knowledge is very preparatory. Freight forwarders tailor-make the complete transportation system; unlike a shipping company, which is connected to one shipping line, it gets quotes from a number of steamship and trucking lines and goes with the best price. Their roles include: keeping the components unscathed during the shipping; locating a guarded storage area in the port; obtaining road permits for oversized loads in different parts of the world; finding equipment large enough to carry the components; and scheduling the just-in-time installation by coordinating the timing of turbine arrival and crane arrival at the sites (Wind Power Monthly 2002c). Transportation equipment manufacturers are also finding a niche market in new equipment design and manufacturing for wind turbine transport, as mentioned above.

5.5.2 Technology Trends

Shift of Technology by Major Manufacturers

Figures 5-13 and 5-14 illustrate the technology shift by the main Danish and German manufacturers since 1990 by showing the introduction of new products and technologies regarding turbine rated capacity, rotor diameter, power regulation methods, rotor speed control and electrical power generation system configurations, power electronics, and blade materials. The figures do not indicate that all product lines of the manufacturers shift to the new technology all at once; old technologies were usually continuously used until the product lines were taken out of market. From these figures, it is clear that specific product lifetimes on the market vary according to manufacturers and turbine models. Also there were many other products on the market by other manufacturers, some of which had different innovative features and technologies incorporated. However, the products by the manufacturers in Figures 5-13 and 5-14 have been more commercially successful and are considered to demonstrate the main market trend.



Key:
FS = Fixed Speed, VS = Variable Speed, DD = Direct Drive, T = Thyristors, CV = Converter, FCV = Full Converter, PS = Pole Switching, Du = Dual Generators, DFIG = Doubly Fed Induction Generator, WRIG = Wound Rotor Induction Generator, WRSG = Wound Rotor Synchronous Generator, PEIG = Permanently Excited Induction Generator, GFRP = Glass Fiber Reinforced Plastic, GFRE = Glass Fiber Reinforced Epoxy, CFRP = Carbon Fiber Reinforced Plastic, C = Carbon, E = Epoxy, GF = Glass Fiber, CF = Carbon Fiber, WE = Wood Epoxy

Figure 5-13: Technology Shift by Manufacturers (1)
(See the notes at the end of the section)

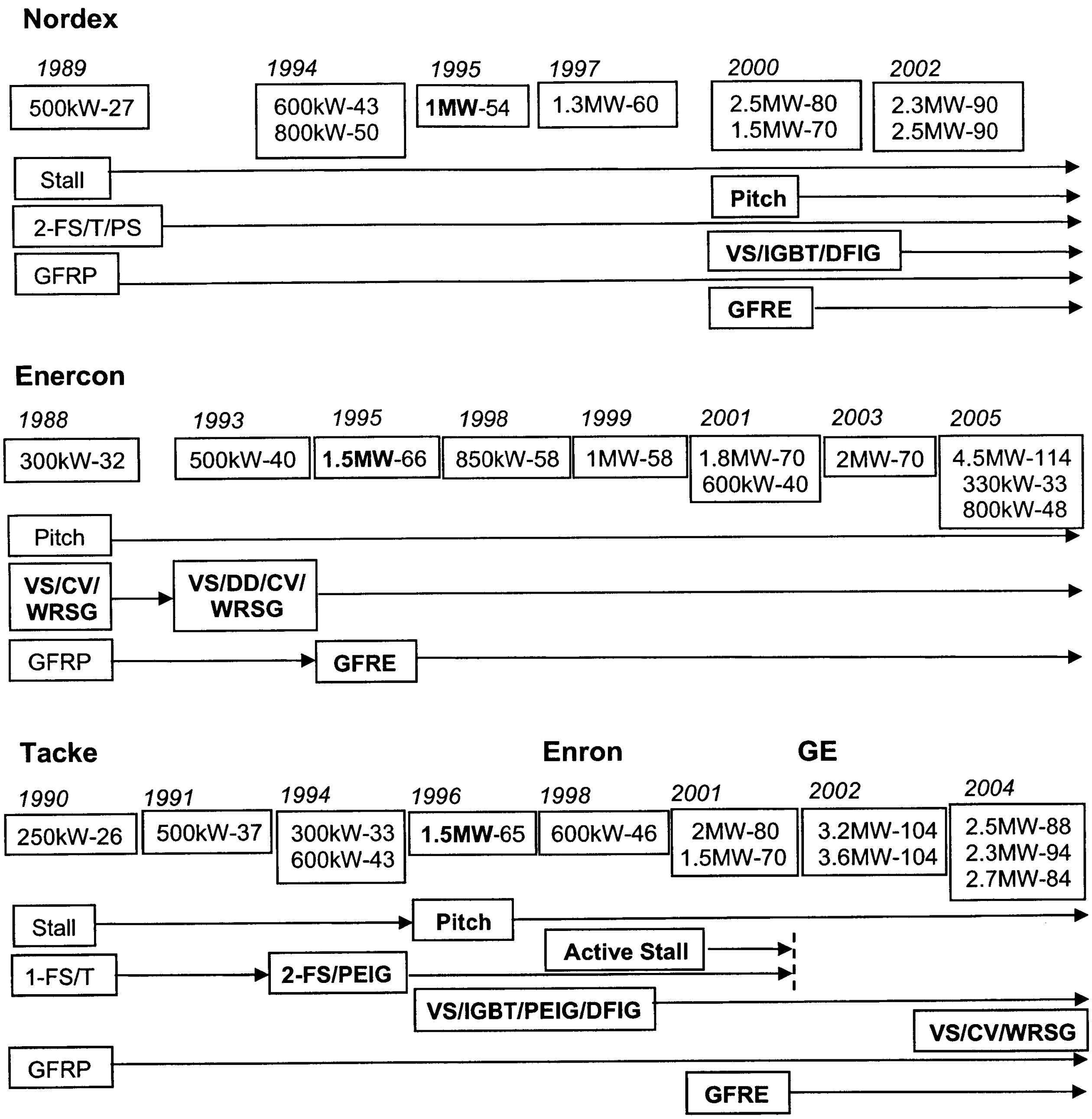


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Figure 5-14: Technology Shift by Manufacturers (2)
(See the notes at the end of the section)

Shift of Technology by Location of Innovations in Technology System

Table 5-53 summarizes technology trend by technology system and value functions. It is clear that the innovations have occurred in a variety of technology subsystems and value activities. There is a strong tendency of innovations in both components and system as a whole.

Table 5-53: Technology Shift by Technology System and Value Functions-
(See the notes at the end of the section)

		1990		1995		2000		2005
Power Control by Blade Angle	Stall	x	x	x	x	x		
	Pitch Collective	x	x	x				
	Individual			x	x	x	x	x
	Active Stall			x	x	x	x	
Rotor Speed and Generator	1-fixed SCIG	x	x					
	2-fixed SCIG	x	x	x	x	x		
	Limited Variable							
	WRIG (OptiSlip)			x	x			
	WRIG in DFIG			x	x	x	x	x
	Variable WRSG		x	x	x	x	x	x
	WRIG						x	x
	PMSG						x	x
Transmission	Gearbox (3 stage)	x	x	x	x	x	x	x
	Direct Drive		x	x	x	x	x	x
	Mlltibrid (1 stage)							x
Power Electronics	Thyristors	x	x	x	x	x	x	
	Transistors		x	x	x	x	x	x
Blade Materials	GFRP	x	x	x	x	x		
	GFRE			x	x	x	x	x
	CFRE					x	x	x
	Wood Epoxy					x	x	x
Blade Aerofoil	Aircraft	x	x	x	x	x	x	x
	Special				x	x	x	x
Blade Production Method	Hand Wet	x	x	x	x			
	Pre-impregnated	x	x	x	x	x	x	
	Vacuum Infusion			x	x	x	x	x
	Monolithic						x	x
	Automation			x	x	x	x	x
Turbine Design Integration			x	x	x	x	x	x
SCADA	Remote Monitor	x	x	x	x	x	x	x
	Internet Report						x	x
	Grid Interface						x	x
	Windfarm Control						x	x
Project Execution (Project Development & Investment)	Data Analysis	x	x	x	x	x	x	x
	Noise Prediction	x	x	x	x	x	x	x
	Visual Impact			x	x	x	x	x
	Micro-siting			x	x	x	x	x
	Energy Prediction	x	x	x	x	x	x	x
	Economics				x	x	x	x
	Optimization					x	x	x
	Grid Connection							x
Project Implementation	Special Transport						x	x
	Modular Transport of Tower/Nacelle						x	x

Technology Trends 1990-2005

From Figures 5-13 and 5-14, it is clear that all the manufacturers have introduced new turbine models every two or three years. New component or subsystem technology is usually introduced with new turbine models, although some technology shifts occur as the improvement for existing models on the market.

Turbine Size - Effects of WEGAII

The market introduction of MW-class machines developed under the WEGA II Program began in 1995 and in 1996 (Table 5-54). Their rated capacity was mostly between 1MW and 1.5MW (the rotor diameter between 50m and 66m), but the turbine concepts varied in terms of the number of blades, power regulation method, and rotor speed configuration. From Figures 5-13 and 5-14, it is clear that the WEGA II Program helped the participating manufacturers leap from their medium-capacity turbines around 600kW to MW-class turbines and introduce several innovative technologies to the market such as active stall regulation by Bonus and a limited range variable speed operation with DFIG by Tacke. These turbines had the tremendous impacts on the market takeoff of MW-class turbines in the late 1990s.

Table 5-54: MW-class Turbines developed under WEGA II Program

Manufacturer/Make	Capacity (kW)	Rotor Diameter	# of Blade	Power Regulation	Rotor Speed
Nedwind NW 53/2/1000-240	1000	52.5	2	Stall	Two-fixed
Nordic 1000	1000	53	2	Stall	Two-fixed
Micon M2300-1000-250kW	1000	54	3	Stall	Two-fixed
Nordex N54	1000	54	3	Stall	Two-fixed
Bonus 1MW/54	1000	54	3	Active Stall	Two-fixed
HSW 1000/57	1050	57	3	Pitch	Two-fixed
Autoflug 1200	1200	60	2	Pitch	Two-fixed
Nordtank 1500/60	1500	60	3	Stall	One-Fixed
Vestas V63-1.5MW	1500	63	3	Pitch	Variable (10%)
Tacke TW 1.5	1500	65	3	Pitch	Variable (1.4:1)
Enercon E-66	1500	66	3	Pitch	Variable (2.5:1)
Kvaerner WTS 80	3000	80	2	Pitch	Variable (1.5:1)

Source: (European Commission 1999)

Based on the technological experiences gained from the WEGA II turbine development and their commercialization, multi-MW class turbines appeared on the market in the late 1990s. Bonus introduced its 2MW (76m rotor diameter or RD) in 1998 and Vestas introduced its V80-2MW in 1999. In the early 2000s, the size of multi-MW class turbines grew further by the following models: Vestas V80-2.5MW and 3MW in 2001; NEG Micon 2.75MW (NM2750/80) in 2002; Bonus 2.3MW in 2002 and Siemens 3.6MW in 2004; Nordex N80-2.5MW in 2000, Enercon E-70 2MW in 2003; and Enron 2000 (2MW, 80m RD) in 2001 and Enron 3.2s and 3.6 offshore (3.2MW and 3.6MW, respectively, both 104m RD) in 2002. In 2005, Enercon introduced its E112 4.5MW to the market and REpower launched a 5MW model.

Dominant Technology Driver – Power Regulation and Rotor Speed Variation

The dominant technology driver for wind energy technology is how to control the variable nature of energy input (wind) to the constant nature of output (grid-quality electricity). Two principal methods are rotor power regulation through rotor blade angle (stall, pitch, and active stall) and rotor speed regulation (one- or two-fixed speeds and variable speeds) with different types of electrical power generation systems (generator and transmission). Therefore, these components and concepts show the constant technology innovations over the past 15 years. In general, the main trend shifted from stall-regulated, fixed-speed WRIG configurations to pitch-regulated, limited-range variable speed DFIG configurations. The geared transmission stays dominant; the only exception is the pitch-regulated, direct-drive, wide-range variable speed WRSG configuration by Enercon.

1990

At the point of 1990, the turbines with the Danish Classical Concept were dominant on the market in general. Vestas, which used pitch-regulation with one- or two-speed operations, and Enercon, which used pitch-regulation with variable speed operation incorporating geared drive WRSG,[73] were the exception among the major Danish and German manufacturers.

The Early 1990s

Two-speed operations using one generator with dual windings became prevailing and one-speed operations gradually lost its popularity. The most notable innovation in this period was the introduction of direct drive mechanism by Enercon E-40 in 1993. E-40 had a very wide variable speed range of 4.75:1, and the subsequent E-30 200kW also had a wide speed range of 3:1. Enercon has not shifted its main technology concept since 1993.

The Mid 1990s

While the WEGA II turbines represented the substantial conceptual advancement, they did not show any sign of uniformity of design concept and each manufacturer retained its particular preference. Two-speed operations were most popular among them, while four manufacturers chose variable speed operations. Only Nordtank stayed to one-speed stall regulation (Table 5-54). The consensus seemed that wide-range variable speed operations were not worth paying for, unless they came as an integral part of direct drive generator design (European Commission 1999). These turbines also successfully accomplished the size growth without any significant weight and cost increase.

The domination of stall-regulated turbines on the market began to change with some of these turbines: Tacke shifted to pitch-regulation and Bonus introduced the innovative active stall concept with Bonus 1MW. Still, however, there was the overall market dominance of stall during the mid 1990s with about 60% of market share (European Commission 1999).

The most popular choice of rotor speed operation remained two-speed operations on the market. The most notable innovations of this period were the first limited-range variable speed turbine with DFIG by TW1.5, commercialized by Tacke in 1996, and OptiSlip® (10% rotor

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[73] Synchronous generators were widely used by German manufacturers such as MAN and MBB in the 1980s. See the technical specification in (Gasch, Robert , and Jochen Twele. 2002).

speed variation by generator slip technology) by Vestas in 1995, introduced with V63-1.5MW and V42/44/47-600kW.

The Late 1990s

Several smaller players in the German industry, Jacobs, DeWind, and Südwind, shifted from stall-regulated, two-speed operations to pitch-regulated turbines with variable speed operations from 1997. Vestas shifted to variable speed DFIG configulation (OptiSpeed®) by the launch of V80-2MW in 1999. Two-speed operations were still popular on the market. The proportion of pitch and stall in MW-class turbines with over 50m RD on the market was almost equal (European Commission 1999). The range of variable speed MW-class turbines with DFIG by the manufacturers in Figures 5-13 and 5-14 was from the factor of 1.6 to 2.3, while two new models by Enercon achieved the factor of 2.3 and 2.4.

2000-2005

The technology shift from stall regulation with fixed-speed operations to pitch-regulation with variable speed operations happened to the three Danish Classical concept companies: NEG Micon shifted to pitch-regulated turbines with DFIG with its NM2705/80 turbine in 2002; Nordex did the same with N80-2.5MW in 2000; and Bonus made a radical shift from active-stall, two-speed operations to pitch-regulated, wide-range variable speed operations with the geared-drive WRIG and full-scale power converter in 2003.

Pitch regulation became dominant on the market: there were more than twice as many pitch-regulated turbines than stall-regulated ones on the market. Some kind of speed variations has become almost mandatory for MW-class turbines; over 1MW size, only three turbines were one-speed, 12 turbines had two-speeds and 37 turbines employed variable speed operations (European Wind Energy Association 2003). Multibrid technology was also introdueced to the market by WinWinD of Finland through WWD 1MW in 2001 and WWD 3MW in 2004.

The variable speed range of MW-class turbines with DFIG introduced in the early 2000s remained mostly between 1.7:1 and 2.3:1. The speed range for Enercon turbines varied between 1.7:1 and 3.6:1; the larger turbines achieve narrower ranges because their rotor speed decreases with size. The speed range of Bonus turbines with WRIG and full-scale converter was between 2.6:1 and 3:1, while WRSG turbines by GE showed a wider speed range between 3:1 and 3.6:1. Multibrid turbines by WWD also showed a wide speed range of 3.3:1.

Blade Technology

Materials composition and manufacturing methods are very proprietary for each manufacturer and where the competitions occur. A tendency of specialization of materials and aerofoil became stronger especially after 2000.

1990

All major manufacturers used GFRP as blade material with aircraft aerofoil. The hand-lay wet production was the dominant manufacturing method.

The Mid 1990s

In 1995 Vestas and Enercon used GFRE as blade material for their WEGA II turbines. The vacumme infusion method was introduced during the mid 1990s. GFRE has become popular blade materials around this period.

The Late 1990s

In 1997 Jacobs, Südwind, and DeWind also began using GRFE blade materials with their pitch-regulated, variable speed turbines. Some manufacturers began using special-purpose aerofoil in the late 1990s for their multi-MW class turbines. LM Glasfiber began using FFA aerofoil in the late 1990s and Vestas has been using FFA and RISØ aerofoil since 1999.

2000-2005

While GFRE became the industry semi-standard blade material during the early 2000s, Vestas, NEG Micon, REpower and DeWind successfully incorporated CFRP, carbon, wood, and wood epoxy into their blades. Special-purpose aerofil has gained more popularity. Enercon developed a very unique aerofoil with winglet for its E-33, E-48, E-70, and E-112 introduced in 2005. Although it is impossible to determine exactly whether their aerofoil is special-purpose one or not for manufacturers such as Enercon, Vestas, and recent GE and Bonus that design blades in-house because the data on general technical specification is rather limited, it is considered that special-purpose aerofoil design has been applied more and more for the products introduced during the 2000s.

The vacumme infusion production method has become dominant in the 2000s. Robotics and automation in blade manufacturing have become popular with the vacumme infusion method.

5.5.3 Characteristics of Wind Energy Innovations

Types of Wind Energy Technology Innovation – Systemic Innovation

Teece and Chesbrought (1999) describe there are two types of technology innovations: one is autonomous innovation that can be pursued independently from other innovations; and the other is systemic innovation that depends on a series of interdependent innovations. The benefits of systemic innovations are realized only in conjunction with the related and complementary innovations (Chesbrough and Teece 1999).

The technology development and trend shifting indicates that wind energy technology innovations is highly systemic.

- The innovations and development of the two technology drivers, rotor power regulation through rotor blade angle and rotor speed control with different types of electrical power generation systems, are closely related; stall-regulation is better suited for fixed-speed operations while pitch regulation is better for variable speed operations. Their market popularity tends to shit closely, as seen in Figures 5-13 and 5-14 as well as Table 5-53.
- The innovations and the choice of blade aerofoil, materials, and manufacturing methods are also closely linked to each other, and their innovation needs derive as a system requirement from the weight and cost reduction needs for enlarged rotor blades due to the continuous turbine upscaling.

- The advancements of SCADA and computer modeling of wind resource estimation, integrated turbine design optimization, as well as project execution technology have fortified the systemic nature of wind energy technology innovations.
- Noise reduction technology is related to both transmission technology advancement and rotor blade aerodynamics technology advancement.

Pacing Technology and Pacing Industry of Wind Energy of Wind Energy since 1990

Every technology system has the components/subsystems that pace the speed of the entire technology advancement. In the case of wind energy technology, the main pacing technology has been high-tech technology components developed by other industries:

- **Computer Science and Technology**: have dictated the systemic innovation and their market diffusion of wind energy technology through speed and capacity of data calculation and simulation, development of mathematical modeling codes, and the user friendliness of software.
- **Power Electronics**: has dictated the introduction of rotor speed variation and its speed range, use of different types of generators, and power conditioning capability through its power handling capability and cost.

These two pacing technologies indicate that wind energy technology has been mainly the adaptation of various innovations from other industries. The early success of the Danish wind industry depended on the use of several standard components such as gearboxes and induction generators; their simple assembly made up the commercial wind turbines in the 1970s and 1980s. Although rotor blades and control systems were tailored for wind energy technology from the beginning, even they were adapted from the innovations in other industries. While specialized component suppliers evolved over the years as the wind energy market grew, the focus of wind turbine manufacturers is still mostly the adaptation of components for wind turbines. Thus, the nature of wind energy innovations is highly adaptive. It is also incremental.

The only pacing technology that is exclusive to the wind energy industry is blade technology. Blade materials development, manufacturing methods and aerofoil design are dictated by the speed of innovations by the wind energy industry.

- **Blade Technology**: has dictated the size of rotor and turbine and energy capture capability through its aerofoil design, materials, and manufacturing methods.

Cost Composition of Wind Energy Technology

Wind projects have three major cost components: wind turbine cost, installation costs, and O&M costs.

Wind Turbine Cost

Capital investment costs of a wind project are dominated by wind turbine cost. The proportion of turbine cost in the entire project cost varies, depending on the sites due to the necessity of infrastructure installation for grid connection and road connection, land price, etc. While the US figures indicate that turbine cost occupies approximately 75% of the project cost (Energy

Efficiency and Renewable Energy 1997; Sterzinger and Svrcek 2004), the Danish figures show that the turbine cost occupies above 80% of the project cost for both 600kW and 1MW wind turbines (Dannemand Andersen 1999; IEA 2004). Based on a limited data from Germany, Denmark, Spain and the United Kingdom for turbines between 850kW and 1.5MW, the turbine cost ranged from 74% to 82% of the project cost (European Wind Energy Association 2003). In any cases, the turbine cost occupies the majority of wind energy project cost. The proportion of turbine cost in total investment costs has not been changed so much over the years.

Turbine cost depends on: 1) weight (heavier turbines are more expensive); 2) complexity (simple turbines are less expensive than complex ones, in unit to unit comparison); and 3) materials (standard materials such as steel, copper, and glass fiber, are cheaper than more unusual materials such as CFRP, etc, in unit to unit comparison). These three factors are interdependent of each other. In addition, the conditions of the component markets and overhead determined by the methods used for R&D, manufacture, assembly, administration, insurance, and marketing change turbine cost (Harrison, Hau, and Snel 2000). Table 5-55 shows the cost breakdown of different sizes of turbines.

Table 5-55: Cost Breakdown of Onshore Wind Turbine

Components	1997* (500kW/RD 38m)*	2001** (1.5MW/RD-70.5m Pitch VS DFIG)	2003*** (2MW/RD-82m Pitch VS DFIG)
Rotor	25%	28%	27%
Blades		17%	19%
Hub		7%	2%
Pitch System/Bearing		4%	6%
Tower	19%	21%	34%
Generator	7%	7%	4%
Electrical	21%	9%	8%
Power Electronics		7%	6%
Yaw System Controls		2%	2%
Transmission	29%	28%	27%
Gearbox		13%	14%
Shaft/Bearing		4%	2%
Brakes		1%	1%
Nacelle		6%	5%
Cables		2%	1%
Miscellaneous		2%	4%
Total	100%	100%	100%

* Cost breakdown based on 50 wind farms in the United States, which include many Danish turbines.
** Cost estimates based on the US component manufacturer survey.
*** Recalculated from the source (real turbine cost in Germany) by excluding transformer.

Sources: (Energy Efficiency and Renewable Energy 1997; Poore and Lettenmaier 2003; Sterzinger and Svrcek 2004; Weinhold 2005)

The proportions of rotor and transmission costs in turbine cost have not changed so much, despite the turbine upscaling trend, while the proportion of electrical system has been reduced greatly due to the price reduction and the increase of power-handling capacity of power electronics. Blades are an expensive part of wind turbine, which can take 15% to 20% of turbine cost. Despite the tremendous upscaling of rotor size, however, the proportion of rotor cost in total turbine cost has been contained with just a slight increase; reduction of blade weights and high energy yield have been the focus of design efforts in recent years and the science-based innovations in materials, aerofoil and manufacturing methods in this area has definitely prevented the blade cost from becoming too expensive. The most substantial constraints for the upscaling of blade size are the transportation cost that rises sharply for length above 46m and becomes prohibitive above 61m (Veers et al. 2003).

Transmission system also takes up 25% to 27% of turbine cost; gearbox is the most expensive component in transmission. Tower is another expensive component, which may account for approximately 20% of turbine cost. The large increase of tower cost in the 2003 figure reflects the recent steel shortage.

The contained costs of rotor blades and power electronics despite the tremendous turbine upscaling indicate the successful innovations in these science-based technologies and their incorporations into wind turbine.

Installation Costs

The other part of capital investment costs is installation costs, which are the costs for site preparation, foundations, grid connection, and turbine erection and commissioning, and other miscellaneous costs (expenses for financing, planning and engineering, permission, and transport). Remote and hostile locations require higher installation costs than average and more accessible locations, although they tend to have better wind resources and yield higher revenues. There are also obvious economies of scale of installation of turbines in these cost components. The limit of economies of scale is mainly posed by the amount of electrical energy that the local grid can handle.

The data on installation costs are difficult to generalize. One study reports that installation costs range from 13% to 40% of turbine price (Milborrow 1998). While the level of installation costs is less than 20% of turbine cost in Spain and Denmark, it is about 24% in Germany and the United Kingdom (European Wind Energy Association 2003). The grid connection is usually the most expensive component in installation costs, followed by the costs for foundation and electric installation.

The share of installation costs in total investment costs decreased over the years. In Germany, the level of installation costs decreased from approximately 31% of total investment costs in 1999 to approximately 28% in 2001. In terms of installation costs per installed kW, almost 29% of total investment costs were the costs other than turbine in 1989. By 1997 this share declined to approximately 20%. For a 1MW turbine, at the point of 2001, the share was further declined to approximately 18% (European Wind Energy Association 2003).

O&M Costs

O&M costs include not only costs for regular operation, maintenance, and repairs but also costs for insurance and management of wind farms (Table 5-56). O&M costs are usually expressed either as a percentage of turbine purchase price or in unit cost terms (cost/kWh), which need to be added to the unit electricity generation cost.

O&M costs interact with turbine cost in complex ways. Turbines with complex mechanisms can optimize the power generation more than simpler turbines, but are more susceptible to breakdown and maintenance costs can be higher.

Annual O&M costs may increase as the turbines get older. In a German study done by Deutsche Wind Energie Institut (DEWI), O&M costs for the first two years were 2-3% of total investment costs, while it increased slightly to less than 5% after six years (DEWI 2002, cited in European Wind Energy Association 2003). For major overhauls of turbines, the price of a new set of rotor blades, a gearbox, or a generator is usually in the order of magnitude of 15 to 20 % of the original price of the turbine (Krohn 2003a). In general, the older the turbines are, the higher the maintenance costs are.

Newer generations of turbines show lower repair and maintenance costs than older generations. Design for maintainability, longevity, and lower service costs conflicts with the demand for low initial costs.

Table 5-56: Average O&M Cost Composition for German Turbines 1997-2001

Cost Items	Average %
Service and Spare Parts	26%
Land Rental	18%
Insurance Charges	13%
Project Management (Administration)	21%
Power from Grid	5%
Miscellaneous	17%
Total O&M costs	100%

Source: (European Wind Energy Association 2003)

Offshore Wind Project Costs

Offshore projects require higher initial investments than onshore due to larger foundation costs (up to 30% of initial capital investment costs) and grid connection costs (around 25% of initial investment costs). With such figures, turbine cost can be less than 50% of total investment costs for offshore projects (Henderson et al. 2003).

Shift to Science-based Innovations and Increased Technological Complexity

The highly systemic nature of innovations, the high-tech nature of pacing technology, and the contained cost increase in high-tech components since 1990, all reveal that wind energy technology has transformed itself from the assemblage of various med-tech standard components in the 1980s to the high-tech integration of increasingly specialized components in the 1990s and 2000s.

Although the significance of mechanical engineering technology never diminishes in wind energy technology system, the shifting innovation focus to science-based technology is obvious. Lighter and stiffer blade materials development required for larger turbines totally depends on the advancement of materials sciences. Design of specially tailored blade aerofoil and precision robotics for manufacturing are governed by the advancement of computer sciences and engineering. Computer sciences and engineering have also dictated the constant advancement of SCADA, wind resource estimation and optimization as well as project execution technology. The growth of individual pitch mechanisms, variable speed operations, and grid interface technology has been subject to the advancement of power electronics and control software. The required high-tech capacity and capability to innovate and manufacture the total wind energy system has increased tremendously.

Technological complexity of wind energy technology has definitely increased as well. Many med-tech basic standard components used since the 1970s and 1980s have become accurately controlled by high-tech hardware and software. This increased the number of components in the system more than 15,000 today (Hjuler Jensen 2005). The advancement of system integration by computer science and engineering has increased the system complexity. The upscaling of turbines has expanded the value system of wind energy technology to new sub-suppliers that handle crucial aspects of turbine transportation and logistics.

Note:
Figures 5-13 and 5-14 and Tables 5-53 and 5-66 were constructed based on the data available on the following sources: (BTM Consult ApS 1995; BTM Consult ApS 1997; BTM Consult ApS 1998a; BTM Consult ApS 1999; BTM Consult ApS 2002; BTM Consult ApS 2003; BTM Consult ApS 2004; BTM Consult ApS 2005a; BWE 1990; BWE 1991; BWE 1993; BWE 1994; BWE 1996; BWE 1997; BWE 1998; BWE 1999; BWE 2001; BWE 2002; BWE 2003; BWE 2004; BWE 2005a; Danish Energy Authority 2006; Gasch and Twele 2002)

Section 5.6: Technology Transfer Results – Technology Development in India and Comparison with Denmark and Germany

This section examines wind energy technology development in India since 1990, in terms of technology transferred from the frontier to India, advancement of domestic technology, and technology gaps between the frontier and India. The section focuses only on wind turbines actually installed, because turbines offered in paper but not installed have very limited impacts on the market, industry and technology development of the country.

5.6.1 Technology Evolution in India

Table 5-57 compares the average sizes of installed turbines by country and the world. It is very clear that the Indian averages have been much smaller than the Danish, German, and the world averages. The Indian average sizes were about a half of Denmark during the 1990s, but they became about one third since 2002. The Indian averages have been always between half and one third of the German averages over the years. India even lagged behind China, which has much smaller installed capacity over the years. The average sizes of India have caught up with the Chinese averages only in 2003 and 2004.

Table 5-57: Average Size of Installed Wind Turbines by Country and the World

	India	Denmark	Germany	Spain	China	World
1995	208	493	473	297	326	394
1996	301	531	530	420	400	433
1997	279	560	623	422	472	528
1998	283	687	783	505	636	699
1999	283	750	919	589	610	784
2000	401	931	1101	648	600	738
2001	441	850	1281	727	681	918
2002	553	1443	1397	845	709	1092
2003	729	1988	1650	872	726	1207
2004	767	2225	1715	1123	771	1246

Sources: DWIA, DEWI, (BTM Consult ApS 2005b)

Table 5-58: Trend of Product Segment in Indian Market (% share)

	0kW≤	<150kW≤	<300kW≤	<500kW≤	<750kW≤	<1MW≤	<1.5MW≤	<2MW≤
1993	---	**100%**	---	---	---	---	---	---
1994	---	**98%**	2%	---	---	---	---	---
1995	1%	**83%**	15%	---	---	---	---	
1996	4%	**71%**	21%	5%	---	---	---	---
1997	15%	**47%**	38%	---	---	---	---	---
1998	1%	**79%**	17%	3%	---	---	---	---
1999	---	**63%**	24%	11%	1%	---	---	---
2000	---	**52%**	42%	1%	1%	---	---	---
2001	---	28%	**44%**	20%	7%	---	---	---
2002	---	**31%**	28%	22%	8%	10%	---	---
2003	---	**24%**	4%	**26%**	**26%**	20%	---	---
2004	---	**31%**	2%	**39%**	18%	9%	1%	---
Turbines with the boundary rated power are included on the right side classes.								

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

Table 5-58 illustrates the interesting pictures of technology trend in India in comparison with the Danish and German markets.

- The turbine class between 150kW and 300kW has been continuously the majority in India from 1993 to 2000, by when the majority of the German turbines moved to the class between 750kW and 1.5MW. Moreover, this class has never been gone from the Indian market; in 2002, it was the majority class again, and in 2003 and 2004 it had the very close second share.
- Unlike Germany where the average sizes of installed turbines have been very close to the majority of the installed turbine class, the shares of installed turbines in India have spread over several different classes and this tendency is increasing since 2000.
- In 2003 and 2004, the installation had twin peaks; while the class between 300kW and 500kW decreased greatly in both years, the majority was spread over the class between 150kW and 300kW and the class between 500kW and 750kW. This twin peaks phenomenon was never seen in either Denmark or Germany, and the Indian market lacks a clear trend shift in terms of installed turbine class.

- In terms of MW-class turbines, the first MW-class turbines appeared in 1994 with NedWind 1MW machine at the frontier. The first 1MW machine was installed in India only in 2001 and the first 2MW turbine was installed in 2005. The class between 1MW and 1.5MW increased the share, but it is still the minority.

The above examination tells that technology introduction is much slower and technology depreciation rate is lower in India, compared to Denmark, Germany, and the world.

5.6.2 Product Technology Transfer and Technology Gaps between Denmark/Germany and India

Wind Turbines introduced before 1993

Table 5-59: Turbines introduced to India before 1993

Introduction	Turbine Capacity	Manufacturers
1986	55kW	Bonus (DK), Micon (DK), Vestas (DK), Windmatic (DK)
	110kW	Micon (DK)
1987	100kW	Bonus (DK)
1988	90kW	Vestas (DK)
1989	55kW	BHEL (India)
	110kW	Wincon West Wind (DK)
	150kW	Danish Wind Power (DK)
	250kW	Micon (DK)
1990	100kW	Vestas (DK)
	200kW	Micon (DK), Vestas (DK)
1991	200kW	HMZ Windmaster (Belgium)
	300kW	Nordtank
1992	225kW	Vestas (DK)
	200kW	BHEL (India)

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

Table 5-59 shows the wind turbines introduced to India before the sector was open to private investments in 1993. All of these turbines were installed in the government-led demonstration projects. Except three models (BHEL 55kW, BHEL 200kW, and HMZ Windmaster 200kW), all turbines were introduced by the Danish manufacturers, indicating active technology collaboration between Denmark and India during this period. The demonstration projects started with 55kW turbines in 1986 but quickly moved to the 100kW class. The first 200kW class was installed by Micon in 1989 (250kW), and the first 300kW class turbines were introduced by Nordtank in 1991.

Although the turbines in India tended to be smaller, distinguishingly large technology differences were not seen between India and Denmark during this period. All the turbines had fixed-speed WRIG and stall-regulated, including the BHEL models that were indigenously developed and manufactured. The only exception was the Vestas models that had pitch regulation.

Wind Turbines introduced between 1993 and 1997

With the privatization of the wind energy sector, more foreign manufacturers began bringing wind turbines to the Indian market from 1993 to 1997.

Wind Turbines introduced by Danish Manufacturers

Table 5-60 shows the turbines introduced by the Indo-Danish collaborations. Although the introduced turbine capacity ranged from 200kW to 600kW, the installation number of medium-capacity turbines was very limited. The only exception of this class was Vestas 500kW introduced in 1995 (still installed as of 2005). Turbines rated between 225kW and 250kW were most common, and no manufacturers introduced large-capacity turbines above 750kW. The new turbine introduction concentrated between 1993 and 1995 with a couple of years of delay from the European introduction. All the introduced turbines used the Danish Classical Concept with the exception of pitch regulated turbines by Vestas.

Table 5-60: Wind Turbines introduced by Danish Manufacturers 1993-1997

Manufacturer	Capacity	RD (m)	Power Control	Rotor Speed	Generator	India Installation	European Launch
AMTL - Wind World	220kW*	N/A	Stall	N/A	WRIG	1993	N/A**
	250kW	25		2-fixed		1994-1999	1991
	500kW*	37		1-fixed		1996	1992
BHEL- Nordex	200kW	N/A	Stall	N/A	WRIG	1994-1996	N/A**
	250kW	29.7		1-fixed		1995-1999	1994
NEPC Micon	225-40kW	29.8	Stall	2-fixed	WRIG	1993-1998	N/A**
	250kW	29		1-fixed		(1989),1993-1998	N/A**
	400-100kW	31		2-fixed		1994-1998	1992
	600kW*	42		2-fixed		1995	1994
Pioneer- Wincon	250kW	29	Stall	1-fixed	WRIG	1995-present	1995
REPL - Bonus	320kW	33	Stall	1-fixed	WRIG	1995 -1997	N/A**
Textool - Nordtank	300kW	31	Stall	1-fixed	WRIG	(1991) 1996	1985
	550kW*	37				1996	1992
Vestas RRB	225-50kW	27	Pitch	2-fixed	WRIG	1993 – present	1988
	500kW	42/47		1-fixed		1995 - present	1993

* The total installation number of these turbines was less than ten.

** No European record available for the makes. The number in parenthesis indicates the year introduced by demonstration projects before 1993 in India.

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

Wind Turbines introduced by German Manufacturers

The turbine introduction by the Indo-German collaborations started in 1994 and the introduced turbine capacity ranged from 230kW to 600kW, but only six of 600kW turbines were installed. In terms of small-capacity turbines, the Enercon and Husumer Schiffswerft (HSW) models had substantial footprints on the Indian market, while the installation of other manufacturer models (Tacke, Pegasus, and Südwind) were limited as the collaborations of these manufacturers did not last long. The most important technology introduction was variable speed turbines with direct drive WRSG by Enercon in 1995. However, none of other important technology development at the frontier; medium- and large-capacity turbines and variable speed technologies by other manufacturers came to India. Mostly, the Indian turbine introduction was only slightly delayed from their European introduction during this period (Table 5-61).

Table 5-61: Wind Turbines introduced by German Manufacturers 1993-1997

Manufacturer	Capacity	RD (m)	Power Control	Rotor Speed	Generator	India Installation	European Launch
Enercon India	230kW	30	Pitch	Variable	WRSG/ DD/CV	1995-present	1995
Flovel Tacke	250-80kW* 600kW*	26 43	Stall Stall	2-fixed Fixed	IG N/A	1996 1995	1990 1994
Grematch - Pegasus	250kW*	N/A	N/A	N/A	N/A	1995	N/A
Suzlon - Südwind	270kW* 350-100kW	N/A 33.4	Stall	N/A 2-fixed	WRIG	1996 1996 - 1997	1993 1996
TTG - HSW	250-80kW	28.5	Stall	2-fixed	PEIG	1994-present	1990
* The total installation number of these turbines was less than ten.							

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

Table 5-62: Wind Turbines introduced by Other Country Manufacturers 1993-1997

Manufacturers	Capacity	RD (m)	Power Control	Rotor Speed	Generator	Installation
ABAN Kenetech (USA)	410kW	33	Pitch	Variable	CV	1995-1997
RES - AWT (USA)	250kW	N/A	N/A	N/A	N/A	1996-1999
Das Lagerwey (The Netherlands)	80kW* 250kW	18 30	Pitch	Variable	IG/CV	1995-1996 1995-2000
Elecon - HMZ (Belgium)	200kW* 300kW	22.5 30	Pitch	1-fixed	WRIG	(1991), 1994 1995-1998
Himalaya (India)	140kW* 200kW	N/A	N/A	N/A	N/A	1995-1996 1995-1996
JMP – Ecotecnia (Spain)	225-50kW*	28	Stall	2-fixed	IG	1996
Kirloskar - WEG (UK)	400kW*	39.3	Pitch	1-fixed	IG	1997-1998
Rayalseema - Mitsubishi (Japan)	315kW*	29	Pitch	1-fixed	IG	1996
Sangeeth - Carter (US)	300kW	24	N/A	1-fixed	IG	1995-1997
Windia Nedwind (The Netherlands)	250kW* 500kW* 550kW	31 40.8 43.8	Stall Stall Pitch	1-fixed	IG	1995-1996 1995-1998 1995-1996
*The total installation number of these turbines was less than ten. The number in ( ) indicates the year introduced by demonstration projects before 1993 in India.						

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

Wind Turbines introduced by Other Country Manufacturers

Table 5-62 shows that wind turbines introduced by the manufacturers of other countries. The new turbine introduction mostly concentrated in 1995. Although five medium-capacity models ranging between 400kW and 500kW were introduced by these manufacturers, they had a small number and short period of installation and all of these firms and their turbines were generally pulled out of the India market by 1998. They did not leave significant footprints. The most significant technology introduction was pitch-regulated, variable speed turbines by Kenetech of the United States and Lagerwey of the Netherlands. They had a relatively large number of installations; however neither ABAN nor Das continued to manufacture those turbines on their own after the collaborations ended.

Wind Turbines introduced after 1999

Wind Turbines introduced by Foreign Manufacturers

No new model by foreign manufacturers was installed to India in 1998 and in 2000, and the number of new turbine introduction was greatly reduced after 1999, compared to the period between 1993 and 1997. Although the introduced turbine capacity moved to the range between 600kW and 1.65MW, the number of turbine introduction was much smaller compared to that to the frontier. The introduction time lags were also definitely increased from a couple of years seen between 1993 and 1997 to several years after 1999. NEG Micon and Enercon tend to bring newer models to the Indian market without long time lags.

In terms of the Danish manufacturers, both Vestas and Bonus had not introduced any new turbines to India since 1993 and 1995, respectively. Only NEG Micon was relatively active in new turbine introduction; however, considering the firm's active model introduction history in Europe, the Indian introduction has been very limited. No variable speed turbines were introduced by the Danish manufacturers. As for the German manufacturers, Enercon introduced all of 600kW, 330kW, and 800kW models simultaneously to Europe and India during the 2000s, after the long absence of new model introduction to India since E30 230kW in 1995. The first DFIG variable speed configuration was introduced to India by the German DeWind in 2001, and then by GE Wind in 2002. But the models by these two firms have had less than ten installations. The DeWind and C-Well collaboration did not last long as the ownership of DeWind was changed in 2003. Nordex formed a new agreement with BHEL in 2003 with stall-regulated, two-speed models (N43 600kW and N50 800kW introduced in Europe in 1994), but they have not been installed in India as of March 2005.[74] Other German manufacturers, Fuhrländer and Jacobs/BWU/REpower, have stayed out of the Indian market (Table 5-63).

Table 5-63: Turbines introduced by Danish and German Manufacturers after 1999

Manufacturer	Capacity	RD (m)	Power Control	Rotor Speed	Generator	Indian Installation	European Launch
NEG Micon (Subsidiary)	750kW	48.2	Stall	2-fixed	WRIG	1999-present	1998
	950-200kW	54.5	Active S	2-fixed		2002-present	2001
	1.65MW	82	Active S	1-fixed		2004-present	2003
NEPC - Norwin	750-180kW*	47	Active S	2-fixed	WRIG	2005-present	1998
Pioneer- Wincon	750kW*	48	Semi-Pitch	2-fixed	WRIG	2002	1998
Enercon India	330kW	33.4	Pitch	Variable	WRSG/ DD/CV	2005-present	2005
	600kW	44				2001-present	2001
	800kW	48				2005-present	2005
Enron/GE Wind (USA-Germany, subsidiary)	600kWa*	46	Active S	2-fixed	IG	2002	1998
	750kWi*	50	Pitch	Variable	DFIG/CV	2002	2001
	1.5MWs*	70.5	Pitch	Variable	DFIG/CV	2004-present	1999
C-WEL - DeWind	600kW*	46	Pitch	Variable	DFIG/CV	2001-2002	1997
* The total installation number of these turbines was less than ten.							

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

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[74] There has been several wind turbines offered but not installed in India. They were not counted as technology introduction or transfer in this research because the real products and technological capability have not landed on India. In addition, they do not show any significant innovation introductions, nor their technology does not seem the up-to-dated ones available in Europe.

Table 5-64: Turbines introduced by Other Country Manufacturers after 1999

Manufacturer	Capacity	RD (m)	Power Control	Rotor Speed	Generator	Indian Installation	European Launch
Elecon - Turbowind (Belgium)	600kW*	48	Active Stall	2-fixed	IG	2002-present	N/A**
Pioneer Asia - Gamesa (Spain)	850kW*	52/58	Pitch	Variable	DFIG/CV	2005-present	2004 (Germany)

* The total installation number of these turbines was less than ten.
** No European record available for the makes.

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

The turbines introduced by other country manufacturers remain a very small minority. Lagerwey did not continue its collaboration with Das; as a result its variable speed wind turbines with direct drive, synchronous generator have not been introduced to India. Although some important innovations such as active stall and DFIG came to India by the Turbowind and Gamesa models, their contribution seems fairly limited with the limited number of installation (Table 5-64).

Wind Turbines introduced by Indian Manufacturers

Meanwhile, several Indian manufacturers manage to introduce wind turbines on their own. C-WEL began offering its 250kW turbines in 2000, although only 11 of the model have been installed by March 2005. Vestas RRB has been also offering a 600kW model, which is the Indian modification of V47 500kW, but no installation has been made.

The notable turbine development has been made by Suzlon. The firm introduced the first MW-class turbine to the Indian market in 2001, 1.25MW in 2002, and 2MW in 2005. Suzlon also offered 600kW and 950kW models in the European and US markets along with MW-class models. The firm shifted from stall regulation to pitch regulation from its 1MW model, and its 1.25MW and 2MW models have incorporated a slip ring system with standard WRIG; however their rotor speed remains two-speed. The slip control provides the maximum slip up to 16% by varying the resistance of the rotor winding dynamically, and increases energy conversion efficiency by ensuring a small amount of power loss from frequent changes in wind speed. From these MW-class turbines, Suzlon incorporated GFRE into their blades and the vacuum infusion production technique (Suzlon Energy Ltd. 2005a) (Table 5-65).

Table 5-65: Turbines introduced by Indian Manufacturers after 1999

Manufacturer	Capacity	RD (m)	Power Control	Rotor Speed	Generator	Indian Installation	European Launch
C-WEL	250kW	29.2	Stall	2-fixed	WRIG	2000-present	No*
Suzlon	1MW-250kW	64	Pitch	2-fixed	WRIG	2001-2004	2003
	1.25MW-250kW	64/66				2002-present	2003
	2MW-250kW	88				2005-present	2004

* No European record available for the makes.

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

Product Technology Gaps between Denmark/Germany and India

Gaps in Introduced Turbine Capacity

In terms of turbine capacity, up to 400kW to 600kW capacity turbines were introduced to India without much of the delay from the European market launch by the mid 1990s by foreign manufacturers. However, those medium-capacity turbines have never become the main stream in India, and the Indian turbine capacity began lagging behind quickly from the mid 1990s. A number of turbines between 600kW and 999kW launched at the frontier between 1995 and 2005 were not introduced to India, including: four models by Vestas; two models by Bonus; four models by NEG Micon (including Micon and Nordtank); five models by Enercon; two models by Tacke/Enron; two models by BWU/Jacobs; and two models by Fuhrländer.

In addition, none of the original MW-class turbines developed under the WEGA II came to India. By 2001 when Suzlon introduced the first 1MW turbines to the Indian market, the major Danish and German manufacturers had already launched several MW-class turbines at the frontier market: Vestas with five models up to 2MW; Bonus with four models up to 2MW; NEG Micon (including Nordtank and Micon) with six models up to 2MW; Nordex (including Südwind) with five models up to 2.5MW; Enercon and Tacke/Enron with two models up to 1.5MW each; BWU/Jacobs/Fuhrländer together with three models up to 1.5MW; and DeWind with two model up to 1.25MW.

By the end of 2005, the turbine capacity gaps were further increased. While India only had the introduction of four new MW-class turbines up to 2MW since 2001, the frontier reached the market introduction of 5MW capacity model and the major manufacturers introduced new MW-class models between 2001 and 2005 as follows: Vestas with eight models up to 3MW (excluding V82 equivalent of NEG Micon NM82); Bonus/Siemens with four models up to 3.6MW; NEG Micon with seven models up to 4.2MW; Nordex (including Südwind) with three models up to 2.5MW; Enercon with four models up to 3.6MW; Tacke/Enron/GE with ten models up to 3.6MW; REpower with three models up to 5MW; Fuhrländer with two models up to 2.5MW; and DeWind with one 2MW model.

Although all the turbines launched at the frontier are not necessarily suitable for the Indian market, the number of non-introduced turbines cannot be simply ignored.

General Technology Trend in India and Gaps in Technology Features

The wind turbines installed from 1993 to 1997 in India were stall-regulated, fixed-speed turbines, which were also the main stream technology at the frontier at the time. Two-speed turbines with dual winding technology were transferred by various manufacturers to India.

However, technology gaps began increasing during the mid 1990s; as the number of new turbine introduction has decreased and many medium- and large-capacity turbines were not brought to India, many important innovations did not come or were introduced with significant time delays. While the increasing number of turbines introduced and installed in India after 1999 have pitch regulation (out of 18 turbines, 11 with pitch, three with stall and four with active stall), fixed-speed turbines are still the majority (out of 18 turbines, 11 were fixed speed and seven were variable speeds). While limited-range variable speed turbines with DFIG occupy a large fraction of the market at the frontier, they have had a very limited number of installations in India. Wide-range variable speed operation technology brought by Enercon remains unique in India, as other type of variable speed turbines have not been introduced nor installed so much if they came.

Table 5-66 shows the product technology innovations after the mid 1990s and their transfer results to India by technology feature and manufacturer.[75] Overall, it is clear that many innovations were introduced to India on a fairly limited basis by a few manufacturers with several years of delay.

Also technology transfer varies greatly among manufacturers. Most of the innovations after 1995 by Vestas, Bonus/Siemens, and Nordex were not introduced to India. Especially, OptiSlip® and OptiSpeed® by Vestas and wide-range variable speed turbines with WRIG and full-scale converter by Bonus/Siemens were left out of India. Active stall regulation was not introduced by its innovator Bonus but by NEG Micon and Tacke/GE after six years of the original introduction to Europe. Individual pitch control technology and limited-range variable speed operations with DFIG by NEG Micon, BWU/Jacobs, and Nordex were not brought to India at all; these technologies were only introduced by Tacke/Enron/GE and DeWind on a very limited basis. On the other hand, the technology transfer records of Enercon are good. The firms' core competence product technologies (WRSG, direct drive system, individual pitch mechanism, and GERE blade materials) have been transferred without time delay, except several SCADA products in recent years.

As for blade technology, a blade supplier LM Glasfiber has contributed to the introduction of product and production technology of blade along with Enercon and Suzlon (see the next part). In terms of SCADA products, because control software is usually upgraded corresponding to the latest turbine controller status, all SCADA advanceement made since the mid 1990 by Vestas, Nordex and Bonus/Siemens clearly have not been introduced to India. The introduction of SCADA products by other foreign manufacturers are also considered limited.

This lag of introduction of more updated models to India, in particular larger-capacity, individually pitch-regulated variable speed turbines, demonstrates that India has greatly missed the important technological advancements, especially in the increase in aerodynamic efficiency and energy capture and the reduction of mechanical loads on drivetrain that which can reduce design requirement and cost of gearbox or generator.

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[75] Blade aerofoil technology was not included in Table 5-66, since the technical specification data regarding special aerofoil usage published by manufacturers is very limited.

Table 5-66: Product Technology Gap Matrix - Germany/Denmark and India

	Market Introduction at Frontier			Transfer	Transfer
	Manufacturer	**Make**	**Year**	**Year**	**Pathway**
Power Control by Blade Angle					
Pitch OptiTip®	Vestas	V47 600kW	1995	Late 1990s	JV
Individual Pitch	Vestas	V63 1.5MW	1995	NO	---
	Bonus/Siemens	2.3MW 82.4	2003	NO	---
	Nordex	N80 2.5MW	2000	NO	---
	Enercon	E40 500kW	1993	1995	JV
	Tacke/Enron/GE	1.5MW 70	1999	2004	S
	BWU/Jacobs	1.5MW 70/77	2000	NO	---
	DeWind	600kW 46	1997	2001	LA
	Suzlon	1MW 64	2001	N/A	N/A
Active Stall	Bonus	1MW 54	1996	NO	---
	NEG Micon	NM2000/72	2000	2004	S
	Tacke/GE	600kW 46	1998	2002	S
Rotor Speed/Generator Type/Power Electronics					
Fixed/Slip Ring	Suzlon	S66 1250	2003	2002	N/A
Limited Variable					
OptiSlip®	Vestas	V63 1.5MW	1995	NO	---
DFIG/IGBT	NEG Micon	NM80/2750	2002	NO	---
	Nordex	N80 2.5MW	2000	NO	---
	Tacke/Enron/GE	1.5MW 70	1996	2002	S
	BWU/Jacobs	1.5MW 70/77	2000	NO	---
	DeWind	600kW 46	1997	2001	LA
OptiSpeed®	Vestas	V80 2MW	1999	NO	---
Variable					
WRSG/IGBT	Enercon	E40 500kW	1993	1995	JV
WRIG/Full Converter	Bonus/Siemens	2.3MW 82.4	2003	NO	---
Multibrid PMSG	(WWD)	1MW 56	2001	NO	---
Transmission					
Direct Drive	Enercon	E40 500kW	1993	1995	JV
MIltibrid	(WWD)	1MW 56	2001	NO	---
Blade Materials					
GFRE	Vestas	V63 1.5MW	1995	2005	JV
	Bonus/Siemens	2.3MW 82.4	2003	NO	---
	Nordex	S70 1.5MW	2000	NO	---
	Enercon	E66 1.5MW	1995	1995	
	Tacke/Enron/GE	Enron 1.5s	2001	2001	S
	Suzlon	1MW 64	2001	N/A	N/A
CF/CFRE	NEG Micon	NM900/52	2000	Unknown	S
Wood Epoxy	NEG Micon	NM1500/64	2000	Unknown	S
SCADA Products	* Products include remote controlling and wind farm controlling functions.				
Remote Monitoring with vibration censors	Vestas Condition Monitoring System		2003	NO	---
	Nordex Condition Monitoring System		2003	NO	---
Remote Reporting (Internet Information Portal)	Nordex Control 2*		2001	NO	---
	Vestas Online™*		2002	NO	---
	Enercon Service information Portal		2004	NO	---
	Siemens WebWPS		N/A	NO	---
Grid Interface Management	Enercon Process Data Interface*		2003	NO	---
	Vestas GridSupport™		2003	NO	---

5.6.3 Turbine Production Technology Transfer and Domestic Technology Development

BHEL already possessed both wind turbine component manufacturing and turbine assembling capability before the wind energy market was opened to private sector. Since 1993, NEPC Micon (NEPC India), Vestas RRB, Enercon India, Pioneer Wincon, TTG Husumer, Elecon Engineering with HZM and Turbowind, Suzlon, NEG Micon, GE Wind India, and C-WEL established production facilities in India.

Turbine Production Technology Transfer and Capability Building at Manufacturer Level

Turbine production technology in India has greatly improved since 1993 through indigenization of transferred technology and its own technology exploitation, which have been encouraged by MNES from the beginning. All Indian production facilities by major collaborations or subsidiaries have been ISO-certified from very early on.

Turbine Assembly Technology Transfer and Capability Building

Turbine assembling technology was one of the first technologies transferred to India and quickly indigenized, because originally all turbine components were imported and assembled on site. After 1993, several manufacturers established in-house assembly lines, where turbine assembly tasks with quality control as well as knowledge of how to streamline its production line were transferred from their foreign collaborators because the Indian firms had a tendency of depending on a large number of workers than Europe (Wind Power Monthly 1994b).

Indigenization of Production Technology of Turbines with Foreign Origin

About two-third of all manufacturers formed between 1993 and 1997 were not successful beyond this period, because they never formed appropriate manufacturing capability nor had very low interest in finer details of technology acquisition. Their business fate ended once the foreign collaborators decided to exit from India or from the business all together; they did not contribute to production technology indigenization in India.

However, for the remaining one-third of manufacturers that established production capacity from early on, high-level technology indigenization of small-capacity turbines was already evident during the mid 1990s. By the end of March 1995, MNES estimated the indigenization of technology for up to 250kW capacity wind turbines as nearly 70% in terms of the number of components, while blades, special bearing, etc. were imported (MNES 1995a). By 1997, the rate grew nearly 80% industry wide (MNES 1997a).

Table 5-67 shows the Indian manufacturers that have indigenized the production of wind turbines originally provided by their foreign collaborators. Many did so after their collaborations ended with various reasons. The models mostly concentrated between 225kW and 350kW turbine class. The collaborations that have lasted until this day also have high level of indigenization of this class of turbines (Vestas 225kW and 500kW models and Enercon 230kW) as they have been installed in India after they were no longer in production in other countries. However, the rate of technology indigenization up to 250kW turbines did not improve greatly since the late 1990s; the rate at industry level had not changed from approximately 80% from 1999 to 2002 (MNES 2000a; MNES 2001a; MNES 2003).

Table 5-67: Foreign Original Turbines Indigenized by Indian Manufacturers

Indian Firm	Original Make	Capacity	RD (m)	Power Control	Rotor Speed	Generator	Independent Installation
AMTL	Wind World	250kW	25	Stall	2-fixed	WRIG	2004
Enercon	Enercon	230kW	30	Pitch	Variable	WRSG/DD/CV	1995-present
NEPC India	Micon	225kW	29.8	Stall	2-fixed	WRIG	1999 - present
		250kW*	27.6				1998
		400kW*	31				1999
		600kW*	42				2004-present
Pioneer	Wincon	250kW	29	Stall	1-fixed	WRIG	1995 - present
REPL	Bonus	320kW	33	Stall	1-fixed	WRIG	2002, 2004
Suzlon	Sudwind	350-100kW	33.4	Stall	2-fixed	WRIG	1997 - present
TTG	HSW	250-80kW	28.5	Stall	2-fixed	PEIG	N/A - present
RRB	Vestas	225-50kW	27	Pitch	2-fixed	WRIG	1993 – present
		500kW	42/47		1-fixed		1995 - present

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

Those highly indigenized small-capacity turbines are mainly stall-regulated, one-or two-speed turbines using WRIG with dual winding. However, the indigenization level is much lower for newer technology; the indigenization of medium- and large-capacity turbines has been much slower because the development of supplier capacity and capability has taken time (MNES 2005), although the level of indigenization has not been reported.

The very limited number of installation of turbines with limited-range variable speed operations with DFIG and newer blade materials such as wood epoxy, carbon fiber, and CFRE verifies very low indigenization levels of these technologies in India as well. The exception is Enercon and Suzlon technology: individual pitch mechanism, direct drive WRSG with IGBT converter and GFRE blades have been well-indigenized through the Indian production of Enercon for both domestic and export usages; and Suzlon incorporated individual pitch mechanism, slip ring generator application and GFRE blades at its Indian production lines as well.

Component Production Technology Transfer and Capability Building

Turbine components have been manufactured in India from 1993. Although many components such as control systems, brakes, gears, and hubs were imported, all wind turbine parts except for blades were already made in India in 1994 (Wind Power Monthly 1994a). Blades manufacturing also began in 1995. Component manufacturing became especially important after the import duty for turbine components was significantly raised in 1997.

Component Production Technology Transfer

It has been different from one manufacturer to another and from one model to another which components to be manufactured in-house in India, outsourced in India or imported. NEPC Micon, Vestas RRB, BHEL-Nordex, Pioneer Wincon, TTG Husumer, and Enercon India began either in-house component manufacturing or using component suppliers in India from the beginning of their collaborations in the early and mid 1990s. In case of outsourcing components to Indian suppliers, these technology providers transferred know-how of how to choose and check the suppliers and their product quality. Their knowledge development also focused on communication building with suppliers in order to transfer knowledge and acquire high quality components.

Technology transfer has also happened directly at component supplier level through joint ventures between foreign firms and Indian firms. The components that tend to have more foreign direct suppliers, subsidiaries or joint ventures are; electronics items, in particular wind turbine controllers, power factor improvement capacitor, reactive power compensation system, bearing, gearbox, and sensors (interpolated from Consolidated Energy Consultants Ltd. 2002; Consolidated Energy Consultants Ltd. 2005).

Blade Manufacturing Technology Transfer

Rotor blades are specific to wind turbine technology and its technology transfer involves more conscious efforts than other component production technology transfer. Three Indian firms entered blade manufacturing business in 1995 through joint ventures,[76] while two other companies began blade production in the 2000s. In all the cases, production began with technology transfer from the European establishments.

- **LM Glasfiber India Ltd**: initially established as a joint venture between LM Glasfiber A/S of Denmark, IFU, and NEPC-Micon Ltd in 1993, but became 100% subsidiary of LM Glasfiber A/S in 2002. The first production unit produced up to 400 sets of 13.4m rotor blades a year (Wind Power Monthly 1996j) and was upgraded to manufacture blades up to 29m in length in 2001 using vacuum infusion technology. The firm has supplied blades to Vestas RRB, GE Wind India, Suzlon, and NEPC India, and has been the largest blade supplier in India, maintaining 50-55% market share (Wind Power Monthly 2003b).
- **Enercon India Ltd**: established its blade production from the beginning of joint venture in 1995. In 1996 the firm exported 150 sets of blades for each of 230 kW and 550 kW turbines (Wind Power Monthly 1996i). In 2001 the firm established its second blade factory for E-40 turbines for both domestic use in India and export.
- **TTG Industries Ltd**: started blade manufacturing in 1995 through its partnership with HSW, exclusively for the HSW turbine installation in India.
- **Suzlon Energy Ltd**: started its own blade production at Daman in 2001 using resin vacuum infusion moulding technology and built the second blade manufacturing facility in Pondicherry in 2003.
- **Vestas RRB Ltd**: has been outsourcing its blades to LM Glasfiber India, but entered blade manufacturing in 2005 by establishing the first blade production facility in India (Business Line Bureau. 2005a).

The production facilities of LM Glasfiber India, Enercon India, and Suzlon are ISO-certified from the beginning. Resin vacuum infusion and automation technologies related to vacuum infusion have been indigenized in India through the production at these three firms, which have established good export capacity of blades as well. LM Glasfiber and Enercon played significant roles in bringing and indigenizing blade production technology from the mid to late 1990s. Production of 34m length blades for 1.5MW turbines and 40ms length blades for 1.65MW turbines has been started in India in 2004 (MNES 2005), but production of large blades for many multi-MW class turbines produced at the frontier, e.g., 40m to 70m blades, are not introduced by LM Glasfiber India, Enercon India, or Vestas RRB.

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[76] In 1995, a Dutch blade manufacturer Polymarin agreed with Jyoti Ltd. to establish a joint venture company, Polymarin India, for production of rotor blades in India. However, it did not materialize because high import duty (80%) posed on blade raw materials did not make the business viable.

Level of Component Production Indigenization

The levels of component production indigenization vary, depending on turbine rated capacity, value of components as well as manufacturers. Higher-value and high-tech components are not indigenized at high rates. In 1994 Micon covered components with 60% of the value of its M700 225kW turbines installed by NEPC (Wind Power Monthly 1994b). Although the ratio improved over the years, still approximately 30-35% of high value components were estimated to be imported in the early 2000s for small- and medium-capacity turbines (C-WET 2002; Vestas RRB 2002).

Indigenization efforts have been concentrated on gearbox and controllers since the late 1990s. However, the progress in this area has been slow; in 2005 NEG Micon India imported gearboxes, alternators, brake systems and controllers, which together accounted for 25% in value terms, although local sourcing of those components would bring down turbine costs by 10-15% (Ramakrishnan and Balaji 2006). Import content in higher-capacity turbines is high, and the Indian wind energy industry is still a net importer, as important components of MW-class turbines are still being imported despite the efforts to reverse the position (MNES 2004; MNES 2005). Technology indigenization in value terms has been much slower than that in the number of component terms.

The Number of Component Suppliers

The number of Indian component suppliers has been increasing in almost every component category, according to the supplier list provided in the 2002 and 2005 editions of Directory Indian Windpower (Consolidated Energy Consultants Ltd. 2002; Consolidated Energy Consultants Ltd. 2005). One notable change from 2002 to 2005 was wind turbine controller and soft starter suppliers; although there were only two Danish turbine controller firms and no Indian soft starter or turbine controller suppliers listed in the 2002 edition, two Indian suppliers appeared in both categories each in the 2005 edition. Since the suppliers on the lists include marketing/sales offices of foreign component suppliers or the Indian firms that only import the components, they do not exactly illustrate the accurate picture of the Indian technological capability. However, component supply capacity has been continuously increasing in some of high-tech components as well as the rest of component categories.

Continuing Quality Issues of Indian-Made Components

While sufficient capacity has been built to manufacture most of wind turbine components indigenously, the quality of components manufactured in India has been a big issue and this has not been solved completely. Indigenization of all components failed early on because the poor quality of control systems and brakes made in India forced many manufacturers returned to imports. In particular, for high-value, high-tech components, the manufacturers continued to rely on imports. Despite approximately 15 years of experiences in wind energy, still 20% of gearboxes failure and blade tips breaking were recorded at the point of 2003 (Wind Power Monthly 2003f).

Overall Production Capacity Building in India

Annual production capacity had stayed at about 500MW level for five years since the 1998-1999 year (MNES 1999a; MNES 2003). MNES reported the upgrade of annual production capacity to 750kW in the 2003-2004 year, as 615MW of wind turbines were supplied and seven 950kW turbines were exported during the fiscal year (MNES 2004).

5.6.4 Project Execution Technology Transfer and Domestic Technology Development

Wind Resource Estimation/Energy Prediction/Optimization Technology Transfer and Capability Building

WAsP program and methodology developed in Denmark has been employed in India as well. So far, however, the utilization of WAsP has been only for regional and local studies. At national level, India has developed strong national wind resource data since 1983 on their own and wind resource estimates have been upgraded with both technical and gross potential. This level of estimation technology is well-indigenized. The indigenization level of wind estimation can be raised further with the application of WAsP to development of the Wind Atlas of India, which has been proposed to estimate the overall potential in various states as well as identify high wind areas for setting up wind power projects (MNES 2005).

Meanwhile, know-how of wind resource estimation and energy optimization technologies such as WAsP and Park at project level for wind resource mapping and optimization have been introduced with project planning and development software such as Wind PRO.

Project Planning and Development Technology Transfer and Capability Building

Skills and know-how of project planning, site assessment, site development and micro-siting were low in the beginning and caused many project failures in the early and mid 1990s. However, project execution capability and knowledge in understating of site conditions and micro-siting related issues have been advanced greatly since the mid 1990s through joint venture/license agreement collaborations. The advancement and transfer of remote monitoring SCADA products as well as project development software tools (WAsP, WindPRO) for siting, local wind resource mapping, optimization and micro-sting have helped the Indian manufacturers. Also, generic project execution technology and capability such as financing, project permissions and land acquisition, and site and infrastructure development have been tailored for wind projects and greatly advanced for all manufacturers since the mid 1990s.

Project Execution/Auxiliary Service Technology Capacity Building

The formation of the sufficient number of service providers happened gradually. In the mid 1990s the lack of trained personnel for wind farm O&M was the major problem of the industry (Wind Power Monthly 1996b). By the late 1990s, however, auxiliary service providers in wind turbine erection and towing of blades and generators through the field, etc. were reportedly well-established (Wind Power Monthly 1999b). Table 5-68 shows the increase of the service providers from 2002 to 2005 in various service categories. In particular, the number of contractors related to wind turbine installation (turbine erection, crane hiring, civil works), component repair providers, and consultants and their service areas increased greatly.

Table 5-68: Number of Indian Service Providers

Service Providers	Number of Providers	
	2002	2005
O&M	24	29
Wind Turbine Erection Contractor	10	25
Crane Hiring Agencies	27	34
Civil Contractors	14	27
Electrical Contractors	24	32
Component Repairs		
Blades	6	9
Generator	19	24
Gearbox	7	11
Electronic Cards/Anemometer	5	9
Turbine Refurnishing	--	6
Yaw System	--	5
Insurance Companies	10	10
Surveyors/Valuers	18	18
Consultants		
General Wind Project Consultants	24	35
Agricultural Consultants	2	4
Condition Monitoring	--	3
Electricity Regulatory Measures	--	1
Land Brokers	--	3
Power Quality Study	--	2
Seller/Purchaser of Old Turbines	7	9
Training Providers	--	6

Sources: interpolated from (Consolidated Energy Consultants Ltd. 2002; Consolidated Energy Consultants Ltd. 2005)

Turbine Transportation and Logistics Innovations

Because only a handful of MW-class wind turbines have been built by the frontier manufacturers in India, their transportation and logistics expertise on these turbines have not been widely transferred to India. However, Suzlon has indigenized transportation and logistics know-how through its domestic installation of the 1MW model from 2001 and the 2MW model from 2005 and their exports to the United States from the 2003-2004 year.

5.6.5 Turbine Testing and Certification Technology Transfer and Domestic Technology Development

India has successfully built the capacity to perform type testing and provide turbine certificate at C-WET since 1999. The technology was transferred from Denmark; DANIDA provided a grant of DKK 15.9 million from late 1996 towards the foundation of a wind turbine testing center in Tamil Nadu, and the RISØ National Laboratory provided the actual knowledge of testing and certification procedure. This helped C-WET develop Type Approval Provisional Scheme–2000 (TAPS–2000) along the line of international certification scheme. TAPS–2000 will be replaced by the Indian Type Approval Scheme (TAS) in the future.

5.6.6 Innovation (R&D) Technology Transfer and Domestic Technology Development

R&D Institutions and Capability Building

International collaborations, in particular bilateral basis, have been evident in R&D area. Besides the establishment of C-WET, Denmark has helped the Indian research institutions to develop technology and guidelines that address the issues related to weak grid. From 2002, C-WET has engaged on the joint projects in wind energy development with the Energy research Center of the Netherlands (ECN, the Dutch National Energy Research Laboratory).

The establishment of R&D Unit in C-WET was to strengthen the connection between R&D institutions and industry in order to provide generic information and knowledge to innovate components and subsystems of wind turbines suited for the Indian specific conditions. In addition, MNES has developed three R&D models involving industry, research institutions and laboratories, academic institutions and end-users for wind energy.

In general, however, innovation capability building has been slow, and the public-private R&D collaboration schemes developed by MNES have been seen as passive and limited by the industry insiders. Majority of the R&D projects supported by MNES and C-WET had sub-optimal level of funding of less than USD 25,000. While research institutions, universities and national laboratories have emphasized theoretical and academic research, majority of resources from MNES were spend on demonstration, evaluation, and resource assessment. Only small amounts have been spent on basic research and product and process technology development or upgrade (Shekhar, Kumar, and Shar 2001).

Manufacturer In-house R&D Capability

In terms of in-house R&D capability building of the manufacturers, Enercon India and Suzlon have built such facilities in India although their main R&D activities occur in Europe.

In 2004 Enercon India set up a full-fledged R&D center and a blade design facility, and the Indian specialists have been working on global research projects, collaborating with the R&D headquarters in Germany. As for capability building, Enercon let the Indian engineers stay in Germany for three months to acquire technical experience. Specific software was developed in India to provide the daily updates on power generation by Enercon turbines to MNES (European Wind Energy Association 2004).

Suzlon also has developed in-house R&D capability in India and the Indian engineers have contributed to software development. However, the firm has German R&D centers for turbine design and precision engineering and a Dutch R&D center for rotor design and development, and control system development is carried out by the collaborations with the Danish and German sub-suppliers. The competitive core technology of Suzlon is still developed in Europe.

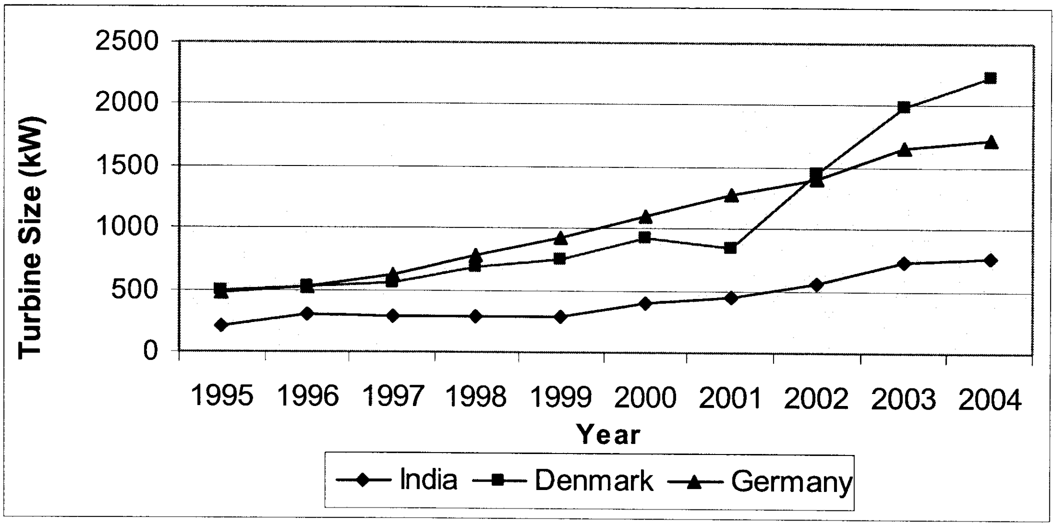
5.6.7 Evolution of Technology Gaps between Denmark/ Germany and India

Change in Product Technology Gaps

Through the analysis above, it has been clear that the commercialized technologies at the frontier and in India have obvious gaps.

Technology Depreciation Rate and Average Size of Turbines

Technology depreciation rates of Denmark and Germany have been much higher than that of India over the years. Many wind turbine models that were no longer available at the frontier have been still installed in India. The average installed turbines capacity of Denmark/Germany and India clearly illustrates the increasing gaps for the past decade (Figure 5-15).



Source: (BTM Consult ApS 2005b)

Figure 5-15: Technology Gaps in Average Size of Installed Turbine

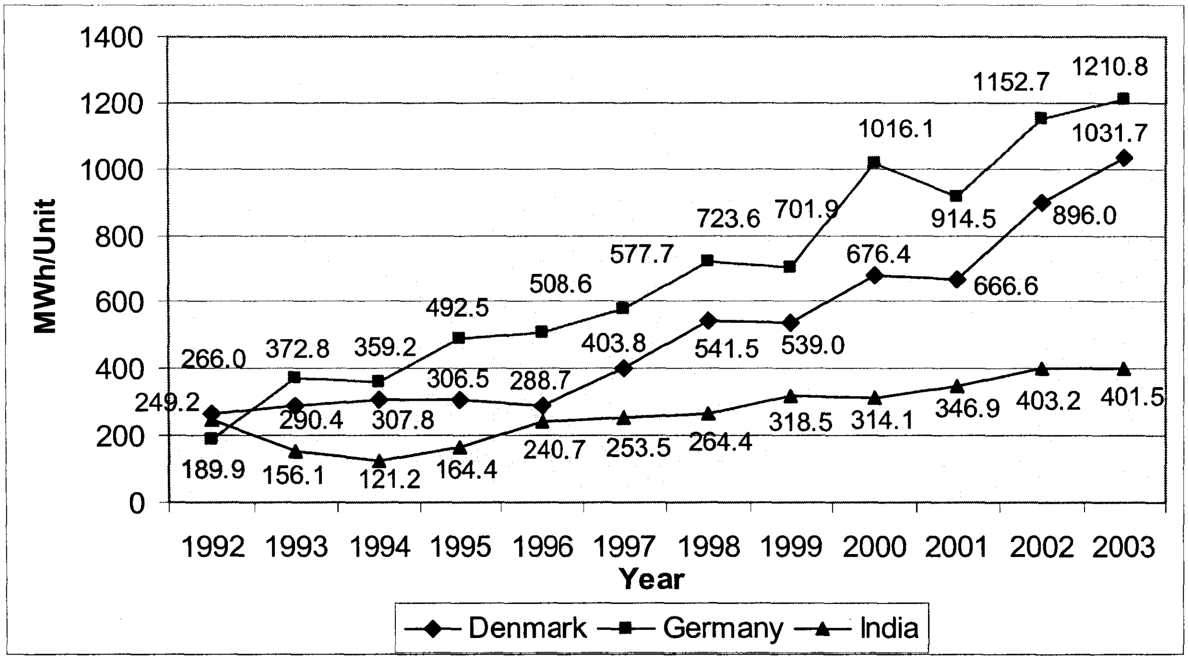
Technological Features

Many technologies commercialized in Europe, including some of the mainstream technologies, have not been introduced at all or introduced only on a limited basis to India since the late 1990s. The technological majority of the Danish Classical Concept was same in Europe and India by the mid 1990s. However, whereas the frontier has shifted to pitch-regulated, limited-range variable or wide-range variable speed operations from the late 1990s, majority of turbines installed in India have been still fixed-speed turbines although pitch regulation has increased its installation number in recent years. The newest Multibrid technology has not been introduced to India at all.

The gaps are increasing in blade and SCADA technology areas as well. Because the introduction of large-capacity turbines have been very limited, blades with specialized aerofoil and some advanced materials such as CF, CFRE, and wood epoxy, as well as SCADA products that have advanced features in remote monitoring, remote reporting, and grid interface management are also limited. Product technology gaps between the frontier and India have increased.

Turbine Productivity

The gaps in both turbine capacity and technological features have created strong efficiency gaps between the frontier and India, in terms of aerodynamic efficiency and energy capture. This can be illustrated by Figure 5-16 that shows a simple comparison of turbine productivity, calculated by the yearly generated wind electricity divided by the cumulative number of turbines.[77] It shows the staggering increase of the gaps in turbine productivity between Denmark/Germany and India over the years, even if taking weather and climate differences between the two sides and year-to-year weather variations into account. Between 1992 and 2003, turbine efficiency in Denmark and Germany increased 3.9-fold and 6.4-fold, respectively, while the productivity growth in India remains only 1.6-fold. The influence of the gaps in turbine capacity and variable speed operations on turbine productivity is evident, as the turbines installed in Germany show the highest productivity increase over the years.



Note: Due to the differences of statistical year between Denmark/Germany and India, the Danish/German calendar year (January to December) is compared to the Indian fiscal year (March of the same calendar year to March of the next calendar year). For example, data for the Danish/German 1992 year is compared to the Indian 1992-1993 fiscal year. The comparison, however, is considered approximate enough. Sources: (Danish Wind Industry Association 2006), DEWI and ISET in (BWE 2005), (Consolidated Energy Consultants Ltd. 2005)

Figure 5-16: Technology Gaps in Turbine Productivity

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[77] Turbine productivity is usually calculated by yearly generated electricity divided by total rotor swept area. However, this calculation method was not taken because the data regarding total rotor swept areas of Germany and India over the years was not available. Yearly differences in wind and weather conditions are also not normalized.

Change in Technological Capability Gaps

The increasing technology gaps in product technology correspond with the increasing technological capability gaps between the frontier and India. While the Indian wind energy industry has successfully indigenized various technologies in production and project execution and developed some innovation capabilities, technology gaps have greatly increased in innovation capabilities and they have not been reduced in production capabilities of med-tech and high-tech components.

Production Capability

The Indian wind industry has indigenized small-capacity turbine production technology at high level. However, the indigenization level of production technology of high value and high-tech components and their quality have stayed low. The dependency of power electronics and controllers on imports has never reduced, and med-tech mechanical engineering components made in India are still prone to failures. The effects of learning and experiences on reduction of mechanical failures are not strong. In addition, many components commercialized at the frontier since the mid 1990s, which require much higher levels of production capability, are not introduced to India, including manufacturing of: power electronics for larger and more complex turbine regulation; new rotor blade materials, special aerofoil blades, and their moulds; and towers, generators, gearboxes and nacelles for the turbines above 2.5MW capacity. The production capability of these large components usually does not come easily at the frontier in the beginning either; initially only a few qualified component suppliers are available. However, the number expands when both experiences and production series volume are accumulated with market demand (De Vries 2005a).

Overall, many gaps in production capability between Denmark/German and India have not been closed, and the gaps in production capability of high-tech and complex components for large turbines have greatly increased.

Innovation Capability

Innovation capability has greatly advanced at the frontier for the past 15 years when many wind turbine components and system technology have become complex, systemic, science-based, and extremely high-tech. The frontier advanced its innovation capability in all of the following aspects: materials science for advanced blade materials innovation; special-purpose blade aerofoil design; smart engineering methods for blade production; control system for individual pitch and active stall regulations; a range of variable generator configurations and rotor speed operations; SCADA and high-capacity control systems that look after different types of rotor speed operations, grid management and the entire wind farm; wind resource estimation and energy optimization technology; project execution software that take care of the whole value functions of wind project development; integrated wind turbine design and optimization technology; transportation and logistics of multi-MW turbines up to 5MW; and offshore specific turbines and foundations. However, none of such innovations were carried out in India. In terms of innovation capability, the gaps have grown greatly between 1990 and 2005.

The next chapter analyzes the reasons behind these changes: why such technology gaps have been created, why they are increasing, and how they have impacted on the Indian efforts of wind energy development.

Chapter 6:
Comparative Analysis of Causal Factors and Processes for Technology Development and Diffusion

Chapter 5 described the evolution and the basic profiles of policy, market, industry and technology of the three research countries and the technology gaps emerged between India and the technology frontier of Denmark and Germany since 1990.

This chapter examines the co-evolution of policy, market, industry and technology that spurred technology development and diffusion at the frontier and in India and explores the causal factors and processes that created the increasing technology gaps between the two sides. The chapter consists of eight sections. The first section analyzes the market size/location, the investment mechanisms, and the characteristics of market demands of Denmark and Germany, and examines their effects on technology development and diffusion. The second section investigates the effects of the changing technological characteristics on industry structure and competitiveness management at the frontier. From the third section, the analytical focus shifts to India. In this section, the relationship between new turbine introduction and capacity development in India is quantitatively examined. The fourth section analyses the causal factors behind the relationship between cross-border technology transfer and market development, focusing on the effects of market demands and investment mechanism on technology development and diffusion in India. The fifth section explores the effects of the changing technological characteristics and industry structure/competitiveness management at the frontier and India on cross-border technology transfer and the growth of technology gaps. The sixth section explores the Indian specific conditions, appropriateness of the European technology to those conditions, and its effects on cross-border technology transfer. The seventh section examines the effects of characteristics of different technology partnerships on cross-border technology transfer. In each section, the role and effects of policy and institutional setting are discussed. The last section synthesizes the findings of the analyses, using value chain policy analysis and causal loop diagram analysis.

Section 6.1: Market Demands and Investment Economics Pressure and Their Effects on Technology Development and Diffusion in Denmark and Germany

6.1.1 Market Size, Market Demands, and Investment Mechanism at the Frontier

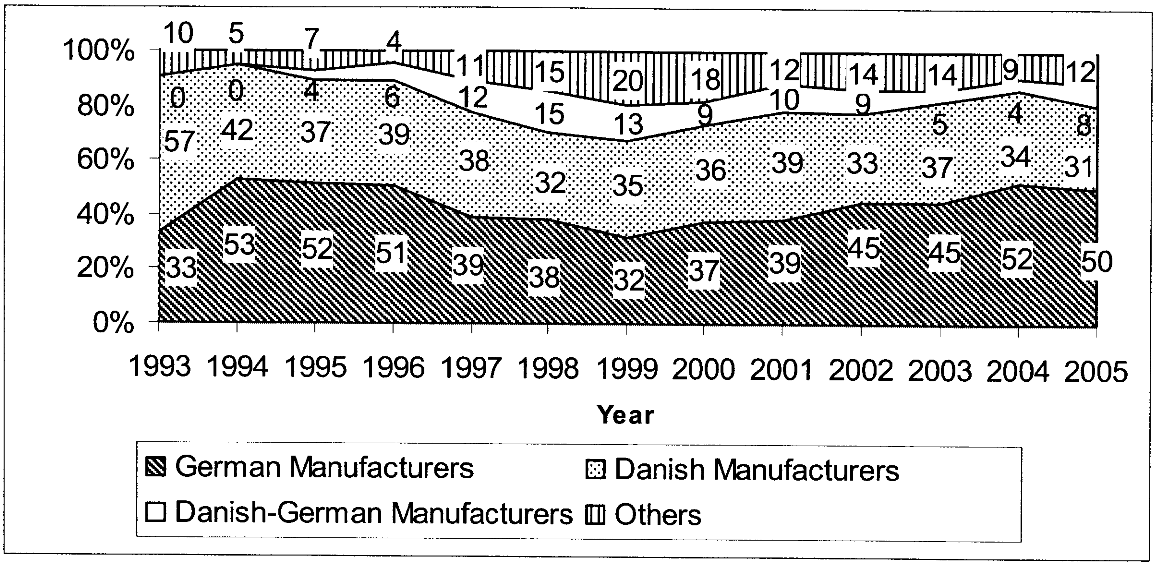
Germany – Growth Pulling Market

As described in Chapter 5, Germany has been the strongest market leader in the world for a decade since the early 1990s. Especially, the growth from the late 1990s to the early 2000s was enormous, and this had immense impacts on the general technology development and trend.

Danish and German Market-Industry Interaction

Danish and German Market Share by Manufacturer

As also mentioned in Chapter 5, while the Danish market has been served entirely by the Danish manufacturers, the share of the German market has been divided mostly by the Danish and German manufacturers (including Tacke/Enron/GE Wind) (Figure 6-1).



Note: Danish manufacturers include Vestas, Micon, Nordtank, NEG Micon, Bonus, Nordex (until 1994), and Wind World. German manufacturers include Enercon, Tacke (until 1996), Husurner Schifftwerft, Hanseat AG, REpower System, DeWind (until 2002), Fuhrländer, Jacobs Energie, and Südwind. The Danish-German manufacturer is Nordex (from 1995). Sources: (DEWI 2002a; DEWI 2003a; DEWI 2004a; DEWI 2005; DEWI 2006; DEWI 1994; DEWI 1995; DEWI 1996; DEWI 1997a; DEWI 1998a; DEWI 1999a; DEWI 2000a; DEWI 2001a)

Figure 6-1: Market Share of Annually Installed Capacity in Germany by Country of Origin of Manufacturers 1993-2004

Danish and German Industry Exports

The growth of the Danish industry has been strongly supported by domestic market but more by export, as described in Chapter 5. The export share has been increasing further in recent years as the Danish domestic market shrunk since 2000. The average share of export in sales capacity by the Danish manufacturers between 1990 and 2004 was about 80% and the main export destination has been Germany throughout the 1990s and 2000s. The export turnover increased from 1992 as the German and Indian markets grew, but the export to India has been greatly reduced since 1997. All major Danish manufacturers had their subsidiaries and production facilities in Germany to serve the market.

On the other hand, the German manufacturers exported only average 13% of total manufactured capacity between 1995 and 2003. The rest was absorbed by its large domestic market, but there are a couple of other reasons too. The German manufacturers have been pushed out of two other important markets; Denmark and the United States. While the Danish market has been served entirely by domestic manufacturers, technology by the most prominent German player Enercon had been banned from the North American markets as a result of patent infringement dispute with Kenetech/Enron/GE since 1996 until the mid 2004[78]; another prominent German manufacturer Tacke Windtechnik, was acquired by Enron in 1997 and became under the German-US ownership; and other manufacturers have not been powerful enough to demonstrate their presence in the United States.

Danish and German Market-Industry Interaction

The German turbine manufacturers and their technology development were mainly influenced by the German domestic market, as the amount of the German manufacturer export and the direct influence of the Danish and other markets on the German manufacturers have been very limited. Meanwhile, the interactions between the German market and the Danish industry have been intense. Thus, the German market demands have had huge impacts on wind energy technology development by both the German and the Danish manufacturers.

Wind Investor Profile and Investment Mechanism in Denmark and Germany

Wind Project Investor Profile and Investment Mechanism in Denmark

Figure 6-2 clearly shows that it was private investors who have led the Danish market development. The utilities only began developing wind projects in the late 1980s but its share in total installed capacity never exceeded 30%; they increased its share in 2002 and 2003 as two large offshore wind farms (Horns Rev and Nysted) became operational. In total, 78% of wind energy capacity was installed by private investors and the rest (22%) was owned by utilities as of the end of 2004 (Danish Wind Industry Association 2006).

The Danish wind investment model has been a series of small, distributed wind plants based on local investments; as many as 150,000 families, 5% of the Danish population, have bought wind turbines or shares of wind turbines by 2000 (Wind Power Monthly 2001b). The private turbine ownership can be largely divided into two: individual household or business owned turbines, and wind cooperative owned turbines. A few turbines are owned by private industrial enterprises and by municipalities. The ownership trend between individuals and cooperatives changed over the years (Figure 6-3). During the 1980s and the early 1990s, wind cooperatives were the most important investors. The turbine ownership restrictions on the amount of share of wind plant since 1985 made it very difficult for single owner to own wind turbines. Wind cooperatives spread the ownership of turbines between 20 and 100 families in the vicinity of the turbines; investors buy the shares of cooperative that makes investments in local wind plants. However, the cooperative ownership decreased gradually as the general installation number declined

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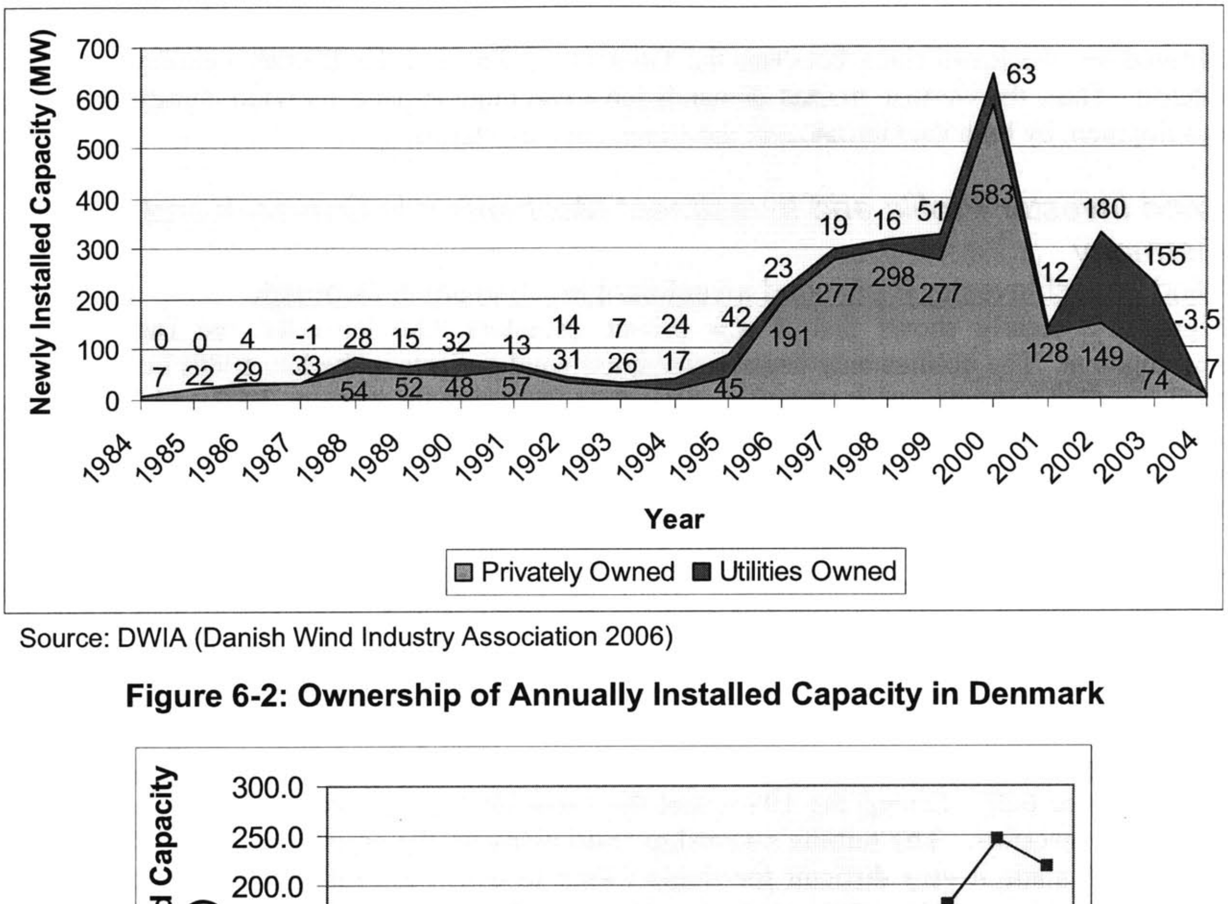
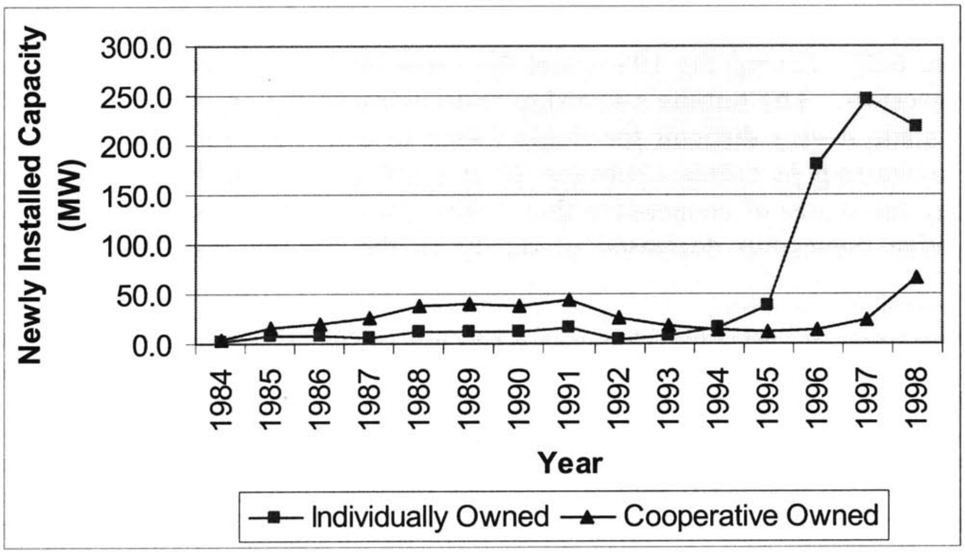
[78] The American patent on wind turbine electronics is now held by GE, but was originally awarded to Kenetech in 1993, which sued Enercon for its infringement in 1995. As a result, in 1996, Enercon technology was banned from the US market by the US International Trade Commission and Enercon lost a major wind plant order in Texas. The patent was later acquired by Zond after the Kenetech bankruptcy, before passing into Enron and then GE's hands. The US Patent Office states that the patent was granted to not the technology but its combination in a unique and unusual way of using the technology. Enercon consistently argued that the patent granted to Kenetech was for the technology already in the public domain, citing a wind energy textbook from 1989, and such prior art cannot be patented. Also Enercon's turbines do not use the same power control factor and power conditioning techniques specified in the patent. Although these Enercon's points were very clear to the industry insiders, the American patent authorities and the courts have consistently turned down its arguments. The patent dispute was finally resolved between Enercon and GE in 2004; both sides agreed on a settlement, forming a long-term worldwide basis, cross-license agreement (Wind Power Monthly 2003g; Wind Power Monthly 2003h; Wind Power Monthly 2003i).

between 1992 and 1994, and hit the lowest level in 1995. The ownership profile changed dramatically in 1996, when individual investors, predominantly farmers, became the main investors, as the 1996 turbine ownership regulation change opened up the possibilities for individual investors, along with the laws for facilitating structural changes in the farming sector to invest in wind projects. From this year on, farmers became the primary owners of newly installed wind turbines. In terms of utility involvement of wind development, a series of the government-utility agreements has been the reason for its growth.



Source: DWIA (Danish Wind Industry Association 2006)

Figure 6-2: Ownership of Annually Installed Capacity in Denmark



Source: EMD cited in (Dannemand Andersen 1999)

Figure 6-3: Ownership of Privately Installed Capacity in Denmark

Another trend in the Danish investment mechanism is the growth of professional wind project developers, who sell turnkey projects to individuals or cooperative investors, by linking them with wind turbine manufacturers and taking care of all administration, project planning, siting and building, and delivering of wind plant to the customers. Professional wind project developers appeared already in the 1980s (Wind Power Monthly 2001c).

The Danish investment professionalization was spurred by the series of government ownership restrictions from the 1980s, which complicated the process of gathering enough investors due to the geographical and share limits on wind plant owners. On the other hand, the turbine type approval and certificate mechanism from 1979 played an important role by making it possible for developers to obtain easy bank financing for investment, standardize the costs for grid connection, and shorten the project lead time. The repowering market boom since 2001 also spawned a breed of professional repowering developers, specialized in buying up old turbines to secure their "scrap certificate" value - a guaranteed premium rate for turbines up to three times of their replacement capacity.

Wind Project Investor Profile and Investment Mechanism in Germany

The German domestic market has also been mostly developed by small, dispersed projects owned by individuals and private operating pools, not by utilities. More than 90% of all wind turbines installed are owned and operated by private investors in Germany. According to an estimate by BWE, more than 100,000 people have invested directly in wind projects since 1991 until 2001 (Wind Power Monthly 2001a). The German utilities had been a strong opponent of the feed-in laws, as they only became eligible to receive the premium payments for wind projects under the EEG in 2000. Unlike Denmark, there were no government obligations for utilities to develop wind projects in Germany. These factors contributed to the low level of utility involvements in wind projects.

Table 6-1: Ownership of 250MW Wind Program in Germany

Ownership	Number of Turbines	Installed Capacity (MW)
Private Individuals (mostly farmers)	722 (49%)	122 (35%)
Commercial Operators	339 (23%)	129 (37%)
Operator Groups, Private Individuals	162 (11%)	35 (10%)
Commercial Enterprises (firms, factories, hotels, etc)	132 (9%)	24 (7%)
Regional/Municipal Utilities	118 (8%)	38 (11%)

Source: (IEA 2001)

Table 6-2: Net Annual Installation by 250MW Wind Program in Germany

		1989	1990	1991	1992	1993	1994	1995	1996
Number of Turbines	**250MW Program**	15	172	252	299	320	259	149	75
	Total	87	250	300	405	586	820	911	798
	250MW/Total	17%	**69%**	**84%**	**74%**	**55%**	32%	16%	9%
Installed Capacity (MW)	**250MW Program**	1.4	29.4	41.4	49.1	62.6	41.6	85.5	24
	Total	11.8	60	51	74	151	309	493	410
	250MW/Total	12%	**49%**	**81%**	**66%**	41%	13%	17%	6%

Source: (IEA 2001)

Although the statistics of wind project investor profile/turbine ownership for all the installed turbines was not obtained, the ownership of turbines installed under the 100MW/250MW Wind Program at the end of 1999 in Table 6-1 demonstrates that private individuals and commercial operators played significant roles in market development. The majority of wind projects between 1990 and 1993 were developed under the 100MW/250MW Wind Program (Table 6-2)

Professionalization of investment mechanism has also happened in Germany. From 1990, investments took a form of traditional local citizen-financed wind farms (Bürgerwindpark). With this mechanism, a group of local project initiators set up a project company for a specific wind project and invited other local citizens to join the project as limited partners. The resulting limited liability partnership developed, owned and operated a citizen-owned wind farm – Bürgerwindpark.

Since 1995, with the increasing demand for wind project shares from the outside of the traditional wind regions, the Bürgerwindpark mechanism evolved into the closed-end wind funds,[79] a more professionalized investment mechanism, taking a hybrid form of GmbH (private limited liability company) and KG (limited partnership). The closed-end funds usually raise 30% to 40% of equity for a project to secure bank loans as debt, nearly 100% of which derives from two wind soft loan sources: Environment and Energy Saving Program of the European Recovery Program (ERP) and Environmental Fund by DtA and KfW. One distinctive feature of the German closed-end fund mechanism is the increasing specialization that has happened over the years: project development and equity acquisition take place separately from each other, and the project shares of wind farms became the standardized financial products; the placement of fund shares are increasingly carried out by sales subsidiaries of project developers, banks and investment consultants; and the O&M tasks are outsourced to special O&M firms. Any financial risks related to the projects are carried out by equity investors (shareholders), but the investors can write some losses off against taxes, subject to some limitations. At the point of 2001, 95% of the wind projects in Germany have been financed through the closed-end wind funds (Enzensberger, Fichtner, and Rentz 2003; Gerdes 2005; Wind Power Monthly 2001a).

Role and Effects of Policy and Institutional Factors in Market Growth at the Frontier

Favorable policy and institutional sensitivity factors in project finance mechanism greatly contributed to the wind energy market growth in Denmark and Germany. Revenue sources and purchase agreements have been secured by law and several fiscal measures such as capital subsidies, tax credits, and favorable tax depreciations have increased the revenue flow. The cost of financing also worked well due to the declining general interest rates during the 1990s.

Guaranteed Payment by Law in Denmark and Germany

First and foremost, the heavy capital requirement in the beginning of wind project made the guaranteed electricity tariffs play the most important role in the project finance mechanism with low equity and high debt, because they offer a certainty for recovery of initial capital investment in long run. The Windmill Law of Denmark as well as the Electricity Feed Law (EFL) and the

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[79] Open end funds bundle various projects together (e.g., biomass, solar and wind) and allow investors to put out at specified intervals.

Renewable Energy Sources Act (EEG) of Germany, which mandated the guaranteed payments to the power generated by wind projects by law, were the most important factor behind the successful market developments in both countries.

Denmark

In Denmark, the investment subsidy from 1976 and the direct production subsidy from 1981 supported the early private investments. The turbine testing and approval requirement for obtaining the eligibility for investment subsidy and grid connection as well as the ownership restrictions for preventing anyone from making enormous amount of profits from the incentives eliminated the abuse of government incentives as intended.

Although the Wind Mill Law was created to shift the support focus to production incentives, its formula that set the tariff at 85% of retail electricity prices caused the market slowdown from 1992 to 1994 because of the drop of payment due to the low-priced retail electricity around that time (the average total feed-in tariffs was around DKK 0.54-0.57/kWh then); the feed-in tariffs were too low to reduce investment risks and sustain profitability. The rise of retail electricity price finally made the feed-in tariffs approximately DKK 0.60/kWh (the average DKK 0.33/kWh as 85% of retail electricity prices with DKK 0.10/kWh of CO_2 tax refund and DKK 0.17/kWh of direct production subsidy) and wind projects profitable, together with the decreased general interest rates from the mid 1990s.

The conflicts over turbine siting that began happening during the early 1990s due to the increased turbine size and the lack of suitable sites also partly contributed to the market slowdown from 1992, until the release of municipal zoning plans after mid 1995. Political uncertainty before the release of municipal zoning plans made some municipalities to refuse or delay siting permission.

In 1997 the investment incentives in terms of tax deduction became less attractive than the previous scheme. However, it did not have large impacts on reducing private investment, as the limit of a household's financial share on cooperative turbine investment was increased from 1996.

The record installation of 2000 was created because all the turbines installed in the year were subject to the payments under the old feed-in tariff system, as all of them were ordered in 1999. The shift to the green certificate mechanism from 2000 made the interim tariffs much lower than DKK 0.60/kWh, and the lack of security due to low and unpredictable purchasing prices of wind electricity on the liberalized market and the saturation of available onshore sites with respect to spatial planning contributed to the disappearance of market on land. However, from April 2001 until December 2004, the Danish market flourished as a result of the well-developed onshore repowering program and offshore development.

In terms of shaping the wind project investor/turbine ownership profile, the turbine ownership regulations had played significant roles. These ownership policies were placed in order to encourage the local acceptance of the projects and they succeeded to eliminate the NIMBY phenomenon. The restrictions on membership share of wind cooperatives during the 1980s spread the ownership over many local citizens. The restrictions were gradually eased and the ownership rules tried to incorporate diverse owners since the mid 1990s. The removal of area restriction in 1994 eliminated the restriction of all the members of a wind cooperative to be required to live near the wind plant and increased investments during 1996 and 1997; this condition was removed in 1996 but all projects approved during 1995 were allowed to proceed. The expansion of allowed share of cooperative members in a wind plant up to 20,000kWh/year from 1994 and further to 30,000kWh/year from 1996 also contributed to the market growth during the late 1990s. In addition, the 1996 change to allow the participation of farmers in wind investments increased individual investments tremendously and was a part of the important reasons for the strong market growth between 1996 and 2000.

Germany

In Germany, the cumulative nature of production subsidy by the EFL and investment and production subsidies by the 100MW/250MW Wind Program initiated the market take-off in the early 1990s. The decrease in general interest rates during the 1990s also had a significant impact. With a pay-back time of ten years, a 3% decrease in interest rate corresponds to a 25% price decrease. The interest rates were approximately 10% in April 1991 but decreased to approximately 5-6% during the 1990s (IEA 2001). Availability of the two federal soft loan programs (ERP and the loan by DtA/KfW) as well as the loan from agricultural financing institutions for farmers contributed to the market growth as well. These loans were made for long enough to ensure turbine operations as least for ten years and the written-off accordingly.

In addition, the taxable income deduction rules and the reduction of taxable income through linear depreciation was another driving force behind the German market growth. The linear depreciation of income about 10% of turnkey cost per year corresponded to approximately DM 100,000 per year. With an assumed tax rate of 30%, the tax paid by investors would be reduced by about DM 30,000 per year (IEA 2001). Total income tax deduction available for the projects filed before the March 1999 tax rule change made the returns from wind investment after tax twice as high as those before tax (Wind Power Monthly 2000a). On top, no spatial or siting regulations until 1994 also eased the early private installations.

The only exception of the continuous growth was the market slowdown between 1996 and 1998 as a result of the investment insecurity caused by political and legal attacks by big utilities against the EFL and the reduction/withdrawal of state policy in the costal states between 1996 and 1997. However, considering the strong installation record after the mid 1990s, the federal policy and good wind resources have much larger impacts on geographical distribution of installation in Germany than state policy. With the great success of the feed-in tariff mechanism, state policy was mostly eliminated from 2000. However, the EEG has created the record installation after 2000.

The 1996 market slowdown was also partially caused by the planning permission delay from the mid 1990s. After the 1994 court ruling that stripped the privilege of single wind turbine in open countryside, the market for single turbine installation stagnated. The 1997 Amendment of Building Stature book contributed to the market growth from 1998 by reintroducing the single turbine privilege and mandated local governments to create wind turbine zoning plans that reduced planning uncertainty.[80]

Unlike Denmark, however, the tariff reduction due to the decrease of retail electricity prices, which was especially evident after the electricity market liberalization of 1998, did not influence installed capacity adversely in Germany, as the EFL Amendment in April 1998 cleared political uncertainty by specifying the financial charges of different utilities and setting a date for reconsideration. Then, the EEG in 2000 further reduced political uncertainty, as the tariffs become defined not by retail electricity prices but by law for 20 years. The EEG also set up the tariffs for initial five years higher than the declining tariffs due to the market liberalization since 1998. The market decline since 2003 occurred due to the lack of opening sites for onshore projects. The German market was ready to move onto offshore development, and the first German offshore turbine was installed in February 2006 after the intensive preparation efforts since 2000.

6.1.2 Effects of Market Demands on Technology Development and Diffusion at the Frontier

Technology Driving Market Demands in Denmark and Germany

The Danish and German policy incentives and market investment mechanisms created various market demands that influenced the wind energy technology innovations and trends greatly. Many of the following market demands created a synergy to push technology to a certain direction.

Technology-related Sensitivity Factors – Technology Upscaling/Upgrading Demands

Wind investments in Denmark and Germany have had to compete with other investments to attract private capital. In Denmark, individual investors, in particular, farmers who began participating in wind energy development after 1996 are reportedly more conscientious about profitability than wind cooperative owners, whose driver was more environmentally motivated ones (Morthorst 1999). In Germany, there are many other fiscally advantaged funds, competing directly with the close-end wind funds. These conditions have made the creation of favorable technology-related sensitivity factors (investment cost, O&M cost, amount of electricity generated and sold, technical system lifetime, size effects of wind project/farm) through technology development very important, in order to increase the competitiveness of wind energy despite the guaranteed feed-in tariff payments and various tax advantages. These incentives were also given to the levels, which were not too generous to ignore the performance.

The most important technology-related parameters are the amount of energy generated and sold by wind turbines and their investment costs (European Wind Energy Association 2003). Increasing the amount of electricity generation from wind turbines creates mainly three technology drivers: 1) utilizing the sites with good wind resources and optimizing energy capture through better micro-siting; 2) installing turbines with higher hub-height to capture stronger wind more constantly; and 3) increasing the efficiency of production through better equipment design

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[80] In the mid 1996, the licensing procedure took average four years compared to 18 months before (Wind Power Monthly. 1996f).

and larger rotor swept areas that increase wind energy capture. The latter two drivers make larger-capacity turbines (taller hub height with large rotor swept areas) more preferable.

Technology-related Sensitivity Factors – Cost Reduction Demands

The other technology-related sensitivity factor is the total investment cost reduction. As described in Chapter 5, wind turbine cost usually occupies more than 75% of total investment costs. Therefore, the foremost efforts to reduce investment costs focus on the reduction of turbine cost through technology innovations. The reduction of turbine cost per rotor swept area or cost per installed kW is an important market demand

In terms of installation cost reduction, it greatly depends on economies of scale, which is another technology-related sensitivity factor. Larger projects can reduce transaction and O&M costs per unit, as they can be spread over the number of turbines and the efficiency of management increases. While this was not possible for the Danish onshore development, where the strict ownership and development regulations by local and regional authorities until 2000 made typical installation in clusters of three to seven turbines and large wind farms very rare, the German closed-end funds prefer large wind plants in order to reduce installation and O&M costs. The 1997 Amendment of German building law to mandate local governments to create the wind turbine zoning plans made wind turbines not to be built as single installation but to be built as clusters in the designated zones that can be owned by different investors. This helped reduce installation costs in Germany by creating economies of scale

Land Development Pressure in Germany - Technology Upscaling/Upgrading Demands

Another important technology driving market demand derives from strong land development pressure in Germany, which is much higher than in Denmark. Germany has high population density and is short of good wind sites. At good sites, diverse land users are often competing against each other. In addition, there have been always complains about noise and shadow effects of wind turbine installation, which is also seen in other European countries. Although the corresponding land around turbines can be still used as farmland, there are many complaints. In both Denmark and Germany, the noise reduction and spatial planning regulations including zoning for wind turbines make areas for wind turbine installations limited (Gerdes 2005). In Denmark, the conflicts over turbine siting that began happening in the early 1990s due to the increased turbine size and the lack of suitable sites. They partly contributed to the market slowdown from 1992 until the release of municipal zoning plans after the mid 1995. However, the limitation has been much stronger in Germany than Denmark. In the limited land areas, higher-efficiency wind turbines are preferred because they increase the efficiency of land use. With this reason, larger-capacity turbines with higher hub-height and newer equipment design are strongly demanded, especially in Germany.

Low Wind Condition of Germany - Technology Upscaling/Upgrading Demands

Another decisive condition in Germany was its limited high wind potentials, compared to the United Kingdom and the coastal regions of France. Geographical distribution of turbine installation in Germany strongly reflects wind resource availability. The states facing or close to the coasts have higher and better winds, but wind resource availability normally declines with the increased distance from the coasts; as a result, the costal states have installed more wind turbines than the inland states. However, the regional distribution changed over the years. The installation in the costal sates with higher wind resources increased continuously, reaching their peak in 2001 and 2002. The inland states that are closer to the coastal regions show a similar tendency, reaching their peak in 2002. The installation in these regions, however, has been declined since, as the number of suitable and available sites declined. Good wind sites are clearly saturated over time (see more details in Figure 6-10 in Section 6.6).

In Germany, the high tariffs set by the EEG in 2000 made low wind sites more economic, but the 2004 EEG amendments eliminated the low wind zones. At the sites with low wind resources, investments take longer time to reach positive balance. In order to compensate this, again, the demand for higher-efficiency wind turbines becomes strong.

Offshore Development Demands

Offshore electricity production by MW-class turbines can give stable production and high production efficiency due to higher wind speeds and less turbulent wind environment than onshore. The market demands for expanding offshore development began stronger after the WEGA II Program successfully helped major European manufacturers develop and commercialize their first MW-class turbines during the mid 1990s. As land development pressures became stronger and the saturation of available land for onshore development in European countries has become inevitable, large continuous areas available for major projects in offshore has made special offshore turbines and technology development a design target in Europe.

Power Quality Control Demands

The grid stability issues posed by distributed power plants such as wind turbine have been pushed by the utilities in Germany, which have demanded higher power control quality to reduce fluctuation of inputs and reactive power. This demand will increase further in the future, as wind energy continues to grow in Germany and the offshore market gears up for massive development, and the electricity network expansion and its stability will become a major issue.

Environmental Demands - Noise Reduction and Environmentally-Friendly Production

Taking care of noise from wind turbines and meeting the noise levels set by regulations are very serious issues in Europe and they have been an important innovation driver. In Germany, the areas and shapes of the wind turbine zones are influenced by the noise from turbines. More number of turbines can be installed in larger areas if they have lower noise emission. As described in Chapter 5, the noise requirements in Germany are different between night time (22:00 to 6:00) and day time, and the night time noise is more important. Noise imission (sound level heard at regulated areas) is determined by two parameters: noise emission of turbines and distance between the turbine and regulated areas (noise imission = noise emission/distance) (Gerdes 2005).

There was also the increasing environmental restriction on the use of polyester on blades. The 1995 German regulation on blade materials began prohibiting styrol emissions during the production of blades using polyester to be less than 20ppm.

Demands for Solution for Mechanical Problems

Mechanical component failures have been the main cause of malfunction of wind turbines that stop turbine operation and increase insurance changes; both are the serious problems for investors. Failures in gearboxes, generators, hubs, hydraulic systems, yaw systems, and mechanical brakes have occurred frequently. In addition, the larger the machines, the more mechanical problems happen. The market demands to cope with mechanical component failures have increased as turbines have become larger and larger.

Efficiency Demands posed by the EEG

The German EEG implemented in 2000 was specifically created to push the efficiency improvement innovation. The law has the different electricity tariffs for onshore and offshore wind projects. In addition, the amounts of hours that the tariffs are paid are differentiated according to turbine size. For example, suppose that 1.5MW turbines receive the premium tariff for the first 2,000 hours of operation, while 1.65MW turbines receive the same payment for the first 1,800 hours. If a 1.5MW turbine generates X/kWh of electricity and a 1.65MW turbine with the same rotor generates only X+1% kWh, the EEG makes the economics of the high-efficiency 1.5MW turbine better because the paid hours of operation are longer. Thus, the new law was formulated to reward the real efficiency improvement rather than the improvement of turbine size on paper; more efficient turbines and better installations can receive higher monetary rewards, and this also makes the power grid receive higher energy yield at the same time (Gerdes 2005).

Technology Development as a Result of Market Demands at the Frontier

Turbine Upscaling

As described above, the needs to increase project profitability, the strong land development competition with other uses, and the increasing needs to cope with low wind conditions created the strong demand for larger-capacity turbines, especially in the German market, which has been the driver of turbine upscaling. The demand has been so strong that the competition for larger-capacity turbines is extremely high in Germany, and this explains why the turbine depreciation rates were higher in Germany than in Denmark for onshore wind development. The recent saturation of onshore development areas in both Denmark and Germany have been a driver for the development of multi-MW class turbines tailored for offshore environments.

Larger wind turbines with taller hub-height and larger rotor swept areas can increase electricity production due to the increase of wind energy capture. They also use materials more efficiently, therefore reduce turbine cost, and lessen the visual impacts and save installation and O&M costs due to the reduction of the number of installations.

Trend toward Variable Speed

The Danish Classical Concept succeeded in the 1980s and dominated the market until the late 1990s because of its simplicity and cost efficiency by using readily available components to produce grid-compatible electricity inexpensively without any sophisticated controls. However, variable speed operations have gradually gained its popularity for the past ten years, because they take care of many market demands mentioned above and because the cost efficient technology options for variable speed configurations have become available due to various innovations.

Suitability of variable speed operations for many market demands described above is obvious. First and foremost, variable speed turbines can achieve higher energy capture than fixed speed counterparts and increase electricity production due to their greater rotor efficiency. Second, by lowering the rotor speeds, they reduce noise in lower wind and reduce dynamic loads on drivetrain which reduce the possibility of component failure and replacement. Third, synchronous power converter or power electronics that conditions the output from variable speed turbines to the grid-compatible electricity takes care of the grid stability demand by improving power quality. Fourth, variable speed turbines also offer the great improvement in operation in low wind speed for the turbines designed for high wind regimes. And lastly, wide-range variable speed turbines have the ability to avoid damaging resonance, which is important for offshore turbines where resonant frequencies have proven difficult to predict accurately. This matches the increasing offshore market demand well. One drawback is the cost increase due to the necessary power electronics (approximately a 10% increase in total investment costs). However, energy capture also increases at onshore sites about 10% per year over that of the similar capacity turbines operating at fixed speeds (Gipe 1995). Such characteristics satisfy the real efficiency improvement demanded by the EEG as well.

Variable speed concepts were already widely used since the 1980s by the German manufacturers, e.g., MBB, MAN and Enercon. Enercon began manufacturing pitch-regulated, variable speed turbines with geared drive from 1985. However, it was the mid 1990s that the suitability to various market demands described above and the increased market size did drive the successful commercialization of variable speed turbines. First, it was Enercon that introduced wide-range variable speed turbines with direct-drive WRSG in 1993. As for limited speed range operations, Vestas OptiSlip® with 10% of speed variation using variable rotor resistance was introduced in 1995 and the first DFIG configuration with a limited speed range was commercialized by Tacke in 1996. The latter concept has been followed by many other manufacturers from the late 1990s and has become dominant in the market today. The number of successful commercialization of the models with wide-range variable speed operations that maximize the benefits of variable speed operation has increased in the 2000s, e.g., Bonus/ Siemens (2.3MW-VS in 2003 and 3.6MW-VS in 2004), GE Wind (GE 2.3, 2.5, and 2.7 in 2004), and Multibrid® technology, due to the cost reduction of power electronics and the increased demands for offshore development that have made the use of expensive power electronics viable.

Trend toward Pitch Control

Like variable speed operations, pitch regulation matches several market demands at the frontier. In principle, pitch regulation provides better power quality, which is very important for the German market, than stall regulation. Especially in the German market, large turbines favor independent pitch mechanisms with each pitch actuator that allows the rotor to be regarded as two independent braking systems, which is an advantage for the turbine certification purpose (European Commission 1999; European Wind Energy Association 2003). Pitch regulation gained its popularity due to its suitability with variable speed technique.

The early favor for stall regulation gradually faded, as variable speed configurations and pitch regulation have become increasingly used together. Cost was not a primary driver of the choice between pitch and stall, because overall cost becomes similar as pitch is more expensive in rotor system than stall, while stall requires more expensive braking system (European Wind Energy Association 2003). Instead, the driver for pitch regulation was the quality of power provided in combination with variable speed operations; variable speed operations give easy control of pitch angle and pitch regulation provides better power quality and lower drivetrain loads. Fixed-speed, pitch-regulated turbines were an early favorite, but they have been rejected due to large transients in power output when controlling the power. In the mid 1990s some manufacturers used stall regulation in variable speed turbines. However, concerns over the power quality of stall-regulated turbines, especially in Germany, and concerns over stall-induced vibrations for large-capacity turbines reduced the interests in stall regulation at large-scale machines (European Commission 1999). In addition, rotor blades of large-capacity, pitch-regulated, variable speed turbines had very few problems, compared to either stall-regulated turbines or pitch-regulated, fixed-speed turbines (Wind Power Monthly 1995).

At low wind velocity, pitch-regulated blades have a large surface against wind, and this surface decreases gradually as wind velocity increases, in order to capture the optimum energy, reduce load on the blades, and elongate the blade lifespan. Active stall regulation also offers better control than stall, but their application is limited to fixed-speed turbines; as a result, its popularity has also faded as variable speed turbines have become dominant.

Innovations to Compensate Problems coming with Large-capacity Turbines

Larger wind turbines have several significant downsides, including the increase in mechanical problems and cost, as well as the difficulty of transportation, logistics, and construction, all due to the increased size and weight of components.

Mechanical Problems with Large-capacity turbines

The strong demand for larger-capacity turbines has been an innovation driver for solving mechanical problems associated with them. For older turbines (smaller, heavier, and sturdy turbines) that had safety factor of 1.5 to 2.0, technical management requirements were actually low because high stress could be coped with the heavily-built turbine mass itself. Weight per rated capacity (kg/kW) was large. However, safety factor becomes lower as turbines get larger; larger-capacity turbines have design safety factors of 1.1 to 1.2. This means that they need to be designed close to the safety limit, which requires more precisely-designed machine load calculation as well as lower stress on the turbines. These requirements are more expensive to materialize for turbines with large mass, and this has been a strong driver for lighter and lower stress turbines (Gerdes 2005). Variable speed operations are again a preferred solution due to the reduction of dynamic load stress on drivetrain.

Another significant innovation to solve this problem was direct drive configuration. Direct drive is only possible with wide-range variable speed operations. The cost of materials for direct drive turbines are 25% higher than geared, induction generator turbines (Madsen 2005), but restriction on the minimum speed can reduce the cost of power electronics. Enercon succeeded in reducing various mechanical problems with its direct drive system and restrained nacelle weight design (Gerdes 2005). Although direct drive generator is heavier than conventional one, the firm's innovative nacelle design made the weight equivalent to other pitch-regulated counterparts. In addition, direct drive also takes care of reducing noise level and eliminates energy loss in gearbox transmission.[81] These elements were the decisive factor of the Enercon's market success in Germany.

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[81] At rate power, transmission consumes 1 to 2% of the rotor's power per stage, but losses in the gearbox can become considerable at low power (Gipe, 1995).

More recent single-stage gearing Multibrid® technology innovation also avoids the complexity of multi-stage gearbox but offers lighter weight with more efficient and compact drivetrain than large direct drive generators. Besides direct drive and Multibrid®, various integrated and partially integrated drivetrain configurations and soft towers have been developed by all manufacturers in order to reduce weight and stress, hence, the mechanical problems associated with large-capacity turbines.

Rotor Blade Technology

The innovations in rotor blade technology have been another part of technology driven by the problems associated with larger-capacity turbines. The design parameters of rotor blade vary, according to rotor power regulation method, rotor speed, and size of rotor and turbine itself. Small- and medium-capacity, fixed-speed turbines with stall or active stall regulation require relatively heavy and rigid blade designs. This changed since the mid 1990s; MW and multi-MW class turbines, many with pitch-regulated variable speed operations, require longer blades and light and stiff blade design. In particular for the newer generations of MW-class turbine blades, blade stiffness has been the key driver, because they have to be dimensioned for the maximum permissible blade deflection (flexion under load) in order to guarantee the minimum tower clearance by the blade tip (De Vries 2004a).

- **Lighter and Stiffer Materials***:* Blade materials can change rotor weight and rotor cost significantly. Lighter and stiffer blades materials reduce blade loads, avoid strain, and reduce rotor weight and cost. Commercialization and popularity of GFRE material since the mid 1990s was mainly due to its capability to create more slender and lightweight blades, along with its easier quality control and the resulting lower variation in material properties than GFRP. The epoxy resin system originally developed for GFRE also prompted the use of wood as light weight materials. Wood-epoxy laminates have become used for some large rotor blades due to its relative ease of disposal and light weight. The beginning of carbon use in blades in the early 2000s was prompted by its capability to substantially increase stiffness without increasing weight.
- **Increase in Aerodynamic Efficiency and Decreasing Cost**: The above materials innovation and improvement coupled with novel manufacturing technology as well as development of special-purpose blade aerofoil designs have successfully restrained the increase of blade mass under a cubic power of radius for many blades (Veers et al. 2003), while substantially improving aerodynamic efficiency of blades.[82] More efficient blade aerofoil that converts more wind energy into rotational energy has contributed to reducing aerodynamic noise level as well.

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[82] In 2004 the newest rotor blade by Enercon achieved aerodynamic efficiency of 56% (Cp=0.56), which is 6% above the state of the art and only 3.3% below the theoretical Betz limit (Renewable Energy World 2004). The aerodynamic efficiency of the process that a turbine rot or extracts the power of wind and converts into mechanical-rotational power in the rotor shaft is known as the power coefficient C_p, defined as the ratio of extracted shaft power to the undisturbed wind power across an area equal to the rotor disc area. The theoretical limit of the power coefficient is known as the Betz limit, first formulated in 1919 by the German physicist Albert Betz. According to Betz, the maximum theoretical achievable power that can be extracted from the wind by horizontal axis turbines is $P_{Betz} = 1/2\rho AV^3 \cdot c_d$, where $c_d = (16\pi/27 \times 8) \approx 0.593$. Thus, even if a power extraction without any losses would be possible, a wind turbine can utilize only about 59.3% of wind power.

Transportation and Logistical Innovations

Transportation and logistical innovations described in Chapter 5 were also the direct result of the demands for larger-capacity turbine development.

Meeting Environmental Demands

In addition to variable speed turbines that lower noise level in low wind, general noise reduction technology, including direct drive technology and more efficient blade aerofoil, has advanced greatly due to the strong and consistent noise reduction demands.

The environmental demand concerning polyester as blade materials was another reason that prompted GFRE to rapidly gain the ground from the mid 1990s and its predominance in the 2000s. For larger blades, all established manufacturers switched from polyester to epoxy resin infusion some years ago, and all new manufacturers now use epoxy-resin-based systems. The development of vacuum infusion process for resin has made the resin more environmentally friendly by not exposing the surrounding to the materials, and provides considerable flexibility of choosing between materials and combinations than the pre-impregnated process. The method became widely used since the late 1990s.

Advancement of Wind Project Execution Technology

The market demand for increasing the amount of electricity generation has created a technology driver for improving the understanding of site-specific wind regime and the skills in micro-siting. This driver was responsible for the advancement of various wind resource estimation/energy prediction and optimization modeling as well as project design and planning software.

Advancement of SCADA

The advancement of SCADA has been driven by the market demands for power quality control and offshore development. Better remote monitoring capability to prevent accidents in the offshore environments as well as strong controllability demanded by utilities for large onshore and offshore wind farms have prompted the SCADA innovations in preventive remote monitoring, remote reporting using the Internet interface, grid interface management, and wind farm controlling.

Increase in Energy Yield

The advancements in aerodynamics and structural dynamics as well as micro-meteorology have contributed to a 5% annual increase in energy yield per squire meter wind turbine rotor area, which was recorded in Denmark between 1980-2001 (Danish Wind Industry Association 2003).

Cost Reduction of Wind Energy as a Result of Technology Advancement and Experiences

The above technology advancements created the significant cost reduction in both wind electricity production and price of turbines at the frontier. Between 1980 and 2000, the annual energy yield increased 10-fold, and it multiplied almost another 5-fold from 2000 to 2005 (BWE 2005). The price of wind energy was USD 0.1/kWh in the early 1980s, but it became USD 0.04 to 0.06/kWh by 2004 (BTM Consult ApS 2005b).

Experience Curve Studies

In order to find the sources of such cost reduction of wind energy, many experience curve studies have been carried out mainly in Europe since the late 1990s. The most prominent study was Experience Curves: a tool for energy policy programmes assessment (EXTOOL), funded partially by the EC. The purpose of EXTOOL was to analyze the experience curves as tool for energy policy program assessment, using wind power as case study. The analysis was done for Denmark, Germany, Spain, and Sweden, and the curves were constructed for different dependent variables (Table 6-3).

The EXTOOL results show higher learning ratios for Denmark than Germany in every category. More importantly, the cost reduction of wind generated electricity in both specific production and levelized production are large, while reduction in wind turbine price/kW, which describes cost of production, price of wind turbines, and total installation price, are quite modest. Dannemand Andersen (2004) notes that experience curves based on the cost of generated electricity are more true and fair than those based on the cost of equipment, because the curves based on the cost of generated electricity include not only experiences and learning of the manufacturing industry (experiences in equipment manufacturing) but also those of the whole business cluster (experiences in installations, improvement of efficiency, and disembodied utilization) (Dannermand Andersen 2004).

Table 6-3: Progress Ratios (PR) and Learning Ratios (LR) of EXTOOL Experience Curves for Denmark and Germany

Dependent Variables	Denmark (1981-2000)			Germany (1987-2000)		
	PR	LR	r^2	PR	LR	r^2
Produced Wind Turbine Price /kW	92%	8%	0.84	94%	6%	0.74
Specific production cost of electricity*	86%	14%	0.97	88%	12%	0.87
Levelized production cost of electricity**	83%	17%	0.97	----		
Installed Wind Turbine Price/kW	91%	9%	0.94	94%	6%	0.88
Total Installation Price/kW	90%	10%	0.92	----		

* calculated by dividing the average wind turbine list price by number of full load hours

** cost reduction of turbines (cost/kWh) calculated with 20 year life time, 6% interest rate with specific O&M cost for individual models

Source: (Neij et al. 2003)

Sources of Cost Reduction

Determining the sources of cost reduction in wind energy has been attempted by many, including the EXTOOL study. However, pinpointing the specific factors and their effects has been impossible as the experience curve studies look at the composite learning system as a whole, not necessarily the processes within the black box. The effects of size factors on turbine cost and on unit cost of electricity have been studied most among all sensitivity factors. The effects of scale factors include: standardization of product (mass production) and redesigning and upsizing of individual product (e.g., upscaling of a gas turbine leads to lower costs of specific component per turbine). The effects of technological learning factors include: innovations and learning-by-searching through Rⅅ learning-by-doing in manufacturing process; learning-by-interacting through the network interactions between research institutions, industry, end-users, policy makers, etc.; and learning-by-using in O&M process (Abell and Hammond 1979; Grubler 1998; Junginger, Faaij, and Turkenburg 2005).

Effects of Scale Factor on Cost Reduction

Higher cost reduction of wind generated electricity in both specific production and levelized production in the EXTOOL study and other studies done by Neij (1999a; 1999b) for wind turbines under 600kW show the effect of scale, specifically upscaling of wind turbine size and capacity, as a key driver behind the cost and price reductions as larger-capacity turbines improve wind capture (efficiency and availability) and decreased load on the turbines (Neij 1999b; Neij et al. 2003; Neij 1999a).[83]

Historically the upscaling of wind turbines has lead to the lower specific costs per kilowatt for turbines under 600kW. However, this trend seems diminishing for the turbine class above 600kW. The study done by Junginger, Faaij, and Turkenburg (2005) shows that the annual energy generation strongly varies within the turbine class above 600kW under the same wind regime condition, as rotor diameter and hub height vary significantly among turbines in the class. They show the potential of cost reduction of electricity by upscaling wind turbines seems to become less significant in comparison to the earlier achievements, as installation costs increase for larger-capacity turbines. This indicates the turbines in the 600kW-900kW range are not likely to extinct in near future as the turbines below 600kW did, since the 600kW-900kW class turbines have advantages in logistics and weak grid condition of developing countries (Junginger, Faaij, and Turkenburg 2005).

Another scale effect, size of wind project (wind farm) has a simpler relationship with unit cost of electricity: larger project has lower unit cost, as all transaction costs are spread over more kilowatt hours, and O&M costs become lower due to the efficiency of managing a larger wind farm (American Wind Energy Association (AWEA) 2002). The discount from manufacturers can be also a factor that lowers the unit cost.

The other scale effect, mass production, will be a significant factor for future cost reduction. Currently the order size of 500 turbines and above is still exceptional. A single order of 1,600 turbines can make a single production plant to operate for several years, and create many advantages such as bargaining power in raw material purchase agreements. Labor costs have been substantially reduced from seven to two employees per MW over the period between 1991 and 2001 of a major turbine manufacturer (Junginger, Faaij, and Turkenburg 2005). The further reduction depends on improvement of production process and location of production facilities.

Other Sources of Cost Reduction

Although the scale factors, in particular turbine upscaling, have greatly impacted the cost reduction of wind energy technology, a number of other factors are considered to cause the cost reduction in wind turbine and electricity generation. Despite the large impact of scale factors, the effects of technological learning (learning-by-searching, learning-by-doing, learning-by-interacting, and learning-by-using), in particular the Danish grassroots networks and R&DD programs that were connected well to the commercial market since the late 1970s, should not be

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[83] Neij studied the penetration of wind turbines with increasing size in the Danish market and each dominant turbine type was replaced by several newer and larger-capacity turbine classes, which had lower turbine costs per kW than the previous ones and a higher yield per unit of swept area, only 2 or 3 years later. (Junginger, Faaij, and Turkenburg 2005) showed this was also true for the German market.

dismissed as the sources of cost reduction in the country. This has given the first mover advantage to the Danish industry and may have induced the higher learning ratios of Denmark than Germany over the past 20 years. Much higher learning ratios in cost of generated electricity than cost of equipment also support the importance of learning factors in the whole business cluster.

6.1.3 Section Summary

Role and Effects of Policy and Institutional Factors on Demand-pull Technology Development and Diffusion at the Frontier

From the above examination, it is very clear that technology at the frontier has been advanced by faithfully following and satisfying various market demands. While policy/institutional sensitivity factors of wind energy project investment mechanism (revenue sources, fiscal measures, cost of financing, purchase agreements) worked favorably to expand market size in Denmark and Germany, technology-related sensitivity factors (investment costs, amount of electricity generated and sold, technical system lifetime, size effects of wind project/farm) directly worked on technology development in order to create the favorable conditions for power generation that can be independent from political uncertainty as much as possible.

Although the investment economics pressure played the most significant role in creating technology efficiency demands, various policies along with the enthusiasm toward wind energy also played important roles in creating the market demands that pulled technology development in Denmark and Germany. In both countries, the strength of the market derives from the participation and support from a broad range of private citizens. Various concerns over wind energy development occurred time to time, but both countries have cleared the way step by step by establishing necessary spatial planning/noise/ownership regulations, fighting the NIMBY phenomenon, and strengthening the local and national supports.

While providing the investment incentives that eased high initial capital investment costs, their gradual retreat and the concentration toward production incentives, in particular, the establishment of guaranteed payments for wind electricity by law increased the motivation for performance efficiency. Although the market experienced some fluctuations when the investment incentives became less attractive, the market prospect was continuous and strong with the laws. The turbine testing and certification requirement from the beginning for eligibility for bank loans, investment subsides, and export as well as the ownership regulations eliminated the abuse of government incentives, especially in Denmark. The success of the Danish quality assurance mechanism created a de facto European and then international standards.

Strong competition with other types of investments also required the seriousness in investment, contributing to restraining the abuse of government incentives and increasing the demands for performance efficiency. In Denmark, the 1996 opening of wind investment to farmers made wind investment more sensitive to profitability. In Germany, the wind turbine zoning and noise regulations put more pressure on land development competition and have pushed the turbine efficiency demands further, together with the new EEG feed-in-tariff setting mechanism.

The emerged market demands under these policy factors and investment economic pressures have created a significant synergy that strongly pulled the direction of technology innovations toward efficiency improvement, leading tremendous wind turbine upscaling in size and capacity, inducing the popularity of pitch-regulated, variable-speed turbines, advancing technology in rotor blade materials/profile/manufacturing methods as well as project execution and SCADA technologies.

Above all, the market continuity and certainty guaranteed by the feed-in laws have played the most significant roles in concerting the whole technology development process by assuring investment recovery for both market and technology investors.

Thus, virtuous cycle of market growth and technology development has been created at the frontier, and the cycle also brought the tremendous cost reduction through scale effect of wind turbine upscaling.

Role and Effects of Technology-push Policy on Demand-pull Technology Development and Diffusion

While market development and investment policy have played the important roles in shaping the technology improvement demands, pragmatic technology development and investment policy has contributed to the materialization of many technologies. The demand-pull synergy has been well supported by technology-push R&DD efforts at both national and the EU levels. It is important to note that in the process the role of Europe and the role of the national governments in R&DD were distinguished well but created an important synergy together; while the European efforts concentrated on the grand scheme of turbine upscaling technology development, the national governments supported basic science, commercialization as well as technology analysis of various components/subsystems and technology system.

JOULE Program– WEGA II and THERMIE

The key contribution of the Europe-wide JOULE program to the development and commercialization of wind energy technology during the 1990s, especially the successful turbine upscaling to MW-class turbines in the mid 1990s, is the most obvious one. Without the program supports, the commercialization of MW-class turbines and many technology development triggered by their commercialization did not happened as it did. The success of the WEGA II Program was partly due to the failed experiments of WEGA I. While many individual developed countries abandoned wind energy R&D for large-capacity wind turbines by the end of the 1980s, Europe as a whole did not give up and concentrated the resources for further advancement. The clear focus on the accumulated experiences by commercially successful technologies and manufacturers was the important factor for the success of the second program.

National Government R&DD Programs

Both the Danish and German R&DD programs were targeted to basic science, commercialization as well as technology analysis of components and system. The German R&DD program also contributed to statistical data accumulation through WEMP. In both countries, many funding has been granted to the collaborative efforts among research institutions and manufacturers and to a wide-range of value chain R&D activities.

Section 6.2: Transformed Technological Characteristics and Industrial Competitiveness Management and Their Effects on Technology Development and Diffusion in Denmark and Germany

The previous section examines the effects of market size and demands on technology innovations at the frontier. This section analyzes the relationships of industry structure and competitive strategies with technology innovations and transformed technological characteristics at the frontier.

6.2.1 Technology Development, Strategic Demands, and Evolution of Industrial Competitiveness Management at the Frontier

Technology Development and Strategic Demands

The strong market demands for constant technology upscaling and efficiency improvement have changed wind energy into high-tech technology since 1990 and created the high technology depreciation rates, forcing the manufacturers to introduce newer models to the market every two or three years at the frontier. This condition has generated the constant high level of competition among manufacturers and placed two significant strategic management demands on them: technological advantage management and cost advantage management.

Strategic Demands for Simultaneous Technology and Cost Management

As described in Chapter 5, wind energy technology innovations have been highly systemic. At the same time, the competitiveness of manufacturers is increasingly relying on the high-tech nature of pacing technologies and components as well as manufacturing methods, which are very much science-based, e.g., computer and materials sciences and technology. With the increased importance of science-based technology within the technology system, technological complexity and system integration needs have also increased across the value chain activities.

To materialize the constant technological advancements across the value chain activities portrayed in Chapter 5, the industry has spent a large amount of development cost. In particular, the role of manufacturers have increased since 1990, as the R&D at the frontier has focused more on incremental innovations and turbine upscaling based on market experiences. Tables 6-4 and 6-5 show the development cost figures for Vestas and Nordex since the late 1990s, respectively. Although the industry-wide figures for technology development cost could not be obtained, the figures for both the firms can illustrate the condition, in which they were placed. Because the Danish business accounting method changed in 2001 for Vestas and because the figures for Nordex before the 2000/01 fiscal year only show the development cost of the German subsidiary (Nordex Energy GmbH) of the Danish Nordex A/S at the time, it is not possible to compare the figures over the years straightforwardly for both. However, it is very clear that both the firms needed to meet the demands to raise technology development fund that increased exponentially every year. Both the firms also show the strong growth of development cost after 2000, which corresponds to the introduction of new generation of multi-MW class turbines.

Table 6-4: Development Cost of Vestas Wind Systems A/S (Million EUR)

	1998	1999	2000	2001	2002	2003	2004	2005
Cost	4.4*	7.7*	N/A	16.0 (old)** 21.0 (new)**	26.8	37.0	50.0	72.7
Growth Rate	---	175%	---	---	127%	138%	135%	145%
% in Turnover	1.17%	1.21%	N/A	1.64%	1.92%	2.24%	1.95%	2.03%

* 1998 and 1999 figures are calculated by exchange rate 1 EUR = 7.4243 DKK (12/31/2002 rate). Development costs of 1998 and 1999 were DKK 33 million and DKK 57 million, respectively.

** From 2001 accounting, the accounting policies applied have been changed as a consequence of the new Danish Financial Statements Act. Development costs are recognized in intangible assets and are measured at cost less accumulated amortization, which is calculated on a straight-line basis over 3-5 years, following the completion of the development work. Previously, development costs were recognized in the income statement on a current basis.

Sources: (Vestas Wind Systems A/S 1999; Vestas Wind Systems A/S 2000; Vestas Wind Systems A/S 2001; Vestas Wind Systems A/S 2002a; Vestas Wind Systems A/S 2003; Vestas Wind Systems A/S 2004; Vestas Wind Systems A/S 2005)

Table 6-5: Development Cost of Nordex AG (Million EUR)

	1997/ 1998	1998/ 1999	1999/ 2000	2000/ 2001	2001/ 2002	2002/ 2003	2003/ 2004	2005
Cost*	1.06	2.50	4.04	6.78	14.80	19.71	20.91	11.27
Growth Rate	---	236%	162%	168%	218%	133%	106%	---
% in Turnover	1.28%	1.11%	1.48%	1.96%	3.32%	9.16%	9.56%	3.53%

* Figures are before amortization. Development cost is written down over a period of five years. They are for the German fiscal year (October 1 – September 30) except 2005. The 2005 figure is for the calendar year.

Sources: (Nordex AG 2001a; Nordex AG 2001b; Nordex AG 2002a; Nordex AG 2003b; Nordex AG 2004)

This evolution of development cost illustrates the increasing demand and pressure of R&D finance and capability management on manufacturers, i.e., finding market demands and technology focus across the entire value chain activities in advance, procuring the necessary fund for R&D, creating a strategic R&D plan, bringing all required capability and capacity into the plan, and executing the plan successfully on time. Even after the R&D is successfully carried out, production and project execution capacity and capability need to be adjusted to bring the results of the R&D into the market fruitfully.

While technology has to be constantly innovated, the price of technology cannot be increased exponentially in order to keep the competitiveness. The cost reduction market demand has been very strong at the frontier, and the manufacturers have been exposed to it in every aspect of the value chain activities. While the turbine upscaling itself has significantly contributed to the cost reduction of electricity production as already mentioned in the previous section, other cost reductions derive from technology innovations and advancements in both production and project execution technology management. Thus, the increasing technology development demand has fortified the cost management demand simultaneously.

Cost management is indeed technology management of procuring necessary capacity and capability for innovation, production and project execution in the least expensive ways. Therefore, the question of asking from where and whom the procurement should be carried out is very important in finding and establishing competitive advantages. The demands for this simultaneous cost and technology management have increased, as the wind energy market has expanded geographically, the market size has increased, and technological complexity and reliance on high-tech components have intensified.

Competitiveness Strategy Evolution for Simultaneous Technology and Cost Management

Various strategies have been employed to manage the simultaneous technological and cost competitive advantages in the wind energy industry and this part explores the evolution of such strategies.

Business Entry Strategy and Technology and Cost Management

Several methods of business entry have been used in the wind industry at the frontier.

During the 1970s to the early 1990s, the most popular entry method was organic business diversification within a corporation from its mechanical or aerospace business branch into wind business. While most of the Danish manufacturers (Vestas, Bonus, Nordtank, Danish Wind Technology) started by diversifying from agricultural or mechanical machinery business, the early large entrants in the United States and Germany (Boeing, GE, Westinghouse, MAN, and MBB) diversified from their aerospace business via the government R&D contracts for large-scale wind turbine development. In Germany, some small manufacturers also took this mode of entry: Tacke grew out of a long-established gearbox manufacturer; HSW diversified from a ship building; and Fuhrländer started from metal processing.

Meanwhile, there were other manufacturers that started from scratch or spilled over from other firms by the engineers with wind energy academic and/or practical backgrounds. The most notable example was the entry by Enercon in 1984, which was founded a graduate engineer Aloys Wöbben, while the establishment of Micon in Denmark in 1983 was a spillover from Nordtank. Other German examples of this entry mode include Südwind in the early 1990s, DeWind in 1995, BWU in 1996, and Jacobs in 1992. The last two later transformed into REpower in 2001.

However, the popular entry mode has changed in the late 1990s into business diversification of major industrial player with extensive capital and vast regional and global network into the growing wind energy business. These firms usually take over the established but often financially struggling wind turbine manufacturers, absorbing their technological know-how but providing necessary future capital needs on return. This was the cases of the following: BDAG and the subsequent Babcock-Borsig AG takeover of Nordex; Enron takeover of bankrupted Tacke and Zond; GE acquisition of the renewable energy division of collapsed Enron; and most recently, Siemens AG purchase of technologically acclaimed Bonus. It is important to note that the business entry or re-entry of these large conglomerates in the 1990s and 2000s is different from the business diversification of large firms during the 1980s. The conglomerates are no longer the primary providers of technology to the wind turbine manufacturing industry, but they are now the takers of the accumulated knowledge of experienced smaller firms.

The changing mode of business entry strategy is the reflection of wind energy technology evolution. In the beginning, the cost of wind energy technology development was low, especially for smaller commercial turbines and for the firms with mechanical, electrical, and aerospace engineering backgrounds, because technology was drawn from the experiences of other industries. Over the years, however, the accumulation of knowledge through experiences began posing formidable entry barriers for even large conglomerates, which contemplate the business entry to the now well-established and lower-risk wind energy industry. Wind energy technology has become unique, original, and costly to develop. The recent large conglomerate takeovers of privately owned manufacturers substantiate the increasing complexity of financial management of the constant technology development demands.

Organizational Growth Strategy and Technology and Cost Management

The most wind turbine manufacturers combine two or three different organizational growth strategies for simultaneous technology and cost management.

First, the public listing of company stocks started during the mid 1990s, becoming a method of acquiring the necessary capital for continuous technology development. It started in the United States with the public listing of Kenetech in 1994. Soon, the major manufacturers in Denmark, which were founded and owned privately by family business or a small number of business owners, began stock floating (Nordtank in 1995; NEG Micon in 1998; and Vestas in 1998). In Germany, Nordex (Germany) initiated the public listing in 2001, followed by REpower in 2002. The Spanish giant Gamesa also began listed on the stock exchange in 2000. The most recent example was Suzlon of India in 2005. Siemens Wind and GE Wind are a part of publicly owned conglomerates. Today, Enercon remains the only major manufacturer wholly owned privately by a single owner.

While the public listing has been used to raise the necessary capital for technology management, the manufacturers have combined technology development on their own (organic growth) and technology acquisition through horizontal and vertical M&A.

Pure organic growth strategies have been taken by several major manufacturers. Enercon is the most notable and successful firm that has taken this strategy. The firm has never engaged in horizontal M&A; it organically grew by establishing in-house manufacturing and R&D facilities for rotor blade (1993), ring generators (1993), electrical engineering (1993), and tower (2000) and by expanding those facilities gradually, both in size and location. Bonus was another example of taking organic growth strategy. Unlike Enercon, however, it never expanded into in-house component production extensively (except rotor blade production from 2001), and geographically the firm mainly focused on the Danish, German and other European markets. The firm never engaged in horizontal or vertical M&A, until it was bought by Siemens at the end of 2004. Many other manufacturers have taken partial organic expansion strategies (expanding not all but some in-house business or production units without M&A) as their business grew.

The global industry structure and competition have changed dramatically for the past 15 years through business entries, exits, and horizontal M&A. Figure 6-4 shows the structural change due to horizontal M&A happened between 1990 and 2005 at the frontier.

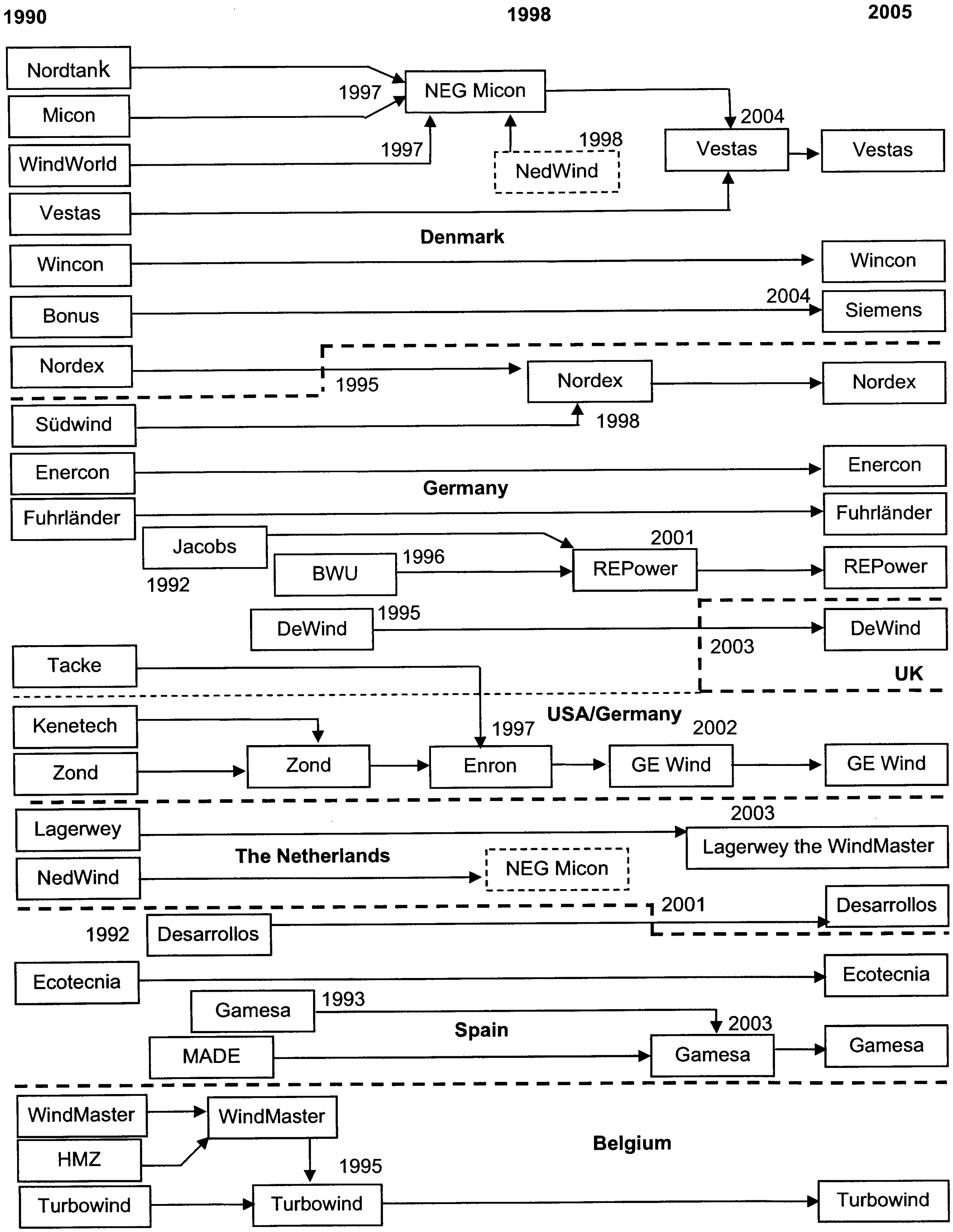

Figure 6-4: Horizontal M&A of Major Manufacturers 1990-2005 at the Frontier

Horizontal M&A occurred both domestically and cross-border. Most major manufacturers except Enercon were involved in some kind of M&A activities, and the industry consolidation occurred in all countries. Horizontal M&A has become an important growth and survival strategy for some manufacturers, in particular, from the mid 1990s. All exited firms have been acquired by other manufacturers; firm acquisition has been an important mode of entry as well as a mode of established technology acquisition. The acquired technology and know-how is always transferred to new owners.[84]

There have been several patterns in horizontal M&A. The first one is to combine and consolidate technology and know-how of the companies at similar level and reorganize them as a new company. This was the pattern for: Nordtank (Denmark) and Micon (Denmark) combined into NEG Micon (Denmark) in 1997; Jacobs, BWU, and pro + pro engineering (all Germany) transforming into REpower (Germany) in 2001; and Vestas (Denmark) and NEG Micon (Denmark) merger in 2004. The second and most prevalent pattern is to take over the technological know-how of financially weakened fellow manufacturers. This was the case for: Kenetech (USA) acquiring US Windpower (USA) in 1994; Turbowinds (Belgium) taking over Windmaster-HMZ (Belgium) in 1995; Zond (USA) acquiring Kenetech (USA) in 1996; NEG Micon (Denmark) taking over WindWorld (Denmark) in 1997; NEG Micon (Denmark) acquiring NedWind (the Netherlands) in 1998; Nordex (Denmark-Germany) taking over Südwind (Germany) in 1999; and Gamesa (Spain) acquiring MADE (Spain) in 2003. The third pattern is to protect against a hostile take-over from foreign capital or conglomerate, and this was another reason behind the Vestas and NEG Micon merger in 2004. The last pattern is the strategy of the firms with larger capital or engineering conglomerates to acquire the specialized technological know-how of wind energy for business entry: BDAG and Babcock-Borsig AG (Germany, Nordex), Enron (USA, Tacke and Zond), GE (USA, Enron in 2002), and Siemens (Germany, Bonus in 2004) took this method as already mentioned.

The Danish manufacturers have engaged also in vertical M&A in order to incorporate technological know-how of sub-suppliers and to ensure component supply and quality control. The most prominent examples of engaging in vertical M&A have been Vestas and NEG Micon (Table 6-6). Many sub-suppliers acquired by both the manufacturers had supplied components to them for long time and had already established good relationships. With their 2004 merger, Vestas directly and indirectly acquired component technologies from all these sub-suppliers, in addition to the accumulated knowledge of turbine development and manufacturing from DWT, Nordtank, Micon, NEG Micon, WindWorld, and Nedwind. The other notable example was the acquisition of the assets of Aeropec bV, a Dutch blade manufacturing firm that was established in 1989 and bankrupted in 2001, by Enron. Some employees of this firm started the production of moulds in a subsidiary of Suzlon in 2001.

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[84] There are two exceptions. Technologies of US Windpower and DeWind completely disappeared from the market after their acquisitions by other firms (Madsen, 2005).

Table 6-6: Vertical M&A of Vestas and NEG Micon

Acquired Technology	Vertical M&A and the Year			
	Vestas		NEG Micon	
Rotor Blade			1998	Taywood Aerolaminates (UK, wood epoxy)
Pitch Rotor Regulation	1989	Danish Wind Technology (DWT) A/S*		
Generator	2005	Weier Electric GmbH (half of the share)		
Casting	2003	Windcast Group A/S		
Tower	1994	Vølund Stalteknik A/S	1999	Alustål A/S
Electronics/Control Systems Hardware & Software	1999	Cotas Computer Technology A/S	1998	Dan Control Engineering A/S
Sales & Marketing			1998	Wind Energy Group (UK) under Taylor Woodrow Construction
Other			2003	Danvest Energy A/S (wind/diesel development)

* The merger was also horizontal as DWT was a turbine manufacturer itself that possessed larger-capacity turbine experience and more advanced pitch-regulated rotor technology (BTM Consult ApS 2005b).

Sources: Vestas and NEG Micon websites (www.vestas.dk) and (Madsen 2005)

In Germany, there has no significant vertical acquisition of suppliers by manufacturers, as Enercon has not engaged in such M&A. However, indirect vertical M&A happened when a conglomerate parent company engages in vertical M&A of wind component manufacturers: in 2005 Siemens AG, the parent company of Siemens Wind Power A/S, purchased Flender Holdiung GmbH, the long-term gearbox supplier for the wind industry, strengthening its holding in wind technology hardware market. Nordex established the electronics control unit in 1999 as a result of the Nordex takeover by Babcock-Borsig AG, which owned an electronics control system production company Babcock Prozessautomation that became a part of Nordex that year.

The latest large takeover of sub-suppliers by wind turbine manufacture comes from India; in March 2006, Suzlon acquired Hansen Transmissions International NV of Belgium, one of the largest wind turbine and industrial gearbox suppliers.

In general, however, vertical M&A of sub-suppliers has never been a general trend (Madsen 2005). Also horizontal M&A involves the issue of timing; the opportunities need to be presented simultaneously by financially-weaken manufacturer and enough capital to acquire it. Both horizontal and vertical M&A, however, have been an effective means of technology acquisition and management, because the acquired manufacturers and sub-suppliers immediately contribute to technology and know-how development and often to the expansion of production facilities. They save the cost of technology accumulation by bringing already existing knowledge bases and by increasing information flow under one roof.

Overall, the increasing public listing and the active horizontal and vertical M&A by larger manufacturers demonstrate that there have been intensifying technology competition and capital requirement from the 1990s behind them.

Value Chain Analysis of Strategies I (Innovation) - Establishment of Industry Level Innovation Collaborations and Networks for Technology and Cost Management

The constant needs for more science-based technology development, however, cannot be sustained by horizontal and vertical M&A and the isolated internal R&D of each manufacturer alone, even with the government R&D funding support. Many of core components of wind energy technology, e.g., blade technology and wind resource estimation/energy optimization technology, require basic scientific research before any commercialization attempts, and they are costly and difficult to achieve by individual manufacturers alone. In order to manage the serious and continuous requirements for those costly new R&D, the industry at the technology frontier have developed successful collaboration networks for knowledge creation and accumulation as well as for sharing of codified information in basic scientific areas.

International Innovation Network of Research Institutions and Manufacturers

In the area of blade technology development, of which distinctiveness creates competitive edges for each manufacturer, international innovation networks have been established since 1990 in order to advance and share basic research that is extremely capital intensive.

Blade aerofoil innovation networks, which develop specialized aerofoil for wind turbines, have been created in several developed countries. The initial detailed CFD modeling of aerodynamics of flow around wind turbine blades/rotors was carried out in Canada in the early 1990s (McGowan and Connors 2000). Then the further development of models have been carried out by the government research organizations and well-funded universities in Denmark, Sweden, the Netherlands and the United States, which have capacity and capability of using supercomputer for the CFD simulation. In the case of RISØ, the network has evolved as an informal one by researchers and industry professionals after an initial government attempt of bringing them together. The works have been continuous for the past 15 years, and the first specialized-blade aerofoil was developed during the mid and late 1990s (Hjuler Jensen 2005).

Blade materials innovation networks are far more extensive internationally. Raw materials of epoxy and fiber plastic can be developed by only three or four companies globally, because dealing with these raw materials require extremely high level of laboratory control, therefore only large manufacturers and materials suppliers can handle the requirement. Then, these materials are brought to the international network of wind turbine materials science R&D. This is the network composed of European research institutions and universities (from Denmark, the Netherlands, and others) and American companies and universities (NREL and the Sandia National Lab that contract with US universities). In the network, blade materials are tailored for wind turbine usage through close collaborations with the R&D branch of various blade manufacturers. Both CFRP and GFRE were developed through this mechanism (Hjuler Jensen 2005).

In terms of blade materials behaviors, the European Fatigue of Composite for Wind Turbines (FACT) database and the US DOE/MSU (Montana State University) database have led to the major advancements in the understanding of fatigue behaviors and testing program development for fiberglass composites since 1990. In the early 2000s, the deficiencies of these databases have led to the establishment of a new EC-funded program Optimatblades, which is composed of ten R&D institutions, two certification authorities and six industrial partners within Europe. The examination of carbon fiber composites is now underway by this program network (McGowan and Connors 2000; Veers et al. 2003).

In addition to these innovation networks, the IEA Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind) founded in 1974 sponsors cooperative research tasks and provides a forum for international discussion of R&D issues. 20 OECD member countries and the EC participated in the agreement (IEA 2006).

It is important to note that these networks are international but not global, as their core existence is highly concentrated in certain developed countries. In addition, in these kinds of mechanisms, national competitiveness and competencies are no longer the issues (Hjuler Jensen 2005). The primary concern is the advancement of the industry itself through cost and knowledge sharing in the area of capital intensive, basic science R&D. In this way, a level playing field is created for all manufacturers and the basic scientific knowledge is shared by every member of the industry. Then, it is up to each manufacturer to tailor the knowledge into its own unique product lines and create competitive advantages.

Manufacturer-Sub-supplier Collaborations

The relationships between manufacturers and component suppliers have greatly changed in the 1990s and 2000s. The standard component suppliers of the 1980s have evolved into the trusted partners for many turbine manufacturers in innovating technology and devising cost effective solutions across the value chain activities. Technology development and production collaborations between manufacturers and sub-suppliers increased significantly since 1990, as wind energy technology has been transformed into highly integrated system technology of many specifically designed, high-tech components.

In blade technology, collaborations between manufacturers and sub-suppliers are frequently behind the creation of successful commercialization of unique products out of the shared basic scientific knowledge created by the international networks described above. The world market leader of the blade industry, LM Glasfiber A/S of Denmark, has engaged in more intensive collaboration with NEG Micon, Nordex and REpower for development of new blades for their specific models since 2000. Abeking & Rasmussen Rotec of Germany has also developed the specialized blades for DeWind and REpower and manufactured the prototype of the Enercon winglet blades before the series production moved to the in-house production unit of Enercon. Other blade suppliers such as NOI Rotortechnik and EUROS (both Germany) have developed and manufactured specialized blades for models of their customer as well. Through these joint developments, sub-suppliers offer manufacturers not only customized blades suited to specific products but also know-how of optimization for series production (De Vries 2004a), and such collaborations have increased since the 1990s and become very common in the 2000s. Strong connections among choices of turbine size, blade aerofoil, blade materials, and manufacturing methods make the development of rotor blade extremely systemic, and this is the important reason behind the intense collaborations between manufacturers and sub-suppliers at the stage of commercialization.

Logistics innovation is another area of strong manufacturer-sub-supplier collaboration, as mentioned in Chapter 5. All specialized transportation and logistics solutions in terms of special equipment design and transportation of MW- and multi-MW class turbines have been devised by such collaborations.

Besides the above two areas, the development of many other outsourced components have been the results of technology collaborations between manufacturers and sub-suppliers. Joint development collaborations with sub-suppliers offer the manufacturers less expensive options of technology management, more of technological options, and short-term production flexibility, although the risks of losing technology control and technology leaking remain. Strong trust between the two sides is crucial and that is why such collaborations are typically built on the established long-term relationships between two sides.

Industry Network for Information and Knowledge Sharing

Besides the formal innovation network arrangements described above, there have been more informal industry networks that have contributed to technology development from the beginning.

This tradition has been particularly strong in Denmark, as described in Chapter 4. The grassroots and industry networks (Table 6-7) have connected research institutions and manufacturers while bringing user perspectives at the same time. In Denmark, R&D collaborations among universities, research institutions such as RISØ, and the industry have been also very active, partly because the national R&D funding selection includes contribution/collaboration criteria. The inclusion of collaboration ideas in the application has been a plus for selection.

Table 6-7: Danish Innovation Networks

Organizations	Roles as Innovation Network
Organization for Renewable Energy (1975-)	Supplementing the formal government R&D programs with grassroots activities, enabling amateurs and professionals to meet each other and discuss ideas and experiences in construction of wind turbines
Wind Co-operatives (the late 1970s-) & Danish Wind Turbine Owners Association (DWTOA, 1978-)	Technology improvement by providing a list of all turbines and regular reports of performance and technical problems in the membership magazine, Naturlig Energi, and by making the manufacturers possible to learn from mistakes quickly and to keep turbines operated and maintained well
RISØ Turbine Certification/Approval Scheme (1978-)	Constant upgrading of turbine approval scheme has allowed the close relationship between the research community and type approval experts allows the state of the art technology to be incorporated in the products.
EMD Grassroots Innovation Network	Annual and bi-annual meetings of activists, researchers, engineers, other experts, users, manufacturers for knowledge exchange for EMD software product development
Research Consortium for Offshore Development (2002-)	RISØ formed a consortium with the Technical University of Denmark (aero-elastic design), Aalborg University (electrical design), and Danish Hydraulic Institutes in order to improve network and coordination between education, research and industry (IEA 2004)

In Germany too, the WMEP Statistics under the 100MW/250MW Wind Program (1989-2006) created market transparency by publishing the statistics through Institut für Solare Energieversorgungstechnik (ISET) for all turbines installed under the Program and provided the database for machine reliability, failures, and verification of wind climate assessment (Krohn 1998) for further technology development. In addition, the federal government has successfully managed coordinating the R&DD programs spread out over various government agencies and diverse R&D network participants, including research institutions such as ISET and DEWI, academia, turbine manufacturers, component suppliers, and testing institutions such as Germanischer Lloyd.

Thus, the wise utilization of industry networks for innovations has added the significant strength to the frontier players while tremendously saving the costs by sharing.

Value Chain Analysis of Strategies II (Marketing and Sales) – Market Expansion Strategy and Technology and Cost Management

Market expansion is another important technology and cost management strategy, because the expansion of market share enhances the capital base for future R&D by increasing turnover as well as quickly recovers the R&D investments already made.

Table 6-8: Export Share (%) of Major Manufacturers

	1996	1997	1998	2001	2002	2003	2004
Vestas (Denmark)	74.0	66.0	77.1	96.9	83.4	98.6	99.9
NEG Micon (Denmark)	---	47.4	65.5	93.9	83.9	98.6	
Micon (Denmark)	44.8						
Nordtank (Denmark)	82.9						
WindWorld (Denmark)	62.1	73.6	83.8				
Bonus (Denmark)	80.3	85.1	81.1	100	85.5	69.2	98.8
Nordex (Denmark, Germany from 2001)	94.7	87.1	98.6	39.9	43.7	47.3	52.2
Enercon (Germany)	11.8	10.5	21.3	26.9	17.3	31.2	34.9
DeWind (Germany, UK from 2003)				3.2	7.8	100	100
REpower (Germany)				0.5	0.7	2.6	32.2
GE (USA)	---	---	---	---	90.4	41.9	75.8
Enron (USA)	---	---	4.5	51.4			
Tacke (Germany)	10.8	8.4					
Kenetech/Zond (USA)	100	58.9					
Gamesa (Spain)	0.0	0.0	0.0	3.8	1.8	11.4	12.5
MADE (Spain)	0.0	0.0	6.9	0.0	5.0	4.0	
Suzlon (India)	0.0	0.0	0.0	0.0	0.0	13.0	0.0
Average*	55.5	45.9	44.4	59.9	51.9	55.8	60.5

*The figures were calculated by BTM Consult ApS as the average of all top 13 or 14 manufacturers of the years. They are not the average of manufacturers on the above lists.

Sources: (BTM Consult ApS 1997; BTM Consult ApS 1998a; BTM Consult ApS 1999; BTM Consult ApS 2002; BTM Consult ApS 2003; BTM Consult ApS 2004; BTM Consult ApS 2005a)

First, horizontal M&A has been used as market expansion strategy. In fact, the most significant reason behind horizontal M&A is getting the market share of the acquired manufacturers although technology acquisition is another important reason (Madsen 2005). Second, oversea expansion is another crucial market expansion strategy, especially for the Danish manufacturers, whose dependence on export has increased since 2001 due to the domestic market reduction. However, the export figures are increasing for the German and Spanish firms as well in recent years (Table 6-8). There has been a clear indication of increasing cross-border activities since 2000. The market locations spread over European countries as well as Asia, North and South America.

Industry oversea expansion follows the markets. The Danish manufacturers have most extensively diversified their market in order to reduce political risks of concentrating in a small number of markets, not to repeat the bitter experience of the California boom and bust of the 1980s. Two strategies have been taken for oversea market expansion by the frontier manufacturers: establishing a 100% subsidiary through FDI and engaging in joint ventures/license agreements with local companies.

Establishing subsidiary is the most prevailing method of oversea market expansion (Table 6-9). The expansion to the European and North American markets has been mainly achieved through this strategy. Most manufacturers have taken joint ventures with local firms or granting license agreement to local firms as exceptional cases. Joint ventures/license agreements are found mostly in Asian countries, namely India, China, and Japan. All the three countries have somewhat different backgrounds that triggered such arrangements. In India, local production was critical for cost reduction in the beginning of the market expansion during the early 1990s. GOI also encouraged joint ventures for technology indigenization by restricting building manufacturing facilities by foreign firms without the collaboration of local firms and created the favorable foreign investment environment by reducing taxes on FI and granting easier approval for foreign venture. In China, the government requires high degree of local contents in total value of wind energy projects and this has triggered joint ventures/license agreements. Lastly in Japan, the manufacturers grant license agreement to well-established dealers because the Japanese market has been too small for setting up and keeping subsidiaries.

In some cases, the manufacturers expand their activities through joint ventures/license agreement initially, but terminate the agreements to withdraw from the market or to replace the local presence with subsidiaries. This is the case for Vestas that bought all shares of its Italian joint venture with Italian Wind Technology in 2000 and made the firm a 100% subsidiary. Vestas also terminated the technology transfer agreement based on joint venture with Gamesa Eólica of Spain in 2003, two years earlier than the original agreement,[85] and replaced it with a sales office. Immediately after the termination, however, Gamesa has become a formidable competitor for Vestas by using the significant knowledge accumulated during the agreement. Vestas could not gain the access to the Spanish market until 2004, when it began using the established NEG Micon channel that became available by the merger between the two. In India, all entries by foreign manufacturers during the early and mid 1990s were through joint ventures/license agreements, many of which were terminated in the late 1990s.

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[85] The termination was due to the conflict over the two company strategies. One conflict was over Vestas being a supplier only, while Gamesa served as developer. In addition, Gamesa's internationalization strategy from 2001 created geographical conflicts; the agreement with Vestas limited Gamesa markets only in Iberian Peninsula and some Latin American countries (Vestas Wind Systems A/S. 2004/2005).

Table 6-9: Geographical Distribution of Joint Ventures/License Agreement/ Subsidiaries/Foreign Branch Offices

Manufacturers (HQs Location)	**Subsidiaries/Foreign Branch Offices**	**Joint Ventures/ License Agreement**
Vestas (Denmark)	**USA** (1983-1986, 1992-), **Germany** (1989-), **Sweden** (1992-), **Spain** (2003-), **The Netherlands** (1995-), **China** (1999-), **France** (2002-), **Poland** (2003-), **Italy** (2000-)	**India** (Vestas RRB 1987-), Spain (Gamesa Eólica,1994-2003), Italy (IWT 1998-2000), **Japan** (2000-),
Gamesa Eólica (Spain)	**Germany** (2003-), **Argentine, Australia** (2003-), **Brazil, France** (2001-), **Greece** (2000-), **Italy** (2000-), **Mexico, Poland, Portugal** (1998-), **Dominican Republic, UK** (2003-), **USA**	**India** (Pioneer Asia 2005-)
Enercon (Germany)	**Greece** (1995-), **Portugal** (1995-), **Italy** (1999-), **Brazil** (1996-), **Spain, Sweden, UK, Turkey, Denmark, Austria, Egypt, Canada**	**India** (Enercon India, 1994-), **Japan** (Hitachi 1997-), **Australia** (WindCo)
Bonus* (Denmark)	**Spain, Italy, Ireland, UK, USA, Norway, The Netherlands, Japan, Greece**	**Germany** (AN 1989-), India (REPL, 1995-1997)
Suzlon (India/Denmark)	**USA, China, Australia** (2005-)	
REPower (Germany)	**France** (2001-), **Australia** (2002-), **Canada** (2002-), **Greece** (2003-), **UK** (2003-), **Spain, Portugal, Italy**	**Japan** (Meiden 2002-), **China** (Goldwind/Zheijang Windey)
Nordex (Germany)	**France, UK, USA, Spain, Austria, Greece, Brazil, Turkey, Italy, Sweden, China**	**India** (BHEL 1993-1999/2003-), **China** (Xi'an Nordex), **Croatia** (AAM), **Egypt** (Ament-Emad Taymour), **Japan** (IHI)

The list is basically the locations of sales/marketing/service activities and wind project developers that have direct connection with manufacturers. As for GE, while it does not list particular wind energy offices, it is considered the network is extensive considering its global reach of the conglomerate.
* as of November 30, 2004

Sources: Company websites

Establishing foreign subsidiaries is preferred, because it enables simpler technology control and management. As the Vestas and Gamesa case illustrates, joint ventures can expose technology providers to more risks of loss of proprietary knowledge control.

Value Chain Analysis of Strategies III (Innovation and Production) - Geographical Management of Capacity and Capability Procurement and Technology and Cost Management

Expanding geographical boundary of technological capacity and capability procurement through internationalization is one important method of technology and cost management. Several authoritative data sources such as DEWI and BTM Consult ApS have reported the increasing difficulty of keeping the track of cross-border activities or assigning the origin of wind turbine manufacturers to a single country. The export figures do not necessarily illustrate the actual cross-border sales as many turbine manufacturers favor local production outside their base country. Because of these reasons, locations of innovation/production/sub-suppliers are a good indicator of the degree of internationalization of firm activities.

Locations for Innovation

Table 6-10 shows geographical locations of innovation activities for major manufacturers. It is clear that they are concentrated in Europe, especially in Denmark and Germany, where the best industry experiences and knowledge are available and are the home countries of most of the major manufacturers. Even Suzlon, an independent Indian manufacturer, places its core R&D facilities in Germany and the Netherlands, not in India. Thus, the degree of internationalization of innovation activities is quite low.

Table 6-10: Geographical Distribution of R&D Facilities

Manufacturers	**R&D Locations** (Established Year)
Vestas	**Denmark** (1979-),
NEG Micon	**Denmark** (Nordtank 1979-), **UK/England** (1998-)
Enercon	**Germany** (1984-), **India** (2004-)
GE Wind	**Germany** (Tacke 1990-), **USA**
Bonus/Siemens	**Denmark** (1981-)
Gamesa Eólica	**Spain, Denmark**
REPower	**Germany** (BWU 1996-)
Nordex	**Germany**
Suzlon	**India** (1996-), **Germany** (Nacelle 1999-), **The Netherlands** (Blade 2001-)

Sources: Company websites

Locations for Production

In terms of production facility location, the degree of internationalization varies greatly among manufacturers (Table 6-11).

Table 6-11: Geographical Distribution of Manufacturing Facilities

Manufacturers	**Production Locations (Established Year)**
Vestas	**Denmark** (1979-), **India** (Vestas RRB, 1987-), **Germany** (1987-), **Spain** (Gamesa Eólica,1994-2003, NEG Micon, 2004-), **Italy** (1998-), **UK/Scotland** (2002-), **Australia** (2003-), **Norway and Sweden** (Acquisition of Windcast 2003-), China (planned, 2006-), Acquired **NEG Micon Facilities** (2004-)
NEG Micon*	**Denmark** (Nordtank 1979-), **India** (NEPC Micon 1987-1996, NEG Micon 1996-), **Spain** (1993-), **The Netherlands** (Acquisition of Nedwind 1998-), **UK/England** (1998-)
Enercon	**Germany** (1984-), **India** (Enercon India 1994-), **Brazil** (1996-), **Sweden** (2000-), **Turkey** (2002-), **Spain** (2003-), **Portugal** (2005-)
GE Wind* **	**Germany** (Tacke, 1990-), **USA**, **India** (2002-), Spain, The Netherlands
Bonus/Siemens	**Denmark** (1981-) **Germany** (AN Windenergie, 1989-)
Gamesa Eólica**	**Spain** (1995-), **India** (Pioneer Asia 2004-), **USA** (planned, 2006-)
REPower	**Germany** (Jacobs 1992, BWU, 1996-)
Nordex	Denmark (1985-2003), **Germany** (1992-), **China**
Suzlon	**India** (1996-)

* As of November 2003

** According to the Gamesa's web site, there are 21 manufacturing facilities as of 2004, but the exact locations could not be obtained.

*** Enron had production facilities in both Spain and the Netherlands. However, as of the end of 2005, these facilities seemed to be consolidated by GE.

Sources: Company websites

As far as looking at Vestas, NEG Micon, and Enercon, the internationalization of manufacturing is increasing throughout the late 1990s and the 2000s. Most manufacturers have built their production facilities in Europe and a few other locations such as India. The facilities are still largely concentrated in Europe, where both strong market and skilled labors are available. Only Enercon has manufacturing facilities in Brazil and Turkey that do not have much of its own market; the firm chose those locations primarily due to low manufacturing cost. Despite the repeated talks, most manufacturers have not put production facilities in the United States because of the strong market instability of the country. However, advanced technologies are exported to the United States.

Sub-Supplier Locations

As locations of manufacturing facilities and markets have expanded geographically, backward and forward linkages have extended accordingly. In terms of project execution, the locals are hired for turbine installation and service/maintenance activities as such skills are more generic and easily transferred than innovation and production skills, and the linkages are extended to both developed and developing countries.

In terms of production, backward linkages have also expanded to many locations, as shown in the Indian production capacity increase in Chapter 5. However, locations of major sub-suppliers are still highly concentrated in Europe, specifically in Denmark and Germany, according to the profile of major sub-suppliers in the World Market Update published every year by BTM Consult ApS (Table 6-12).

Table 6-12: Major Component Suppliers and their Country of Origin

Component	**Major Suppliers and their Country of Origin**
Rotor Blade	LM Glassfiber A/S (**Denmark**), Abeking & Rasmussen Rotec (**Germany**), Polymarin–Bolwell Composites (**the Netherlands**), NOI Rotortechnik (**Germany**), Tecsis (**Brasil**), EUROS (**Germany**), Umoe (**Norway**)
Gearbox	Jahnel Kestermann Getriebewerke Bochum GmbH (**Germany**), Hansen Transmission (**Belgium**), Winergy AG (**Germany**), Metso Drives Technology (**Finland**),
Generator	ABB (**Germany**), Elin (**Austria**), Siemens (**Germany**), Weier Elektrotrenwerk GmbH (**Germany**), Winergy AG (**Germany**)
Tower	KGW Schwerier Maschinenbau GmbH (**Germany**), Chemieanlagenbau Stassfurt AG (**Germany**), Omnical Borsig Energy GmbH (**Germany**), Pfleiderer AG (**Germany**), Bladt Industry A/S (**Denmark**), Valmont Wind Energy (**USA**), Erik Roug A/S (**Denmark**)
Bearing	FAG OEM and Handel AG (**Germany**), SKF (**Germany**)
Contorller/Control System	KK-electronic A/S (**Denmark**), MITA Teknik A/S (**Denmark**), Bachman electronic GmbH (**Austria**), DEIF (**Denmark**)
Grid Connection Systsem	Peter & Thiding (**Germany**)
Brakes	Svendborg Brakes A/S (**Denmark**)
Steel Componenets	Skoda Steel (**Czech Republic**), Welcon A/S (**Denmark**)

Sources: (BTM Consult ApS 2002; Danish Wind Industry Association 2005a; De Vries 2004a)

In particular, there are significant concentrations of sub-suppliers in Germany; the real strength of the German wind industry indeed comes from its extensive component industry. German component suppliers such as Siemens (generators) and FAG (bearing) have very large markets shares, close to 50% in the wind turbine manufacturing industry worldwide (Krohn 1998). Besides Germany, solid backward linkages in all major components across Europe are found, utilizing geographical proximity, regional political and economic integration movement, and technical abundances inside the region. For example, Denmark has strong domestic supply-chain networks in every component of wind turbine as well as planning, consulting, O&M and services, including Danish subsidiaries of large German component suppliers such as Siemens, ABB, SKF, and FAG (Danish Wind Industry Association 2005a). In Germany, although Enercon has the production sites in India, Brazil, Sweden, Spain, Turkey, and Portugal, the firm has an extensive supplier network in the home country alone; it had more than 150 component suppliers in Bavaria alone at the point of 2001 and more than 250 component suppliers in North Rhine-Westphalia at the point of 2005 (Enercon GmbH 2002c; Enercon GmbH 2005c).

Overall, the innovation and production facilities of manufacturers and their backward linkages are not evenly globalized but highly regionalized within Europe, although the degree of internationalization in terms of location of subsidiaries/joint ventures/sales and/or service offices has increased continuously. Despite the merits of lower production and transportation costs and the necessity of diversification of currency exchange rate risk through the internationalization of manufacturing, globalization of innovation and production capacity and capability management is limited. Most manufacturers have chosen their manufacturing locations based on the combination of market and availability of high level of human skills and experiences. The strong European regionalization is a result of the existence of strongest markets in the region and the high level of quality control that the markets demand. Without strong and stable market environments, the manufacturers are hesitant to build the facilities oversea as seen in the case of their reluctance over the US facility expansion.

In addition, the highly systemic nature of wind energy technology development strongly contributed to this phenomenon as well. When innovation is systemic, the decentralized approach to innovations poses serious strategic hazards because the innovation requires information sharing and coordinated adjustment throughout an entire product system (Chesbrough and Teece 1996). Highly systemic technological nature of wind energy makes modularization of technological knowledge across innovation-production value chain difficult. The increased importance of technology development collaborations between manufacturers and subs-suppliers, the close proximity to the international innovation networks, and the large and stable markets have thus contributed to the European regionalization of innovation and production capacity and capability management.

Value Chain Analysis of Strategies IV (Innovation and Production) - Strategy for Sourcing

Sourcing strategies are closely linked to geographical expansion of the markets, geographical capacity and capability management, and horizontal and vertical M&A. There are three main sourcing strategies: 1) in-house sourcing; 2) outsourcing, which often engages in the close collaboration in R&D and manufacturing with sub-suppliers; and 3) mixed sourcing (the combination of in-house sourcing and outsourcing). The choice of sourcing strategy depends on manufacturers and components.

Table 6-13 illustrates the increasing trend for in-house sourcing and vertical integration since 1990. The strong vertical integration orientation of Vestas and Enercon is most obvious. While Vestas achieved it through the combination of organic growth and horizontal and vertical M&A, Enercon has done it through pure organic growth. Gamesa is also clearly orientated toward the vertical integration according to the firm's statement (Gamesa Eólica 2006), although the detailed data regarding the sourcing of the firm was not obtained. Expansion of in-house sourcing capacity and capability has become an important strategy throughout the 1990s and 2000s, especially for larger manufacturers. The global market share of vertically integrated manufacturers has been increasing since 2000, as the above three companies and NEG Micon have been the top five in the global market share in recent years. The increasing vertical integration demonstrates that these manufacturers have shifted to more tightly-controlled technology development and management through keeping tacit and proprietary knowledge in-house.

Table 6-13: Component Sourcing Strategies of Manufacturers

Components	In-house Sourcing	Outsourcing
Rotor Blade	Bonus/Siemens (1998-), DeWind (R&D), Enercon (1993-), Gamesa, GE Wind (2001-), NEG Micon (1998-2004), Nordex (2000-), REpower (R&D), Suzlon (2001-), Vestas (1983-)	Bonus/Siemens, DeWind, GE Wind, NEG Micon, Nordex, REpower, Suzlon, Ecotecnia, Fuhrländer, Lagerwey the Windmaster
Gearbox	Vestas (partial, 2004-)	All manufacturers except Enercon (gearless)
Generator	Enercon (1993-)	All other manufacturers
Electrical Components	Enercon (1993-)	All other manufacturers
Electronics Hardware	Vestas (1999-), NEG Micon (1998-2004)	All other manufacturers
Control Systems Software	Nordex (2001-), Vestas (1999-) NEG Micon (1998-2004)	All other manufacturers
Steel & Die-Cast Components	Vestas (partially, 2003-)	All manufacturers
Tower	Enercon (2000-), Vestas (1994-), NEG Micon (1999-2004)	All other manufacturers
Data on in-house sourced components of Gamesa and GE were not obtained.		

Sources: Company websites, (De Vries 2004a)

The trend of increasing vertical integration is more obvious in core components. Manufacturers vertically integrate the components crucial for their competitiveness creation and tightly control their development and proprietary characteristics. The most notable example is rotor blade, a technology that truly creates the competitive edges for each manufacturer. The main driver of in-house sourcing of blade is not purely economic but to have full knowledge and control (Madsen 2005). At the point of 1997, only a few manufacturers produced their own blade in-house (European Commission 1999). However, total level of in-house sourcing of rotor blade has increased from approximately 35% in 1998 to 60% in 2002, because of the growing market shares of three firms Vestas, Enercon, and Gamesa, which source 100% of their rotor blade in-house (De Vries 2004a). Table 6-13 shows that many other manufacturers also developed in-house R&D and/or manufacturing capability in rotor blade.

As for other components, generator and electrical components are integrated by Enercon, of which competitiveness derives from its unique multi-pole synchronous ring generator and direct drive mechanism. Control software is another critical component for competitiveness creation and the manufacturers have strong willingness to vertically integrate it.

Vertical integration reduces the dependence on component sub-suppliers, while increasing flexibility of product development and maintaining high level of manufacturing know-how. However, no manufacturers have comprehensive in-house sourcing capability in all components; they still use outsourcing or mixed sourcing strategies for many components, including highly vertically integrated Vestas and Enercon. Even for rotor blade, those with in-house supply capability still have purchased many blades from independent suppliers (European Wind Energy Association 2003). Creating in-house blade innovation and production capability and capacity is more expensive in the beginning than later on. Vestas and Enercon are large enough to afford their own in-house sourcing.

For outsourced components, most manufacturers maintain two or more large suppliers with good international reputations for each component, in order to reduce the dependence on one supplier and to operate with comparatively low level of resources. This practice started by the Danish manufacturers from the late 1980s for their expansion to other European markets, in order not to repeat their bitter experiences of mechanical failures of many core components such as blades, generators, and gearboxes in the California market during the 1980s by depending only on one supplier.

In general, while larger manufacturers with larger capital base choose mixed sourcing with increasing in-house sourcing for core components, smaller manufacturers choose outsourcing strategy for all components. In either case, using off-the-shelf products by component suppliers has been greatly reduced and customization of products for different markets and different makes of turbines through in-house sourcing or close collaboration between sub-suppliers and turbine manufacturers has increased. In any cases, technology control by manufacturers has been tightened in sourcing strategy, while know-how sharing through sub-suppliers has contributed to cost reduction.

6.2.2 Relationship of Competitive Management Strategy with Technology Development Demands and Direct Role and Effects of Policy

Industry Stability - Change Adjustment Level and Degree of Change

The above examination reveals that competitive strategies for technology and cost management at the frontier have changed significantly since 1990 and the degree of change is high in every category of those strategies. Consequently, the industry structure and the nature of competition have greatly changed; the number of wind turbine manufacturers has been decreased but the competition among the survivors has been intensified for market expansion and technology development. While the dominance of larger manufacturers has increased, smaller manufacturers also survive by offering high-quality technology options and finding some niche in domestic and regional market.[86] The wind turbine manufacturers have adjusted to the constantly changing environment, but there were many casualties that exited from the business and were taken over by fellow manufacturers.

Adjustments and transformations happened not only at manufacturer level but also at sub-supplier level. Although vertical M&A has not been the general trend for most of component suppliers, the structure of rotor blade industry has changed greatly since 1990 as this component is specific to wind energy technology and receives the direct influences from the wind market movement and the strategic modifications of turbine manufacturers. While larger wind turbine manufacturers embarked on in-house blade R&D and manufacturing, numerous independent blade manufacturers exited from the business through bankruptcy or acquisition by other suppliers. Blade manufacturer exits in both the United States and the Netherlands have been especially noticeable, as the wind turbine industry of both countries declined over the years. The structural adjustment of rotor blade industry is clearly and closely connected to the transformation of wind turbine manufacturing industry. In Denmark and Germany, only three blade manufacturers established before 1990 (LM Glasfiber, Vestas, and Abeking & Rasmussen Rotec) have survived today.[87]

Transformed Business Entry and Growth Barriers and Industry Consolidation Logic

The industry structural change and the transformation of business entry and organizational growth strategy are due to the raised barriers for business entry and growth. In both Denmark and Germany, the governmental and institutional barriers for business entry and exit have been very low or non-existed. The barriers have been purely technological.

Technical entry and business growth barriers were low in the beginning for the wind turbine manufacturing industry, as technology and know-how could be easily brought from other industries. However, the height of technical cost of building and keeping business has become higher and higher, as the constant and intense technology upscaling and upgrading demands have shifted wind energy technological characteristics into more science-based and more systemic innovations. This also raised the height of capital requirement for business entry and growth. In addition, technical barriers of wind energy technology are cumulative. While the knowledge based on scientific R&D can be generated through the international and national research

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[86] For example, smaller manufacturers in Germany, e.g., REpower and Fuhrländer, are more willing to finish projects during the busy December season than larger manufacturers. The German market has seen strong demand since the implementation of the EEG, which reduces tariff payment for newly installed turbines every year. This has created robust demand to install turbines before December 31 every year in order to receive higher tariff payment. However, this is also the time that usually business slows down due to holidays. These newer and smaller firms serve this niche demand and have gotten chances to get on the market (Gerdes, 2005).

[87] The business exits include: Aeropec of the Netherlands in 2000; Rotorline B.V. of the Netherlands in 1999; Polymarin of the Netherlands in 2000; Aeroconstruct GmbH of Germany in 1994; Gougeon Brothers of the Unites States; Stork of the Netherlands; and, Peterson Products of the United States. The blade units of the wind turbine manufacturers also exited as their parent companies exited business. They are: Kenetech, Carter, Flowind, Fayette, Stormaster, Windtech, and Blue Max of USA; WEG and Howden of UK; Polenko and Bouma of the Netherlands; and, WindMaster of Belgium (Glenn, 2004).

networks, the required specialist knowledge and technical know-how to tailor such basic knowledge into successful commercial products are acquired only by long-term experiences and learning. Although the wind energy industry has successfully created equal access to the codified information of basic science, building the resources to utilize such information in-house presents significant barriers for business entry. The cumulative experiences, thus, are extremely important for wind energy technology innovation. Also, in the highly competitive environment of wind energy, the market and brand reputation for quality and performance also poses as cumulative entry barrier, which is only built through long-term, continuous high-level performance of the firms.

All these increased technical barriers with cumulative nature caused the shift of competitive strategy and consolidated the industry by eliminating the firms that could not keep up with the pace of technology development demands and raised growth barriers. Only the manufacturers, which could afford to keep up with the turbine upscaling/upgrading demands and create successful commercial products, cleared these raised business barriers and survived.

Direct and Indirect Role and Effects of Policy and Institutional Settings on Industry Structure and Competitiveness Management

Direct Role and Effects

In both Denmark and Germany, government policy and regulations on concentration of firms in industry and business entry and exit have been minimal, except that any M&A attempts need to be examined and approved by the EU. As a result, policy and regulations on industry concentration have had very little direct influence on the transformation of wind energy industry structure and competitive strategy for simultaneous technology and cost management.

As for direct influences of industrial policy, they have been seen not in Denmark but in Germany. First, the federal and some state governments offered the protections for local firms, and both Tacke and Enercon benefited from their local government supports for selling their turbines in preferable terms. Enercon was also saved from a potential bankruptcy by receiving financial help from the state of Neidersachsen in 1993, when it needed to replace 300 blades on the market as the state covered the loss (Twele 2005). Without the state rescue, the German industry might have not had any major manufacturers today. Second, the German federal government subsidies for building production plants in the former East Germany after the reunification of 1990 were wisely used by Enercon. This type of support was actually offered by the EU to the Danish manufacturers as well. As a result, all major turbine manufacturers used these subsidies to build production plants in Eastern Germany, e.g., Vestas established blade ring manufacturing facilities at north of Dresden and Enercon has expanded production plants all over Germany (Madsen 2005; Michaelowa 2004).

Indirect Role and Effects

On the other hand, there have been indirect but significant influences by policy and institutional settings on the industry structure and competitive strategy evolution at the frontier.

First, as examined in the previous section and this section, market development and investment policy in both Denmark and Germany have indirectly forced the manufacturers to adjust their competitive strategy for technology and cost management by creating the market that have strongly demanded the constant turbine upscaling and various technology upgrading. The change in market policy did also influence the industry structure more directly. The market slowdown of 1996 in Germany due to the sudden withdrawal of some regional and federal government subsidies contributed to the industry consolidation in the country, as smaller manufacturers and Tacke bankrupted and exited in the following years.

Second, technology development and investment policy supported the manufacturers and the industry as a whole, in the process of meeting the technology development demands created by the markets. In Denmark, the early R&D programs such as New Energies Technologies Program of the 1980s helped the manufacturers focus on commercial manufacturing of new energy technology and the industry development. The creation of the international and domestic innovation networks for basic science R&D was initiated and strongly supported by the individual government R&D programs. The EU-wide WEGA and THERMIE as well as the R&D for offshore turbine development by the individual national governments have helped sort competitive firms out of many manufacturers while supporting technology development. In addition, the turbine certification and approval schemes that have been constantly upgraded over the years have deterred the entry of low quality firms by working as institutional-technical barrier for business entry. They also have influenced geographical management of the industry capacity and capability building by containing the facility locations in the regions with higher capacity and capability. In addition, the certification and approval schemes gave tremendous advantages for the Danish manufacturers' oversea expansion by providing them technological guarantees.

Lastly, some cross-border technology transaction and investment policy have also helped manufacturer oversea expansion strategy, in particular in Denmark. The Danish manufacturers actively used the DANIDA tied-aid which requires 50% of the contract value to be Danish technology, for their oversea market expansion. However, the DANIDA supports have been reduced as the industry grew stronger and the assistance shifted its target to other areas in recent years. Meanwhile, the German manufacturers did not expand to oversea by using the government supports as much as their Danish counterparts did. The German TERNA program is neutral for the use of German technology and it has been characteristically similar to the RISØ WindConsult. As a result, the German manufacturers have not been vigorously involved in the TERNA projects. Besides those differences in the program characteristics, it also illustrates that the weaker oversea orientation of the German industry than the Danish industry.

As for export support, the German government had offered the El Dorado assistance to the manufacturers during the 1990s, targeting developing countries in other climate zones. El Dorado helped several small companies, which did not have the resources to pursue foreign markets on their own, survive in Germany. However, larger companies were breaking into these markets without the government finding (Wind Power Monthly 1997a), and there was a political doubt about the usefulness of the program, which was terminated after 1999. On the other hand, the Danish government has never had official export policy. However, the tax benefits for the Danish investors on wind project investment in the United States during the late 1980s and the Wind Turbine Guarantee Company, which warrants the long-term finance of large projects with Danish wind turbines outside Denmark, helped the Danish manufacturers expand to the market oversea.

6.2.3 Section Summary

Transformed Competitiveness Management due to Transformed Technological Characteristics

The constant technology upscaling/upgrading market demands and the resulted technological characteristics transformation since 1990 created the significant shifts in competitive strategy by the wind turbine manufacturing industry at the frontier.

The capital intensiveness of meeting the increasing demands for more science-based technology development has created the international innovation networks for basic science R&D, where all industry players can share the cost and codified information for industry-wide competitiveness development.

Meanwhile, each manufacturer has enthusiastically pursued its own unique competitiveness building and employed every means of competitive strategies from business entry, organizational growth, innovation network building, to geographical management of capacity and capability procurement and sourcing, in order to survive the fierce technology development competition. Public stock listing has become a means of raising the necessary R&D fund for many privately owned firms, and horizontal and vertical M&A are often used as business entry and organizational growth strategy to acquire technology and capacity and increase market share instantly. Oversea and domestic market expansion has been zealously pursued to increase the capital base for future R&D and recover the R&D investments already made. Whereas larger manufacturers have increased their vertical integration tendency for core components to control and accumulate tacit knowledge, mixed sourcing and outsourcing of component development through intense collaborations with sub-suppliers have also increased in general in order to accomplish cost reduction by know-how sharing through subs-suppliers while enhancing technological options and flexibility of manufacturers. Although project execution has extended over a large part of the world as the market expands, production of high value components and innovation are not truly globalized but carefully managed in the contained region of Europe, where the access to the international innovation networks, high level of capacity and human resource capability, and the collaborations with subs-suppliers are easily available. Increasingly more systemic nature of wind energy technology and tighter control of proprietary knowledge have prevented innovation and production capability and capacity management from being globalized over extended geographical areas.

In the process of this technology-industry co-evolution at the frontier, technical barriers for business entry and growth have become increasingly cumulative and the firms that could not keep up with the pace of technology development demands and the rising growth barriers were eliminated, consolidating the industry, while technology and cost management has been tightened by the surviving manufacturers.

Role and Effects of Policy and Institutional Settings on Supply-Push Technology Development and Diffusion at the Frontier

While the direct role and effects of policy and institutional settings on industry structure have been rather limited in both Denmark and Germany, market development and investment policy, technology development and investment policy as well as policy on cross-border technology transaction and investment have had indirect but significant effects on technology development and diffusion at the frontier through modifying the industry structure and competitive strategies.

The most important effects were the constant technology upscaling and upgrading market demands supported by market development and investment policy in both Denmark and Germany. This was the driving force behind the rapid and intense competitiveness management strategy modification to push technology-supply at the frontier.

Technology development and investment policy, in particular the R&DD programs offered by both the EU and the individual governments, has been very important technology supply-push by creating a synergy with the market demand characteristics, as mentioned in the previous section. Besides these direct technology development supports, however, technology development and investment policy also have played important roles in assisting technology supply by nurturing the industry indirectly, through the initiation of various network creations, the R&D programs that assisted the selection of competitive firms, and the turbine certification and approval schemes that have worked as institutional-technical barrier for business entry of lower quality firms as well as the technological guarantees for oversea expansion.

As for industrial policy and cross-border technology transaction and investment policy, the effects on technology development and diffusion have been different between Denmark and Germany. While no direct and formal industrial and export policy has been provided in Denmark over the years, the DANIDA tied-aid, the tax benefits for the Danish investors on the US wind project investments during the late 1980s, and the Wind Turbine Guarantee Company helped the oversea expansion by the Danish manufacturers greatly in the earlier years, advancing their technology supply capacity and capability. On the other hand, the German policy supports for oversea expansion did not have significant effects on the industry, while the industrial policy was more explicitly used at local level for manufacturer survival during the 1980s and 1990s. In general, however, industrial and cross-border technology transaction and investment policy has lost the significance as supply-push measures over the years, as the industry in both countries has grown strong enough not to require any protective measures.

Section 6.3: Quantitative Analysis of Market Development and New Wind Turbine Introduction in India

From this section, the research focus shifts to India, examining technology development and diffusion in India through cross-border technology transfer from Indian perspectives. First, this section quantitatively examines and establishes the relationship between new turbine introduction to India and market development of the country.

6.3.1 Observations of Indicators

Indicators

Market Indicator

As an indicator of market development, this research has been using installed capacity of wind turbine. One reason is that capacity development is proportional to the amount of market investments. Using installed capacity as market indicator is also the general practice in other wind energy related research. Therefore, installed capacity is going to be used as market indicator continuously.

Technology Transfer/Diffusion Indicator

As examined in Chapter 5 and the previous sections in this chapter, newer technology in wind energy system has been developed through turbine upscaling and mostly introduced to the market through new turbine models. Therefore, the number of new turbine introduction to the market is going to be used as technology transfer/diffusion indicator.

Observations

Table 6-14: New Turbine Introduction and Annually Installed Capacity in India

Year	Number of New Turbine Introduction	Capacity (MW)
1992-93	2	15.575
1993-94	5	57.44
1994-95	11	256.515
1995-96	16	385.04
1996-97	2	155.905
1997-98	1	70.536
1998-99	0	42.33
1999-2000	1	132.915
2000-01	4	180.89
2001-02	4	285.135
2002-03	2	239.785
2003-04	1	594.05
2004-05	6	1103.86
Total	55	3519.976

Source: Interpolated from installation data in (Consolidated Energy Consultants Ltd. 2005)

Table 6-14 shows the number of new turbine introduction to the Indian market and annually installed capacity. Correlation between the two indicators in the entire period is only 0.274720807; the two indicators do not have a strong relationship.

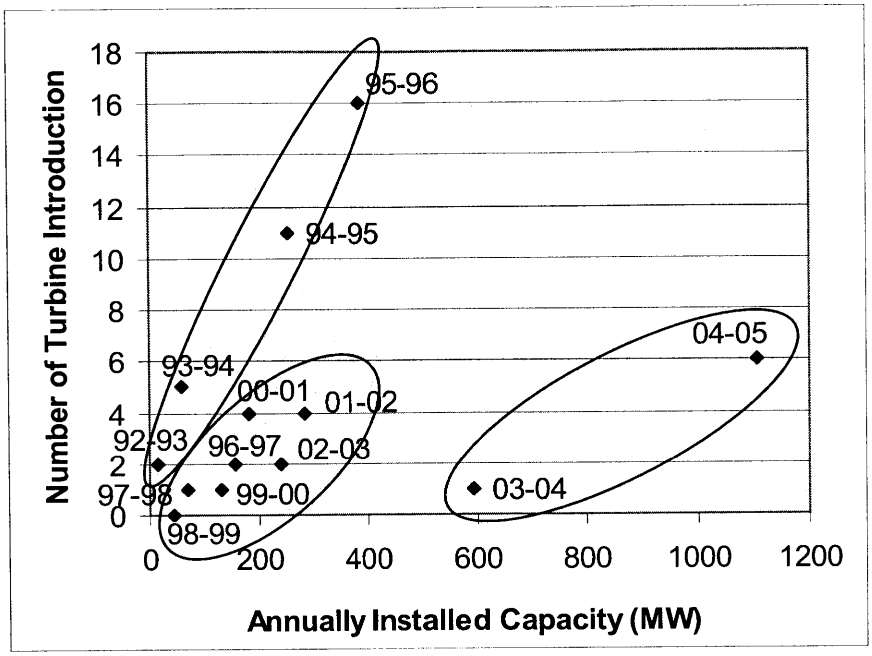


Figure 6-5: Plot of New Turbine Introduction and Annually Installed Capacity in India and Three Possible Structural Groups

Figure 6-5 is a plot of the indicators. At a glance, the two indicators do not show any strong relationships, as the correlation between the two indicated. However, a close observation of the plot reveals that there may be three different structural relationships according to the timeline: 1) between the 1992-93 year and the 1995-96 year; 2) between the 1996-97 year and the 2002-03 year; and 3) from the 2003-04 year. Correlation between the two indicators of the first period is 0.994699009 and that of the second period is 0.810936694. Because there are only two observation points in the third period, their correlation is 1. These correlations indicate the possibility of the existence of different structural relationships.

6.3.2 Econometric Analysis

The above statistical observations reveal that relationships do exist between the two indicators but it is not appropriate to assume one relationship is continuous through the entire timeframe of the observations. This part tries to establish the relationships by employing switching regression model method, using dummy variables (Pindyck and Rubinfeld 1998).

Regression Models with Two Structural Breaks

Figure 6-5 shows two possible structural break points: the 1996-97 year and the 2003-04 year. In order to establish three different structural relationships between the two indicators in the research timeframe, three regression models are constructed and tested. The three models are: 1) regression model from the 1992-93 year to the 2004-05 year with an assumption of no structural break; 2) regression model from the 1992-93 year to the 2002-03 year with structural break at the 1996-97 year; and 3) regression model from the 1996-97 year to the 2004-05 year with structural break at the 2003-04 year. In the latter two models, the variance of the error term is assumed to be the same throughout the time period being studied, but both the intercept and the slop may change at the point of structural break (Pindyck and Rubinfeld 1998)

Regression Model with No Structural Break

The following regression is estimated by using ordinary least squares (OLS).

$$TNUMBER = c + \beta_1 * CAPACITY + \varepsilon \qquad \text{(Equation 1)}$$

Where:

$\beta_1 > 0$
TNUMBER: Number of New Turbine Introduction
CAPACITY: Annually Installed Capacity

The OLS regression result produced the following equation with t-statistics values in the parenthesis.

$$\begin{aligned} TNUMBER &= \underset{(1.75)}{3.082} + \underset{(0.95)}{0.004} * CAPACITY \\ R^2 &= 0.08 \end{aligned}$$

The calculated regression coefficient (R^2) was only 0.08. The t-statistics value indicates that the variable CAPACITY to be statistically insignificant at the 5% level. In this model, the impact of installed capacity on the number of new turbine introduction seems to be fairly low.

Regression Model from the 1992-93 Year to the 2002-03 Year with Structural Break at the 1996-97 Year

The following regression using dummy variables was estimated by using OLS for the period between the 1992-93 year and the 2002-03 year. Both the intercept and the slop are assumed to be changed at the point of structural break.

$$TNUMBER = c + \beta_1 * CAPACITY + \beta_2 * D_1 * CAPACITY + \beta_3 * D_1 + \varepsilon \qquad \text{(Equation 2)}$$

Where:

$\beta_1 > 0, \beta_2 < 0, \beta_3 < 0$
TNUMBER: Number of New Turbine Introduction
CAPACITY: Annually Installed Capacity
$D_1 =$ 0 before structural break (from the 1992-93 year to the 1995-96 year)
1 otherwise (from the 1996-97 year to the 2002-03 year)

The OLS regression produced the following equation with t-statistics values in the parenthesis.

$$\begin{array}{lllll} TNUMBER = & 2.091 & + 0.0359*CAPACITY & - 0.0216*D_1*CAPACITY & - 2.353*D_1 \\ & (2.896) & (11.592) & (-4.027) & (-2.221) \end{array}$$

$R^2 = 0.98$
$F = 89.969$

The calculated regression coefficient (R^2) of 0.98 shows the high explanatory power of the model. The t-statistics values indicate that each of the estimated coefficients is significant at the 5% level in absolute value, except the t-statistics for D_1, which is slightly lower than the critical value of 2.262. Since the significance of the effects of dummy variable D_1 could not be verified statistically, the initial regression model was adjusted as follows by excluding D_1. The adjusted model assumes only the slop was changed at the point of structural break.

$$TNUMBER = c + \beta_1 * CAPACITY + \beta_2 * D_1*CAPACITY + \varepsilon \qquad \text{(Equation 3)}$$

Where:

$\beta_1 > 0, \beta_2 < 0$
TNUMBER: Number of New Turbine Introduction
CAPACITY: Annually Installed Capacity
$D_1 =$ 0 before structural break (from the 1992-93 year to the 1995-96 year)
1 otherwise (from the 1996-97 year to the 2002-03 year)

The regression produced the following equation with t-statistics values in the parenthesis.

$$\begin{array}{llll} TNUMBER = & -0.999 & + 0.0395*CAPACITY & - 0.0315*D_1*CAPACITY \\ & (1.548) & (12.238) & (-8.736) \end{array}$$

$R^2 = 0.96$
$F = 88.830$

The calculated regression coefficients (R^2) of 0.96 shows that the capacity variable helps explain 96% of the variation in the number of new turbine introduction. Each of the estimated coefficients is significant at the 5% level in absolute value.

In order to test the hypothesis of structural change, the F-test (Chow test) is performed. The large F-statistics value (88.830) allows rejecting the null hypothesis that the regression models before and after the 1996-97 year are identical. It is safe to conclude that there was a structural change in the 1996-97 year.

Regression Model from the 1996-97 Year to the 2004-05 Year with Structural Break at the 2003-04 Year

The following third regression model using dummy variables was estimated by using OLS for the period between the 1996-97 year and the 2004-05 year. Both the intercept and the slop are assumed to be changed at the point of structural break.

$$\text{TNUMBER} = c + \beta_1 * \text{CAPACITY} + \beta_2 * D_2 * \text{CAPACITY} + \beta_3 * D_2 + \varepsilon \qquad \text{(Equation 4)}$$

Where:

$\beta_1 > 0, \beta_2 < 0, \beta_3 < 0$
TNUMBER: Number of New Turbine Introduction
CAPACITY: Annually Installed Capacity
$D_2 =$ 0 before structural break (from the 1996-97 year to the 2004-05 year)
1 otherwise (from the 2003-04 year to the 2004-05 year)

The OLS regression produced the following equation with t-statistics values in the parenthesis.

$$\begin{array}{lllll} \text{TNUMBER} = & -0.262 & + 0.0143*\text{CAPACITY} & - 0.0045*D_2*\text{CAPACITY} & - 4.564*D_2 \\ & (-0.320) & (3.099) & (-0.839) & (-1.795) \\ R^2 = 0.84 & & & & \\ F = 89.969 & & & & \end{array}$$

Although the calculated regression coefficient (R^2) of 0.84 shows the high explanatory power of the variables, only the t-statistics of the estimated coefficient for the variable CAPACITY shows statistical significance at the 5% level in absolute value. The F-statistics value (8.764) is smaller than the critical value at the 5% significance ($F_{3,3} = 9.28$). The null hypothesis that the regression models before and after the 2003-04 year are identical cannot be rejected. A regression model without D_2 intercept dummy variable did not produce statistically significant results either. The second structural break could not be verified statistically.

Regression Models with Two Structural Breaks

The above examination could not verify the second structural break. A small number of the observations (two) after the possible second breaking point are considered as the reason. In order to prove the hypothesis of the second structural breaking point in the 2003-04 year, more observations have to be made and a new regression model needs to be constructed and tested by including those future observations. However, the first structural break was clearly established statistically if the research period is limited to the one until the 2002-03 year.

Regression Models with One Structural Break

Considering the above results, this part tries to establish two, not three, structural relationships between the two indicators in the research timeframe; a new regression model is constructed and tested. The new model is the regression model from the 1992-93 year to the 2004-05 year with only one structural break at the 1996-97 year. The following regression using dummy variables was estimated by using OLS for the period between the 1992-93 year and the 2004-05 year. Both the intercept and the slope are assumed to be changed at the point of structural break.

$$\text{TNUMBER} = c + \beta_1 * \text{CAPACITY} + \beta_2 * D_3 * \text{CAPACITY} + \beta_3 * D_3 + \varepsilon \qquad \text{(Equation 5)}$$

Where:

$\beta_1 > 0, \beta_2 < 0, \beta_3 < 0$
TNUMBER: Number of New Turbine Introduction
CAPACITY: Annually Installed Capacity
$D_3 =$ 0 before structural break (from the 1992-93 year to the 1995-96 year)
1 otherwise (from the 1996-97 year to the 2004-05 year)

The OLS regression produced the following equation with t-statistics values in the parenthesis.

$$\begin{array}{l} \text{TNUMBER} = \underset{(1.920)}{2.091} + \underset{(7.683)}{0.0359} * \text{CAPACITY} - \underset{(-6.545)}{0.0320} * D_3 * \text{CAPACITY} - \underset{(-0.754)}{0.9575} * D_3 \\ R^2 = 0.93 \\ F = 39.886 \end{array}$$

The calculated regression coefficients (R^2) of 0.93 means that the variable CAPACITY helps explain 93% of the variation in the number of new turbine introduction. The t-statistics for D_3 is lower than the critical value of 2.262 at 5% significance level in absolute value. Since the significance of the effects of dummy variable D_3 could not be verified statistically, the initial regression model was adjusted as follows by excluding D_3. The adjusted model assumes only the slop was changed at the point of structural break.

$$\text{TNUMBER} = c + \beta_1 * \text{CAPACITY} + \beta_2 * D_3 * \text{CAPACITY} + \varepsilon \qquad \text{(Equation 6)}$$

Where:

$\beta_1 > 0, \beta_2 < 0$
TNUMBER: Number of New Turbine Introduction
CAPACITY: Annually Installed Capacity
$D_4 =$ 0 before structural break (from the 1992-93 year to the 1995-96 year)
1 otherwise (from the 1996-97 year to the 2004-05 year)

The regression produced the following equation with t-statistics values in the parenthesis.

$$\begin{array}{l} \text{TNUMBER} = \underset{(2.532)}{1.386} + \underset{(11.091)}{0.0382} * \text{CAPACITY} - \underset{(-10.691)}{0.0347} * D_3 * \text{CAPACITY} \\ R^2 = 0.93 \\ F = 69.227 \end{array}$$

The calculated regression coefficient (R^2) of 0.93 shows the high explanatory power of the model. The t-statistics values indicate that each of the estimated coefficients is significant at the 5% level in absolute value. The large F-statistics value (69.227) allows rejecting the null hypothesis that the regression models before and after the 1996-97 year are identical. It is safe to conclude that there was a structural break in the 1996-97 year.

Structural Break and its Effects

The above examination verifies that there was a structural break in the 1996-97 year for the relationship between the number of new turbine introduction and installed capacity. This is true for both the cases with and without the 2003-04 year and the 2004-05 year. Before and after the structural break, the relationship was changed as follows:

For the entire period of the research timeframe (between the 1992-93 year and the 2004-05 year)

Before the structural break: TNUMBER = 1.386 + 0.0382*CAPACITY
After the structural break: TNUMBER = 1.386 + 0.0035*CAPACITY

For the period between the 1992-93 year and the 2002-03 year

Before the structural break: TNUMBER = -0.999 + 0.0395*CAPACITY
After the structural break: TNUMBER = -0.999 + 0.0080* CAPACITY

The above results show the existence of the structural break in the 1996-97 year. In both the cases, the intercepts were not changed before and after the break, but the slopes became much gentler, suggesting that more capacity installation has become required in order to introduce new wind turbine models to the Indian market.

6.3.3 Section Summary

The examination of this section succeeded in establishing the quantitative relationships between installed capacity (capacity development) and new turbine introduction. Capacity development has a very strong relationship with new turbine/technology introduction in India, and the structural relationship between the two changed after the 1996-97 year.

There may be many reasons behind this structural change. This type of structural transformation itself is not either necessarily harmful or something should be avoided, because capacity development is not only indicating the investments made, hence used as market indicator, but also closely related to the size of models used in projects. To a certain degree, as the wind turbine upscaling progresses, the shift to the structure that the same number of turbine installations brings more capacity naturally happens, as medium- and large-capacity wind turbines became dominant since the mid 1990s at the frontier when the Indian structural change happened. If this is the only reason, the line that shows the new structure in Figure 6-5 with a gentler slope should have appeared without accompanying the dramatic capacity decrease of observed data. In reality, however, the structural change accompanied the reduction of both capacity and new turbine introduction and the great increase of technology gaps. Also as examined in Chapter 5, the Indian market did not move onto newer medium- and large-capacity turbines in the late 1990s. This indicates that there should have been other factors that brought the structural change to the Indian wind energy sector in the 1996-97 year.

The following sections try to find various reasons behind the structural change and its effects on cross-border technology transfer and the growth of technology gaps.

Section 6.4: Market Demands and Investment Economics Pressure and Their Effects on Capacity and Technology Development and Diffusion in India

This section analyzes the effects of market demands and investment economics in India on the relationship between cross-border technology transfer and capacity development and its structural change as well as on technology development and diffusion.

6.4.1 Market Size, Market Demands, and Investment Mechanism in India

Indian Market Characteristics

Increased Gaps in Installed Capacity with Europe

Although the Indian market has been among the top five world markets since the mid 1990s, the size of the market has been much smaller, compared to that of Germany and Spain.

Table 6-15: Comparison of Annually Installed Capacity in MW

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Germany	500	420	533	793	1568	1665	2627	3247	2674	2054
Spain	58	116	262	368	932	1024	1050	1493	1377	2064
India	375	244	120	82	43	169	236	220	423	875
Denmark	98	200	285	310	325	603	115	530	218	---

Source: (BTM Consult ApS 2005b)

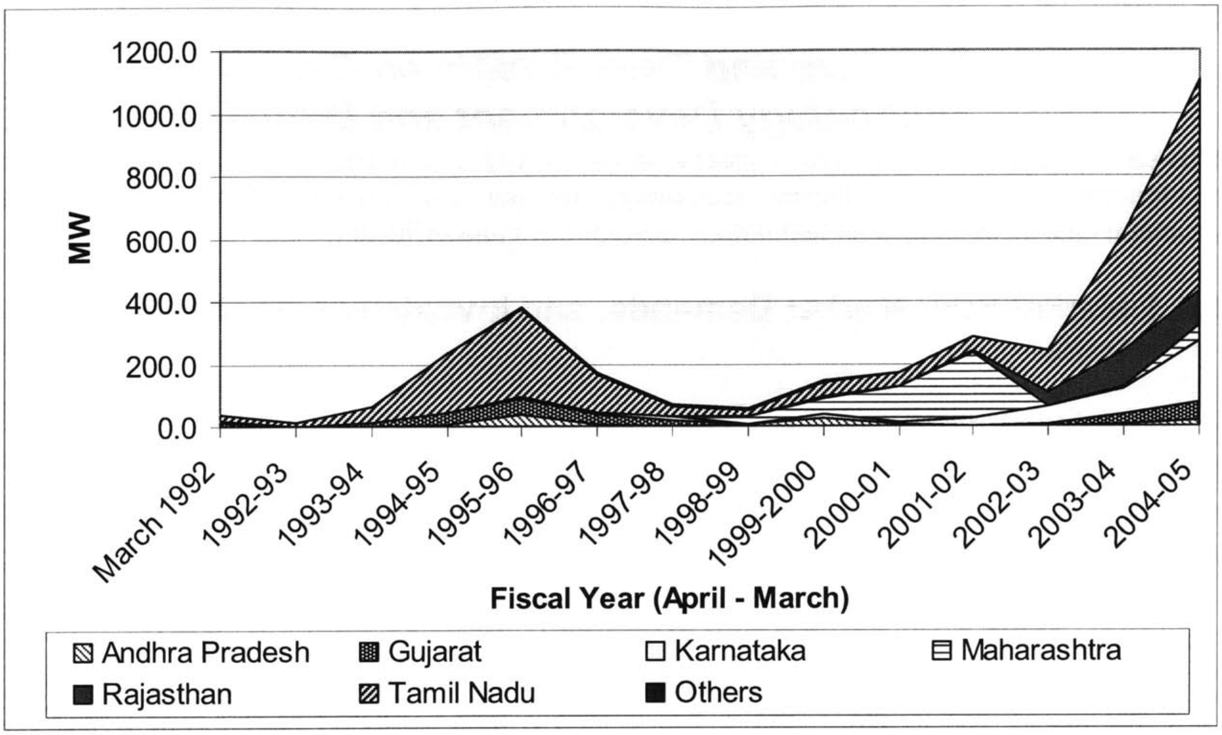
In particular, the market size disparity began after 1996 and grew larger from 1998; the German market installed almost ten times as much as the capacity of the Indian market in 1998, and the difference grew into almost 15 times in 2002. When India finally surpassed the level of the 1995-96 installation in 2003, the German installation was still six times larger than that of India (Table 6-15).

Weak Regional Market

Although the Danish installation capacity was not particularly strong, compared to India during the same period, unlike Europe, India has no other robust wind energy markets nearby. The Indian market has been rather isolated in the region. In addition, the Indian export has been weak while the country has been a net importer of wind turbines and components. The Indian local production facilities are mostly targeted for the domestic market demand. Therefore, the effects of other market demands on the Indian technology development have been fairly limited.

Strong Market Fluctuation and Segmentation

As illustrated in Chapter 5, the Indian market fluctuates greatly; it does not show a stable and steady growth pattern seen in Germany and Spain. The market slowdown after the 1996-97 year, in particular, the recession between the 1997-98 year and the 1999-2000 year was severe. After the recession was over, the market slowly gained the strength. The growth in the 2003-04 and 2004-05 years was explosive. This fluctuation is seen not only at national level but also at state level, and there is a strong disparity of wind development among states.



Source: MNES cited in (Consolidated Energy Consultants Ltd. 2005)

Figure 6-6: Installed Capacity in MW by State in India

Figure 6-6 shows geographical distribution of the market within India. It is clear that only handful states out of 25 states and seven union territories contributed to wind energy development. The first wave of development concentrated in mainly Tamil Nadu and Gujarat between the 1992-93 year and the 1995-96 year. Maharashtra was the main market between the 1998-99 year and the 2001-02 year when other state markets stagnated. The picture changed again from the 2002-03 year; Tamil Nadu, Rajasthan, and Karnataka have become the main installation locations. Gujarat also shows the growth in the 2003-04 and 2004-05 years, while Maharashtra and Andhra Pradesh had smaller market development. In total by the end of March 2005, 57% of installed capacity has been in Tamil Nadu, followed by 13% in Maharashtra, 11% in Karnataka, 8% in Rajasthan, 7% in Gujarat, 3% in Andhra Pradesh, and 1% in all other states. The difference and fluctuation of growth patterns by state illustrate strong segmentation of the market within India. Overall, the Indian market demand, in terms of size, location, and stability, has been highly uncertain.

Wind Investor Profile and Investment Mechanism in India

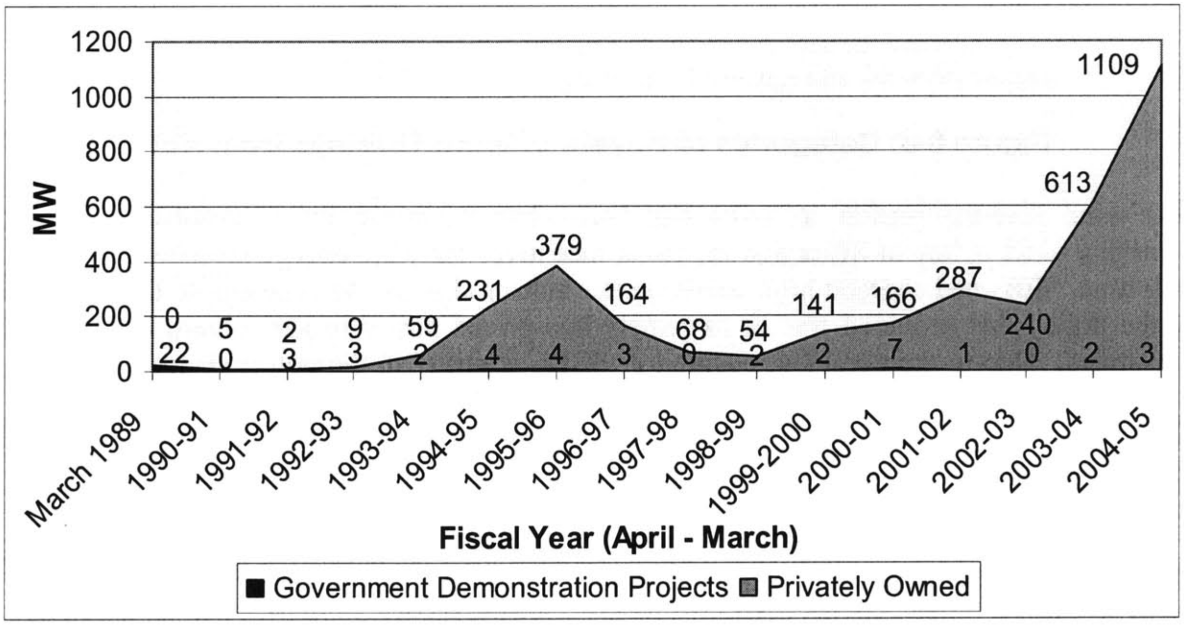
Wind Project Investor Profile in India

By March 1989, there were no private wind power projects in India; only total 22MW of the government-led demonstration projects existed. This situation changed dramatically, when private investment started in the 1992-93 year. On the other hand, the number of government-led demonstration projects has been fairly constant but small. More than 98% of total installed capacity of 3,595MW by March 2005 has been developed by private sector since 1992 (Figure 6-

7). Similar to Denmark and Germany, the Indian wind energy development has been led by private investment.

However, the Indian investor profile shows a very different picture from Denmark and Germany. When the private market began developing in the early 1990s, there were many small investors who invested in from one- or two-turbine projects to ten- or more turbine projects, creating diverse size of projects (TERI 2002). However, this pattern was eroded very quickly as the large and energy intensive industrial companies began investing in wind projects. Since then, the investors have been overwhelmingly the industrial sector, and they fall broadly into three categories: 1) energy intensive production companies using wind power for captive use; 2) wind turbine manufacturers selling the power to the grid; and 3) financial companies setting up wind farms as a profitable investment due to fiscal incentives (Winrock International India 2003).

According to MNES, 80% of wind power fed into the grid has been used as captive consumption, consumed by the investors in distance.[88] Table 6-16 illustrates that production companies have the highest share in installed capacity, although the number of financial company investors in both Tamil Nadu and Gujarat is larger than the number of production company investors. This means the average installed capacity by production company for captive power usage is larger than the average installed capacity by financial company. Also the categories of buyers of wind turbines (Figure 6-8) indicate that 78% of buyers are energy intensive production companies.



Source: MNES

Figure 6-7: Installed Capacity in MW by Ownership in India

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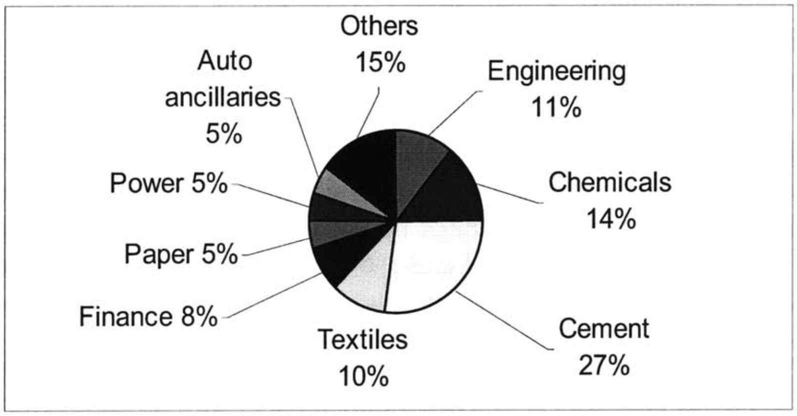
[88] In India as a whole, captive power production almost doubled during the 1990s and reached 15,000MW by 2002, although the estimates vary among different sources. This number is said on conservative side, which may not take into account the units under 1MW that many represent another 7,000MW (IEA. 2002b).

Table 6-16: Wind Power Investor Profile in Tamil Nadu and Gujarat by 1997

State	Investors	Number of Investors	% in Number of Investors	Installed Capacity (MW)	% in Installed Capacity
Tamil Nadu	**Production Companies**	86	**22%**	306	**56%**
	Financial Companies	288	**75%**	169	**31%**
	Turbine Manufacturers	13	3%	63	12%
Gujarat	**Production Companies**	37	**39%**	74	**76%**
	Financial Companies	56	**60%**	17.4	**18%**
	Turbine Manufacturers	1	1%	5.8	6%

Source: (Economics of wind power: Impact of fiscal incentives by TERI and ORG (1997), cited in Winrock International India 2003)



Source: (Winrock International India 2003)

Figure 6-8: Categories of Buyers of Wind Turbines from NEPC

This wind investor profile in India has been shaped mainly by cross-subsidized general electricity tariff policy of SEBs and the fiscal incentives for wind energy investments. For very long time, SEBs had charged high tariffs on the industrial sector to compensate the loss created by the policy that provided free or extremely low-priced power to agricultural and residential consumers. Due to the dominant position of SEBs as utility in the power sector until recently, the industries had to bear this pricing for long time. This cross-subsidized tariff structures by SEBs have encouraged captive power wind ownership by industry investors. The typical generation cost of captive power plants (INR 2.5/kWh) is much lower than SEB tariffs for the industry (the average 1999-2000 SEB tariff for industry of INR 3.5/kWh) (IEA 2002b).

The popularity of captive usage can be also illustrated by the comparison of wind energy feed-in tariffs in various states with the national average industry electricity tariffs charged by SEBs over the years (Table 6-17). The national average industry electricity charges are much higher than wind feed-in tariffs paid in each state. In some states and for some industries, electricity tariffs are much higher than the national averages. It is much more profitable to save the payments to SEBs by constricting captive power plants than to earn the payments from SEBs by selling wind generated power to them.

Table 6-17: Wind Energy Feed-in Tariffs and Electricity Tariff for Industry (INR)

	Tamil Nadu	Gujarat	Maharashtra	Andra Pradesh	Karnataka	Rajasthan	National Average Industry Tariff
1992-93	2.00						1.72
1993-94	2.00						1.98
1994-95	2.00	1.75		2.25	1.75		2.21
1995-96	2.75	1.75	2.25	2.25	2.25		2.20
1996-97	2.25	1.75	2.25	2.25	2.25		2.76
1997-98	2.25	1.75	2.25	2.25	2.25		3.13
1998-99	2.25	1.75	2.25	2.25	2.25		3.29
1999-00	2.25	1.75	2.25	2.25	2.25	2.75	3.51
2000-01	2.25	1.75	2.25	2.25	2.25	2.75	3.59
2001-02	2.70	1.75	2.25	2.25	2.25	2.89	3.67
2002-03	2.70	2.60	---	2.25	2.25	2.89	3.46
2003-04	2.70	2.65	3.50	3.48	2.25	2.89	N/A
2004-05	2.70	2.70	3.50	3.37	3.40 (from 1/05)	2.91 (from 10/04)	N/A

Sources: (Central Electricity Authority 2003; Consolidated Energy Consultants Ltd. 2005; Lok Sabha 2001; MNES 1995a; MNES 1996a; MNES 1997a; MNES 1998; MNES 1999a; MNES 2000a; MNES 2001a; MNES 2002a; MNES 2003; MNES 2004; MNES 2005; Planning Commission 2001 and 2002)

Indian Wind Investment Mechanism

Although there has been disparity of wind energy policies among states, the investment mechanism is basically same across India. Wind projects in India have been financed with low equity and high debt, as they have been in Denmark and Germany. The IREDA wind farm project financing scheme plays the central role in the investment scheme; the IREDA loan requires the minimum 25-30% of equity from the project promoter, mostly the industrial firm, and the rest is financed as debt from IREDA. This equity-debt ratio is similar to that of closed end wind fund in Germany. The equity-debt ratio was lower until the 1996-97 year (40:60).

The biggest difference between India and Germany/Denmark, however, was that the Indian investors (industrial firms) primarily saw wind project as tax planning and management tool. Although there are some tax advantages for wind investment in Denmark and Germany, they have never been the primary investment objectives.

6.4.2 Quantitative Analysis of Wind Energy Investment in India

Econometric Analysis of Direct Relationship between Policy Incentives and Market Development

Various attempts were made to form regression models to establish quantitative relationship between policy incentives and annually installed capacity development in India. Independent variables include: IREDA interest rates; corporate tax rates; MAT rates; tax holiday; first-year tax depreciation schedules; import duties; national average industry electricity tariffs; and the requirement of wind turbine certificate. However, none of the attempts was successful and none of the above variables directly showed strong relationships with annually installed capacity development.

Profitability and Tax Saving of Wind Energy Investment in India

The failed econometric attempts to establish direct quantitative relationship between various policy incentives and annually installed capacity development led to the next analytical attempt, which analyzes the relationship of profitability or tax saving of wind energy investment with capacity development.

Profitability Indicators

The indicator of profitability used in the analysis is Internal Rate of Return (IRR). IRR embodies the effects of various market development and investment policy incentives, as the cash flow analysis to reach an IRR includes the effects of those incentives.

The indicator of tax saving used in this analysis is the first-year tax saving materialized by the accelerated depreciation (100% in the first year until the 2002-03 year, then 80% in the first year). In reality, this tax incentive works as capital subsidy during the first year of operation. From the 1997-98 year, taxes due to MAT and Income Tax are deducted from the saving materialized by the accelerated depreciation.

Modeling Tool for Cash Flow Analysis

To establish the relationship of profitability or tax saving with capacity development, a time series data for those three variables is required. Although diverse policy and market conditions have made the market conditions in each state very different from one another, the research tires to analyze the national average conditions since the core financial and fiscal policy incentives are same nationally, and more importantly, a time series data of industry electricity tariffs for different states was not obtained.

A modeling tool was developed to perform the calculations. The tool includes the main data for wind project investment and various assumptions (economic lifetime; capital cost of project per MW; project size; conditions for tax treatment; IREDA financing terms, such as equity-debt ratio, interest rates, and loan payoff period; Capacity Utilization Factor (CUF)[89]; O&M cost; electricity tariffs for the industrial sector; and de-rating of wind turbine, etc) (see detailed assumptions and data in Appendix C-1). Since the policy variables in the model of each fiscal year are fixed and capital cost of project per MW use the estimated average cost for the year, The IRR results produced by each model are not sensitive to project sizes. In order to make the results fairly comparable, the following common assumptions are used in the calculations:

- All calculations are carried out in current prices.
- The input data reflects the expectation in the stated year.
- The main results include measures of net present value (NPV) and IRR after payment of tax. The tax conditions prevailing in the year of turbine investment are expected to be fixed for the time period under consideration.
- All data are stated as average.

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[89] CUF is a ratio of the annual energy output to the theoretical maximum output, if the machine were running at its rated (maximum) power during all of the 8760 hours of the year. Wind energy CUF states the ratio of annual energy output for a wind turbine in a particular location to its rated power, CUF = Energy generated per year (kWh)/ Turbine rated power (kW) x 8760 (hours).

- The economic lifetime of all wind turbines under considerations is assumed to be 20 years.
- The calculations are performed only for captive use plants and all generated electricity is assumed to be used by the producers via wheeling. Selling the wind generated power to SEBs and third-party sales are not considered in this model in order to simplify the assumptions and because captive use has been the majority of investment form. Therefore, the revenue stream of the model comes from the saving created by not paying the industry electricity tariffs to SEBs.
- The expected annual raise of industry electricity tariffs is assumed based on the growth rate of tariffs of the previous several years. However, the maximum ratio was set to 10%, as the annual raise of more than 10% for 20 years of project life time is unlikely, considering the actual industry electricity tariffs for the past 15 years.

National Average IRR and First-year Tax Saving

The cash flow models between the 1992-93 year and the 2004-05 year produced the following results (See Appendix C-2 for Base Cash Flow Calculations for each year).

Table 6-18: Annually Installed Capacity, Expected IRR, and First-year Tax Saving

Year	Annually Installed Capacity (MW)	Expected Average IRR	First-year Tax Saving (INR)
1992-93	15.575	1.44%	8671000
1993-94	57.44	0.50%	14490000
1994-95	256.515	5.23%	20240000
1995-96	385.04	-0.79%	22770000
1996-97	155.905	2.69%	28704000
1997-98	70.536	10.11%	17242000
1998-99	42.33	6.92%	13621608
1999-00	132.915	5.43%	19055880
2000-01	180.89	4.76%	19578240
2001-02	285.135	0.55%	16686000
2002-03	239.785	1.77%	17353400
2003-04	594.05	3.08%	14908320
2004-05	1103.86	4.37%	13843440

In general, it is very clear that the IRR results fluctuate over the years but more importantly they are very low. However, this is not a surprise. One of the reasons for the low IRR results is high interest rates. In addition, the low revenues stream due to low CUF (technology efficiency) and high capital cost make IRR low. In India, the revenue income from wind project is said to be too low to gain the benefits on its own and this makes the investors must have very high taxable income from other businesses, and the wind project solely depends on the balance sheet of the investor company with very high tax liability (Consolidated Energy Consultants Ltd. 2005). For the constructed cash flow models too, IRR could not be calculated without the first-year tax saving (capital subsidy). This can explain why the Indian wind investment is primarily seen as tax planning and management tool rather than real investment in the technology.

Capacity Development and Expected National Average IRR and First-year Tax Saving

Observation of Indicators

Statistical analysis was performed for two different structural time periods identified in the previous section. Between the 1992-93 year and the 1995-96 year, correlation between installed capacity and IRR was 0.038, while correlation between installed capacity and first-year tax saving was 0.951. Installed capacity and first-year tax saving shows a very strong correlation. During the second structural period between the 1996-97 year and the 2004-05 year, correlation between installed capacity and IRR was -0.272, while correlation between installed capacity and first-year tax saving was -0.387.

Econometric Analysis

For the period between the 1992-93 year and the 1995-96 year, the following regression was estimated by using OLS.

$$\text{CAPACITY} = c + \beta_1 * \text{TAXSAVING} + \varepsilon \qquad \text{(Equation 7)}$$

Where:

$\beta_1 > 0$
CAPACITY: Annually Installed Capacity
TAXSAVING: First-year tax saving

The OLS regression produced the following equation with t-statistics values in the parenthesis.

$$\text{CAPACITY} = -254.44 + 0.00002618 * \text{TAXSAVING}$$
$$(-2.421) \quad (4.338)$$
$$R^2 = 0.90, F= 18.82$$

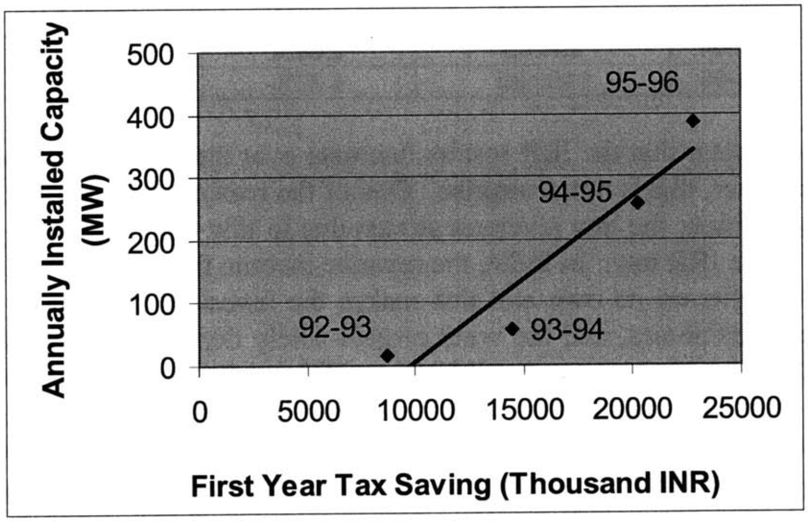

Figure 6-9: Relationship between First-year Tax Saving and Capacity between the 1992-93 year and the 1995-96 year

The calculated regression coefficient (R^2) of 0.90 tells that the tax saving variable helps explain 90% of the variation in the capacity variable. The t-statistics for the estimated variable is higher than the critical value of 3.182 at 5% significance level. A regression analysis between installed capacity and IRR did not produce a statistically significant result. The annually installed capacity, hence the market development, during the first structural period can be largely explained by the first-year tax saving (Figure 6-9).

On the other hand, similar regression analysis for the period between the 1996-97 year and the 2004-05 year did not produce any statistically significant results. The market development in the second period cannot not be explained quantitatively by either the expected national average IRR or the first-year tax saving.

Summary Results

The above examination reveals the difficulty of explaining capacity development in relation to the national average IRR in India. However, profitability did not necessarily explain all investment decisions made at the frontier either. The research done by Morthorst (1999) also concluded the poor relationship between profitability and capacity development in the projects invested by wind cooperative owners in Denmark, although there was a strong relationship between the two variables in the projects invested by individual owners. The investments in co-operatively owned turbines in Denmark were influenced by expected profitability to only a minor extent, compared to other determining factors such as environmental concerns and planning procedures (Morthorst 1999).[90]

For India, building the cash flow models based on the national average data in the above examination was a rather forceful effort, due to the lack of data availability of state industry electricity tariffs in India. However, the poor relationship between the national average IRR and capacity development was also expected to some degree, as the strong dependency of the Indian investment mechanism on tax saving measures was pointed out.

Still, IRR is sensitive to technology-related sensitivity factors such as capital cost per MW, CUF, and O&M costs as well as the industry electricity tariffs and their expected annual raise. CUF and the industry electricity tariffs vary significantly among states. Also, wind conditions, various utility charges and project-related fees differ greatly from one state to another, and they are frequently changed, altering project economics and IRR across the nation and creating market fluctuation. Thus, the state conditions and technology-related sensitivity factors are important for market development in India. Taking this point into account, the next part examines the different causal factors behind the Indian market development and the structural break of the relationship between new turbine introduction and capacity development.

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[90] In his research, profitability was defined by the difference between the nominal IRR after tax and the nominal discount rate after tax. The nominal discount rate was taken to be equivalent to the IRR that could not be obtained by an alternative investment. See (Morthorst, 1999).

6.4.3 Causal Factors of Market Development in India

First-boom Years – from the 1992-93 Year to the 1995-96 Year

The first structural period confirmed by the quantitative analysis in Section 6.3 was the first boom years in the Indian market development. Various factors influenced the rapid market growth of the period. The most important factors were the policy incentives offered not only to the wind energy sector but also to the power sector in general.

Tax Incentives

The rapid market growth since the 1992-93 year until the 1995-96 year was due to the combination of the 1993 tax rule (the first-year 100% depreciation of capital equipment and zero-tax planning),[91] as confirmed by the analysis in the previous part. It was estimated that up to 80% of wind turbines between the 1992-93 year and the 1995-96 year in India have been installed to take advantage of the available tax depreciation (Wind Power Monthly 1996e).

The strong connection between wind energy projects and corporate tax management in India is also illustrated by the concentration of project commission in September and March, as the tax mechanism of the country requires wind projects to be finished from planning to commission within the six-month periods that end in either September and March, in order to take the tax benefits, creating a roller coaster order process. September is the preferred commission timing, in order to receive the full tax saving benefits within one year. This short lead time given for each project prompts turnkey provision by one developer, unlike Germany where different legal entities take care of each value activity from equity acquisition, project planning, project commission, to O&M.

On top of this, the benefits of tax saving through the highly accelerated depreciation can be realized only if taxable income is substantially high to absorb the high rate. In general, IPPs do not have tax income liability high enough in order to receive the benefits from this kind of tax saving measures, and this is why the Indian wind investors are confined within large industrial business entities. Also it is only the industrial firms which have financial capacity to bear large initial investment costs. The Indian wind investment mechanism, thus, was constructed to help other business of the investors, not to make wind project itself viable. This explains the low IRR and weak relationship between IRR and capacity development.

Gold-plating

The tax saving practice that supported the tremendous market growth of the first boom years also created dubious practice of "gold-plating" by many bogus investors, who cared only for the reduction of tax liability; they wanted higher capital price tag in order to gain larger tax benefits from it. This 'gold-plating' of wind turbine prices (price increase of wind turbines despite the international price reduction trend and the sharp increase in the sales volumes in the same time period) were seen until the 1996-97 year in India. Many damaged and low-quality second-hand turbines were imported mainly from California, tagged with extremely high prices, and sold. The percentage increase of installation cost per MW from the 1992-93 year to the 1996-97 year

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[91] The effects of the other tax saving, the five-year 100% tax holiday on the income from sales of wind electricity, was considered small, as most of projects were created for captive power consumption.

was 27.5% in India, while the Danish wind turbine prices fell approximately 30% during the same period (Rajsekhar, Van Hulle, and Jansen 1999; TERI 2002).

Table 6-19: Gold-plating of Capital Cost

Year	Capital Cost per MW (INR, 1992-93 price)	Estimated Nominal Cost per MW based on CPI	Capital Cost Inflation	General Inflation in India (CPI based)
1992-93	29 Million	---	---	---
1993-94	32.5 Million	35 Million	20.1%	7.5%
1994-95	33.6 Million	40 Million	14.3%	10.1%
1995-96	34.7 Million	45 Million	12.5%	10.2%
1996-97	37 Million	53 Million	17.8%	9.3%

Source: Capital cost per MW from (Rajsekhar, Van Hulle, and Jansen 1999). Nominal cost and inflation were calculated by the author based on CPI from Ministry of Commerce and Industry, GOI.

Other Factors

The IREDA soft loan was another important measure that enabled the large private investment boom.[92] However, no project quality standards placed by the government during this period created many bogus investors with the sole purpose of taking the IREDA loan along with the generous tax credits. Many projects performed very poorly and some were abandoned without being ever operated. Usually, once these corporate investors took the IREDA loan and zero out their tax liability in the first year, they abandoned the projects. As a result, a large portion of the IREDA revolving fund after the first boom years was not recovered. The total pay-back ratio from borrowers was still 83% even at the point of 2002 (IREDA 2002d); it reached to 90% only in 2005.

The FDI stimulation from 1991 and the import duty reduction from 1993 were other factors behind the strong market development by bringing necessary technologies from abroad. The policy change that made the grid-connected wind energy investment possible was another major contributing factor.

Recession Years – between the 1996-97 Year and the 1998-99 Year

The first boom years ended by the sudden policy changes at both central and state levels.

Policy Change

The largest policy reason for the structural break was the introduction of quality assurance measures in July 1995 and the 1997 tax rule change (the elimination of zero-tax planning by imposing MAT and the reduction of marginal corporate tax in 1997 and again in 1998). The 1995 quality assurance measures suddenly made it difficult to erect low quality wind turbines and/or leave them without proper operation, as MNES began requiring the turbine certification and the detailed project report before and after the commission. The new tax policy plunged corporate investments in wind from the 1997-98 year, because the size of tax benefits was greatly reduced as the corporate tax rate was reduced. Many corporate investors quickly lost

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[92] Only manufacturers and developers that never used IREDA financial schemes for any of their wind power projects was BHEL, which is a state-own enterprises and no need for external loans (BHEL, 2002).

their interests in wind, as they could no longer zero out their tax liability and the projects process became cumbersome.

In addition to the above policy change, the interest rates of the IREDA loans were also significantly raised in 1996, approximately 4-5% across the board and reaching 18-20%. The IREDA interest rates, which have been between 10% and 20%, are significantly higher compared to those in Denmark and Germany, where the rates move around 5-7%. This worsened project economics significantly. The increased import duty from April 1997 also contributed to deter new investments from the year.

The market slowdown lasted until the 1998-99 year. The 1996-97 year seems to be the transitional year structurally, as the gold-plating of capital cost still continued and the first-year tax saving amount was also still large but the installed capacity was greatly reduced due to the introduction of quality assurance measures and the raised IREDA interest rates.

IRR in Table 6-18, however, show that the investment climate and profitability seemed improved in these recession years despite these new tax policy and higher interest rates. This is largely because the gold-plating effects on capital cost were no longer in presence in the model; the elimination of gold-plating effects lowered tax savings significantly but improved IRR. It was also because the average industry electricity tariffs and their annual raises estimated during these years in the model were much higher. Yet, behind these high industry electricity tariffs of the period, there was great uncertainty involving the power sector.

Financial and Technical Problems of SEBs

While the new policy measures successfully eliminated bogus investors, many obstacles remained for serious investors. And a large part of the problems came from their relationships with SEBs, which were in great trouble in the mid 1990s.

SEBs had accumulated huge financial debts by the mid 1990s due to the buildup of high T&D loss, poor revenue collection, and their cross-subsidy tariff policies. These conditions deterred power investments by private sector in general in many states.[93] The high T&D loss and grid abnormalities directly affected the wind investment climate as well (Madras Cement 2002). For example, grid abnormalities reportedly induced the average 20% loss of potential revenue in wind investment in 1996 (Rajsekhar, Van Hulle, and Jansen 1999). There was also great uncertainty for the future of SEBs and their pricing policy. Power plant investment became much riskier business during the mid 1990s.

Another detrimental factor caused by SEBs was their considerable resistance to grant third-party sales to wind investors. Wind plants can increase the revenue flow by selling generated power directly to third parties by bypassing SEBs, if SEBs permit it. However, third-party sales can

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[93] The poor financial situation of SEBs also deterred IPP investments in India. In general after the liberalization of the power sector, the initial IPP responses to the governments were enormous. Most of international heavyweights, Indian corporate houses and small companies with no previous experience in power sector proposed over 100,000MW of capacity in total. However, along with the constantly changing government policy and the inconsistency among policies among various agencies, the poor financial situations of SEBs have made 20-30 year Power Purchase Agreements (PPAs) very risky for IPPs and have deterred the IPP involvements in the power generation (Indiapoweronline. 1999).

cause SEBs a significant revenue loss because they lose the most profitable industrial customers to wind investors. Tamil Nadu changed its third-party sales policy from granting to not granting after the first boom years, and this contributed to the market slowdown of the state.

In addition, during this period, SEBs began generally showing more hostile attitudes toward wind energy plants, e.g., imposing additional charges on reactive power consumption by wind power plants during peak hours, while not offering any extra feed-in tariffs to wind power generation during peak hour. The extra charges during off-peak hours were often imposed as well. This kind of attitude changes happened because SEBs saw wind energy plants as nuisance due to their low reliability. However, many investors did not find such pricing strategies by SEBs as fair or attractive to induce further investments to the sector (Madras Cement 2002). Also there was a disparity between actual T&D loss and wheeling charges by SEBs; according to the MNES guidelines, SEBs could only charge 2% of the power that they wheel, while their T&D loss were close to 20% in Tamil Nadu and Gujarat (Rajsekhar, Van Hulle, and Jansen 1999). This made the investors consider that they were losing their high quality wind power through high T&D loss via wheeling due to the poor grid system of SEBs (Madras Cement 2002). The relationship between SEBs and wind investors was deteriorated quickly during the recession years.

Inadequate Technical Performance and Lost Investor Trust

The problems with SEBs were mainly triggered by the extremely low level performance of wind energy plants during the first boom years. This also deterred serious investors.

During the first boom years, many wind turbine manufacturers and project developers were not adequately prepared for O&M and repairs of wind turbines and the system. Inadequacy of repair facilities, disregard for earthing regulations, and the lack of lightening protections led to long breakdown periods and often resulted in expensive repairs. The lack of safety design and technical quality in rotor blades caused many failures as well (Jagadeesh 2000). Low level of project execution skills was another issue. During the first boom years, many projects suffered from inadequate wind resource assessments and improper siting practices. Little efforts were made to adopt the European and American technology to the weak Indian grid conditions. These conditions left many projects at sub-optimal levels of CUF, which were well below 20% (Rajsekhar, Van Hulle, and Jansen 1999). The Indian average CUF in 2001 was still 15% (Consolidated Energy Consultants Ltd. 2002).[94] Low CUF causes low viability of wind projects. The sub-optimal level of operation and the low CUF also exacerbated reactive power consumption from the grid. These were the reasons behind the significant turbine productivity decline in India during the first boom years shown in Figure 5-16 in Chapter 5.

Thus, the high initial capital cost and the low CUF under 20% have made the competition against conventional thermal power generation very difficult (Indiapoweronline, 2001). The low technical performance, the reduction of tax benefits, the higher interest rates, and the great uncertainty involving wind energy policy and financial conditions of SEBs, all contributed to the market decline, despite the potential huge savings in terms of fuel inputs and O&M costs as well as the savings due to the raised industry electricity tariffs during the late 1990s.

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[94] Wind energy CUF in Europe is mostly around 25-30% (Consolidated Energy Consultants Ltd, 2005).

Recovery and the Second Boom from the 2003-04 Year

Political Certainty

The market began gradually growing again from the 1999-2000 year, as the direction toward sustainable market and industry development with various quality assurance measures after 1995 began taking positive effects; the market confidence slowly came back.

The continuous SEB reform efforts were another important factor. However, the explosive market growth since 2003 can be explained mainly by the enactment of the 2003 Electricity Act. Many wind investors waited for the new Act from the beginning of the new millennium and began participating in crafting the 2001 draft of the Act. Although there are still rooms for improvement, the new law was enough to clear many political uncertainties.

The process of participation and communication in making of the 2003 Act and the SEB reforms gradually contributed to regain the investor confidence and increased the understanding between utilities and investors. The formation of political power by the Indian Wind Turbine Manufacturers Association (1997) and the Indian Wind Energy Association (2002) and the open communication process of the SEB reforms led by CERC and SERCs were another important factor of change.

State Policy Conditions

Many states began implementing more detailed and clear wind energy policy that is suitable for their own SEB conditions during the early 2000s, as not SEBs but SERCs have increasingly became responsible for deciding general electricity tariffs and wind feed-in tariffs as the result of the 1998 Reform Act. The 2003 Electricity Act finally clarified SERCs to be responsible in all tariff decisions, provided open access to transmission grid, permitted free captive generation by removing all licensing and permission requirements, and clarified to take suitable measures for grid connection and power sales to any person to promote electricity generation from renewable energy sources. In particular, the 2003 Act ensured third-party sales to be made in all states and finally eliminated the resistance from SEBs, although the final decision is still subject to each SERC decision. This will open up more diverse possibilities of wind energy business.

During the early 2000s, several states began offering high feed-in tariffs for wind power. This has increased wind energy plants built for sales to SEBs in those states. In particular, more than 95% of installed capacity in Rajasthan has been for sales for SEBs, not captive use. Andhra Pradesh, Karnataka, and Maharashtra also have relatively high percentage of plants built for power sales for SEBs, due to their high feed-in tariffs (Consolidated Energy Consultants Ltd. 2005).

Technology Upgradation Funds (TUF)

Although the total installed capacity utilizing TUF offered by Ministry of Textile since April 1999 has not been reported, the scheme also helped the market recovery, especially in the state of Tamil Nadu, where a large number of energy intensive textile business exist. TUF greatly improved project viability by lowering the interest rates for debt from any financial institutions by 5% for wind energy projects facilitated by textile business entities. The effects of TUF, however, were not immediate; the projects utilizing the scheme increased after the enactment of the 2003 Electricity Act. For example, approximately 57% of total installed capacity by Suzlon in Tamil Nadu since 1999 was materialized under TUF, but 87% of them concentrated in the 2003-04 and 2004-05 years[95] (Consolidated Energy Consultants Ltd. 2005).

Sensitivity Factors of Investment Economics

Sensitivity factors in project economics have changed greatly during the 2000s. First, the industry electricity tariffs have not increased since 2000 as fast as they did during the 1990s. Although the higher electricity tariffs improve wind energy investment economics by making the revenue flow created by captive power consumption larger, they worsen general business conditions. The industry electricity tariffs skyrocketed during the 1990s due to the poor financial conditions of SEBs. The SEB reform efforts have contributed to strengthening the general trust in the power sector. Uncertainty regarding the tariff and pricing structure has been reduced greatly, and this also contributed to increasing the certainty for wind energy investment.

Second, the tax saving has been further reduced as the first-year accelerated depreciation of wind energy investment was reduced from 100% to 80% from the 2003-04 year. However, this did not influence capacity development at all. On the contrary, installed capacity greatly increased from the year. This may be an indicator of the shift of the Indian wind energy investment toward more performance-oriented investment, although project economics still cannot be viable without the tax saving. There are also some states that began offering higher feed-in tariffs that can make wind project economically viable by selling the power to SEBs, as mentioned. This movement toward higher feed-in tariffs and the lower effects of tax saving suggest that there is a good prospect of verifying the second structural shift in the 2003-04 year, once more observations are made.

Other factors have worked for wind investment favorably too. For example, the IREDA interest rates have been gradually reduced throughout the 2000s, reaching the lowest level in history in 2005. The gradual increase of turbine capacity and improvement of project execution technology such as micro-siting have slowly improved CUF, although it is still far from the European level.

Effects of State Conditions on Market Growth

The state conditions, in particular state policy, have influenced the Indian wind energy market greatly.

Tamil Nadu

The market domination of Tamil Nadu in the early 1990s was due to the following clear state policy: 1) the demonstration projects led by TNEB from the 1980s showed viability of many sites to private investors; 2) the wheeling and banking incentives offered by TNEB made energy intensive textile and cement industries in the state to invest in captive wind power projects; 3) the third-party sales was permitted to power producers with much higher rate than selling to SEBs, although the wheeling charge was also high (15%) for third-party sales; 4) the approval process of private projects was accelerated by issuance of NOC and Chief Electrical Inspectorate to the government clearance; and 5) TNEB created an effective registration system of wind turbines, making the turbine owners to easily adjust either their energy bills or payment to those who sold

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[95] 229.25MW out of total installation of 403.1MW by Suzlon in Tamil Nadu between the 1999-2000 year and the 2004-05 year was under the scheme (Consolidated Energy Consultants Ltd. 2005).

the power to TNEB. In addition, TNEB succeeded in effective implementation of the above policies by its officials with knowledge accumulated through demonstration projects (Jagadeesh 2000; TNEB 2002).

The market slowdown in Tamil Nadu from the 1997-98 year was also greatly influenced by state policy. The following policy changes reduced the market in the state: 1) from 1996, TNEB no longer allowed the third-party sales in order to avoid losing their industry customers to wind power producers; 2) the withdrawal of capital subsidy from the 1997-98 year and the placement of new penalties for excessive reactive power consumption from June 1995 made project economics less favorable; and 3) the inadequacy of substations provided by TNEB and the weak grid systems created unsatisfying performance (Jagadeesh 2000; Madras Cement 2002).

The resurge of the Tamil Nadu market from the 2002-03 year greatly depended on the incentives under TUF, combined with the enactment of the 2003 Electricity Act.

In addition to state wind energy policy, many other factors contributed to the strong performance of Tamil Nadu. First, Tamil Nadu has the best wind resources available in the country (see Table 6-25 in Section 6.5 for more details). Second, a fair degree of political stability, good industrial culture with enterprising spirit, and very liberal and pragmatic state industrial policy, focusing on strengthening its industrial and social infrastructure since 1991,[96] made Tamil Nadu one of the most successful industrial states in the country (Bajpai and Sachs 1999). Especially, energy-intensive textile and cement industries boomed during the early and mid 1990s and invested in captive wind power projects, although the recession in those industries in the late 1990s contributed to the market slowdown. Third, the wind power demand and supply matched well for industry investors in Tamil Nadu, because the windy summer season meets their high power needs (Madras Cement 2002; Vestas RRB 2002). Fourth, the infrastructure was better compared to other states; the port facilities of Chennai made it easy to import heavy machinery and components of wind turbines (IWTMA 2002; Jagadeesh 2000; TNEB 2002), and the technical wind resource availability was also high from the beginning due to its well-connected infrastructure (roads and the power grid) and good labor supply from nearby towns to windy sites. Lastly, unlike many other states, lands with good wind resources were privately owned and easily purchased. However, the decline of available prime wind resources locations and the rising land cost contributed to the market slowdown in the late 1990s.

Maharashtra

Maharashtra contributed to the national market recovery greatly between the 1999-00 year and the 2001-02 year. The Maharashtra market had been also strongly influenced by state policy: 1) new state policy implemented from December 1999 had strong fiscal and financial incentives components (the third-party sales, the capital subsidy of 30% of project cost, and the sale tax exemption up to 100% of investment); 2) Maharashtra had high commercial electricity tariff

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[96] Measures include increasing general power generation, transmission and distribution arrangements, improving road and rail network, bringing in technological advanced telecom facilities, opening new minor ports and developing existing minor ports and strengthening the technical training facilities. All these measures also successfully attracted many foreign direct investment into the state since August 1991 (Bajpai, and Sachs, 1999).

(INR 5/kWh) for the industrial sector[97] and this encouraged captive power projects (MEDA 2002); 3) the state removed the 100% sales tax exemption policy as of March 31, 2002, and this wiped out the investment; and 4) the market only came back slowly with a new policy with higher tariffs for newer projects, but only after the 2003 Electricity Act enacted.

In addition, like Tamil Nadu, Maharashtra has been a strong industrial state with Mumbai as the nation's business capital and has had the financially strong SEB. The state implemented robust industry/trade/commerce policy from 1995, encouraging the participation of private sector for large scale developments at all levels. As a result, Maharashtra has attracted a large share of FDI as well as domestic industrial investments and continues to remain a favored destination for both types of investors (Bajpai and Sachs 1999). The industrial giant such as Tata Group and Bajaj Group, who have shown strong interests in wind investments, are based in the state. The state has offered investment incentives in infrastructure, fiscal, and thrust industries areas that created good infrastructure, including the state power grid system that has contributed to high-technical wind resource potential of the state.

Other States

State policy incentives have been the largest market driven factor in other states as well.

- The early market development in Gujarat was due to its early placement of state policy, but the market was not as large as Tamil Nadu because Gujarat did not allow the third-party sales in early years. The complete state policy withdrawal from 1998 stopped the market from the year. The market resumed again with a new policy from June 2002.
- The market in Karnataka has grown greatly after 2001 due to a new policy with capital subsidy and high feed-in tariffs. As a result, the state has high percentage of wind power sold to SEBs, instead of captive use (Consolidated Energy Consultants Ltd. 2005).[98]
- The market in Rajasthan started with the first state policy implementation from 1999, but has grown dramatically with a new policy, which cleared the tariff structure for the period of 20 years. Unlike other states, more than 95% of installed capacity has been for sales to SEBs due to its high feed-in tariffs (Consolidated Energy Consultants Ltd. 2005).
- Utter Pradesh, West Bengal, Kerala, and Madhya Pradesh have not experienced much success in wind market development, mainly due to their unattractive policy measures and general policy uncertainty, along with their lagging attitudes toward political and institutional reforms.

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[97] Those industries could save INR 2.5 million per year by investing captive power consumption and third-party sales in wind energy development in Maharashtra (MEDA, 2002).

[98] Although the data from the states were no available, 100% of installed capacity by Suzlon (up to March 2005) and 70% of that by Enercon (up to June 2005) were for sales for SEBs in Karnataka (Consolidated Energy Consultants Ltd. 2005).

Role and Effects of Policy and Institutional Factors on Indian Market Growth

Effects of Institutional Settings

The strong market fluctuation and segmentation in India is largely due to its institutional setting of the power sector. Diverse state policy incentives, specific to each state, have created diverse economics environment. As many detailed policy decisions are up to each state, there was persistent inconsistency between national policy and state policy. In addition, power transmission across states is not generally permitted; the absence of cross-state wheeling for captive power consumption confines the benefits of wind installation within one state. These factors created a number of small and segmented markets. Diverse financial and technical conditions of SEBs exacerbated the market segmentation as well. In such environments, political uncertainty is quite large. The exponential market growth since the 2003-04 year has been mainly due to the implementation of the Electricity Act of 2003, which cleared many uncertainties regarding electricity pricing structures and set a clear future direction of renewable energy generation nationwide.

The Indian market fluctuation has been also greatly influenced by the limited and distorted form of power sector privatization and commercialization. In general, under commercialization, governments maintain ownership of power utilities but remove subsidies and preferable policies, while requiring full recovery of capital, operations and maintenance costs. Privatization follows commercialization, and can include sale of existing facilities to private firms, the purchase of electricity from private power producers, and independent regulation (The President Committee of Advisors on Science and Technology (PCAST) 1999). In the economic reforms since 1991, however, India took quite a mishmash process; a part of privatization took place in private sector power generation, while commercialization was incomplete, leaving cross-subsidies and preferable policies in electricity pricing and not targeting the recovery of capital, operation, and maintenance cost in general. Thus, the hasty power sector liberalization process posed larger costs later by creating the self-contradictory mechanisms, affecting the wind energy market growth negatively in the process.

Effects of Policy Incentives on Investment Mechanism

The most outstanding character of the Indian wind energy investment mechanism is its high dependency on tax saving measures. Although creating the IREDA revolving fund and soft loans, bringing technologies from foreign manufacturers by encouraging FDI, and lowering the import duty on wind turbine components greatly helped the creation of market, the subsidy-driven mechanism by tax saving measures has made profitability and viability of project almost irrelevant for investors. This is well-illustrated by the strong relationship between the first-year tax saving and installed capacity during the first boom years.

However, this initial structure could not last long. The low-performance oriented mechanism paid high price. The structural break was caused by the sudden policy change by lowering tax benefits and placing the quality assurance measures in order to correct technical and economic problems of the initial mechanism. However, these counteracting measures pulled the market to the opposite direction too fast and too strongly. The abrupt policy change only added political uncertainty to the already problematic mechanism; the market adjustment was slow and the lost confidence could not come back quickly.

The continuous improvement of quality assurance measures and the SEB reform efforts have been paid off by the gradual return of investor confidence. However, the main investment mechanism has not been changed. It is very difficult to pin point the causes of market recovery quantitatively. Although the influence of the first-year tax saving on capacity development has become much smaller, it still plays an important role in the investment economics because many projects cannot even produce positive IRR without the subsidy. The recent changes in state policy incentives as a result of the SEB reforms and the 2003 Electricity Act have shown the potential of transformation of this subsidy-driven investment mechanism into a more performance-based investment mechanism. In states such as Karnataka and Rajasthan, the higher feed-in tariffs and the ensured third-party sales options are providing opportunities for wind energy projects to be viable as non-captive power generation plants. Offering higher feed-in tariffs or other performance-oriented incentives will be very important to change the current subsidy-oriented investment mechanism in the future.

Structural Break and Market Size

The market recession from the 1996-97 year is considered an important reason behind the change in the structural relationship between capacity development and new technology introduction examined in Section 6.3. It is true that the beginning of the Indian market recession from the mid 1990s seems to correspond to the natural transformation point of structural relationship between installed capacity and new turbine introduction, as the frontier was moving toward larger-capacity turbine introduction at the time. However, as mentioned in the summary of Section 6.3, if turbine upscaling at the frontier were the only reason behind the structural break and if those newer and larger capacity turbines were introduced to India in the late 1990s, the new relationship could have shown the increased capacity installation even if the number of turbine installation were somewhat reduced. Yet, in reality, most of medium and large-capacity turbines that became dominant at the frontier in the mid 1990s were not introduced to the Indian market during the recession years, as examined in Chapter 5.

The new structure after the 1996-97 year showed the reduction of both installed capacity and the number of new turbine introduction. This means that as the investments to wind energy in general were stagnated, the Indian market simply lost the power to attract the introduction of newer and larger models, which required stronger and larger investments.

6.4.4 Effects of Market Demand Characteristics on Technology Development and Diffusion in India

This part examines the market demands derived from the Indian specific investment mechanism and conditions and their effects on technology development and diffusion.

Technology Driving Market Demands in India

Cost Reduction Demands

Similar to Denmark and Germany, the cost reduction demands to reduce initial capital investment, repairs, and O&M costs, have always existed in India, especially from serious investors. In addition, the ownership of one wind turbine in wind farm in India is usually one company, while one turbine can be owned by many individuals in Denmark and Germany where the cost of turbine can be spread over many investors. This makes the demands for capital cost reduction strong in India to make the economics better for serious industry investors.

Weak Technology Demands in the First Boom Years

Although the cost reduction demands existed, the investment mechanism in the first boom years simultaneously created a totally opposite demand, as already mentioned. Many investors did not care for operation of wind plants and their demands for technological efficiency was extremely weak; they had no interests in taking full advantage of available wind resources. Also, there was no government policy to check the quality of technologies used in project and project economics viability. There were no efficiency improvement demands from these bogus investors.

Demands for Higher Level Project Execution Technology – After the First Boom Years

While the bad practice of importing second-rated turbines and leaving them without operation caused the decline of investor confidence in wind power project and technology, many technical problems also contributed to low performance during the first boom years. One of the reasons was inadequate understanding of wind resources and micro-siting that turned out to be state-of-the-art technique, which needed to be learned from experiences. During the first boom years, the understanding of location-specific aspects of wind resources was limited due to inadequate information. The National Wind Assessment Program was not created to provide the data necessary for micro-siting. Technical understanding of developers about micro-siting was also fairly limited at the time. After the first boom years, serious investors began demanding improvement of wind resources estimation, energy prediction and optimization technology.

A series of project and technology quality assurance measures by MNES from 1995 spurred this demand too. Site selection and micro-siting, selection of equipment, means of financing, annual energy output, cost of generation, and planned operation and maintenance systems became required to be included in the detailed project report (DPR) submission. On top of these increased tasks, the short lead time required by the Indian tax mechanism have also contributed to creating the market demands for higher technological capability and improvement of wind project execution technology after the first boom years.

Demands for Efficiency Improvement – After the First Boom years

Besides wind resources estimation, energy prediction and optimization as well as project design and planning technologies, there were many other technical issues needed to be improved. It was the only way of regaining the lost investor confidence after the first boom years. In order to improve technical performance of wind turbines, MNES mandated the turbine approval and certification by the recognized foreign testing and certification centers for all projects from 1995, and has placed the CUF improvement as one of core R&D subjects (MNES 2004). Serious investors also began demanding higher quality components and turbines in order to reduce failures and repairs, lower the insurance costs, raise CUF, and improve the economics.

Demands for Low Wind Technology

Wind resources in India are low wind, similar to the inland states of Germany, but even lower. The low wind condition of India makes higher capacity turbines more profitable, as mentioned in Section 6.1. India has had the potentially strong demand for larger and higher efficiency turbines that make low wind operations more profitable.

Demands for Weak Grid Technology

A large part of wind energy development in India has been concentrated in rural areas where the existing T&D grids are weak. While the power quality at wind turbine connection points is poor, the connected wind turbines can also worsen the power quality further because grid reinforcement for turbine integration is insufficient; there is the mutual influence between weak grid and wind turbines. This creates the market demands for both grid improvement and wind turbines designed to compensate the weak grid conditions.

This demand is in a sense similar to higher-power quality demand posed by the German utilities. While the German utilities did not pose extra charges, however, many SEBs in India began imposing additional charges on power consumption by wind plants during both peak and off-peak hours. In addition, the general inadequacy of power facilities such as the lack of substations and the weak grid system also often caused the shutdown of power generation and contributed to the loss of revenue. Considering such financial pressures, the potential demands for weak grid technology has been quite large in India.

Technology Transfer and Development in India as a Result of Market Demands

Several market demands found in India are similar to those in Denmark and Germany, including the cost reduction demands, the efficiency improvement demands, the demands for low wind technology, and the power quality improvement demands. Meanwhile, the land development pressure for technology upscaling, the offshore development demands, and the environmental demands in noise reduction and environmentally friendly production seen in Europe have not been present in India. In contrast, there was the gold-plating demand in India, which was not seen in Europe.

Gold-Plating Demands and Hindered Technology Development

The gold-plating demands greatly hindered the Indian industry in building local production capacity and capability. First of all, many joint venture companies established between 1993 and 1995 did not build any local production capability, as they were just importing wind turbine sets and components and assemble them on sites. Secondly, project execution technology capability was not advanced by these developers either, during the first boom years. In addition, the gold-plating demands diminished many opportunities for introducing better-quality turbines; instead the early Indian market was flourished with a large number of low-quality and second-hand turbines. During the first boom years, the entire industry lost technological capacity building opportunities that could have been materialized otherwise.

Improvement in Project Execution Technology

At first, the transfer of project execution technology was rather difficult due to the differences in investor profile and investment mechanism between the frontier and India. The experiences accumulated in the professionalized mechanisms of Denmark and Germany, especially in terms of financial aspect of project planning as well as permission processes, were not useful in India at all. The difference in wind regimes also made the transfer of knowledge for technical aspect of project execution difficult (Twele 2005).

Project execution technology in India after the first boom years, however, has greatly improved. Both the policy and market demands for improvements in project planning/O&M/repair capability and for turnkey provision capability increased since the mid 1990s, and they have helped the industry advance and introduce higher project execution technology from the frontier. The foreign collaborators that decided to stay in India after the first boom years helped their Indian partners more actively cultivate these skills and know-how further by providing additional supervised trainings (see Section 6.7). Project monitoring recommended since 1995 and mandated in 2000 also spurred the industry to improve project execution capability and knowledge in understating the site conditions and micro-siting related issues. The advancement of software products that support project execution are introduced and helped raising the level of project execution in India as well.

Slow and Limited Introduction of Large-capacity Turbines and Variable Speed Turbines with Pitch Regulation

As mentioned in both Chapters 5 and this Chapter already, the low wind condition of India makes higher capacity turbines more profitable. In addition, variable speed turbines with pitch regulation and synchronous converter or power electronics have the great advantages for achieving higher energy capture and higher efficiency in low wind conditions, reducing dynamic loads on drivetrain lessening the mechanical problems, and clear many weak grid problems. However, despite this suitability, the introduction of turbines with these features lagged behind since the mid 1990s.

Limited Effects of Efficiency Improvement Demands

In case of wind energy, to a certain extent, there is a choice between a relatively stable power output (close to the design limit of generator) with high CUF and a fluctuating high energy output with low CUF. For example, at a very windy location, substantially larger annual production can be realized by using larger generator with the same rotor diameter, although it lowers CUF by using less of the generator capacity. Whether it is worthwhile to use a relatively large generator with lower CUF depends both on wind conditions and on the prices of different turbine models (Danish Wind Industry Association 2003). However, the case of India does not match either pattern; smaller capacity generators are run at low wind sites, creating low annual power production.

Despite the demands for CUF improvement, the factor still floats well below the European average of 25%-30%.[99] This is largely due to the limited introduction of larger and more efficient turbines. Turbine upscaling, the largest source of cost reduction at the frontier, has not happened in India and did not bring the benefits of more economical project operation. Technologically and economically more efficient pitch-regulated, variable speed turbines are not dominant in India. As a result, the Indian CUF and turbine productivity have not improved so much. Low CUF by older and smaller-capacity turbines is still prevailing.

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[99] Consolidated Energy Consultants Ltd (2005) estimates CUF of older and less efficient turbines installed at the low wind sites, which is more common in India, to be 18%, while CUF of newer and more efficient turbines installed at high wind sites to be 26%.

Effects of Cost Reduction Demands

The cost reduction demands for small-capacity turbines introduced during the first boom years was largely satisfied by rapid and high-level indigenization of turbine assembling as well as component production. However, the effects of cost reduction through local production have been limited for medium- and large-capacity turbines as well as higher-value components, as described in Chapter 5.

Capital cost per MW has not changed since the early 2000s in India; the slow indigenization of high value components contributed to this stagnation. The limited effects of technology indigenization efforts for cost reduction have made wind investment in India still very expensive, compared to Denmark and Germany. The market recession and market uncertainty also slowed down the expansion of production capacity, which did not increase from the annual 500MW level since the 1998-99 year until the 2003-04 year (750MW level); thus, the cost reduction through the increase of production scale was also limited since the late 1990s. Installation cost in Denmark and Germany was estimated approximately USD 0.36/kWh, while that of the Indian figure was USD 0.51/kWh in 2002 (Consolidated Energy Consultants Ltd. 2002).[100]

Limited Effects of Market Demand Characteristics

The above examination shows that in general, the effects of market demands for efficiency improvement, cost reduction, and low wind technology on the Indian technology have been fairly weak. Despite the similarity of demand characteristics with the frontier, they did not induce technological change through replicable technology transfer.

6.4.5 Section Summary

Missing Elements – Market Size and Certainty

In Denmark and Germany, the technology has been developed to satisfy specific market demands; the market demands are the technology driver. On the other hand, despite the similarity of characteristics of various market demands, the introduction of larger and more advanced turbines to India have been limited.

The largest reason behind the difference between the frontier and India was not market demand characteristics but market size. It was the regional European market, especially the shear market size of Germany, which strongly pulled the technology development for the Danish and German manufacturers. Besides Germany, there were other stable markets in Europe, e.g., Denmark and Spain. The size of regional market has been growing continuously and this created a fairly stable market environment in Europe. The market size was the factor that pulled technology development to the direction that the characteristics of market demands induced.

In addition, the beginning of the Indian market recession since the mid 1990s reduced the market pulling force in India. As a result, larger investments required to introduce the same number of newer models to the market did not happen.

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[100] The original figures were INR 17.80/kWh for Installation cost in Denmark and Germany and INR 25.14/kWH for India (Consolidated Energy Consultants Ltd. 2002). The USD figures were calculated by exchange rate 1 USD = 48.86 INR (6/30/2002 rate).

Yet, it is also true that market size alone could not pull technology development continuously and create the replicable technology transfer demands if there were no prospect and certainty for the future. Technology development of wind turbines takes time; at least a couple of years of R&D are necessary for introduction of new models. The continuity and certainty of the market is necessary to support constant turbine upscaling and upgrading.

And the large market size and the market certainty and continuity were the missing elements in India; even though many market demand characteristics are similar to those of the frontier, without sizable market and its puling power, technology upgrading through replicable technology transfer did not happen. Although production indigenization is important to reduce turbine cost, technology providers did not invest in building new production facilities tailored for newer models because the market prospect was too small and too weak.

In addition, even though larger-capacity turbines can produce more power more efficiently, they cost more in installation. This makes operating them in a collective manner in large wind farm very important to save O&M costs through economies of scale; it is difficult to bring large-capacity turbines to the market with limited prospect of economies of scale. Thus, it is natural that the firm with the largest market share (Suzlon Energy Ltd.) offers the largest-capacity turbine in the Indian market. However, in general, the market prospect for new production facility investments and economies of scale was too small in India.

Thus, the Indian market has been too small, too weak, and too uncertain to pull the investments in technology upscaling and upgrading and replicable transfer from the technology frontier, especially during the late 1990s and the early 2000s when much important technological advancement was made in Europe. The lack of prospect and the strong uncertainty toward future market development as well as the absence of economies of scale have made many technology providers hesitant to bring larger-capacity turbines and newer technologies to India. The small market made all technology driving demands insignificant.

Role and Effects of Policy and Institutional Settings on Demand-Pull Technology Development and Transfer in India

The wind market is policy driven; the market of wind energy is basically triggered by policy incentives. While policy clarity and continuity that support the continuous market prospect has been the most important factor behind the successful technology development and diffusion at the frontier, the Indian investment mechanism was created to attract industry investors whose primary drive has been tax management and escape from unreasonably high electricity prices posed on them. Although this created the strong market growth in the early 1990s, without any proper mechanism to prevent the abuse of government incentives, the market created extremely weak technology driven demands. The strong dependency on investment incentives in the beginning was difficult to recourse.

After the first boom years, the problems in policy, market and technology were mounted. Many investors did not find wind investments attractive anymore due to the sudden withdrawal of tax incentives, the low economic performance, and the rising O&M/repairs/insurance costs because of numerous project failures during the first boom years. Instead of investing in further technology improvement, many of them just left wind, as their primary investment driver, the lucrative tax savings, was gone.

The situation was more difficult for the remaining serious wind supporters. Although the government continuously provided various incentives, the reduced tax incentives, the raising interest rates, and many miscellaneous charges sank the market for the next three years, along with the problematic finance and pricing strategies by SEBs caused by the limited and distorted power sector commercialization and privatization that have reduced the attractiveness of wind investment by adding policy inconsistency and uncertainty at state level. The inconsistency with the central government policy was not improved either, as the entire power sector of India needed to embark on the very serious reforms. In India, market continuity and certainty for wind were far from reach under such conditions.

The setback between 1996 and 1999 was devastating for the Indian technology upgrading through replicable technology transfer, because there were simply no attractive markets to pull numerous technological advancements made at the frontier during this period. The regional market demands were also weak, not helping utilize the established Indian production facilities and augment production capability by bringing new export orders. Although the market gradually improved from 2000, India was not the primary investment spot for technology upgrading by technology providers at the frontier, as the market size has been far smaller, compared to the combined regional European markets. The market uncertainty persisted until the enactment of the Electricity Act in June 2003 that finally rationalized the institutional responsibility and clarified the direction of the power sector. In particular, the restructuring of problematic SEBs and relieving them from tariff making and implementing responsibility have had large and positive effects. However, the policy and institutional inconsistency and uncertainty after 1996 have created the ineffective demand-pulling force in the market for technology transfer from the frontier.

Section 6.5: Transformed Technological Characteristics and Industrial Competitiveness Management and Their Effects on Technology Development and Diffusion in India

This section focuses on the effects of the changing technological characteristics and industry structure/competitiveness management in both Europe and India on cross-border technology transfer and the growth of technology gaps.

6.5.1 Effects of Indian Policy and Competitive Strategy and Industry Modification at the Frontier on Indian Industry

Indian Industry Formation and Structural Modification

Although there were three private firms in the wind turbine manufacturing industry already in the 1980s in India, it was the economic reforms after 1991 that triggered the industry expansion.

Industry Formation since 1993

The Indian wind turbine manufacturing industry has been largely formed by business diversification of local companies through technical collaboration agreements (joint venture or license agreement) with manufacturers from the technology frontier. Table 6-20 shows that turbine manufacturer entry and exit in India, and it is clear that most of the Indian firms have had foreign technology collaborators. BHEL, the wind energy division of which was formed in 1985, was the exception in the beginning, but the firm began engaging in license agreement with Nordex from 1994 after successfully developing turbines up to 200kW on its own. Both Vestas RRB and NEPC Micon were joint ventures from the beginning.

Table 6-20 illustrates the concentration of new entry between 1993 and 1996, all with foreign collaborators except one firm (Himalaya). However, the majority of those firms exited from the Indian market between 1996 and 1999, which corresponds the three-year market slowdown. The reasons of exit varied; while some Indian companies lost their technology providers due to their business exit at the frontier, other collaborations seemed to come to an end simply because of the market slowdown and high risks of further investment in India although exact reasons are unknown. For several foreign manufacturers, it seems that the Indian market slowdown and their own status change at the frontier happened coincidentally within a relatively short timeframe. Several frontier firms such as Micon and Tacke reportedly had financial, technical and ethical problems with their Indian partners.[101] Some Indian firms (C-WEL, Elecon, and Pioneer) show the switching of foreign collaborators over the years as the position of their original technology providers at the frontier had weakened.

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[101] For example, Flovel and Tacke engaged in the bitter court dispute over the compliance of their joint venture agreement each other after Tacke dissolved their partnership. Tacke was restrained by a High Court injunction from doing business in India in late 1995 (Wind Power Monthly. 1996a). Micon dissolved its joint venture with NEPC in 1997, as the Danish firm was reportedly strongly dissatisfied with the Indian partner's business practice. After that, NEG Micon and NEPC got into a court dispute regarding manufacturing rights of the turbines introduced by Micon during their joint venture years. In 1999, the Chennai High Court ruling permitted NEPC the exclusive right of manufacturing NEG Micon turbines up to 400kW in India (Wind Power Monthly. 1999c).

Table 6-20: Turbine Manufacturer Entry and Exit in India

Entry Year	Indian Firm	Foreign Collaborator	Exit Year
1985	BHEL	----	
1986	**Vestas RRB**	**Vestas (Denmark)**	
1987	NEPC Micon	Micon (Denmark)	**1999***
1993	AMTL	Wind World (Denmark)	*****
1994	**BHEL**	**Nordex (Denmark)**	**1999****
	Elecon	HMZ (Belgium)	**1998**
	TTG Industries	Husumer Schiffswerft (Germany)	*****
1995	ABAN Loyd	Kenetech (USA)	**1997**
	Das Lagerwey	Lagerwey (The Netherlands)	**2000**
	Enercon India	**Enercon (Germany)**	
	Flovel	Tacke (Germany)	**1997***
	Grematch CNC	Pegasus (Germany)	**1995**
	Himalaya	----	**1996**
	Windia	Nedwind (The Netherlands)	**1998**
	Pioneer Wincon	Wincon West Wind (Denmark)	*****
	REPL	Bonus (Denmark)	**1997**
	Sangeeth	Carter (USA)	**1997**
1996	JMP	Ecotecnia (Spain)	**1996**
	Rayalseema	Mitsubishi (Japan)	**1996**
	RES	AWT (USA)	*****
	Suzlon	Südwind (Germany)	**1996**
	Textool	Nordtank (Denmark)	**1996**
1997	Kirloskar	WEG (UK)	**1998**
	Suzlon	-----	
1998	**NEPC India**	-----	
1999	**NEG Micon (subsidiary)**	**NEG Micon (Denmark)**	
2000	**C-WEL**	-----	
2001	C-WEL	DeWind (Germany)	**2002**
2002	**Elecon**	**Turbowind (Belgium)**	
	GE Wind Energy (subsidiary)	**GE Wind Energy (USA)**	
2005	**Pioneer Asia**	**Gamesa (Spain)**	

Bold letters show the firms active as of March 2005.

Entry year is defined as the year that the firm installed its first turbine, and exit year is defined as the firm installed its last turbine in this table. Although the original source shows some other manufacturers on the list, this table only included the ones that installed turbines and those locations and dates were verified by the data in the source.

* These collaborations already ended in the late 1990s or before the specified exit years. However, the turbines originally provided by the providers were continuously manufactured and offered in India independently by the Indian firms after their partnerships ended. Flovel stopped the installation of turbines all together in 2001.

** Nordex and BHEL ended its first license agreement in 2002 but a new agreement was in place from 2003. However, no installation was made after 1999 until March 2005.

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005).

Only four technology collaborations established before 1996 (excluding TTG Industries) survived in 2005. The new entry from 1997 includes two subsidiaries, which are 100% owned by foreign manufacturers (NEG Micon and GE Wind), and three independent firms, two of which (Suzlon and NEPC India) became independent after the dissolution of their original partnerships with foreign technology providers. NEG Micon India (subsidiary of NEG Micon) and Vestas RRB are both still in business separately in India, as their new parent company Vestas has not announced any organizational plan in its Indian operation publicly as of the end of 2005.

Effects of Industry Modification at the Frontier on Indian Industry and its Technology Options and Sources

The Indian business entry and withdrawal have been strongly influenced by the business decisions as well as the status of technology providers at the frontier. Table 6-20 shows that total 16 technology collaborations formed since 1993 practically ended their relationships by 1999 (including TTG Industry-HSW). Out of the 16 collaborations, only six foreign collaborators survived at the frontier as of 2005 (Bonus/Siemens, Wincon West Wind, Ecotecnia, Mitsubishi, DeWind, and Lagerwey) and all other firms exited from the business during the 1990s. Their exit from India corresponded to not only the Indian market slowdown but also their weaker presence at the frontier. Even out of these six survivors, however, five fell into somewhat obscure existence in the industry by 2005, and only one of them, Bonus/Siemens, remains as technologically and financially strong industry player. Bonus made a conscious decision of staying out of the Indian market and has kept doing so since 1997. Thus, most technology providers that left India by 1999 also did not survive the intense technology competition at the frontier during the 1990s; their business exit at the frontier certainly consolidated the available technology options in general and reduced the potential technology introduction to India.

As for technology introduction by those collaborations ended by 1999, none of the following WEGA II participants, Bonus, Lagerwey, Nedwind, Micon, Nordtank, and Tacke, introduced large-capacity turbines before their exit from India, although they brought many models under 400kW. Their MW-class turbines were just coming out for the frontier market, but the timing coincided with the Indian market slowdown. In terms of medium-capacity turbines, Micon, Nordtank, and Nedwind brought turbines between 500kW and 600kW, and non-WEGA participants, Wind World, Kenetech, and WEG brought turbines between 400kW and 500kW too. However, only the 410kW models by Kenetech and the 550kW models by Nedwind had more than ten installations in India. All other turbines did not leave significant footprints on the Indian market and the industry, and all the Indian partners did not continue manufacturing or installation of these medium-capacity turbines after the collaborations ended.

The significant technological innovations that India missed by the exit of the WEGA II participants, which had relatively strong technological and financial position in the mid 1990s, were: 1) limited-range variable speed turbines with DFIG introduced at the frontier in 1996 by Tacke; 2) medium-capacity, full-range variable speed turbines with synchronous generators and full-scale converter by Lagerwey; and 3) all innovations made by Bonus since 1995, especially active stall regulation introduced at the frontier in 1996 and full-range variable speed turbines with WRIG and full-scale converter introduced in 2003.

Roles and Effects of Policy on Industry Formation and Structural Modification in India

Unlike the Danish and German governments, GOI more actively employed industrial policy measures for wind energy industry development from the beginning. In particular, new FDI and trade policy implemented as a part of the 1991 economic reforms played important roles.

First, the new FDI policy that reduced barriers for foreign investment and foreign corporation taxes made the formation of joint ventures easier, but there were still the rules prohibiting foreign manufacturers to set up a shop independently in India. Therefore, foreign wind turbine manufacturers actively sought for Indian partners for their market entry. While GOI thus strongly encouraged the formation of joint ventures with foreign companies, cost reduction by technology indigenization, which benefited both technology providers and their Indian partners, was another driver behind many serious joint venture/license agreement formations. The new trade policy since 1993 also played a role; although the policy generally reduced import duty for critical components such as rotor blades and electronics of controllers to zero, the duty free status was applied only on up to ten components and this still made the import of the whole technology expensive. Local manufacturing and technology transfer through technical agreements was the solution for foreign firms that seriously contemplated the market expansion in India.

The policy strategy, which lowered the custom duty on imported components, is opposite to the ordinary infant industry protection strategy of import substitution, which uses high custom duty in order to create domestic demand for goods and protect infant domestic firms. However, the low custom duty strategy was taken because many components could not be manufactured domestically in India at the time and the domestic wind market was too small to make the high custom duty protection viable. Thus, the lowered custom duty structure was another strong push for many joint venture formations.

The use of revolving fund by IREDA also contributed to the formation of diverse technology collaborations, as it effectively eliminated the danger of bilateral concessionary financing, which often distorts the market and promotes technologies from the donor's domestic industry. The revolving fund, which pooled financial resources from various multilateral and bilateral sources together, has given tremendous freedom for the Indian investors and manufacturers to choose their technology from diverse countries of origin and avoided potential technology-lock-in situation.

The Indian industry consolidation during the late 1990s happened mostly due to the dissolution of technology collaborations. In terms of the effects of policy and institutional setting on the industry consolidation, the institutional setting for taxation and various quality standards placed from 1995 were responsible in eliminating many low-capability firms and collaborations. The short six-month lead time of project development makes the initiation of wind power project a highly stressful and often expensive business due to necessity of rapid transactions. In addition to this, the increasingly tightened MNES requirements for project and technology clearance and approval since 1995 have further increased transaction costs and time pressures on wind power project developers and investors. Under these circumstances, capability to perform turnkey projects became a key determinant of survival of manufacturers. Offering the guarantees to products and services also became necessary requirement for manufacturers to attract investors.

Many foreign providers were not keen about investing such technological capability building for the Indian partners under the strong market uncertainty. This was an important part of the reasons that prompted business exits and consolidation of the Indian wind turbine manufacturing industry.

In addition to the reduction of the number of manufacturers, this industry consolidation process created an entry barrier for small-and-medium sized enterprises (SMEs), which do not have high financial and technological capability to perform turnkey projects. MNES and IREDA together with the Ministry of Industry and Commerce have been promoting SMEs in wind and other renewable energy sectors by offering various fiscal and financial incentives while eliminating restrictions on firm location, products, and services (MNES, 2001b). However, the restriction over equity share holding, which limits capital from any industrial undertaking of both foreign and domestic to 24% for SMEs, as well as the market slowdown since late 1996 made it very difficult for them to enter wind turbine manufacturing/wind energy development business.

Relationship of Industry Transformation with Structural Break in Capacity-Turbine Introduction Relationship

The Indian industry transformation mentioned above corresponds the second structural period of the relationship between capacity development and new turbine introduction. The reduction of the number of manufacturers and the industry structural change were triggered by the structural break of the 1996-97 year, which was primarily caused by the market slowdown set off by the sudden policy change. There were chain reactions in the event. The European industry consolidation coincidentally contributed to the transformation.

The capacity-turbine introduction relationship was also shifted, partly because the number of manufacturers, hence the number of technology options, was reduced by the industry structural transformation. In this regard, the structural shift to the second period examined in Section 6.3 was due to the combined reasons of market and industry transformation.

6.5.2 Technology Transfer and Development in India by Surviving Manufacturers and New Comers

As the number of manufacturers decreased since the mid 1990s, technology development and diffusion in India depended on the surviving manufacturers and new comers.

Technology Control - Type of Technology Agreements/Technology Ownership and Technology Transfer Results

Although the formation of joint ventures or license agreements was the policy and market requirements for foreign manufacturers to enter the Indian wind market in the early and mid 1990s, this condition eroded from the late 1990s. In 1997 GOI permitted the market entry by NEG Micon through the establishment of 100% subsidiary, after Micon and NEPC ended their joint venture NEPC Micon and Nordtank and Micon merged into NEG Micon in Denmark. GE Wind founded its subsidiary in India in 2001. Several independent Indian manufacturers were begun formed as well (Suzlon, NEPC India, and C-WEL).

Table 6-21: Firm/Technology Ownership and Introduced Turbine Capacity by Surviving and New Manufacturers in India

Divided Firm/Technology Ownership (Joint venture/License agreement)			**100% Firm/Technology Ownership (100% subsidiary/Independent Indian firm)**		
Turbine Make and Capacity	**Introduction**		**Turbine Make and Capacity**	**Introduction**	
	India	Europe		India	Europe
Small-Capacity (less than 500kW)					
Vestas RRB **225-50kW** (JV)	1993	1988	C-WEL **250kW** (I)	2000	
Pioneer Wincon **250kW** (JV)	1995	1995			
Enercon India **230kW** (JV)	1995	1996			
Enercon India **300kW** (JV)	2005	2005			
BHEL-Nordex **200kW** (LA)	1994	N/A			
BHEL-Nordex **250kW** (LA)	1995	1994			
Medium-Capacity (between 500kW and 1MW)					
Vestas RRB **500kW** (JV)	1995	1993	NEG Micon **750kW** (S)	1999	1998
Pioneer Wincon **755kW** (JV)	2002	1998	GE Wind **600kWa** (S)	2002	1998
Enercon India **600kW** (JV)	2001	2001	GE Wind **750kW** (S)	2002	2001
Enercon India **800kW** (JV)	2005	2005			
Pioneer Asia **850kW** (JV)	2005	2004			
NEPC-Norwin **750-180kW** (LA)	2005	1998			
C-WEL-DeWind **600kW** (N/A)	2001	1997			
Elecon-Turbowind **600kW** (N/A)	2002	N/A			
Large-Capacity (larger than 1MW)					
			NEG Micon **950-200kW** (S)	2002	2001
			NEG Micon **1.65MW** (S)	2004	2003
			GE Wind **1.5MW** (S)	2004	1999
			Suzlon **1MW-250kW** (I)	2001	2003
			Suzlon **1.25MW-250kW** (I)	2002	2003
			Suzlon **2MW-250kW** (I)	2005	2004
JV = Joint Venture, LA = License Agreement, S = Subsidiary, I = Independent					

Table 6-21 shows the relationship between firm/technology ownership structure and turbine capacity introduced to India. Medium- and large-capacity turbines are mostly introduced from 2001 after the worst of the market recession was over. However, more importantly, it is obvious that technology control through ownership is strongly related to the introduced turbine capacity; the firms with 100% ownership of technology have introduced larger-capacity turbines than the firms with divided ownership structure. In particular, turbines over 1MW are only introduced by the firms with 100% technology ownership.

Tight technology control through the resistance of most foreign manufacturers to pass turbine licenses of 500kW and larger to their Indian joint venture/license agreement partners is obvious. It was sited as one of the most important reasons of delay of technology introduction to India in the 1998 EC report, "Market Analysis and Opportunities for Wind Energy in India" (Wind Power Monthly 1998b). When the introduction of medium-capacity turbines and their component production increased during the 2000s after several years of the EC report release, the frontier had already moved onto multi-MW class turbines. The tight technology control and delayed turbine introduction still continue until this day.

The low level of indigenization of high value components in India is also intended by technology providers to keep such portions of production on their sides. In addition, technology control by providers is imposed on not only new technology but also on already-transferred technology. Technological capability building in R&D or innovation is mostly limited by technology agreements; in many joint venture/license agreements, the technology licenses prohibit any in-house R&D in India and/or R&D collaborations with other companies and institutions in India (BHEL 2002).

Significant reasons behind such resistance for replicable technology transfer and technology upgrading in divided technology ownership are the tightened technology and proprietary knowledge control and competitiveness management at the frontier since the mid 1990s. First, joint venture relationships can be quite risky for technology provider; the risk was well-demonstrated by the growth of Gamesa Eólica, which absorbed critical technology through its joint venture with Vestas A/S. That is why the oversea market expansion by wind turbine manufacturers has been done mainly through the establishment of 100% subsidiary, wherever the local governments permit. Second, there is a difficulty of keeping good long-term joint venture relationships under the condition of constantly changing technology and industry competition. Joint ventures require strong mutual benefits between the partners, and they are usually materialized in production advantages (cost reduction) and/or innovation advantages (higher value input). In the beginning, the Indian partners could only offer production advantages derived from low labor cost and they were strong by the mid 1990s. Once the Indian market slowed down from late 1996, however, the production advantages diminished for the local market as the market size was reduced. In addition, this timing was coincided with the increasingly tightened control and management by wind turbine manufacturers at the frontier as a result of the intensified technology competitions. Thus, both the diminished production advantages and the intensified innovation advantage control by technology providers interrupted replicable technology transfer and technology upgrading to medium- and large-capacity turbines in joint ventures/license agreement firms.

On the other hand, 100% technology ownership firms have much smaller concerns over technology control. Although there are always risks for technology spillovers from employee turnovers, knowledge accumulation in individual can seldom exceed that in organization, in particular, in the business environment with the raised technical and financial barriers for entry and growth such as wind energy. Technology ownership and control are the strong reason behind why undivided technology ownership has shown the lead over divided technology ownership in technology introduction to India.

Strategic Role of Indian Partners/Manufacturers in Global Value Chain and Geographical Capacity and Capability Management and Sourcing

Although the Indian market slowdown diminished the production advantages by local labor, there is another production advantages that the Indian partners could have offered to keep and enhance joint venture/license agreement relationship benefits for their frontier partners; manufacturing high-quality products for export to meet the ever growing market demands outside India.

Although the exact export figures by the Indian manufacturers were not available, in general, the export from India has been weak. Again, the joint venture/license agreement manufacturers have not been active in export from India (Table 6-22). In particular, the export activity of Vestas RRB has been extremely weak, despite the large world market share of Vestas A/S. Pioneer and BHEL also have not shown any significant export activities. The only notable exception is Enercon India, which has been used by Enercon GmbH as an export base of generic turbine components from the beginning of their joint venture. Now, the production facilities of Enercon India have manufactured the blades for E-66 1.8MW, which is not offered in India, to export to Europe.

Table 6-22: Export Activity from India by Manufacturer

Manufacturer	Export Activities
Enercon India (JV)	First Indian manufacturer that exported blades and synchronous generators back to Europe during the 1996-97 year, and its 230kW Indian-made wind turbine was exported on March, 1998 to Australia, for the first time (MNES 1997a; MNES 1998). Continuously export to the European markets.
Vestas RRB (JV)	Very weak. Is expected to increased with the commission of new facility for blade and controller in 2005
Pioneer (JV)	No noteworthy export activity
BHEL-Nordex (LA)	
NEG Micon India (S)	Commissioned a new manufacturing facility for export of 950MW turbines to Europe and other locations in 2003 (Wind Power Monthly 2003d). However, due to the merger between Vestas and NEG Micon, the export did not happen as it was planned originally and the export decision was still pending as of the end of 2005 (Ramakrishnan and Balaji 2006).
GE Wind India (S)	Reportedly, assembling and exporting components to China and other European markets (Siliconindia.com 2005).
NEPC India (I)	Export orders from Turkey, Tanzania, Abu Dhabi, Kenya and Kazakhstan (Wind Power Monthly 2003e) for its 225 kW turbines
Suzlon Energy (I)	First Indian manufacturer that exported a complete wind project to overseas; the 12.5MW project using the firm's turbines shipped from Mumbai was exported to Huston, Texas in 2002.

JV = Joint Venture, LA = License Agreement, S = Subsidiary, I = Independent

As for subsidiaries, GE Wind has been reportedly increasing activities using the Indian production facilities as manufacturing hub for export. NEG Micon India has been planning to export since 2003 but it has not happened yet as of the end of 2005 due to the merger between NEG Micon and Vestas. The independent manufacturer NEPC India has also been receiving a string of export orders from other developing countries for its 225kW turbines, but the model does not have high-tech features of much larger-capacity turbines offered by manufacturers at the frontier.

Suzlon is another independent company that actively targeting export growth and offers its turbines on various international markets. Despite the efforts for export and international marketing, however, the firm's sale largely depended on the domestic Indian market; in 2005, only about 8% of its sales by capacity came from outside India. However, this dramatically changed in the first half of 2006 as three-quarters of its order comes from the markets oversea. Suzlon Chairman Tulsi N. Tanti explanes that a part of the reasons of this dramatic shift is the Suzlon's acquisition of Hansen Transmissions, a Belgian maker of wind-turbine gearboxes in

March 2006 (The Economist 2006). This was the second-largest foreign purchase ever made by an Indian firm and a part of strategy of backward integration to overcome the component supply bottleneck that has been the main barrier in the firm's growth, according to Suzlon (Suzlon Energy Ltd. 2006). The acqusition instantenously gave Suzlon an ability to manufacture the first-class gearboxes and to perform R&D required for new generation of wind turbines, as the products of Hansen range from outputs of 1.5MW to 3MW.

The weak export performance is an indicator that the Indian manufacturers have not played significant strategic roles in global value chain and sourcing/geographical capacity and capability management of their technology providers. Although the availability of finance to explore oversea market could be a reason for the general weak export performance, it is not a robust one. All the Indian firms have enough capital to support their export business development on their own if their technology providers seriously want them to do so. The independent Suzlon also had strong capital base from its parent group and the firm was listed publicly in summer 2005. The market development assistance offered through the IREDA Manufacturing Equipment Financing Scheme that can be applied to the promotion of export activities has been underutilized because the firms that target the export have enough capital to do so on their own (IREDA 2002d).

The more robust reason for the weak export performance has been the lack of sufficient technological capacity and capability of producing high-tech turbine components in India and strong concerns over the quality of the Indian-made components, as the Suzlon' case clearly illustrates. As described in Chapter 5, development of the Indian capability of production of medium- and large-capacity turbines are still weak; the import contents in higher-capacity machines are still very high and the Indian wind energy industry is still a net importer. Key components of MW-class wind turbines are imported (MNES 2004; MNES 2005). However, the technologies demanded in the frontier markets are far more advanced than those indigenized in India, and the Indian-made technologies have persistent high component failure ratios. With such deficiency in technical capacity and capability, the Indian facilities have not been as a part of global network to solve the strong supply-chain bottlenecks reported since the 2001 in the industry as a whole (Wind Power Monthly 2002b). The bottleneck still continues as the orders placed in 2005 is expected to be delivered only in 2008 (Danish Wind Industry Association 2005b) for the companies such as Vestas and NEG Micon, but their Indian facilities are not included in their global production networks and sourcing strategies. And due to the lack of reputation for high level capacity and capability, Suzlon have had a hard time to expand its market outside India until the acquisition of Hansen Transmission.

According to DWIA, specifically-tailored wind turbine components are not outsourced to developing countries for manufacturing, because their specification is very detailed and their production requires very high level technological capability. Local networks within Denmark make adaptation and improvement much easier. The Danish and German sub-suppliers are directly supplying their components to India and China today, also because the manufacturers cannot offer any guarantees to the locally produced components; internal quality control is impossible with the local production of gearbox/controller/generators within India or China. On the other hand, the manufacturers with already established global component sub-supplier networks such as Siemens (Bonus) have become using their local sourcing, which creates the cost advantages while keeping high level of technological quality (Danish Wind Industry Association 2005b).

Such conditions have contributed to the lack of forward linkages and demonstration effects for the Indian manufacturers. Without making more conscious efforts of meeting the higher quality demands, India has had only limited opportunities to improve the quality of production, and this further deters the chances to be a part of global value chain and sourcing network of technology providers, hence the chances of replicable technology transfer.

6.5.3 Effects of Transformed Technological Characteristics on Easiness and Cost Change Potentials of Technology Transfer

This part examines the effects of technological characteristics other than turbine upscaling itself on technology transfer from technological capability and cost perspectives.

Easiness of Cross-Border Transfer of Technology System and Components

The effects of easiness of cross-border technology transfer on the transfer results will be examined from technological management perspective, based on technological capability required to perform specific value chain activities and the level of system integration needs for specific technology. As examined in Chapter 5, many innovations were introduced to India on fairly limited basis by a few manufacturers with several years of delay. The transformed characteristics of wind energy technology innovations at the frontier are an important reason behind the delayed and limited technology transfer.

Easiness of Product Technology Transfer

In terms of product technology transfer, the increased systemic nature and system integration needs of wind energy technology and progressively more specialized design and function of components for specific models have made it extremely unlikely for components to be transferred without the introduction of the entire turbine models. Especially, the close relationship between the choice of rotor power regulation and the choice of rotor speed control, the necessity of integration of blade technology in materials/aerofoil designs and production methods, the correspondence of SCADA software to specific turbine controller, and the computerized design optimization of entire technology system make it impossible for these technologies to be transferred on individual component basis.

Easiness of Production Technology Transfer

As for production technology transfer, the Indian wind industry quickly indigenized small-capacity turbine production technology due to the combination of the following reasons besides the necessity of cost reduction: 1) relative simplicity of small-capacity wind turbine technology; 2) basic similarity of small-capacity turbine component manufacturing with other mechanical engineering parts such as gas turbines and electricity generators that made the component suppliers easily adopt foreign know-how; and 3) availability of capable and versatile engineers in India due to high level science and engineering education.

However, the increased high-tech nature of components in medium- and large-capacity turbines and their technological complexity require very high level of technological capability for production and adjustment. In India, they cannot be manufactured to the level that satisfies the guarantees that each manufacturer is required to provide to buyers. As a result, transfer and indigenization of production technology of more updated technology have been fairly limited, as already mentioned.

Easiness of Project Execution Technology Transfer

In terms of project execution technology, technology transfer has gotten easier with advancement of computer technology and software products. The limitation, however, can be posed by the system integration needs of project execution technology product, e.g., SCADA products. Still, many generic knowledge of project execution can be relatively easily transferred and accumulated, once initial differences are cleared.

Increased Difficulty of Component Technology Transfer

In general, cross-border transfer of individual technology components innovated at the frontier has increasingly difficult as their system integration needs and technological capability requirements have become higher and higher.

Cost Change Potentials by Cross-Border Technology Transfer

The cost reduction/increase potentials are another very important factor that determines the transfer results from cost management perspective. Costs can be reduced by reduction of labor/materials/transportation costs through relocating innovation/production/project execution activities, while they can be increased by initial and continuous investment needs on the relocation of various activities.

Cost Reduction by Project Execution Technology Transfer

Due to data deficiency, it is very difficult to examine the exact cost change potentials for various technologies by cross-border technology transfer. However, it is clear that the easiest and most cost-effective activity relocation is project execution technology transfer and that is why this value activity has been indigenized internationally. It only requires minimum facility investments, and project execution cost is reduced greatly by low cost labor in India. The continuous education cost is not extensive either, as the experiences accumulate locally and much of knowledge is inherently generic.

Cost Reduction by Innovation Technology Transfer

On the other hand, innovation activity relocation requires high initial investment costs in facility development. However, the labor cost reduction potential is large, as long as human resources with required high-level innovation capability are available and technology holders are willing to reduce technology control and take risks of releasing tacit knowledge from their original home grounds.

In general, this is not a case. Looking at the case of Suzlon, its core R&D facilities are still in Germany (nacelle) and the Netherlands (blade technology), while the Indian R&D facility engages in control software development with some European sub-suppliers such as MITA Teknik A/S of Denmark. In the case of Enercon, its core R&D facilities are also located in

Germany, although a support R&D facility does exist in India. These cases clearly illustrate that required innovation resources and human capability are still scarce in India. All other Indian manufacturers do not have innovation facilities. The needs for high-level human resources and technology control outweigh the cost reduction possibility through innovation activity relocation to a low labor cost country such as India.

Cost Reduction by Production Technology Transfer

The cost change potentials of various components by production technology transfer are most difficult to examine because of unavailability of such cost data due to its proprietary nature. It has been reported that local production of blade and controller (approximately 30-35% in value terms) planned to start in late 2005 at Vestas RRB is expected to reduce the cost of its wind turbines (225kW and 500kW) by 25% (Business Line Bureau 2005a) and local sourcing of gearboxes, alternators, brake systems and controllers, which currently imported by NEG Micon India and together accounted for 25% in value terms, would bring down turbine costs by 10-15% (Ramakrishnan and Balaji 2006). These numbers suggest that the cost reduction potentials vary according to components and their combination of indigenization.

Necessary Economies of Scale

Although the cost reduction potentials by indigenization are quite large mainly due to low labor cost (in particular for high value components such as blade and controller) and high cost of transportation, they also depend on how large the manufacturer can create the effects of economies of scale, which are determined by the manufacturers' market share and export status. For example, in order to make indigenization of blade production cost effective in India by creating economies of scale large enough, 300 per year production of blades for small- and medium-capacity turbines are required (Vestas RRB 2002). This explains why only three companies (LM Glasfiber, Suzlon, and Enercon India) could have blade manufacturing capacity and capability in India until recently; all the three firms have enough economies of scale through the Indian domestic market shares and/or export. The 2003 expansion of blade production facilities by Suzlon and the 2005 Vestas RRB decision of entering in-house blade manufacturing were prompted by the Indian market growth and its good future prospect since 2003.

Relocation Costs

In terms of cost increase potentials, the initial investment costs for relocation of production activities are large due to the necessity of setting up new facilities and education/training of employees.

6.5.4 Effects of Manufacturing Incentives on Cost Reduction and Technological Capability Building

Import Duty

Import duty can be used for different purposes; low import duty can be used as market stimulation policy by reducing the cost, while high duty can encourage indigenization of production. Table 6-23 shows the ratio of cost increase per total turbine cost for four imported components, calculated from the Indian import duty since 1993 (Table 5-23) and the approximate ratio of component costs in total turbine cost (Table 5-54). Table 6-23 illustrates that the duty increase during the 1997-1998 year from zero to 22% raised the cost of the four components by almost 10% in medium-capacity turbines.

The purpose of the raise was the stimulation of technology indigenization of high value components; GOI suddenly turned to the original use of import substitution. However, the change did not attain the goal; the duty change came too suddenly for the manufacturers and sub-suppliers to adjust their production capacity and capability, as they were not ready to manufacture many of high value components. Also the market at that time was too weak for them for additional investment. Although the raised import duties could have encouraged production technology transfer if the market was stronger, they only lowered the demand-pulling force for technology transfer by contributing to the further market slowdown.

Realizing their negative effects by the strong industry protests at that time, GOI lowered the duties in 1998 (IWTMA 2002). As a result, the cost increase was almost halved at least for these four components. However, technology indigenization has not advanced well, in particular for gearboxes and controllers, despite the lowered duties since 1998. In 2003, the duties for sensors, brake hydraulics and calipers, and flexible coupling were raised from 5% to 25% to encourage indigenization. They were lowered again to 5% in the following year as the attempt did not produce the hopeful result.

Table 6-23: Cost Increase by Import Duty on Four Components

Components (Approx. Ratio in Total Turbine Cost)		1993 | 1997	4/1997 | 3/1998	4/1998 | 3/2002	4/2002 | 3/2003	4/2003 | 6/2004	7/2004 | Present
Blade	Duty	**0%***	12%	9%	5%		
500kW 15%	Cost Increase		**1.8%**	**1.4%**	**----**		
1.5-2MW 17-20%		**----**	**----**	**1.5-1.8%**	**0.9-1%**		
Controller	Duty	**0%***	22%	9%	5%		
500kW 21%	Cost Increase		**4.6%**	**1.9%**	**----**		
1.5-2MW 8-9%		**----**	**----**	**0.7-0.8%**	**0.4-0.5%**		
Gearbox	Duty	**0%***	22%	9%	5%		
500kW 15%	Cost Increase		**3.3%**	**1.4%**	**----**		
1.5-2MW 13-14%		**----**	**----**	**1.2-1.3%**	**0.7%**		
Brake System	Duty	**0%***	22%	9%	5%	25%	5%
500kW 1%	Cost Increase		**0.2%**	**0.1%**	**0.05%**	**0.25%**	**0.05%**
1.5-2MW 1%		**----**	**----**				
Total 500kW	Cost Increase	**0%***	**9.9%**	**4.8%**	**----**		
of Four 1.5-2MW		**----**	**----**	**3.5-4%**	**2.1-2.2%**	**2.3-2.5%**	**2.1-2.2%**

* 0% duty applied to these components as long as the number of total imported component did not exceed ten.

The cost increase figures for 1.5-2MW in the 1990s and those for 500kW in the 2000s were not calculated because the cost ratios for these turbines were based on the numbers for turbines produced in different time frames.

Another conflicting use of import duty was 80% duty posed on blade raw materials between 1993 and 1997. In 1993 the Indian wind industry just began its formation, and it was blades that the industry most strongly pushed for indigenization for cost reduction. With the consistent efforts by the industry players to bring the frontier blade production to India, several joint ventures (LM Glasfiber India, Enercon India, TTG Industries, and Polymarin-Jyoti) were formed by 1996. However, GOI did not reduce the import duty on blade raw materials (glassfiber and resin). Blade raw materials require high technological capacity and capability for handling and temperature control for production, and it was not possible for any Indian firms at that time to handle without the inputs from foreign technology providers. This import duty raised the production cost 80%, wiping out the possible 20% cost reduction by low labor cost; the imported blades were cheaper than the ones made in India (Wind Power Monthly 1996c). The high duty made one joint venture Polymarin-Jyoti terminate the agreement without producing any blades at all and forced to slow down the business for LM Glasfiber India as well (Wind Power Monthly 1996c; Wind Power Monthly 1996d). After the removal of the 80% duty in 1997, the blade manufacturing advanced in India, especially by production at LM Glasfiber India and Enercon India.

Exercise Duty

As the record of import duty as manufacturing incentives has been mixed, the Indian exercise duty policy also shows inconsistency. The 1993 tax rule that set wind turbines exempt from excise duty and sales tax was in place to reduce manufacturing cost. This was a good incentive. The 1998 change of exercise duty system set no exercise duty on first parts of wind turbines and rotor blades, while placing both exercise duty and sales tax on spare parts, in order to encourage high-quality production and assembly of the first parts to avoid repairs and replacement. This policy successfully encouraged high quality production and assembly of the first parts (IWTMA 2002), and these measures were effective as cost reduction and manufacturing incentives.

However, exercise duty has been also used as a sort of manufacturing disincentives at the same time. Exercise duty has been zero on domestically manufactured components, final output, assembling and shipping, but imposed if further values are added by domestic manufacturers to the inputs. The duty ratio is average 16% on the cost of the inputs. This was one important reason that has prevented indigenization of higher value components (BHEL 2002).

Lack of Political Capacity and Capability

Both import duty and exercise duty in India have shown the conflicting usage as manufacturing incentives and had both positive and negative effects on market development and technological capability building.

The timing and the level of change of import duty have been abrupt and inadequate, indicating that GOI has not adequately grasped the realistic conditions of the industry players. In the early years, it was because the Ministry of Finance decided the duty, while MNES possessed weak power in the government. Over the years, MNES increased its influence and the coordination skills with other ministries, and the industry has successfully built political capacity and capacity though the formation and lobbing activities of IWTMA (formed in 1997) and the Indian Wind Energy Association (IWEA, formed in 2002). However, the frequent change of import duty still shows the insufficiency of policy formation ability, which is also seen in the use of exercise duty as well.

6.5.5 Section Summary

Effects of Competitiveness Management Transformation at the Frontier on Technology Development and Diffusion in India

The transformation of technological characteristics and its effects on industry structural modification and transformation of competitive strategy at the frontier have had the significant impacts on cross-border technology transfer to India.

Technology transfer was active in the early to mid 1990s through technology collaborations with technology providers from various countries. By 1998, however, many providers pulled out of the Indian market. The reasons varied from the market slowdown since late 1996, financial/ technical/ethical problems with the Indian partners, to their own business exits as a consequence of industry consolidation at the frontier.

Technology gaps between the frontier and India began appeared during the mid 1990s. The reduction of technology providers decreased the introduction of technology. In addition, the surviving technology collaborations also slowed down the introduction of updated technology. The tendency of continuously using less-updated technology is stronger in divided technology ownership firms (joint ventures and license agreements) than undivided ownership firms (100% foreign subsidiaries and an independent Indian ownership firm with European innovation base). The increasingly tighter technology and cost management and control at the frontier and the market slowdown since the mid 1990s have reduced strategic advantages of joint ventures and license agreements with the Indian partners, which require continuous and strong mutual benefits from the partners on both sides. The resistance to pass production licenses to the Indian partners became obvious from turbines above 500kW since the mid 1990s. While the growing high-tech nature of wind energy requires advancement in production capacity and capability, the persisting low quality production despite the long-time indigenization efforts in India offset any production (cost) advantages derived from low cost labor. At the same time, the market was slowing down; production advantages themselves were diminishing as the revenues from the Indian market were reduced. There were very little advantages for technology providers in joint ventures to keep updating technology, as the Indian partners could not offer them much return. The lack of proper technological capability to meet higher quality demands at the frontier and the absence of forward linkages and demonstration effects have limited the opportunities to improve the quality of production in India and further deterred the chances to be a part of global value chain and sourcing network of technology providers, creating a negative feedback loop regardless ownership structure.

The transformation of technological characteristics also has had direct impacts on cross-border transfer. Technology components innovated at the frontier has increasingly become difficult to be transferred as individual basis as their system integration needs have become higher and higher. Acquiring high level technology by transfer also requires high level capability as well as cumulative experiences, but technological capacity and capability supply to attract more updated technology have been weak in India. Thus, supply-push technology transfer has been weak, as the Indian side has not built up sufficient capacity and capability to support the transformed global technology and cost management needs of technology providers.

Role and Effects of Policy and Institutional Settings on Supply-Push Technology Transfer

In contrast to the frontier, the Indian government employed various industrial policy measures for industry development from the beginning. Wind energy policy became a part of the massive economic reform efforts since 1991, which eased the requirements for FDI, reduced corporate taxes, and began utilizing import duty mechanism to manage cost and technological capability building. Along with the market boom created by lucrative tax incentives, these industrial policy measures brought more than 30 foreign wind turbine manufacturers to India through numerous joint ventures and a couple of license agreements from 1993. The revolving fund used by IREDA for wind project financing effectively eliminated the danger of bilateral concessionary financing, allowing diverse sources of technology introduction.

However, the lack of supervision of firm operations and technology/project quality control measures contributed to the limited production capacity formation, as only handful collaborations actually built manufacturing facilities and it allowed many low quality projects to be prevailed. Placing the technology and project quality control measures was urgent requirements for healthy and sustainable industry development in the mid 1990s. Gradual strengthening of the technology and project quality controls since 1995 contributed to eliminating low-quality technology collaborations and projects and raised the industry technology standards by influencing the Indian manufacturer-developer strategy and technological capability building.

Several other measures placed to support the industry capability building had very limited effects. The Manufacturing Equipment Financing Scheme by IREDA, which offers the market development assistance loan for domestic and export market development, has not been used by developer-manufacturers which have enough capacity to finance such market developments on their own. The export cultivation efforts by MNES have also been limited to its financial and consultancy services to other developing countries. There has been the lack of more direct and specific technology-push policy to support the manufacturers to build higher capacity and capability to become the export bases, due to the limitation of government intervention to individual joint ventures/license agreements. Most of technological decisions are left to the mercy of foreign technology providers, but they have strictly controlled which technologies to be introduced and how they are to be handled in India.

As for technological capacity and capability building, the contradictory use of import duty for cost reduction and indigenous technology development discouraged not only technology transfer but also market investment. The conflicting use of manufacturing incentives has been seen in the use of exercise duty as well; imposing high exercise duty on high value activities has had negative impacts on improvement of technological capability building, while the differentiation between the first and second components did contributed to the improvement of production and assembly activities. The lack of consistency in these manufacturing incentives have confused the industry and contributed to hindering technology transfer and production capability building of higher value components.

Section 6.6: Suitability of European Technology to India

This section examines cross-border technology transfer from the frontier to India from the perspective of suitability and adjustment needs of the European technology to several Indian specific conditions. The market demands for technology for low wind and weak grids mentioned in Section 6.4 are examined in more details in this section.

6.6.1 Indian Specific Conditions

There are three Indian specific conditions, which have been particularly important for wind energy technology development and diffusion: low wind, weak grids, and infrastructure deficiency in both power T&D system and transportation.

Low Wind

Wind resource of a specific site can be expressed by annual average power per unit area called Wind Power Density (WPD, expressed in watt per square meter or W/m^2) and mean wind speed (m/s).

Wind Conditions and Turbine Installation in Denmark and Germany

A comparison of geographical distribution of wind turbines with wind resource maps at the frontier shows the concentration of turbine installations on sites with good high wind resources.

Table 6-24: Wind Resources in Denmark and Germany at 50m above Ground Level

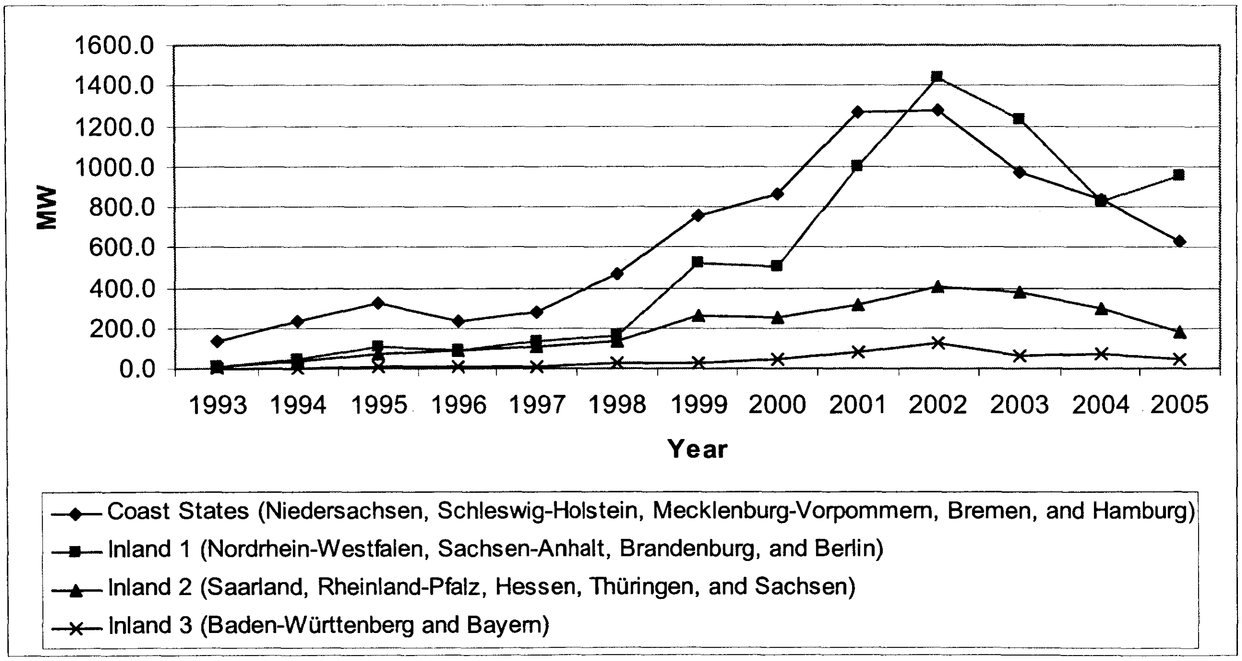
	Sheltered Terrain		Open Plain		Sea Coast		Open Sea		Hills and Ridges	
	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2
Denmark & German Costal States	5.0 | 6.0	150 | 250	6.5 | 7.5	300 | 500	7.0 | 8.5	400 | 700	8.0 | 9.0	600 | 800	10.0 | 11.5	1200 | 1800
German Inland States A	4.5 | 6.0	100 | 150	5.5 | 6.5	200 | 300	6.7 | 7.0	250 | 400	7.0 | 8.0	400 | 600	8.5 | 10.0	700 | 1200
German Inland States B	3.5 | 4.5	50 | 100	4.5 | 5.5	100 | 200	5.0 | 6.0	150 | 250	5.5 | 7.0	200 | 400	7.0 | 8.5	400 | 700
German Inland States C	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400

German Costal States = Niedersachsen, Scheleswig-Holstein, Mecklenburg-Vorpommern, Bremen, and Hamburg
German Inland I = Nordrhein-Westfalen, Sachsen-Anhalt, Brandenburg, Berlin, Sachsen, Thüringen, Hessen, Saarland, Rheinland-Pfatz, and Northenr part of Baden-Württenberg
German Inland II = Bayern
German Inland III = Southern part of Baden-Württenberg

Sources: Interpolated from European Wind Atlas by RISØ National Laboratory in (Danish Wind Industry Association 2003) and a German state map

The Wind Atlas of Denmark by the RISØ National Laboratory (Danish Wind Industry Association 2003) tells that the inland sites in Denmark have mostly wind resources indicated as Sheltered Terrain in Table 6-24, but other locations belong to either Open Plan and Sea Coast, which have good resources with high wind (mean wind speed above 6.5m/s and WPD above 300W/m^2). The examination of a wind turbine siting map of Denmark (Dannemand Andersen 1999) shows that turbines are spread across the entire country fairly evenly. However, the increased awareness of wind resources and the focus on economics led to heavier siting on rural areas in North and Western Jutland and Southern part of Zealand (BTM Consult ApS 1998b). The active offshore development efforts also increased the concentration of turbines, especially on open sea off the coasts of North and Western Jutland and Southern part of Zealand, which have very high wind resources (mean wind speed above 8.0m/s and WPD above 600W/m^2) during the early 2000s.

The geographical distribution of turbine installation in Germany more strongly reflects wind resource availability than Denmark. In Germany, the states facing or close to the coasts have better wind resources available, as wind resources normally decline with increased distance from the coasts (Table 6-24). As a result, the costal states have more wind turbine installed, but the regional distribution changed over the years.



Sources: (DEWI 2002a; DEWI 2003a; DEWI 2004a; DEWI 2005; DEWI 2006; DEWI 1994; DEWI 1995; DEWI 1996; DEWI 1997a; DEWI 1998a; DEWI 1999a; DEWI 2000a; DEWI 2001a)

Figure 6-10: Geographical Distribution of Installed Capacity in Germany

DEWI categorizes all German states into four groups by distance from the coasts (Figure 6-10).[102] The new installations in the first row (costal states) increased continuously, reaching their peak in 2001 and 2002. The second row of Inland 1 shows a similar tendency, reaching their peak in 2002. The installations in both the regions have declined since. The third row of Inland 2 and the fourth row of Inland 3 have had much lower numbers of installations. This demonstrates that the majority of turbines in Germany have been installed on sites with similar wind resource with Denmark (Sheltered Terrain, Open Plain, or Sea Coast for the row for Denmark and German Costal States in Table 6-24) and with a little bit lower wind resources (Sheltered Terrain or Open Plain for the row for German Inland States A in Table 6-24). Considering that turbine hub heights of medium- and large-capacity turbines installed since the mid 1990s are much higher than 50m and the amount of power produced by wind turbine is proportional to the cubic of wind speed (m/s) which increases as the height increases, most of the turbines installed since the mid 1990s at the frontier have been at sites with much better wind resources than those described in Table 6-24.

Wind Conditions and Turbine Installation in India

Table 6-25 shows wind resources of six states that have more than 99% of total installed capacity in India (Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan, and Tamil Nadu) as of the end of March 2005, based on the results from testing stations established by the National Wind Resource Assessment Program since 1983.

It is very clear that Tamil Nadu has the best wind resources in the country, which obviously contributed to its largest installed capacity along with its conducive state policy. Karnataka also have several locations with above 350W/m^2 WPD (Consolidated Energy Consultants Ltd. 2005). However, other states have mostly WPD below 300W/m^2, which corresponds to Sheltered Terrain (lowest wind) of Denmark and German Costal States and Sheltered Terrain and Open Plain (low wind) of German Inland States A in Table 6-24.

Table 6-25: Wind Resources in Six Wind States in India

State	Installed Capacity (% in Total)	Number of Stations*	Number (%) of Stations with WPD		
			<200 W/m^2 at 50m	200-300 W/m^2 at 50m	300< W/m^2 at 50m
Andhra Pradesh	120.6MW (3%)	61	26 (42%)	25 (41%)	10 (16%)
Gujarat	253.5MW (7%)	55	17 (31%)	26 (47%)	12 (22%)
Karnataka	410.7MW (11%)	40	14 (35%)	15 (38%)	11 (28%)
Maharashtra	456.3MW (13%)	68	39 (57%)	25 (37%)	4 (6%)
Rajasthan	284.8MW (8%)	32	26 (81%)	5 (16%)	1 (3%)
Tamil Nadu	2036.9MW (57%)	57	14 (25%)	13 (23%)	30 (53%)**

* The number only includes the stations that WPD at 50m above ground level are available.
** 14 stations among them have above 400W/m^2 WPD.

Source: Interpolated from (Consolidated Energy Consultants Ltd. 2005)

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[102] The DEWI categorization of inlands 1, 2, and 3 is slightly different from the categorization of inland states A. B. and C in Table 6-24 but roughly corresponds.

The above examination illustrates that Denmark, German and India all installed turbines on the sites with low wind resources. This verifies that the technology driving market demand for low wind conditions have existed both at the frontier and in India. However, there is a significant difference between the two sides. While India has very limited locations with relatively high wind resources, Open Plain, Sea Coast, as well as Open Sea of Denmark and the German costal states, which have been the most densely installed locations at the frontier, offer excellent high wind resources. Turbines at the frontier first occupied those high wind sites, and then gradually moved to lower wind sites in recent years, especially in Germany.

Weak Grids

The term "power quality" refers to voltage stability, frequency stability, and the absence of various forms of electrical noise (e.g., flicker or harmonic distortion) on electricity grid. AC with a nice sinusoidal shape without instability in voltage/frequency and electrical noises is preferred by power companies and their customers (Danish Wind Industry Association 2003). Weak grids are more often found in remote areas, where better wind resources are available and therefore wind energy development is usually concentrated. But in those areas the T&D grids are usually very weak because they are the remote corner of the grid.

Weak electrical grids have low-power carrying ability that can frequently cause the following problems by wind turbines: 1) voltage instability caused by power surge due to the electricity fed by wind turbines into the grid and reactive power; 2) flickers, which are short-lived voltage variations caused by turbines feeding to the grid; and 3) harmonic and inter-harmonic distortion caused by the application of power electronics for power supply and motor drives as well as by variable speed wind turbines with power converters. In addition, on weak grid networks, because the majority of customer loads are single-phase, voltage unbalance can be high if loads are not correctly shared out between the phases (Danish Wind Industry Association 2003; European Commission 1999).

While wind turbines influence the power quality of grid, the power quality of grid also influences the power performance and safety of wind turbines as well as the lifespan of their mechanical and electrical components. First, wind turbine performance is compromised by: 1) shutting down of turbines during frequent power outages that are common in India; 2) frequency variation; and 3) large voltage unbalance that increases the loss in WRIG and can cause the shutdown by overheating WRIG. Second, the safety of wind turbines is also influenced by weak grids as follows: 1) a high number of power outages increases turbine failures; 2) voltage and frequency variations or voltage unbalance can trip relays or result in generator overheating that can cause failures (this can also reduce the lifespan of WRIG by exposing it to overstress); and 3) low voltage can reduce the maximum torque of WRIG, which is essential to the safety of wind turbines with directly connected WRIG. Third, frequent power outages increase wear and tear of mechanical brakes, which will be used for full-braking instead of electrical braking in normal condition (Sorensen, Unnikrishnan, and Mathew 2001).

Indian Weak Grids

The Indian power system has been described very weak in general. While the power quality of connection points of wind turbines is basically poor, wind turbine connections themselves also worsen the power quality because the grid reinforcement has been insufficient to integrate wind turbines into the grid system. In the areas with many wind turbines installations, insufficient capacities of the grid cause large variations in steady-state voltage as well as in frequency and trigger power outages on the grid. Variations in steady-stage voltage and frequency exceed the tolerance set by the Indian standards are said significant compared to the European systems (Sorensen, Unnikrishnan, and Mathew 2001). In general, the Indian grid frequency fluctuates between 48 to 51 Hz, while the European grids offer constant 50 or 60 Hz. The Indian grid frequency is extremely unreliable and does not adequately translate the generated power into T&D facilities, which creates the profit loss to investors.

In terms of power quality problems caused by wind turbines, all of the above problems of weak grids are common in India. However, their seriousness varies. For example, while harmonic emission is generally associated with variable speed wind turbines with power electronics, in India it had also been measured from turbines with WRIG with irregular windings. Yet, the measurements indicate that the limits in the European voltage quality standard EN 50160 are not exceeded in terms of harmonic emission. The measurements of substations in Tamil Nadu and Gujarat also showed that voltage unbalance did not exceed the limits set by EN 50160 (Sorensen, Unnikrishnan, and Mathew 2001). Instead, the most serious weak grid related issue in India has been the problem of voltage instability, in particular reactive power consumption.

Reactive Power Consumption

Reactive power is the consumption of power from the grid to create a magnetic field inside WRIG in order to start it. The problem is specific for wind electricity generation using WRIG at low loading stage. Reactive power shifts the phase of AC in the grid near the turbines and reduces the efficiently of transmission. Reactive power is generally consumed by the following components: wind turbines themselves; step-up transformers from turbines to wind farm feeders; wind farm feeders; and substation transformers. Reactive power needs to be adjusted by switchable electrical capacitor banks.

The reactive power issue becomes more intense after the mid 1990s in India. Although the problem can be eased by placing capacitor banks, a large difference in attitude toward the reactive power between SEBs and wind power investors has created political problems. Most of the SEB directives mention that reactive power should not be more than 30% of the wind generated power. However, in reality, the prevailing low-wind conditions can create repeated start-stop operations and reactive power could consume up to 70% of wind generated power (Indiapoweronline 2001). TNEB began charging the reactive power fees from June 1995, which has increased over the years, hoping investors to place capacitor banks into their projects. Unfortunately the uncertainty surrounding the levels of reactive power taken from the grid and the costs related to it caused many developers to hesitate making the further investment, and made the issue very contentious, in particular in Tamil Nadu. Wind investors consider that SEBs have passed their own responsibility of upgrading the T&D facilities and eliminating the weak grid related problems to them by placing extra charges (WINPRO interview 2002). In general, unclear responsibilities regarding who need to take care of these problems on the grid interface have created different perceptions toward viability of wind power projects among investors, consumers, and policy makers, and this has caused the conflicts among them.

Infrastructure Deficiency

Besides the weak grid problems, the best wind resources on remote areas also make resource costs extremely high due to the necessary of building additional road infrastructure and power grid. Historically, India had shown low investments on infrastructure; infrastructure deficiency has been considered as one of the important causes of deterring economic development in general.

T&D System Deficiency and Losses

In India, the weak grids described above are a part of the large electricity grid system problem. Especially, the rapid decay and deficiency of grid penetration and T&D facilities, including the lack of substations, have been exacerbated by the financial problems of SEBs during the 1990s.

The T&D losses due to system inadequacy are very significant in India, varying between 20% and 45% (IEA 2002b). Table 6-26 shows no improvement of the losses over the years; in fact, the average T&D losses have been constantly increasing during the 1900s and 2000s. Also in some urban areas, the reported losses are a couple of times higher than the numbers in Table 6-26 due to more frequent theft. These high T&D losses have been considerable investment disincentives, because only 80% to 90% of the generated power (or less) has been used to create the profit (C-WET 2002).

Table 6-26: T&D Losses in India

Year	T&D Loss (%)
1992-93	21.8
1993-94	21.41
1994-95	21.13
1995-96	22.27
1996-97	24.53
1997-98	24.79
1998-99	26.45
1999-00	30.93
2000-01	32.86
2001-02	33.98
2002-03	32.54
2003-04	32.53

Source: (Central Electricity Authority 2004)

Transportation and Logistical Infrastructure Deficiency

Other infrastructure deficiencies have been also a problem, especially in transportation and logistics.

Surface Transportation

Although the privatization took places in various infrastructure sectors since 1991 in India, the road and highway facilities in many sections of the country are still at inadequate levels. As of March 2006, India has 3.34 million kilometers of road network, which is the second largest in the world. Annually the traffic on roads is growing at a rate of 7 to 10% and the vehicle population growth is 12%. It is estimated that roads carry almost 67% of freight. The total length of National Highways in the country as of March 2006 is 65,569km, which comprises only 2% of total road network, but carries over 40% of total traffic (Department of Road Transport and Highways 2006).

The World Bank (2005) reports that constantly overcrowded roads, government-imposed multiple check point systems, mixed use of roads by motorized and non-motorized traffic, almost complete lack of highway safety enforcement, and poor quality of equipment have contributed to the slow transit times and the poor reliability of timely delivery by modern standards in India. In terms of vehicle fleet, the Indian surface transportation industry today uses mainly two- and three-axle rigid trucks with an open top freight box of 1,100 to 1,400 cubic feet. The low cubic capacity reflects the freight market of predominantly heavy, often unpackaged commodities, which are hardly suitable for just-in-time logistic needs of computer industry and other high-tech undertakings. Additional introduction of high cube vans, fast line-haul transit, and large multi-axel tractor-trailer trucks, which occupy only 2% of total vehicle fleet and 10% of market share today, are necessary to serve high-tech commodity transportation needs and reduce costs. In general, the road transportation service is not adequate for higher value manufactures or time-sensitive export trades that comprise a growing share of the Indian economy (World Bank Energy & Infrastructure Operations Division 2005).

Port Infrastructure

Similar weakness can be found in the Indian port system. India has 12 major ports under the Union List of the Constitution, which are managed by the Port Trust of India under GOI, and 184 minor ports. The ports handle 90% of all foreign trade in India. The major ports accounts for almost 76% of total sea trade while the remaining 24% is handled by the minor ports. The liquid and dry bulk cargo constitutes about 83% of total volume of traffic handled, while the container and general cargo comprise the remaining 17% (Ministry of External Affairs Investment and Trade Promotion Division 2006).

The productivity of ports in terms of the Average Ship Turn Around (ASTA) and the Average Ship Berth Output (ASBO) has improved in recent years. The ASTA has decreased from 8.1 days in the 1990-91 year to 7.8 days in the 1996-97 year to 4.84 days in the 1999-2000 year and further to 3.47 days in the 2002-03 year. The ASBO also increased from 3,372 tones in the 1990-91 year to 4,249 tones in the 1996- 97 year to 6,321 tones in the 1999-2000 year, to 8750 tones in the 2002-03 year (Indian Ports Association 2003).

Due to the lack of modernization, however, the performance of the Indian ports does not compare favorably with that of efficient international ports at all. The Indian ports suffer from inefficiency, low capacity, and low productivity, which are resulting in high costs and long vessel turnaround times. In international terms, the labor and equipment productivity levels are still quite low due to outdated equipment, poor training, low equipment handling levels by labor, uneconomic labor practices, long idling time at berth, and time loss at shift change (Indiacore.com 2006). Inefficiency of Indian ports and services has resulted in higher through-port and sea transport costs.

Installation Equipment

The lack of adequate cranes was another problem for installation of medium-capacity turbines during the mid to late 1990s. For example, when Tacke first brought the 600kW turbines that exceeded the size of standard container to India in 1996, the firm took nine months to deliver them to the planned site, because of not only infrastructure limitation of the Indian road system but also the lack of cranes necessary for erecting turbines in that class. At that time, only two cranes were capable to build turbines of the size in India, and NEPC Micon occupied all drivers (Twele 2005). Since then, improvements were made gradually by the efforts of each manufacturer. Today, there are cranes available to install 2MW-class turbines.

Infrastructure Deficiency and Gaps between Gross Resource Potential and Technical Potential

According to the National Wind Resource Assessment Program updated as of March 2005, approximately only 30% of wind resources are available technically in India, compared to gross potential (Table 6-27). The infrastructure problems are an important reason of high cost of wind resource availability and installation in India.

Table 6-27: Wind Power Potential as of March 2005 in India

State	Gross Potential (MW)	Technical Potential (MW) (Ratio in Total)	Technical/ Gross Ratio
Andhra Pradesh	8275	1920 (14.3%)	23.2%
Gujarat	9675	1780 (13.3%)	18.4%
Karnataka	6620	1180 (8.8%)	17.8%
Kerala	875	605 (4.5%)	69.1%
Madhya Pradesh	5500	845 (6.3%)	15.4%
Maharashtra	3650	3040 (22.7%)	83.3%
Orissa	1700	780 (5.8%)	45.9%
Rajasthan	5400	910 (6.8%)	16.9%
Tamil Nadu	3050	1880 (14.0%)	61.6%
West Bengal	450	450 (3.4%)	100%
Total	45195	13390 (100.0%)	29.6%

Source: (MNES 2005)

Table 6-27 shows that the industrial states such as Andra Pradesh, Gujarat, Maharashtra, and Tamil Nadu demonstrate higher technical potential than other states because they tend to have better grid penetration rate and infrastructure in general and their SEBs are financially better shape than other agricultural states. Among them, both Maharashtra and Tamil Nadu have particularly high level of gross-technical potential ratios (83.3% and 61.6%, respectively).

The general road and port infrastructure problems have forced the wind turbine manufacturers and their production facilities to concentrate on several locations with better transportation infrastructure such as Tamil Nadu, Maharashtra, and the Union Territories of Daman and Pondicherry. The proximity between market and manufacturers is important due to high transportation cost in India, as these locations are also close to the strong markets (Gujarat, Tamil Nadu, and Maharashtra). However, the transportation infrastructure problems are a part of significant reasons of weak development of export business in wind too.

6.6.2 Appropriateness of European Technology to Indian Specific Conditions and Technology Transfer Results

This part examines appropriateness of the European technology to the Indian specific conditions described above as well as the effectiveness of the efforts made to solve any inadequacy.

Ready-available Frontier Technology

Pitch Regulations and Variable Speed Turbines with Power Converter

Most of the problems associated with the Indian weak grids are related to the direct grid connection without power converter, seen in stall-regulated, fixed-speed turbines or turbines with variable rotor resistance (Vestas OptiSlip®). The most typical problem is reactive power consumed by WRIG. Although capacitor banks compensate this problem technically, the best solution is to use variable speed turbines with partial- or full-scale power electronics converter that generates or absorbs reactive power, thus eliminating the source of the problem itself.

Besides the reactive power problem, variable speed turbines with power converter solve many other weak grid related problems. First, they eliminate the need for smooth grid connection, i.e., soft starter. Second, frequency variations in the grid do not affect the performance of wind turbines with power converter, which controls the frequency on the generator side independently of the grid frequency. Third, they generally produce significantly lower flicker than fixed-speed turbines. Incorporation of power conditioning equipment also provides the control of power factor to turbine operators/utilities (BTM Consult ApS 2005b; European Wind Energy Association 2003).

In terms of frequency variations of the grid, pitch regulation can address the issue quite well; although the fluctuating Indian frequency between 48 to 51 Hz affects the performance of wind turbines, the effect is only limited to stall-regulated wind turbines. The performance of stall-regulated wind turbines is lowered because the changes in grid frequency cause the changes in rotor speed, which changes the angle of attack of relative wind speed as seen from rotating blades. The calculation of variations in values of power curve[103] of stall-regulated wind turbines demonstrates that the maximum value of power curve varies by approximately 20% due to frequency variation from 48 to 51 Hz. Stall-regulated wind turbines designed for the European 50 Hz grid connection can have the blades pitched to avoid power production above 51Hz, or they may trip owing to the generator heating when the power gets too high. In either case, the performance of wind turbines will be affected. Meanwhile, the similar calculation for pitch-regulated turbines shows that blade angle control by pitch regulation ensures a maximum steady

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[103] Power curve of wind turbine is a graph that indicates the net electrical power output from the turbine with a specific rotor diameter as a function of wind speed at hub height.

state power for frequency variation between 48 and 51 Hz, although the 48 Hz power curve is not quite as good as the 50 Hz curve. The results demonstrate that although the performance of pitch-regulated turbines will be slightly reduced due to the frequency variations in India, the influence is much smaller than that of stall-regulated wind turbines (Sorensen, Unnikrishnan, and Mathew 2001). Thus, pitch-regulated wind turbines can reduce the effects of frequency variations in the Indian grid quite nicely.

Thus, although pitch-regulation and variable speed opreations do not solve all the problems associated with weak grids such as the performance loss due to frequent outages, these ready-available European technologies are quite suitable for dealing with low wind and many weak grid conditions in India.

Utilization of Readily-available Solutions for Reactive Power

Even without the introduction of pitch-regulated, variable speed turbines, the installation of capacitor banks could have solved the reactive power problem nicely. However, the problem can worsen if capacitor banks do not perform well, and it was the case in India in the beginning. During the early 1990s, approximately a half of capacitors in wind turbines in Gujarat were defective and the condition in Tamil Nadu was similar. However, the performance in Tamil Nadu improved since the mid 1990s; most of wind turbine capacitor banks became performing well and the reactive power consumption of wind farm substations became lower in Tamil Nadu than in Gujarat (Sorensen, Unnikrishnan, and Mathew 2001).

The high ratio of defective capacitors in Gujarat was mainly because wind plant owners had no incentive to replace defective capacitors, while TNEB forced wind plant owners to pay reactive consumption charges (Sorensen, Unnikrishnan, and Mathew 2001). Although the charges have been disliked by many investors, they have worked well to improve technical performance of capacitor banks. From the 2000s, all other states began placing reactive power consumption charges.

Site-Specific Turbines for Low Wind Sites

Developing site-specific wind turbines, especially for low wind conditions, has been attempted in Europe. An EU supported project was carried out during the late 1990s and early 2000s to explore various possibilities of developing site-specific design optimization of wind turbines. The project found that optimized site-specific designs showed the reductions in cost of energy by up to 15% due to increase in annual energy yield and reduction in manufacturing costs. In particular, the greatest benefits were found at sites with low mean wind speed and low turbulence, although site-specific design could not offset intrinsic economic advantages of site with high-wind speed (Fuglsang et al. 2002).

Several wind turbines designed specifically for low wind sites begun introduced to the market from the early 2000s, as many high wind sites began being saturated in Germany. For example, Vestas V90 1.8MW and 2MW (2003) as well as V100 3MW (2004) are all designed to optimize low wind resources. However, these turbines are large-capacity turbines, because larger rotor shifts power curve slightly to the left, which means that the turbines generate more power at low wind speeds. Also while turbines with larger rotor shaft will endure greater loads at higher winds than smaller rotor, the greater energy efficiency can be achieved and they suffer less wear and tear if winds at higher speeds occur less frequently (Gipe 1995). These multi-MW machines are designed to be ideal for the areas where space for siting is scare, e.g., sites in the German inland states, in order for them to exploit local wind resources better. Thus, in Europe, wind turbines specifically designed for low wind have been developed, but they are large-capacity turbines and their number is still quite small on the market.

R&D Efforts for Technology Adjustment and Indian-specific Solutions

To overcome the Indian specific conditions, some manufacturers have tried to tailor special solutions. For example, Vestas RRB developed a frequency adjustment controller, which looks at grid frequency and adjusts the generated power to the available grid frequency in order to overcome the frequency fluctuation problem. Such controllers have been developed in Europe with the inputs from the Indian engineers and have contributed to technology development (Vestas RRB 2002).

R&D institutions in India have also contributed to solve this issue through international collaboration projects. Electronics Research and Development Centre has taken up a project on "Power Quality and Integration of Wind Farms in the Grid," by jointly undertaking R&D with the RISØ National Laboratory to prepare the guidelines for the integration of wind turbines with weak grid (MNES 1998).

Domestically, MNES has focused on providing generic information and knowledge to innovate components/subsystems of wind turbines suited for the Indian specific conditions through industry collaboration since 1997. Three R&D models (Industry in-house R&D model, Consortium model, and Industry and MNES joint entrustment of R&D project to an institution or research laboratory) were developed. However, the effects of these new public-private R&D collaboration efforts have been limited, as mentioned in Chapter 5. The majority of R&D projects supported by MNES and C-WET had sub-optimal level of funding. Another important reason for little progress in public and private sector R&D collaboration is the license issues of technology, as discussed in the previous section. These reasons have limited R&D contribution in the Indian wind energy sector.

Effects of Infrastructure Deficiency on Upgraded Wind Turbine Introduction

Deficiency in Surface Transportation and Port Infrastructure and Turbine Size

In general, larger-capacity turbines can deliver electricity at lower cost than smaller machines, because they can save the costs for materials, foundation, electrical connection, and O&M due to economics of scale. This makes them more suitable for single installation in the areas where the siting of many turbines is difficult and for offshore development. On the other hand, the most significant downside of larger-capacity turbines is the difficulty of construction and logistical coordination due to their size and weight. In particular, this poses significant obstacles in developing countries where surface infrastructure is vastly underdeveloped for transportation of MW- and multi-MW class turbines. Cranes necessary for installation of MW-class turbines cost more than double for the ones for 500kW turbines. For the area without sufficient infrastructure for construction, therefore, smaller machines are generally more suitable.

The insufficient capacity of surface transportation of India has definitely a significant contributing factor for the delayed and limited introduction of MW- and multi-MW class turbines. The 1998 EC report, "Market Analysis and Opportunities for Wind Energy in India" mentioned that the bad surface transportation system and high costs of large cranes have been an important reason that have deterred the introduction of medium- and large-capacity turbines, in addition to the tight technology control by technology providers (Wind Power Monthly 1998b).

Logistical coordination and special equipments designed for transportation of large-capacity turbines in developed countries cannot simply work in India, because the Indian roads are too narrow and segmented, their vehicles are too small, and many parts of the roads are unpaved. In addition, although the highly segmented state markets increase the needs for good transportation networks between production facilities and installation sites across various locations, in reality, such networks are scarce and the road conditions worsen in remote areas where better wind resources are found.

The poor Indian port facilities and networks have also hindered both export and import of larger-capacity turbines. As described in Chapter 5, MW- and multi-MW class turbines require the highest level of logistical knowledge and capability even with the most updated port facilities. Also, the six-month project lead-time in India makes the use of inefficient and time-consuming port and road networks highly risky. High costs and high risks involved in exporting from the Indian ports has been another significant factor hampering India to increase its export.

Deficiency in T&D System and Turbine Size/Technology Level

In general, smaller turbines are also more suitable for the areas with deficient T&D system. If a large size turbine suddenly stops delivering electricity to weak T&D grid, it can cause a catastrophe in the system. However, if there are several turbines making up for the same capacity with one large-capacity turbine and even if one of them suddenly stops, it does not cause a substantial problem to the system.

In addition, wind turbines at the frontier have become more and more high-tech, which is originally developed for high grid standards of Europe. Significant risks are involved for connecting the intricate electronics control of MW- and multi-MW class turbines to the crude grid system of India, because the system can easily hamper the entire technology system. Without upgrading of the grid system or development of proper interface technology between weak grids and extremely high-tech wind turbines, it is very hazardous to connect them together.

6.6.3 Section Summary

Appropriateness of Frontier Technology to India and Technology Transfer Results

In general, the technologies and technical solutions developed at the frontier show sufficient adequacy to control the negative effects of the Indian low wind and weak grids, in particular pitch-controlled, variable speed turbines. However, the technology transfer results show that these technologies are minority in India. The Indian specific problems of low wind and weak grids are not considered as primary reason hindering the introduction of technologies appropriate to solve the problems. The more significant problem is rather the infrastructure deficiency, which has greatly limited the size of turbines to be transported and installed in general.

However, it is also true that there have been discrepancy in installed turbine size among manufacturers. In addition to technology control by ownership structure examined in the previous section, creative marketing and development approach by manufacturers has made a difference. With little governmental supports and slow improvements in various aspects of infrastructure, each manufacturer has needed to address the infrastructure deficiency on their own as much as they can. For example, one of the reasons that Suzlon could install the first MW-class turbines in India in 2001 and has been leading the packs in terms of turbine size is that the firm began the so-called Wind Park approach, which solves many infrastructure-related problems (see details in the next section).

Role and Effects of Policy and Institutional Settings for Technology Adjustment

In addition to weak demand-pull and supply-push transfer of technology, the infrastructure deficiency in surface transportation, port facilities, and power T&D system was another significant factor behind the increasing technology gaps. As the insufficient infrastructure has hindered the introduction of large-capacity high-tech turbines, other technologies that can address the problems related to the weak grids and the low wind conditions have not been brought and/or diffused in India because they are as a part of large-capacity turbine technologies.

The lack of supports from MNES for improvement of infrastructure deficiency is not a surprise, considering the issues cannot be solved by MNES and the wind energy industry alone. As for the T&D deficiency, despite the principle that SEBs should be responsible for upgrading facilities and fortifying weak grids, this has not been done because of their severe financial difficulty. The issues also involve many other energy related ministries and industries.

As for the transportation and logistical infrastructure deficiency, regardless of the privatization of these sectors since 1991, the improvements have been slow. MNES have not offered any significant supports for improvement of logistical issues (Twele 2005). The Equipment Financing Scheme that finances equipment for turbine installation including cranes offered by IREDA is the only direct measure to engage in the problems. Under such conditions, the manufacturer-developers have taken the responsibility to develop road infrastructure to reach the sites and fortify power evacuation facilities wherever necessary. However the efforts by individual manufacturers have limitation. Policy supports necessary to solve the infrastructure deficiency systematically require a better coordination among various ministries and larger and continuous investments, which cannot be provided by the wind energy industry alone.

As for better utilization and diffusion of readily-available European technologies, reactive power charges have worked well as an incentive for technology diffusion. As for adjustment of readily-available European technologies, however, the industry level R&D collaboration schemes by MNES for meeting the Indian specific needs have been unrealistic, as the technologies brought by joint ventures and license agreements are tightly controlled by providers and usually any adjustments and R&D on them in India are prohibited.

Section 6.7: Effects of Technology Provider/Partnership Characteristics on Cross-Border Technology Transfer

The previous sections explored the effects of general conditions on cross-border technology transfer to India. Meanwhile, each Indian manufacturer has taken unique development path and has demonstrated different technology transfer results. This section explores those differences by examining the evolution of different Indian manufacturers and their relationship with foreign collaborators.

6.7.1 History and Profile of Six Indian Manufacturers

This part takes six Indian manufacturers, which have had significant influences on the Indian industry development.

Vestas RRB Ltd. – Joint Venture between Vestas Wind A/S of Denmark and RRB Consultants & Engineering of India

Vestas RRB India Ltd. was established in 1987 as joint venture between Vestas A/S of Denmark and RRB Consultants & Engineers Private Limited (RRB) of India. RRB owns 51% of the venture share and Vestas held the rest (49%). The company has the headquarters in New Delhi and manufacturing plants in Chennai, Tamil Nadu. Vestas RRB is the longest surviving joint venture in the Indian wind energy sector today.

Technology Transfer in the Early 1990s

Between 1987 and 1993, the company imported the turbines from 50, 65, 90, 100, to 200kW from Denmark for the government-led demonstration projects. All components were imported, then assembled and erected directly on sites by Vestas RRB. In 1994, due to the growing domestic private market, Vestas and RRB modified their business structure and technology agreements; Vestas RRB began manufacturing wind turbine components using local suppliers in India, and immediate technology infusion between Vestas and RRB through constant and instant information sharing and Indian personnel training in Europe began. Indigenization of technology became a strong focus of the joint venture for cost reduction.

The new technology agreements with Vestas allowed RRB to purchase engineering documents such as drawings, specifications and technical requirements from Vestas and to import components that were not capable to be manufactured in India. RRB carefully chose local suppliers for component manufacturing. Then, a prototype wind turbine set was assembled at the RRB plant with the components manufactured by local suppliers as well as the imported components. The indigenization was gradual in this process. Two or three new components became locally manufactured for each new order. Local manufacturing experiences in heavy industries were crucial for this arrangement, because RRB did not have to engage in too much of additional investments to build capability of local suppliers as well as in-house engineers. Thus, the availability of initial capacity in Chennai area to absorb foreign know-how was critical for the indigenization process. Then, knowledge accumulation through both learning-by-doing and backward linkages and through the feedback mechanisms between RRB and suppliers contributed to local production capacity building further. Quality control was another important capability, demonstrated by Vestas to the Indian partner; after both Vestas and RRB oversaw the quality of components from local suppliers, Vestas inspected and gave quality approval and assurance to the prototype turbines assembled at the RRB plant.

Local project execution capability was also quickly built up through personal training offered by Vestas in Denmark. The Danish technical experts carefully instructed the RRB employees for site selection and planning, on-site assembling and turbine erection. In particular, site development has been carefully executed. After general locations with good wind resources were identified by the National Wind Resource Assessment Programme, the employees of both Vestas and RRB conducted the minimum of one additional year of site assessment as normal procedure. Personal exchange was continuous; every one or two months, the Indian personnel visited Denmark for training and the Danish personnel came to India whenever their assistance is needed.

However, local capacity building for RRB was limited to manufacturing of certain components and project execution. All critical engineering and innovation capability was retained by Vestas, although all R&D set-up formed in Denmark was immediately informed to RRB to avoid costly mistakes because manufacturing of large components and modifications in wind turbine design are costly. Technical and managerial inputs from RRB had also played important roles for R&D to deal with several Indian specific technical problems such as low wind conditions and weak grids, for example, the development of frequency adjustment controller, mentioned in the previous section.

The amicable relationship of Vestas RRB, supported by the common goal of cost/responsibility sharing as well as strong conviction in quality control, contributed to the successful building of local technological capability during the early 1990s.

Stagnated Technology Transfer – after the Market Slowdown

The strong commitment for quality control through close involvement of Vestas from the beginning worked well to adjust to the new quality control measures began imposed by MNES in 1995. RRB has developed the capacity to perform turnkey project with high level of quality control in both production and site development. However, technology transfer of this venture since 1995 is most puzzling among all the technology partnerships in India. Despite the strong market share by Vestas in the world, RRB seems to be struggling to keep updating its technologies for many years. No new turbine models by Vestas have been introduced to India for more than ten years after the introduction of V39 500kW in 1995.

A turning event happened with the Indian market downturn in the mid 1990s. In 1995 after a large order was sent from Denmark to India with limited guarantee of payment, the spiraling interest rates in India jeopardized the total payment. Although the loss was finally averted, the 1995 stocks were still in India at the point of 1997 due to the market downturn. Facing the public listing in the Danish Stock Exchange at the time, Vestas wrote off some DKK 150 million (net receivable) in order to remove any future risks related to the large balance in the Group's favor for Vestas RRB. The decision left the Group with a net loss of DKK 18 million in 1997 (Vestas Wind Systems A/S 1998; Vestas Wind Systems A/S 2002b).

After the write-off in 1997 and the successful public listing of Vestas on the Copenhagen Stock Exchange in 1998 as well as with the falling interest rates and inflations in India, in November 1998 Vestas RRB was awarded a mixed credit loan by DANIDA which partially financed a 15MW wind farm in Tamil Nadu. The loan covered 60% of the project costs, with the remainder being met equally by other financial institutions and the project developer (Vestas Wind Systems A/S 1999; Wind Power Monthly 1998c).

Despite the successful commission of the project, however, the introduction of new wind turbines did not follow. Vestas has expanded its product line to MW- and multi-MW classes since 1995, introducing more than 15 models ranging from 600kW to 3MW[104] for both onshore and offshore markets by the end of 2005. Yet, none of them has been introduced to India. Vestas RRB still provides only two Vestas models (225kW introduced in Europe in 1988 and in India in 1993 and 500kW introduced in Europe in 1993 and in India in 1995). Many other manufacturers currently provide larger models in India. Technology had not been upgraded for many years, and all the innovations by Vestas since the mid 1990s are not brought to India at all. As a result, RRB has never been the dominant firm in the Indian market, in terms of market share and technology. The firm only has been between 6% and 10% of the market share throughout the 2000s.

This technology transfer stagnation limited spillovers and slowed capability building. Although the technology indigenization level continuously grew throughout the mid and late 1990s at Vestas RRB, high value components had been still imported. As of 2002, the firm indigenized approximately 90% of components for the 225kW model. The rest 10% was electronics of controller and rotor blade. For the 500kW model, the indigenization was completed up to 85%. However, in terms of value term, the indigenization level was at 80% for the 225kW model and at only 55% to 65% for the 500kW model. Electronics of pitch regulation system is imported due to the absence of production capability in India. All parts other than the main controller portion, however, have been slowly indigenized throughout the early 2000s.

As for blade manufacturing, Vestas RRB had hesitated to enter in-house production of blades for long, because it requires low temperature in material handling condition and the firm's domestic share had not been large enough to create economies of scale to make the production economically viable. Finally in 2005, however, Vestas RRB commissioned a new in-house manufacturing facility for electronics controllers and blades, which makes the indigenization level of the 500kW model up to 75% in value term. Years of indigenization efforts of controllers have paid off and the Indian market has been showing the strong prospect for growth since 2003. Vestas RRB also has successfully built testing capability: each individual machine is tested in-house at RRB for fine tuning after receiving the type certificate from C-WET (Business Line Bureau. 2005a).

Yet, the relationship between Vestas and RRB remains obscure. As Vestas engaged in massive corporate reorganization after the merger with NEG Micon in 2004, Vestas RRB is no longer directly included as a part of the corporate structure. In addition, Vestas has not informed publicly about the commission of new Vestas RRB production facility through its news release;

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[104] V120 4.5MW has been already developed for offshore, but has not been installed yet (Vestas Wind Systems A/S. 2006).

the construction of the facility seems out of touch of Vestas. The relationship with NEG Micon India Ltd. (100% subsidiary of NEG Micon in India) is also unclear. (The information in the above Vestas RRB case is based on (Vestas RRB 2002) unless other sources are noted.)

NEPC-Micon – Joint Venture between Micon A/S of Denmark and Non-conventional Energy Product Company (NEPC) of India

NEPC-Micon was the first joint venture firm formed in India with collaboration with foreign wind turbine manufacture. About 40% of the company was held by the Indian firm Non-conventional Energy Product Company (NEPC) and the rest was owned by Micon A/S, a Danish wind turbine manufacture.

Fate of NEPC-Micon Ltd.

In 1987, TNEB, which was interested in demonstration project, entered an agreement with DANIDA with help from DNES. TNEB and DANIDA identified Micon as the best wind turbine manufacturer at that point. TNEB entered a contract with Micon to erect 21 of the 250kW turbines and looked for a local contractor to erect the machines. NEPC was chosen, and NEPC and Micon eventually formed a joint venture.

Similar to Vestas RRB, 100% of wind turbine components were imported from Denmark and NEPC assembled on site in the beginning. However, as the market expanded from 1993, the firm built a production facility in Chennai, Tamil Nadu. The joint venture enjoyed the strongest market share in India between 1993 (81.3%) and 1996 (21.8%).

However, the partnership suddenly ended in 1996. Despite the technology agreement with the first-rated Danish manufacturer Micon, NEPC had created many low quality projects during the first boom years. NEPC was a pioneer firm, instrumental in technology indigenization, and it produced many spinoff entrepreneurs and human resources base for other companies in India (IWTMA 2002). In this regard, the firm's contribution to the industry should not be undermined. However, business practice with low quality control and its financial problems worried Micon, which subsequently decided to break up the joint venture agreement with NEPC in 1996. The time also coincided to the formation of NEG-Micon, created by the merger between Micon and Nordtank.

NEG Micon India Ltd.

Following the break-up of NEPC-Micon and the new company formation, NEG-Micon immediately started the first 100% subsidiary firm in India in 1997. However, for the first two years, the firm concentrated only on replacing the Micon models installed by NEPC and by other firms that imported the second-hand Micon turbines from California during the first boom years to clearn up the bad reputation created by them. NEG-Micon began taking its first new order in India only in 1998 (IWTMA 2002; NEG-Micon India 2002).

As 100% subsidiary, NEG Micon India has introduced larger-capacity turbines than joint venture/license agreement firms. In 1999, the firm brought the first 750kW model to India, followed by the 950-250kW model in 2002 and the 1.65MW model in 2004. All were introduced to India within one year of their European launch. NEG Micon India also put great efforts in project execution technological capability and know-how building as developer, in order not to repeat the mistakes of creating low quality projects under the name of the company.

In addition, the firm was also planning to make the Indian facility an export hub since 2003. However, the merger with Vestas seems halted the decision. As mentioned, the relationship between Vestas and Vestas RRB has been unclear and the new company Vestas after the merger has not shown a clear direction in its Indian operation publicly. As of 2005, NEG Micon India and Vestas RRB have taken different paths, and NEG Micon India is planning to export from the 2007-2008 year (Ramakrishnan and Balaji 2006).

With the years of effort to take back good reputation and to introduce newer turbines, NEG Micon India has increased its market share since 1999 and enjoyed more than 25% of the share in both 2003 and 2004.

NEPC India Ltd.

After the break-up with Micon, NEPC became an independent wind turbine manufacturer. Since 1997 NEG Micon and NEPC involved in a court dispute regarding the manufacturing rights of turbines introduced by Micon during their joint venture years. In 1999, the Chennai High Court ruling permitted NEPC the exclusive right of manufacturing the Micon models up to 400kW in India (Wind Power Monthly 1999c). As a result, NEPC has continuously manufactured and installed the Micon 225kW, 250kW and 400kW models. Among them, the most popular make has been its 225kW, which the firm indigenized best. In 2005 NEPC began installing 750kW turbine developed by Norwin, a small Danish manufacturer.

It seems that technological capability of the firm has not advanced greatly since the joint venture break up, as no indigenously developed turbines were introduced. The market share of NEPC India has never exceeded 10%.

BHEL-Nordex – License Agreement between Nordex of Denmark/Germany and Bharat Heavy Electricals Ltd. (BHEL) of India

BHEL is a Public Sector Undertaking company, currently under the Department of Heavy Industries (Ministry of Heavy Industries and Public Enterprises) in India. It was first established in 1956 in Bhopal in order to develop strong domestic technological capacity of power generation. Over the years it expanded to 13 divisions and the headquarters is located in New Delhi. It was 100% state-owned until 1991, but the state share was reduced to 66% due to the privatization efforts after 1991. BHEL manufactures and offers a wide range of equipment, systems and services in the field of power, transmission, industry, transportation, oil & gas, non-conventional energy sources, and telecommunications. It has been the largest engineering enterprises of its kinds in India and has had the major R&D divisions across the areas of power engineering, electronics and mechanical engineering (Sagar, 2002). The Ranipet division, established in 1982 in Tamil Nadu, has engaged in wind turbine manufacturing operation.

Wind Turbines Development as Independent Manufacturer in the 1980s

In the 1980s, while engaging in various demonstration projects, DNES began exploring the possibility to develop fully indigenous wind turbines in India. To do so, it created a R&D project funding and asked BHEL to develop wind turbine prototypes suitable for the Indian conditions. As the largest engineering enterprise of its kind in India, BHEL had high capacity to experiment technology development and its central R&D center at Hyderabad started working on the prototype development. This attempt successfully produced small-capacity turbines in 20kW and 50kW capacity and they had reasonably good market in the demonstration projects. By 1992 the BHEL R&D division developed a 200kW model, which was supplied to total of 10MW of demonstration projects in Andra Pradesh and Gujarat that year.

License Agreement with Nordex

BHEL signed technology collaboration agreement in 1993 with Nordex, another prominent Danish wind turbine manufacture at the time. BHEL was the only company that chose license agreement over joint venture in the early 1990s, and several reasons contributed to this decision. As state-own-enterprise (SOE), there is a restriction to incorporate foreign assets into its capital structure. Also as SOE, it had certainly no need of financial supports from foreign collaborators or external financial institutions such as IREDA.[105] In addition, BHEL already had very high in-house technological capability to support new technology as well as produce necessary components for wind turbines due to its manufacturing experience in electrical equipment (turbines, transformers, boilers, etc). Joint venture was not the best option for this flagship-engineering firm of India.

Just before forming the license agreement, BHEL had an experience to erect Nordex turbines on site for a demonstration wind farm in Maharashtra in 1992. All components were imported from Nordex. This experience encouraged BHEL to consider technical collaboration with the Danish manufacturer, rather than continuing in-house technology development. One reason that BHEL sought for Nordex technology was certification issues. Wind turbines developed by BHEL by 1992 were not certified by any of the prominent institutions in Europe such as the RISØ National Laboratory or Germanischer Lloyd, which could give the quality assurance to investors. Another reason was that the Indian market was looking for larger-capacity turbines, e.g., 250kW or more, around the time. Along with these reasons, the private market prospect created by the new government policy measures prompted BHEL to form the license agreement with Nordex, in order to take advantage of its state-of-art European technology. The Ranipet division was chosen due to its location in Tamil Nadu for wind division, although any of other 12 divisions in BHEL could accommodate the function easily.

The technology agreement included procurement of engineering documents, specifications, and drawings. There was no procurement of components in the agreement because BHEL had enough experience and capacity to manufacture them in-house. Technology transfer of necessary know-how was carried out by both purchase of documents and personnel training for the 150kW and 250kW turbines. Training was done in both India and Denmark through the personnel exchange. The license agreement included the payment arrangement of price of technology (documents and know-how) and the small percentage of sales of each turbine (3-5%), following the GOI guidelines.

In terms of building local manufacturing capability, the self-contained SOE system did not create any backward linkage formation with local suppliers. Learning-by-doing was the only factor to accumulate manufacturing capability. However, the learning-by doing experience was not

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[105] In fact, BHEL has never used the IREDA financial schemes for any of their wind power projects (BHEL, 2002).

translated into innovation capability. Indigenous technology development target of 400kW and 500kW capacity turbines set by 1994 was abandoned, and BHEL shifted to the 100% collaboration with Nordex. Although there was the good prospect of market development during the first boom years, it was not still enough to force BHEL to invest further resources into R&D to develop original wind turbines, considering the availability of state-of-art technology from the first-class European manufacturer.

Project execution capability was also advanced through personal training offered to the Indian personnel in Denmark, although BHEL already had original high capability due to the existence of various well-established departments such as Planning and Development, Marketing, Engineering and Contract management. Quality control was carefully carried out; both the demonstration effects from Nordex and the traditional responsibility of SOE to provide high quality engineering and services prompted it.

In terms of knowledge spillovers, the effects of Nordex-BHEL license agreement were rather small due to the BHEL's self-contained system, low-employee turnover, and high initial capacity as SOE. BHEL simply increased its internal technological capacity by incorporating the state-of-art technology from Europe.

Termination and Reinstatement of License Agreement

The fate of the BHEL-Nordex partnership changed after MNES issued the guidelines for project and technology quality control in 1995. As mentioned previously, the quality control measures have tightened the six month project leadtime further and contributed to the Indian industry consolidation. All other surviving private firms could manage the situation and improvised the solutions by improving project execution capacity and capability in a short amount of time. However, the status as SOE made BHEL very difficult to provide turnkey projects within the six month period, especially after the placement of quality control measures despite its high technological capacity and capability.

Besides external transaction costs for initiation of wind power project, BHEL has extremely high internal transaction costs due to the rules and restrictions posed on SOE by GOI in general. All expenses and investment decisions need to be undergone lengthy internal approval. Marketing wind power projects to private investors are very difficult for the company, because making a contract and gaining the approval from GOI by clearing all required paper works consume a large amount of time. Contract negotiation is also restricted because the set prices cannot be changed easily and private land acquisition is prohibited for SOE as well. It also cannot issue long-term guarantee easily because the firm owes high responsibility as a part of GOI. Although all these aspects work as advantages to create high credibility, they become huge disadvantages to initiate wind project within the short gestation period required for wind power project. The number of projects by BHEL-Nordex peaked in 1995 (total 32.3MW), but sharply decreased in 1996 (13.5MW) and in 1997 (2MW). The export market cultivation is also limited by both the SOE structure and the technology agreement with Nordex.

The license agreement with Nordex was periodically reviewed and BHEL kept manufacturing and installing wind turbines until 1999. The agreement finally expired in 2002 and it was not renewed immediately. However, BHEL had strong willingness and feels the responsibility to keep its wind turbine division in order to support sustainable development as the flagship-engineering firm of India. (The information in the above BHEL case is cited from (BHEL 2002) unless other sources are cited).

In 2003, with the great expectation of market expansion again, BHEL and Nordex reinstated their agreement. This time, Nordex offers two stall-regulated, fixed-speed models (N43 600kW and N50 800kW introduced in Europe in 1994). However, none of the models have been installed as of March 2005. In addition, their technology is a decade old. Although Nordex offered pitch-regulated, limited-range variable speed turbines with DFIG configuration to the frontier market since 1999, they have not been introduced, despite there is a Nordex 800kW model with this configuration since 2001 and they are considered more suitable for the Indian low wind and weak grids.

Pioneer Asia Group and its Joint Ventures with Wincon West Wind of Denmark and Gamesa Eólica of Spain

Pioneer is a South-Indian family-own company that has been active in paper, textile, timber, chemicals, and firework businesses for years. Energy intensity of these businesses prompted Pioneer to begin investing in wind energy and it became the owner of 15MW of wind capacity by 1993. This experience encouraged Pioneer to embark on wind energy business on its own; since then, Pioneer Asia has formed two joint venture companies, Pioneer Wincon Pvt. Ltd. for manufacturing and marketing of the 250 kW turbines and Pioneer Asia Wind Turbines for higher capacity wind turbines. Pioneer has the manufacturing facilities in Chennai and Pondicherry, one of the tax free union territories of GOI.

Pioneer Wincon Private Ltd.

In 1994, Pioneer decided to buy wind turbines from Wincon West Wind, a Danish manufacturer, and sell them in India. Although the market was on down-slope in 1996, Pioneer wanted to stay in wind energy business and asked Wincon to form a joint venture agreement. Wincon, which had a conservative attitude toward the joint venture formation, asked IFU of Denmark to become a financial partner of the joint venture. In 1998, after two years of negotiation, IFU, Wincon, and Pioneer reached a joint venture agreement and formed Pioneer Wincon Ltd., which both the Danish and Indian sides share equal 50% of holdings (24% by IFU 26% by Wincon West Wind, and 50% by Pioneer Asia Group), and then Pioneer and Wincon formed technology agreement.[106]

The technology agreement divided the responsibilities for Wincon to design technology and for Pioneer Wincon to manufacture components for the Indian market. Cost sharing was the primary motive of the agreement. The agreement let Pioneer Wincon to receive full information from Wincon through drawings, specifications and vender lists. Pioneer Wincon outsourced components to local suppliers. For capital items, suppliers are more carefully chosen among those approved by Wincon. All components are then assembled at the company's assembly plant in Chennai, brought to the project site, and installed with blades at the site. Although Pioneer Wincon uses three to four reliable civil, electrical and mechanical engineering

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[106] The 50-50 share holdings ensure no domination from either side. IFU would like to sell the share eventually after technology transfer but the agreement restricts selling its share only to Wincon to keep the 50-50 share holding between Denmark and India (Pioneer Wincon Ltd., 2002).

subcontractors for site installation, its in-house team deals with 100% of O&M for turnkey projects during the two-year warranty period. After the warranty expires, the in-house team usually extends the contract on annual basis with their clients and continues offering high quality O&M.

Within a couple of years since the joint venture started, Pioneer Wincon upgraded the manufacturing capacity from the 250kW model to the 755kW model. The initial indigenization level was 27% in 1998 on component basis. The rate of indigenization improved to 90% at the point of 2002. The other 10% includes electronics of controllers. Pioneer Wincon uses blades made by LM Glasfiber India. In the beginning, Wincon came to inspect and guide the commission of projects. However, this know-how was indigenized within one to two years of the joint venture formation, and Pioneer Wincon has become to take care of commission independently of Wincon. (The information in the above is cited from (Pioneer Wincon Ltd. 2002).

Although the joint venture was amicable, the technology transfer from Wincon was limited to the above two models. The important reason was the weak status of Wincon West Wind at the frontier. Wincon has not introduced new turbines since 1998 after the launch of the 755kW model at the frontier. It has been a small manufacturer and has had difficulty to keep up with the intense technology competition at the frontier.

The market share of Pioneer Wincon has never exceeded 5%; the highest share was 4.6% in 1999, and the share fell into less than 2% during the early 2000s.

Pioneer Asia Wind Turbines Ltd.

The growing market prospect since 2003 and the endeavor to gain access for newer technology prompted Pioneer Asia to form another joint venture with Gamesa Eólica of Spain.

In January 2004, both the firms entered an initial operational agreement, which allows Pioneer Asia to purchase and assemble the Gamesa turbines. Gamesa introduced the pitch-regulated 850kW model with limited-range variable speed with DFIG. The model was introduced to Germany in 2004. The first seven turbines purchased by Pioneer in 2004 and installed in Tamil Nadu in early 2005. After this initial arrangement, both the firms entered the formal negotiation to form a joint venture company. The exact equity holding structure between Gamesa Eólica and Pioneer group was still being worked out in 2005.

The two companies were contemplating a technology transfer agreement, which allows Pioneer to manufacture the Gamesa 850kW models in India. The disclosed agreement indicates that the turbines would be imported and assembled at the Indian plant initially, but as volumes picked up, the company hoped to substantially indigenize component manufacturing. The joint venture already announced the investment about INR 100 crore in production facility, which handles component manufacturing, import-handling, turbine assembly, and maintenance services (domain-B.com 2005; Gamesa Eólica 2005).

Enercon India, Ltd. – Joint Venture between Enercon GmbH of Germany and Mehra Group of India

Enercon India Ltd. was established in 1994 as joint venture between Enercon GmbH of Germany and Mehra Group of India. Enercon GmbH owns 56% of the venture share and the Mehra Group has the rest (44%). The commercial operations started in 1995. The Indian market share by Enercon India was not particularly strong during the 1990s; it never exceeded 15%. However, the share grew to 35% in 2001. Since then, Enercon India has achieved approximately 25 to 30% of the market share, competing against Suzlon Energy and NEG Micon India.

Locations

Unlike other early joint ventures that chose the locations in Tamil Nadu because of the strong market of the state, Enercon India placed its headquarters is in Mumbai, Maharashtra, and set up the first manufacturing plant in 1995 and the second facility in 2000 in Daman, one of seven union territories in India, which imposes no commerce, capital and profit taxes on business. Although Daman is a subject to GOI, the location is very popular among western entrepreneurs due to the problems of the Mumbai port as well as its tax free status. The firm chose the western locations not only in order to reduce business taxes and costs associated with production but also to export back turbine components to Europe (Enercon GmbH 2002a).

Subsidiaries under Enercon India Ltd.

Enercon India has a distinctively different way of managing and expanding its business from other wind energy technology collaborations established in India. One of the most distinguished methods is to establish various subsidiaries for different business purposes. Using these subsidiaries as conduit, Enercon GmbH has brought various business know-how and technological capacity and capability necessary for each activity. 100% subsidiaries established under Enercon India are: 1) Enercon Export Ltd, established in 1995 as a 100% export oriented unit; 2) Enercon Wind Farms Ltd, established to demonstrate and exhibit the variability of Enercon wind energy project on stand alone basis in various locations; 3) Enercon Financial Consultancy Private Ltd, founded to assist the projects (either customer's or its own) with various funding options by structuring innovate funding options and products as well as by developing financial markets to make wind project more profitable (Enercon India Ltd. 2005b); and 4) Enercon (India) Power Development Private Ltd. (Enercon Power), established in 2004 to develop, establish, own and operate 1,000MW of clean energy by 2010 in India as well as to set up and manage IPP business for the Enercon Group in selected world market. Enercon Power has become not only the largest renewable energy based IPP in India, but also has become managing several Enercon Wind Farms Ltd. which were established in different locations (Enercon India Ltd. 2005a).

Product Technology Transfer

As for product technology introduction, like other technology collaborations, not all the turbines developed by Enercon GmbH were introduced to India. E-30 230kW model was introduced to the frontier and India simultaneously in 1995. The radical innovation by Enercon GmbH, the direct drive, full-range variable speed turbines with full-scale power converter, was brought to India by this model for the first time. While Enercon India installed only this model for the next five years, Enercon GmbH launched E-66 1.5MW (1995), E-58 850kW and 1MW (1998 and

1999, respectively), E-44 600kW (1999), and E-66 1.8MW (2001). None of these models were introduced to India for installation.

In 2001, with a recovering sign of the Indian market, E-40 600kW model was introduced to the frontier to India simultaneously, and the second large production facility was built in India for its production. In early 2005, the newest Enercon models E-33 330kW and E-48 800kW were introduced worldwide to replace their best-seller predecessors E-30 and E-40 models. There was no time delay between India and the frontier for their introduction. Between 2001 and 2005, Enercon GmbH launched E30-300kW (2002), E-66 2MW (2003), and E-112 4.5MW (2005) to the frontier market, but they have not been introduced to India.

None of MW- and multi-MW class turbines developed by Enercon GmbH have been brought to India yet. Nonetheless, the technological essence and most of the innovative features of the Enercon products have been introduced to India, because the uniqueness of Enercon technology has made the German firm possible to stick to the same technological path since 1993; all the turbines launched and not launched to India have had pitch-regulated, direct drive, full-range variable speed operations with synchronous ring generators and full-scale power converters. However, some of the SCADA products and several features developed along with the latest and largest turbine E-112, e.g., special rotor blade with winglet, are among the technologies not brought to India.

Positive influences of the Enercon technology on India should not be underestimated. The firm's pitch-regulated, direct drive, variable speed turbines have frequency operational band of 50 ± 5 Hz, ensure steady state power for frequency variation between 48 and 51 Hz, reduce reactive power consumption, eliminate the needs for soft stator and capacitor banks, and minimize the mechanical stress on drivetrain, solving many problems mentioned in the previous sections. In low wind conditions, they improve the performance, extracting the maximum energy by optimizing turbine speed. Considering the limited introduction of variable speed turbines by other manufacturers, the contribution of Enercon India to the Indian wind energy development is quite significant.

Production Technology Transfer and Export

Enercon India has the production lines for complete turbines, including blades, synchronous ring generators, and electrical components. They are not only for domestic use, but blades and electronics components have been exported back to Europe. Unlike any other joint venture companies, Enercon GmbH has used its Indian facilities as the export base of those generic turbine components from the beginning of their joint venture. The introduction of production technology of high value components are not held back by Enercon GmbH. The tax free status of Daman on high value components also helped. Strong forward linkages and demonstration effects have improved product quality of components made in India.

Enercon India has expanded its production capacity constantly to meet the domestic and export needs. The expansion has been constant and aggressive, compared to any other technology collaborations. In 1994 the construction of the first production factory began in Daman for E-30/230kW (Unit 1), from where the first three E-30 turbines have left for export back to Germany in the following year. In 2000 the construction of the second production factory was commenced in Daman for E-40 (Unit 2). In the following spring (2001), the production of E-40 600kW started there. In addition to 150 turbines produced for the Indian market for the year, 600 of the E-40 blades were exported back to Germany. In 2003 the blade factory was expanded to manufacture E-66 1.8MW blades for solely export purpose, as the model has not been installed in India yet (Enercon GmbH 2002a).

In 2004, Enercon India built an 8,000m^2 mobile factory to produce prefabricated concrete tower. It was the first of the kind even for Enercon GmbH, and can be moved anywhere in the world. It will remain in Jamnagar, Gujarat until 2007 to produce 30 of the E-40 towers. The factory produces 18 segments of the 74m tower with 5.5m-diameter base and 1.8m-diameter top. Enercon GmbH has been using both steel and prefabricated concrete towers, but the prefab concrete towers are used for E-40, E-48 and E-70 models because the price of steel has become increasingly expensive and the transportation cost for prefab concrete tower sections are much less expensive (Enercon GmbH 2004a).

Project Execution Technology Transfer

Enercon GmbH has actively transferred project execution technology to India, using different methods.

Project Planning and Development Technology

Enercon India established two 100% subsidiaries, Enercon Financial Consultancy Private Ltd and Enercon Power during the early 2000s and fortified the transfer of project execution and development know-how from Germany to India. These two firms have helped raise Enercon India's project execution skills further to the level of independent professional service firms. In particular, Enercon Power was created to be a base toward business expansion to other selected world markets in the future, as Enercon GmbH itself does not have such an independent project development unit in Germany. The range of services provided by Enercon Financial Consultancy includes: financial modeling; initial project analysis of project; investor/ customer assistance in approaching/liaisoning/negotiating with funding entities; achieving optimum financial closure; and documentation support. Enercon Power initiates wind farm IPP business development, plans and implements the IPP projects in collaboration with Enercon Financial Consultancy, and conducts the assessment of the projects (Enercon India Ltd. 2005a; Enercon India Ltd. 2005b).

As for improvement of wind energy estimation/optimization technology, Enercon India Ltd. has set up a dedicated Wind Resource Department in 2001 to conduct siting, wind monitoring, wind resource mapping, and optimization and micro-siting (Enercon India Ltd. 2005d).

Enercon Training Academy

As for O&M technological capability building, Enercon GmbH provided personnel training on-going basis. However, in order to meet the growing needs for high-level service personnel for increasingly high-tech turbines and wind farm O&M as well as to re-educate the Indian technicians with diverse cultural, linguistic and educational backgrounds to the level that equally satisfies the Enercon service standards, a training academy was established in Daman in 2004. The fully residential academy not only provides practical technical training but also requires trainees to go through a well designed physical training curriculum, to meet the service needs often in harsh environments and on 24-hours, 365 days basis (Enercon GmbH 2005b).

Business Process Technology

Enercon GmbH has been also very active on transfer of business process technology. The most notable example was the introduction of SAP, German software which is one of the most used ones for management of finances, production, purchasing, and other company processes in the world. SAP was first introduced by Enercon GmbH for logistics and accounting purpose in 1996. Enercon GmbH expanded the application of SAP to production planning and management, project management, service, and sales by 2001 (Enercon GmbH 2005a).

In 2002 Enercon India introduced the first SAP system to streamline the business process and enhance technical skills to meet the high-standard work culture by harmonizing working methods and organizational structure with Enercon GmbH. The firm also uses Lotus Notes communication system, which enables the immediate database sharing between Germany and India (Enercon GmbH 2002b). Strong demonstration effects and forward linkages were established. The SAP introduction to India enabled the firm to develop a system of online Daily Generation Report of every turbine operation through coordination through the SAP on-line & real-time information. In 2005 a decision support system with SAP BW was implemented as technology platform to offer enhanced analysis of data, ad hoc reporting capabilities, various drill-downs in the reports, exception reporting, trend analysis, and internal benchmarking etc.

Innovation Technology Transfer

Another distinguished characteristic of Enercon India is that the joint venture has a full-fledged R&D facility in order for the Indian engineers to work on global research projects in collaboration with the R&D headquarters in Germany. For example, the Daman blade facility engages in not only blade manufacturing but also blade design (Enercon India Ltd. 2005c). In addition, specific software was developed in India to provide the daily updates on the Enercon turbines production to MNES. Before deciding the further financing for wind farms, the minister can thus evaluate personally the performance of technology. Due to this complete transparency, MNES asked all other manufacturers to do the same, which resulted in a competition to increase the quality and performance (European Wind Energy Association 2004). However, the exact extent of R&D project contents in India has not been disclosed and the level of innovation capacity and capability is unknown.

Continuous Technology Path and Transfer

The uniqueness of Enercon technology definitely helped the Indian side to accumulate technological capacity and capability over the years. Most of other major frontier manufacturers, especially the Danish manufacturers, shifted their technology path from the Danish Classical Concept to pitch-regulated, variable speed operations during the past decade. On the other hand, the technology path of Enercon stays the same because of the great and early commercial success of its unique innovation – direct drive, full-scale variable speed turbines with synchronous ring generators. During the five-year technology introduction blank after 1995 to India, the basic characteristics of Enercon technology did not change and the new model introduction in 2001 had no difficulties of technological path adjustment.

Reciprocal Technology Transfer

The above story illustrates that Enercon India has established much deeper technology collaboration relationship than any other joint venture/license agreement collaborations.

Similar to other technology collaborations, Enercon India and Enercon GmbH engages in personnel training in Germany. The period is usually for three months for the Indian engineers (European Wind Energy Association 2004). However, their technical exchange goes beyond this level. Enercon India has developed high level production capacity and capability of almost every component of the high-tech Enercon turbines, including high vale added blades, synchronous generators, and electronics components, and they meet the high-quality standards at the frontier through export. The Indian engineers have been participating in the R&D activities in collaboration with engineers at the frontier. In addition, the level of project execution technology has been upgraded constantly and reached to high level through the constant personnel exchange for training, the establishment of special training academy, and the introduction of universal business software and the cross-border sharing of database. The establishment of subsidiaries under the joint venture has worked well as conduit for technology transfer as well. From the very beginning of the collaboration, the Indian partner was included in the global strategy of the German technology provider; unlike other early collaborations that set up their facilities in Tamil Nadu where the market exists, the Enercon India's choice of production locations in Daman was targeting for export and low cost production.

However, the most notable characteristics of Enercon technology transfer probably come from the sole ownership of Enercon GmbH by Aloys Wöbben. The venture share of Enercon India by Wöbben is 56%, which gives him strong control over his technology. Moreover, he has strong enthusiasm for technology transfer to developing countries. Wöbben attributes technology transfer for developing countries as one of the key success factors of Enercon GmbH. In addition to India, he has established the production lines for complete turbines and/or blades in Brazil and Turkey. Wöbben says,

> "Our main production and R&D center is in Germany but we are also focusing on developing countries like India and Brazil. I think it is important to support these countries via technology transfer. .... India is doing what so-called developed countries do not. In terms of technology and knowledge transfer, it does not only go from the industrialized world to the developing world. So we could also take some lessons from the developing countries back to here........ India is a market where normally you make no fast profit, but at Enercon we want a long-term investment strategy and we think that India is growing very fast. ....Until now we have a very good experience (European Wind Energy Association 2004)."

From the very beginning, Wöbben has frequently met the family owners of the Mehra Group and has built strong mutual trust and respect at personal level, which resulted in not only the continued expansion of production lines in India but also the establishment of various subsidiaries, the R&D center, and Enercon Training Academy.

Suzlon Energy Group - First 100% Indian-own Wind Energy Multinational

Suzlon Energy Group has taken an entirely different path from other Indian manufacturers; it became the first fully Indian-owned wind energy firm that built the R&D facilities in Europe and expand its business worldwide. Suzlon Energy Ltd. has become the first Asian company that ranked among the world top ten in the wind energy development field. In 2005 the firm became publicly listed on the Mumbai Stock Exchange and climbed up to the fifth position globally with 6.1% share of installations worldwide (BTM Consult APS 2006). With the public listing in 2005, Tulsi N. Tanti, the owner of Suzlon Energy, became the seventh richest Indian with nearly USD six billion-worth of assets (The Economist 2006). The Indian market share of Suzlon has steadily grown from 7% in 1997 to 51% in 2000. The firm has had approximately 40% of the domestic market share throughout the 2000s.

Beginning- License Agreement with Südwind of Germany

The parent company of Suzlon Group was established in 1986 in Ahmedabad in textile business, which expanded to international trade, hotels and financing business. The Group started as an investor in wind energy development first; facing the serious power shortage problems for their business, the Group started to build captive wind power projects in Gujarat during the first boom years. The success of its own wind farms led the Group to diversify its business into wind energy. Suzlon Energy Ltd. was founded in 1995, in Pune, Maharashtra. The location was chosen due to the state's political stability, favorable industrial policy and good infrastructure, and strong educational base (Suzlon Developers Pvt. Ltd. 2002; Suzlon Energy Ltd. 2002).

At the beginning, Suzlon formed one-year technical agreement with a German wind turbine manufacturer, Südwind Energie Systeme. However, after Suzlon Energy Ltd. imported ten of the 350kW turbines from Südwind and completed the first project within three months in 1996, Südwind bankrupted. Suzlon immediately bought a part of Südwind in 1997 and created a R&D center in Germany, where subsequent models of Suzlon have been developed (Twele 2005). Although Südwind was eventually reformed as a new company, which was incorporated under Nordex AG in 1999, the license agreement formed with Suzlon under the previous business entity left its technology for Suzlon to use freely without any further loyalty payment to the new Südwind. Suzlon quickly established itself as independent Indian manufacturer and the business took off rapidly.

Domestic and International Expansion

By 2001 Suzlon Energy Ltd. focused on the domestic market with four subsidiaries. While Suzlon Energy Ltd. offered R&D, engineering, and manufacturing, the four subsidiaries managed other wind business as follows: Suzlon Developers Pvt. Ltd. developed and implemented projects; Suzlon Windfarm Service Ltd., provided O&M services; Suzlon Green Power Ltd., invested in wind power projects as IPP; and Suzlon Realties Ltd, managed land acquisition and development.

Suzlon started its international expansion in 2001 with a project export to the United States. By March 2006, the group expanded into 22 domestic and international subsidiaries. The corporate structure has been greatly restructured and expanded during the early 2000s. While Suzlon Windfarm Service Ltd remained as it was, Suzlon Towers and Structures Ltd. was established to expand the IPP activities by the former Suzlon Green Power Ltd and to include business activities pertaining to towers. Suzlon Structures Pvt. Ltd. was added as a new subsidiary. The firm was most active in restructuring during the 2005-06 year due to the initial public offering in September; Suzlon Developers Pvt. Ltd., Suzlon Realties Ltd., and several operations at Suzlon Energy Ltd. were restructured into the following new subsidiaries: Suzlon Generators Pvt. Ltd. (manufacturing of generators), Suzlon Power Infrastructure Pvt. Ltd., and Suzlon Gujarat Wind Park Ltd. In addition, Sarjan Engitech Pvt. Ltd. was acquired and became Suzlon Engitech Pvt. Ltd. for production of various engineering products (Suzlon Energy Ltd. 2006).

As for international expansion, several subsidiaries for R&D units (AE-Rotor Holding B.V., AE-Rotor Techniek B.V. and Suzlon Energy B.V. in the Netherlands in 2001, and Suzlon Energy GmbH in Germany in 1999) were established before the 2001 international business expansion.

During the early 2000s, Suzlon established the US headquarters in Chicago (Suzlon Wind Energy Corporation USA), the Chinese headquarters in Beijing, and the Australian office (Suzlon Energy Australia Pty. Ltd. Australia) in Melbourne for global expansion. However, the lack of credibility of Indian brand created tough competition against the established European multinationals. To overcome this problem, the Group founded Suzlon Energy A/S in Denmark as its new world headquarters in January 2005, began managing all international sales and marketing activities outside India by tapping into the Danish human resources and brand image. Suzlon became a member of DWIA. During the 2005-06 year, the establishment of the international subsidiaries was most active: both Suzlon Rotor Corporation USA and Suzlon Energy (Tianjin) Ltd. China were founded to start manufacturing in the United States and China, respectively. In Europe, Suzlon Windpark Management GmbH was formed in Germany. The firm and the existing Suzlon Energy GmbH acquired three German companies Windpark Olsdorf WATT GmbH & Co KG, Constellation GmbH, and SE Drive Techniek GmbH in order to expand R&D activities. Constellation GmbH became Suzlon Windkraft GmbH. In addition, on March 2006 Suzlon acuqired the Belgian firm Hansen Technologies, specializing in gearboxes for wind turbines, as mentioned. Suzlon Energy Ltd. also founded a new subsidiary in Mauritius for investment and provision of turnkey solutions for setting up of wind farm projects (Suzlon Energy Ltd. 2006).

Innovation Technology

Technological development at Suzlon strongly depends on the European expertise. Most of important R&D and innovations have been carried out in Europe. Three companies in the Netherlands, AE-Rotor Holding B.V., AE-Rotor Techniek B.V., and Suzlon Energy B.V, are for rotor blade R&D. They were established by the Suzlon acquisition of a part of Aeropec, a Dutch blade manufacturer bankrupted in January 2001, and they form the blade R&D center in the Netherlands. Many former employees of Aeropec continuously worked for AE-Rotor Holding B.V. and they brought the Resin Infusion Moulding (RIM, equivalent to vacuum infusion) techniques to Suzlon. In Germany, Suzlon Energy GmbH was established in Rostock by acquiring a part of the bankrupted Südwind. This subsidiary has been carrying out R&D of components in nacelle, especially controllers since 1999. Two new German subsidiaries incorporated in the 2005-06 year, SE Drive Techneik GmbH and Suzlon Windkraft GmbH (Formerly Constellation GmbH), have been carrying out R&D in the area of gearboxes and wind turbine components, respectively. In addition, the 2006 acquisition of Hansen Transmissions International NV brought the R&D capacity of high quality gearbox to Suzlon. The R&D

headquarters of Suzlon, however, is located in Pune, India, taking advantages of the growing expertise of the Indian IT business.

Product Technology Development

From 1996 to 2000, Suzlon marketed only one 350kW model, the technology acquired from Südwind. In 2001 the firm installed one 1MW turbine in India, the first MW-class turbine introduced to the Indian market. Suzlon installed three of 1.25MW model in 2002. In 2003 the market started responding the firm's MW-class turbines enthusiastically; 78% of the number of turbines installed by Suzlon was the 1.25MW model, while the installation ratio of the 350kW model dropped from 74% in 2002 to 18% in 2003. In early 2005 Suzlon introduced its first 2MW model to the Indian market (interpolated from (Consolidated Energy Consultants Ltd. 2005). In addition to these MW-class turbines, Suzlon has marketed the 600kW and 950kW models in Europe and the United States.

The original 350kW model from Südwind was stall-regulated, two-fixed speed turbines with WRIG. GFRP was the blade material. Suzlon shifted to pitch-regulated turbines from its 1MW model, and its 1.25MW, and 2MW models have incorporated slip ring system with standard WRIG; however their rotor speed remains two-speed. The slip control provides the maximum slip up to 16% by varying the resistance of rotor winding dynamically, and increases energy conversion efficiency by containing the loss of power from wind derived from frequent wind speed changes at low wind level. From these MW-class turbines, Suzlon incorporated GFRE into their blades and vacuum infusion production technique (Suzlon Energy Ltd. 2005a). This slip mechanism is unique to Suzlon, and there are obvious technological influences of the European R&D on the development of these MW-class models.

Production Technology Development and Vertical Integration

Suzlon first set up its production facilities in the union territory of Daman, utilizing its tax free status and excellent port facility, as Enercon India did. The additional facilities were built in Maharashtra and Gujarat. Between 2003 and 2005, the firm expanded its production to two other union territories, Diu and Pondicherry. Two of the five production locations are dedicated to blade manufacturing. In 2005 the firm began the construction of integrated wind turbine manufacturing facility in China (including production of rotor blades, nacelle covers, control panels and generators) and a blade manufacturing facility in Minnesota in the United States.

The contribution of Suzlon to the Indian production capability building has been important. By 2001, the technology indigenization level of the firm was still not 100%, although it was quite high. Some components such as controllers were still imported from Europe (Suzlon Developers Pvt. Ltd. 2002; Suzlon Energy Ltd. 2002). From 2001 Suzlon began targeted vertical integration, starting from in-house blade manufacturing. It was the time that not only the firm began its international expansion but also the supply chain bottle necks in the industry started. With the incorporation of AE-Rotor Holding in the Netherlands, Suzlon started manufacturing rotor blade using the high-tech RIM techniques in India. Since then, the firm has gradually increased control over various components and built the capacities for manufacturing of all key components of wind turbines. Suzlon Structures Pvt. Ltd. was set up to manufacture tubular towers. The activities toward vertical integration have been most active since 2005. In 2005 Suzlon Generators Pvt. Ltd. set up a joint venture with Elin EBG Motoren GmbH of Austria to manufacture generators. The acquisition of Hansen Transmissions brought its three world-class gearbox manufacturing facilities to Suzlon along with the R&D capacity and will bring high-tech manufacturing technique of gearbox to India soon. During the 2006-07 year, the firm's manufacturing capacity will expand into the United States and China. At the point of 2006, Suzlon manufactures rotor blades, generators, gearboxes, control systems and tubular towers on its own (Suzlon Energy Ltd. 2006). The firm enjoys the cost advantages over its global competitors by way of operating its major manufacturing capacities in India. Strong capability building through learning-by-doing has been evident (Suzlon Developers Pvt. Ltd. 2002; Suzlon Energy Ltd. 2002).

Project Execution Technology Development – Wind Park

Project execution skills of the Suzlon professionals have also proven very high. Generic skills were inherited from the parent Corporate Group and supported the initial diversification into wind energy business. Then the skills have been further polished by developing several Wind Parks on remote, high plateau in Maharashtra.

The most innovative marketing and project development method developed by Suzlon was a new concept called "Wind Park." It is a turnkey development concept. However, in this method, Suzlon acquires a large area of land that is suitable for wind project development on its own rather than buying a small patch of land as order comes in. The entire land is developed and engineered together, and Suzlon sells each turbine to different investors as order comes in with guaranteed care of lifetime (Suzlon Developers Pvt. Ltd. 2002; Suzlon Energy Ltd. 2002). This concept could be only materialized with the extensive capital base, which Suzlon has enjoyed as a part of large business group. The first Wind Park project in Vankusawadw near Satara in Maharashtra was conceived already in 1995, before Suzlon began importing Südwind turbines. The Suzlon Group acquired the land identified by the National Wind Resource Programme of MNES. Vankusawade became the largest wind farms in Asia, offering the turnkey ownership of turbines to many major Indian industrial companies, including Tata Finance, Bajaj Auto, Bajaj Electricals and Savita Chemicals (Power Line 2002). Another project, the Kavdya Dongar Wind Park with total 58MW of installed capacity, is also located in Maharashtra.

The advantages of this concept is that each wind turbine set up under the Suzlon Wind Park gains several economies of scale and efficient wind farm design, which enables: extensive infrastructure development through collective design; minimized power transmission losses; increased array efficiency leading to optimized the power generation; adequate flow of wind available to all wind turbines; project execution under the ISO 9001:2000 quality requirements; 24-hour on-site monitoring & control; increased return on investment; and coordinated dispatch management with transmission operator. The Wind Park package comprises of host of services, which includes: site selection; micro-siting; site infrastructure development; installation of wind turbine; power evacuation facilities; interfacing with state grid; 24-hour services at site; liaison with the government departments and agencies; and financial arrangements for third-party sales (Suzlon Energy Ltd. 2005b).

Additional but very important advantage of Wind Park is overcoming the infrastructure deficiency by building strong grids and road infrastructure collectively. In particular, the issues of transportation and logistics of large capacity wind turbines are solved by establishing road infrastructure that connects the site and the Suzlon production facilities. Once the connections are made, a large number of turbines can be transported easily. The other important feature of Wind Park was its sophisticated use of SCADA in wind farm environment. All wind turbines in Wind Parks are monitored for 24 hours in real time by the Centralized Monitoring Stations, which linked to satellite systems and can be controlled to produce optimal energy output from the Stations as well as the Pune headquarters. This total quality control system ensures more than 98% of annual availability factor (Power Line 2002).

Making of Indian Wind Giant

Suzlon has become an Indian wind giant through its aggressive but careful and innovative business expansion. It has not been hesitant to seek technology help necessary for its growth from the outside, but the firm has done so very wisely.

This making of the Indian wind giant started almost accidentally by the bankruptcy of Südwind. Südwind was the stronger partner (technology holder and provider), when it formed the license agreement with Suzlon in 1995. However, the Südwind bankruptcy wiped out the restriction; Suzlon became the technology holder, making decisions without any business restrictions from Südwind and not paying any license fees. On business side, this presented a huge opportunity for Suzlon to understand the business on its own, and it certainly succeeded to learn business know-how rapidly. At the same time, on technical side, Suzlon was pressured to absorb the Südwind technology and its technical know-how before the license agreement was expired and the technology disappeared from its hands; this pressure pushed Suzlon to improve the Indian capacity and capability quickly. As a result, Suzlon grew to succeed in installing approximately 750 of the 350kW turbines licensed by Südwind after the bankruptcy. The market that did not move to medium- and large-capacity turbines also helped Suzlon master business and technology through the installation of this model. In addition, the Südwind bankruptcy created an opportunity to directly tap into the human resources of Südwind. Suzlon could form its R&D centers in Europe only by acquiring the parts of Südwind in 1997 and Aeropec in 2001 (Twele 2005). Thus, the Südwind bankruptcy created the business and technological basis of today's Suzlon, and unintentionally speeded up knowledge transfer from Germany to India.

However, it is very important to stress that it was Suzlon that grasped the opportunity and grow on its own. Thus, Suzlon have proven the importance of technological ownership as well as the formidable high potential of the Indians.

6.7.2 Section Summary

Knowledge Transfer and Spillover Effects

All the above manufacturers have been successful in accumulating technological capability through knowledge transfer and spillovers from their foreign collaborators. It seems that all backward linkages, forward linkages, learning-by-doing, and demonstration effect have been present.

- Careful selection process of local suppliers and personnel training by foreign collaborators created good backward linkages, providing local suppliers higher incentives to adopt new technologies.

- The Indian partners gained knowledge directly through leaning-by-doing and training that build human capital and skills. Some entrepreneurs who worked and accumulated experiences in some of these joint venture firms spun off and started forming their own companies to provide services in especially in O&M for projects developed by their former employers (IWTMA 2002).
- Forward linkages created by Enercon and Suzlon have raised the product and service quality of the Indian sides by linking them to the developed country market.
- Demonstration effects also happened when the Indian sides adopted managerial, marketing and production processes of higher efficiency technologies of the frontier, e.g., acquiring the ISO standards.

However, the size of developmental and spillover effects are ambiguous with two reasons. One is because the technology transfer has not been very active in recent years compared to the initial stage by the mid 1990s; the above effects have not been large for some newer technologies that were not introduced to India or introduced with several years of delay from the frontier. WTO (2002) reports that development spillover effects are smaller, as technology gaps are larger (World Trade Organization 2002). In this regard, the size of developmental effects is considered getting smaller more recently in the wind energy sector. The second reasons are the dominance of the Indian industry by large-scale developer-manufacturers; considering the lower presence of SMEs, developmental and spillover effects could be limited.

Effects of Technology Provider/Partnership Characteristics on Cross-Border Technology Transfer - Technology Ownership and Control

The above examination demonstrates that the results and effects of cross-border technology transfer also vary tremendously among manufacturers. Different partnership characteristics influence the results greatly.

The cases of Vestas RRB, BHEL, NEPC-Micon, and Pioneer Wincon illustrate the difficulty of joint venture/license agreement and various reasons behind the stagnation of technology transfer. The Vestas RRB case shows the strong hesitation of Vestas toward technology transfer for more than a decade. The stagnation is simply dreadful, considering the exceptional advancement that Vestas made at the frontier and the strong mutual collaborations until 1995. Although the exact reason is unknown, the technology control and unwillingness of passing new technology to RRB by Vestas is obvious, as the Indian partner has the majority of the venture share. The BHEL-Nordex case tells the special circumstances of SOE; the firm has suffered from the shortcoming of its own bureaucratic structure. BHEL has been assigned to an impossible task of performing as the industry frontrunner for sustainable development while all the restrictions on SOE have prevented it from doing so. Both Vestas RRB and BHEL could have contributed to the Indian wind energy much more, considering their high potentials and technological capability. Meanwhile, the NEPC-Micon case points out the importance of business ethics for keeping up good collaborations. Unfortunately, many broken joint ventures including this one and Flovel Tacke left bad reputations of the Indian firms during the early years, which affected the development of the industry. On the other hand, the Pioneer Wincon case demonstrates the effect of the weak status of technology provider Wincon at the frontier.

All the above cases tell that long-lasting technology collaborations require stable and constructive conditions from both sides of the partnerships. And the case of Enercon India demonstrates such conditions can be successfully created, but only with the continuous efforts from both sides. Enercon GmbH has incorporated its Indian partner into its global strategy and the strong trust existed from the beginning. The locations of manufacturing facilities and the establishment of export-oriented subsidiary were all decided around the strategy. The sole private ownership of the unique technology by the innovator Aloys Wöbben and his enthusiasm for technology transfer as well as high-level business expertise offered by the Mehra Family contributed to the successful technology transfer and collaborations. The decision making for technology development and transfer has been quick and decisive due to this ownership structure and mutual trust. The other aspect of Enercon India that is different from other joint ventures is the holding share of the venture. While the technology providers in Vestas RRB and Pioneer Wincon do not have the majority holding, Enercon GmbH has 56% of the venture share. Because of this, Aloys Wöbben still has the control over the technology that he passed to the Indian side. The continuous technological pathway of Enercon also helped creating the exceptional results of this collaboration and benefited to alleviate several Indian specific problems.

The case of Suzlon also illustrates the importance of technology ownership and control for indigenous technological capacity and capability building from the opposite side. The strong financial position of the Suzlon Group has made the acquisition of key resources at the frontier possible as well as the innovative business concept such as the Wind Park from the early on. The firm has been able to advance oversea market expansion and create forward linkages and demonstration effects on its own by acquiring reputation and high-level of innovation and production technology through vertical M&A at the frontier. Although the technology ownership was first created almost accidentally by the bankruptcy of Südwind, it was the Indians that flourish on its own by grasping the presented opportunities and grow into the Indian wind giant.

The Enercon and Suzlon cases also illustrate that the low quality production prevailing in India is not the absolute condition. India can definitely produce high-quality products and services and can be a part of global sourcing. Creating forward linkages to the frontier markets and inducing active transfer and strategic training that absorb the transferred knowledge and technology can quickly improve technological capacity and capability in India.

Section 6.8: Synthesis – Value Chain Policy Analysis and Causal Loop Diagram

This section synthesizes the analytical results of the previous sections by using value chain policy analysis and causal loop diagrams, focusing on the roles and effects of policy. Policy value chain analysis clarifies the target of each policy and causal loop diagrams illustrate the effects and the extent of each policy measure within the entire dynamics. Through the two analyses, the effectiveness of the system structure of wind energy sector development of the frontier and India as well as the effectiveness of policy measures are evaluated.

6.8.1 Framework of Value Chain Policy Analysis and Causal Loop Diagrams

Framework of Value Chain Policy Analysis

Wind energy policy instruments of the three countries are analyzed along wind energy technology and project value chain. The aim of value chain policy analysis is to clarify the target of various policy measures and the complexity of policy framework of each country and to highlight the similarities and differences of policy mechanisms of the three countries.

Policy Value Chain Matrix

In order to perform value chain policy analysis, a matrix that clarifies policy target stages in value chain of wind energy project and policy clusters are constructed for each country.

Targeted stages of value chain represent broad functions, not each individual value activities at firm or business unit levels. Target activities in the value chain are divided into two categories: power supply-push activities and power demand-pull activities. Power supply and cost are defined in the earlier stages of value chain, and policy instruments targeting these phases can be called power supply-push measures. On the other hand, power demand is stimulated by instruments targeting consumption, and they can be called power demand-pull measures (Van Dijk et al. 2003). Target stages and target activities are expressed in rows in the matrix.

Target policy clusters are divided into four categories: 1) domestic market development, investment and transaction; 2) technology development and investment; 3) industry structure and development; and 4) cross-border technology transaction and investment. Some policies have effects on more than one activity clusters. Target policy clusters are expressed in columns of the matrix. Policy measures may have more than one target functions and/or target clusters. Policy incentives will be classified into the four clusters as follows.

Policies related to domestic market development/investment and market transaction:

- measures reducing project investment costs (fiscal and financial incentives for project investment includes subsidy, grant, low interest loans, tax advantages for wind energy investment and loans, etc)
- measures reducing wind electricity production cost (price control measures such as feed-in-tariffs, tax advantages on wind energy generation income, etc)
- measures reducing wind electricity price (tax advantage on the wind electricity consumption)

- non-financial measures on production and consumption (quantity control measure such as quota obligation on production or consumption)
- measures reducing resource cost and availability (national and regional data/information system, financial and technical support for grid connection and infrastructure, etc)
- rules on investor characteristics (ownership restriction, domestic and foreign investment restriction, tax exemption or advantages on domestic and foreign capital investment, etc)
- rules on market size and location (institutional boundary, rules regulating regional transmission and distribution, etc.)
- rules on market transaction (rules regulating electricity banking, wheeling, regional electricity trade, etc.)

Policies related to technology development and investment:

- government R&DD programs
- measures support private sector R&DD (fiscal and financial support and incentives including subsidy, grant, low interest loans, tax advantages for R&DD investment and loans, etc)
- establishment of R&DD focal point and partnership between public and private sectors
- establishment of testing facilities
- rules on project development requirement (project development/planning application requirement, etc)
- rules on product and service quality requirement (technology standards, technology certification requirements, environmental requirements, grid interface and management regulations, etc)

Policies related to domestic industry development and structure:

- rules on concentration of firms in an industry (antitrust regulation that concern merger, vertical mergers, monopoly, and oligopoly)
- rules on entry and exit (control of entry of new firms and foreign firms, control of entry of existing regulated firms, restriction of the decision to exit to provide services to wider consumers)
- measures supporting specific types of firms (fiscal and informational supports for small and medium sized enterprises and women's firms, etc)
- rules on firm investment (investment regulation entails government intervention into production facility and process (firm's choice of technology and inputs) and the ownership of investments (foreign ownership restriction, etc)
- rules on product and service quality requirement (technology standards, technology certification requirements, environmental requirements, etc)

Policies related to cross-border investment and transaction between countries:

- rules on trade (custom tariffs and duties, trade quota)
- rules on Intellectual Property Right (IPR)
- rules on Foreign Investment
- rules on product and service quality requirement (technology standards, technology certification requirements, environmental requirements, etc)
- measures supporting trade (fiscal and financial incentives for export and import, trade supporting programs such as information support from trade association and government)

- oversea project development support measures (oversea development aids, fiscal and financial incentives for oversea projects, etc)

Framework of Causal Loop Diagram Analysis

Causal loop diagrams are one of diagramming tools to capture the structure of systems in system dynamics. They can present the feedback structure of systems (Sterman 2000). The aim of use of causal loop diagrams is to synthesize the analytical findings of this chapter, to see the dynamics of market, technology, and industry, to clarify the relationships between the dynamics and their co-evolutionary process, and to see the effects of policy measures categorized by the policy value chain matrix. The effects of policy measures can be seen easily in causal loop diagrams that identify positive or negative feedback structures created by policy measures and other variables. Thus, the diagrams are used to examine the effectiveness of policy, which is evaluated by whether or not it has had the targeted effects and the effects beyond the original policy intention.

Causal Loop Diagram Notation

A causal diagram consists of variables connected by arrows denoting the causal influences among variables. Variables are related by causal links, shown by arrows. Each causal link is assigned a polarity, either positive (+) or negative (-) to indicate how the dependent variable changes when the independent variable changes. A positive link means that if the cause increases, the effects increases above what it would otherwise have been, and if the cause decreases, the effects decreases below what it would otherwise have been. A negative link means that if the cause increases, the effects decreases below what it would otherwise have been, and if the cause decreases, the effects increases what it would otherwise have been. Link polarity describes not the behaviors of the variable but the structure of the system; they describe what would happen if there were a change and they do not describe what actually happens. These positive and negative links complete loops, which are either positive or negative. Positive loops are self-reinforcing. Negative loops are self-correcting and counteract and oppose change (Sterman 2000).

The causal loop diagrams in this research deviate from common causal loop diagrams in several points.[107] Although usually causal loop diagrams do not put circle, hexagons or other symbols around the variable, diagrams here use different shapes to distinguish policy variables (in rectangular) and external variables (in hexagons) from other variable (in ovals). Also some variables are circled by rectangle with round corners to show their aggregated characteristics. External variables are defined here as variables belong to the outside of the local wind energy sector. They can be either domestic or foreign factors. Lastly, a loop identifier that usually used to show whether the loop is a positive or negative feedback is not drawn, in order to simplify the complicated diagrams visually.

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[107] See Sterman (2000) for the basic principles of graphic design of causal loop diagrams.

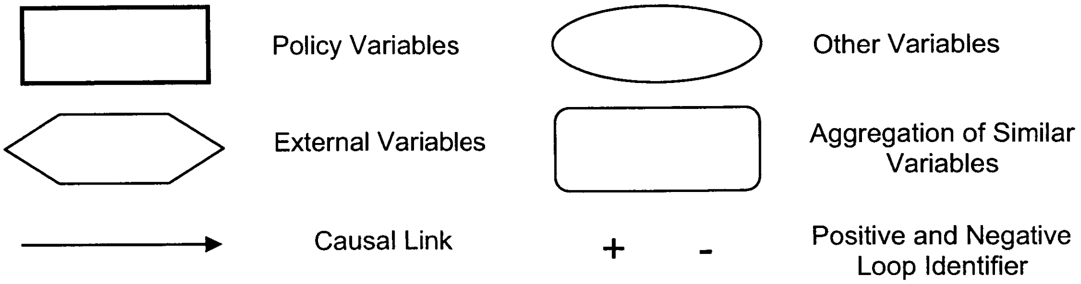

Figure 6-11: Causal Loop Diagram Notation and Key

Causal loop diagrams constructed here do not necessarily complete within the expressed structure, because the diagrams only represent regional/domestic wind energy sector structure and there are some external factors that internal variables of the regional/domestic wind energy sector structure cannot influence. Also, the diagrams can be disaggregated far more in details. However, because the purpose of this analysis is to capture the basic dynamics of system structures, the diagrams do not have every detail examined in the previous sections.

6.8.2 Policy Value Chain and Causal Loop Diagram at Technology Frontier

Policy Value Chain at Frontier during the 1990s and 2000s

Value chain matrix is created for each country. The JOULE Programme by the EU is incorporated into the matrixes of both Denmark and Germany due to its important impacts although it was not the national R&D programs.

Denmark

Table 6-28 shows the policy value chain of Denmark. All measures in Denmark have been in power supply-push measures. As seen, policy measures are heavily concentrated in the domestic market development/investment/transaction and the technology development/investment clusters. All power supply-push value chain activities are covered by the measures in both clusters.

Policy measures in the domestic market development/investment/transaction cluster range across all supply-push value chain activities down from project investment, while policy measures in the technology development/investment cluster also cover all activities except project investment. The main measures in the domestic market development/investment cluster (ownership limits, feed-in tariffs, production subsidy) that supported the market growth during the 1980s and 1990s were retreated from the beginning of 2000, simplifying the framework of policy. No formal and specific measures have been provided in the industry development/ investment cluster. Three policy measures in the cross-border transaction/investment have focused on the project investment and development/execution activities oversea. Some R&DD projects covered by EEP and UVE have also focused on reinforcement of exports of Danish technologies and expertise and international standardization from technology development perspectives.

Table 6-28: Policy Value Chain Matrix of Denmark after 1990

Target Policy Cluster / Target Value Chain Activity		Domestic Market Development/ Investment/ Transaction	Technology Development/ Investment	Industry Structure/ Development	Cross-border Investment/ Transaction
Power Supply Push	Turbine Technology		EEP R&DD (1978-) UVE R&DD (1982-2002) Noise regulation (1991-) JOULE-WEGA II (1990s) EEP & DEA R&DD (2003-05) PSO R&D (1998-)		
	Manufacture		Turbine Testing & Certification (1979-)		
	Project Investment	Tax deduction (1976-) Repowering subsidy (1994-97) Utility Agreement (1985-)			Wind turbine guaranteed company (late 1980s-)
		Ownership area/project capacity limits (1979-99)			
	Project Development & Execution	Spatial planning (1995-) Noise regulation (1991-)	EEP R&DD (1978-) UVE R&DD (1982-2002) PSO R&D (1998-) JOULE-THERMIE (1990s)		DANIDA project development aid (1980s-)
					RISØ WindConsult (1980s-)
	Power Generation	Feed-in tariff (1992-99) Production subsidy (1981-99) Green certificate (2000-) CO_2 tax refund (1992-) Repowering feed-in tariffs (2001-03)	PSO R&D (1998-)		
	Power T&D	Grid connection obligation	PSO R&D (1998-)		
Power Demand Pull	Wind Power Consumption				

Germany

Table 6-29 is the policy value chain matrix of Germany. The German policy covers both power supply-push and power demand pull functions in value chain. Like Denmark, the policy measures are heavily concentrated in the domestic market development/investment/transaction and the technology development/investment clusters. All supply-push and demand-pull value chain activities from project investment are covered by policy measures in the domestic market development/investment/transaction cluster.

Table 6-29: Policy Value Chain Matrix of Germany after 1990

Target Policy Cluster	Target Value Chain Activity	Domestic Market Development/ Investment/ Transaction	Technology Development/ Investment	Industry Structure/ Development	Cross-border Investment/ Transaction
Power Supply Push	Turbine Technology		Energy Research & Energy Technology (1980s-) WEMP (1991-) ZIP (2001-) BMU R&D (2004-) Noise regulation Blade material regulation (1995-) JOULE-WEGA II (1990s) Turbine Certification (1992-)		El Dorado turbine export assistance (1991-99)
	Manufacture			Subsidy for plant building (1990s) State support for local manufacturer (1990s)	
	Project Investment	250MW program capital subsidy (1989-96) Federal loans (1990-) Tax Income deduction (1990s-) State capital subsidy (1993-1999)		State subsidy for use of local manufacturer turbines (1990s)	Public-Private Partnership (2003-)
	Project Development & Execution	Zoning (1997-) Turbine privilege (1997-) Licensing (2001-) Noise regulation	Energy Research & Energy Technology (1980s-) WEMP (1991-) ZIP offshore (2001-) BMU R&D (2004-) JOULE-THERMIE (1990s)		TERNA (1995-)
	Power Generation	250MW program production subsidy (1989-96) Feed-in tariffs (1991-, EFL & EEG)			
	Power T&D	Grid connection obligation	BMU R&D (2004-)		
Power Demand Pull	Wind Power Consumption	Eco Tax (1999-) on fossil fuel electricity consumption			

Policy measures in the technology development/investment cluster also covered a wide range of value chain activities. The main policy measures in these two clusters have been continuous from the early 1990s to the 2000s. Unlike Denmark, there were several federal and state policy measures that support manufacturing and project investment value chain activities in the industry development/investment cluster during the 1990s. The German policy in the cross-border transaction/investment cluster also differs from those of Denmark; the turbine exports were supported by El Dorado Program, while two other measures have targeted the project investment and project development/execution activities oversea.

Wind Energy Sector Causal Loop Diagram at Technology Frontier

Figure 6-12 is the regional causal loop diagram of the wind energy sector at the technology frontier. Due to the similarity of policy measures of both countries and the strong influence of the German mechanism on both the Danish and German technology and industry development, only one diagram was constructed to express the regional structure.

Structural Characteristics

At a glance, it is very clear that there have been many positive links which have created positive feedback loops in the frontier structure and dynamics.

The policy-driven wind energy market dynamics starts with market development/investment incentives. Both the production incentives (the feed-in tariffs guaranteed by laws in both countries; the production subsidy and the CO_2 tax refund in Denmark; and the 100MW/250MW program production subsidy in Germany) and the investment incentives (the tax deduction in both the countries; the 100MW/250MW capital subsidy, the federal loans, and the state capital subsidy in Germany)[108] as well as the strong environmental concerns pulled the market investment, then the market development. However, this link soon created the utility/general development resistance variable, hence, negative links to market investment and political certainty. Also both the market development and utility/general development variables created negative effects on resource availability. However, at the frontier, these negative elements were corrected by new policy variables and technology-related variables. The utility/general development resistance induced the formation of ownership/land use regulations and noise/materials regulations, which generated positive feedback loops by increasing political certainty and by positively affecting technology development. The decreased resource availability due to the utility/general development resistance, the growing market, and the ownership/land-use regulations fortified the technology development/efficiency demand variable, which worked on technology upscaling/advancement directly as well as indirectly through changing the industry dynamics. The production incentives also directly increased the technology efficiency demand.

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[108] Denmark already retreated the investment subsidy by 1989.

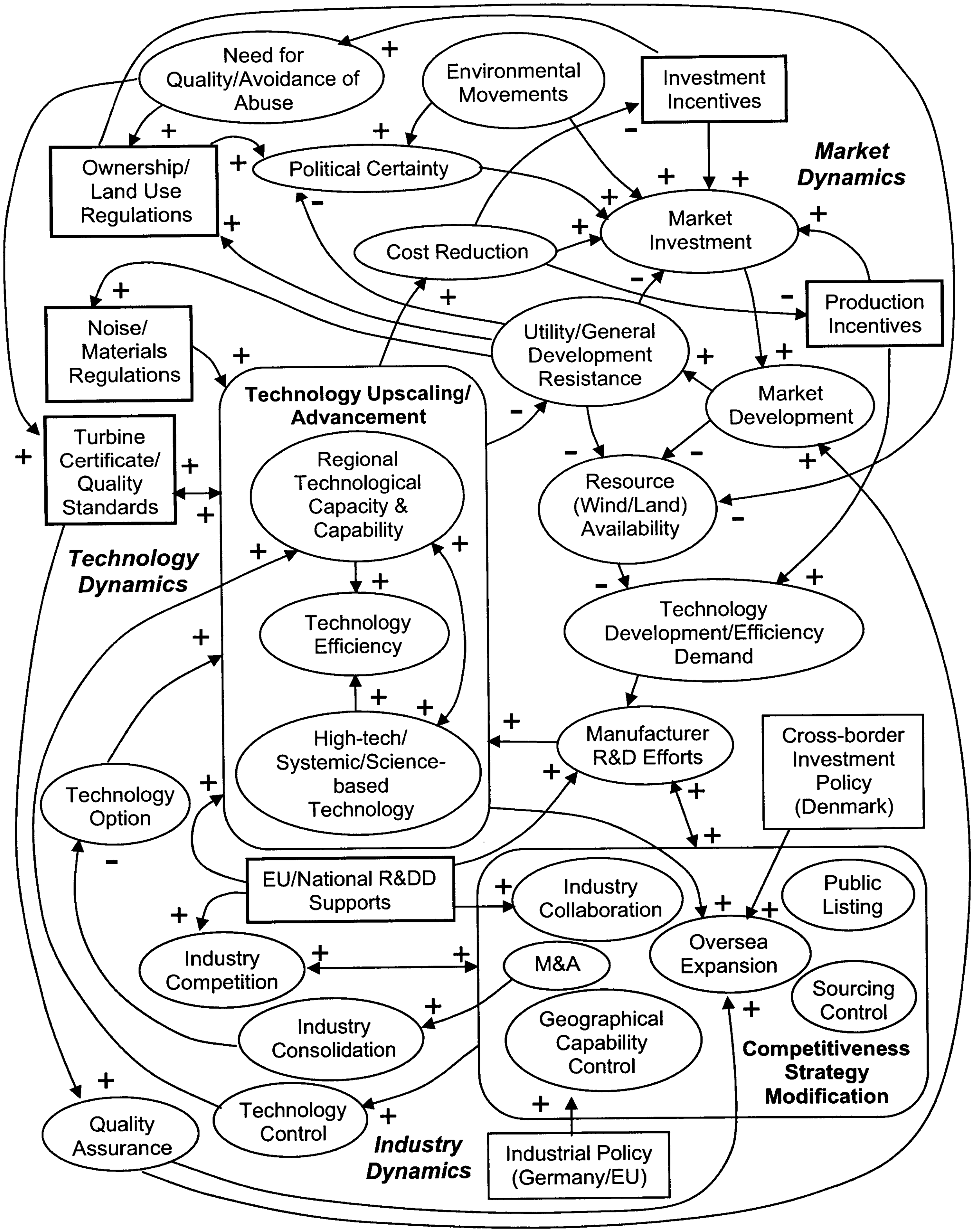

Figure 6-12: Regional Causal Loop Diagram of Technology Frontier

In the technology dynamics, the technology development/efficiency demand intensified the manufacturer R&D efforts, which directly influenced technology upscaling/advancement. In addition, the EU/national R&DD supports assisted the development of high-tech/systemic/science-based technology through basic science research directly, while the industry collaboration was also stimulated by both the EU/national R&DD supports and the manufacture R&D efforts. Throughout these processes, both the regional technological capacity and capability and the development of high-tech/systemic/science-based technology were advanced, resulting in the technology efficiency increase. The technology certification/quality standard policy, created by the need for quality improvement and avoiding the abuse of the investment incentives, enhanced technology advancement, which in return improved technology certification/quality standards. This reciprocal relationship also increased the quality assurance, which helped both regional market development and oversea expansion. In particular, the Danish technology certification efforts have continuously contributed to international standardization, fortifying the Danish industry position in oversea expansion.

The industry dynamics was basically triggered by the technology development/efficiency market demand and the manufacturer R&D efforts. These two variables were the driving force behind the modification of various competitive strategies, resulting in the increase of public listing, M&A, industry collaboration, geographical capacity control, and sourcing control. Several policy variables directly influenced some of the competitive strategy modifications. Cross-border transaction/investment policy in Denmark supported oversea expansion of the manufacturers. Industrial policy from the EU and Germany enhanced geographical capacity management in the region. Then, the EU/national R&DD supports enhanced the industry collaboration in R&D, which supported the manufacturer R&D. The R&D supports also intensified the industry competition through the process of project selection. While the competitive strategy modification and the industry competition intensified each other, the industry consolidation and the technology control were increased by the manufacturer strategy modification. The increased technology control then enhanced the regional technological capacity and capability in Europe. Although the industry consolidation decreased the available technology option, which is considered influencing technology advancement negatively, its effects were relatively small, as all other links had larger positive effects on the technology dynamics.

All these links in the technology and industry dynamics, then, came back to the market dynamics, reducing the cost and the utility/general development resistance by improving technology efficiency. The cost reduction then reduced the needs for both investment and production incentives, which are actually gradually reduced in both Denmark and Germany, completing a virtuous cycle of policy, market, industry, and technology development.

Frontier Policy Evaluation

Policy Evaluation based on Effectiveness

Policy measures are evaluated by the effectiveness based on whether it has created the originally intended effects on the activities they targeted. In this regard, the policy measures at the frontier were quite effective. In particular, the policy measures in the market development/investment/transaction cluster were very effective, triggering the market dynamics by stimulating the project investment and power generation activities as intended. Then, the policy measures that targeted the project development/execution activity helped increase political certainty and orderly development, correcting the negative effects created by the market development.

The policy measures in the technology development/investment cluster were also effective, because they supported the specific technology development/efficiency demands derived from the market dynamics. This was not the case before 1990 in Germany, as the policy measures in this cluster targeted technology development that was not necessarily connected to the commercial market at the time.

Not all policy measures in the industry structure/development cluster in Germany were effective, as many manufacturers that the measures were trying to support did no survive. Effective policy measures in this cluster were the ones that more focused on providing financial assistance in manufacturing activity, not the ones that give preferable treatment to the manufacturers or the product buyers; as such treatments distort the competition and do not help the proper industry development at the end.

The effectiveness of policy measures in the cross-border transaction/investment cluster was also not as large as the indirect effects of the policy measures in the market and technology development/investment clusters, in terms of assisting cross-border activities by the manufacturers; the manufacturers that gained enough competitiveness in the regional/domestic markets did not require strong cross-border investment policy supports for their oversea expansion. At the same time, however, the focus of the measures such as RISØ WindConsult and TERNA has not been the supports for the domestic manufacturers but the international knowledge dissemination. In this regard, their contribution is quite large.

Policy Effectiveness on Virtual Cycle Creation

The effectiveness of policy measures at the technology frontier also derived from their power that balanced out some negative effects created in the process of market development.

At the frontier, as mentioned, the policy measures that targeted the project development/ execution activities have played the roles of correcting the negative links and turned them into positive loops or create new positive loops that offset the effects of the negative loops. The ownership regulations, the land use/spatial planning regulations, and the environmental regulations concerning noise and materials addressed the concerns and resistance for further development, reinstated political certainty, and triggered technology advancement directly, while the continuity of policy measures, in particular, the production incentives guaranteed by law, have supported the basic mechanism of the market dynamics.

It is also important to note that the balancing-out happened only in the market dynamics and the technology and industry dynamics just followed what the market dynamics required. The frontier system structure proved that the properly functioning market is most important to offset the negative effects that could have discouraged the technology and industry dynamics. Thus, the market policy measures at the frontier succeeded to create rippling positive effects on the activities beyond the ones that they originally targeted, resulting in virtuous cycle creation.

6.8.3 Policy Value Chain and Causal Loop Diagram in India

Policy Value Chain of India

Table 6-30: Policy Value Chain Matrix of India

Target Policy Cluster / Target Function in Value Chain		Domestic Market Development/ Investment/ Transaction	Technology Development/ Investment	Industry Structure/ Development	Cross-border Investment/ Transaction
Power Supply Push	Turbine Technology		Indigenous turbine R&DD (-1992) Commercialization R&DD (1992-) Turbine certification (1995-)		Import duty measures (1993-)
	Manufacture		Import duty measures (1997-) Exercise & Sales tax exemption (1993-) Exercise & Sales Tax on spare parts (1998-) Exercise Tax on high value added activities (1993-)	Corporate tax reduction (1991-) Promotion of FI (1991-)	
	Project Investment	IREDA project loan (1992-) Tax holiday (1993-) Accelerated depreciation (1993-) Zero-tax (1993-96) Import duty measures (1993-) MAT (1997-) Wind Estates (1994-) TUF (1999-05) State subsidy			IREDA manufacturing equipment loan (oversea market) (1990s-)
	Project Development & Execution	IREDA equipment loan (1992-) Eased industrial clearance (1991-)	Demonstration (1985-) Wind resource assessment (1983-) Project guidelines (1995-)		MNES consultancy (late 1990s-)
	Power Generation	Feed-in Tariffs Third-party sales			
	Power T&D	Wheeling Banking Grid connection obligation	International collaboration in R&D (late 1990s-)		
Power Demand Pull	Wind Power Consumption				

Table 6-30 is the policy value chain of India. All measures have been in power supply-push measures. Similar to Denmark and Germany, the policy measures are heavily concentrated in the domestic market development/investment/transaction and the technology development/ investment clusters, and they cover all supply-push value chain activities. The policy measures in the market development/investment/transaction cluster range across all power supply-push value chain activities from project investment, but they are most heavily concentrated in the project investment value chain activity. Although the industry electricity tariffs determined by SEB of each state are a very significant incentive for project investment and production, they are not the wind specific policy measure but an external factor to the sector; hence they are not included in the matrix. One big difference from the frontier policy is that India has had more policy measures in the technology development/ investment cluster that focus on manufacturing activities. Also as seen, the import duty measures have been used to stimulate different value chain activities in three policy clusters.

Wind Energy Sector Causal Loop Diagrams in India

Due to the structural break happened in the mid 1990s, two causal diagrams are constructed for India: one for before the structural break and the other for after the structural break.

Structural Characteristics of Causal Loop Diagram of India before Structural Break

Figure 6-13 is the causal loop diagram of the Indian wind energy sector before the structural break. Many positive links were in present.

The market dynamics started with the two external variables: the 1991 economic reforms/limited power sector commercialization and privatization and the multinational/bilateral funding for IREDA revolving fund. These two variables contributed the creation of the investment incentives (IREDA project loan, tax holiday, accelerated depreciation, and zero-tax), which was the largest contributor in increasing the market investment. Another external variable, the high electricity tariffs for the industrial customers by SEBs, also initiated the first positive link for the market investment. The power sector privatization and commercialization encouraged the private power producer participation, hence the wind energy sector investment, through the creation of the production incentives. However, the feed-in tariff incentives offered by SEBs were too weak to initiate a positive link on its own. Other production incentives such as third-party sales in Tamil Nadu, wheeling, and banking, were also important contributors. The eased clearance also positively influenced the market investment. Then, the market development stimulated by the investment growth boosted the technology transfer demand. The demonstration and wind resource assessment measures contributed to the market development by increasing the information of suitable sites for projects as well as by reducing the resource availability cost. On the other hand, without any counteracting measures, the investment incentives created the gold-plating/incentive abuse variable, which reduced the cost reduction demand greatly.

In the industry dynamics, the technology transfer demand created by the market development, the increased interest in oversea expansion by the frontier manufacturers, and the GOI encouragement of foreign investment all contributed to increasing the number of technology providers and their local joint venture partners, resulting in the formation of the industry as well as the increase of technology introduction and local capacity/capability building.

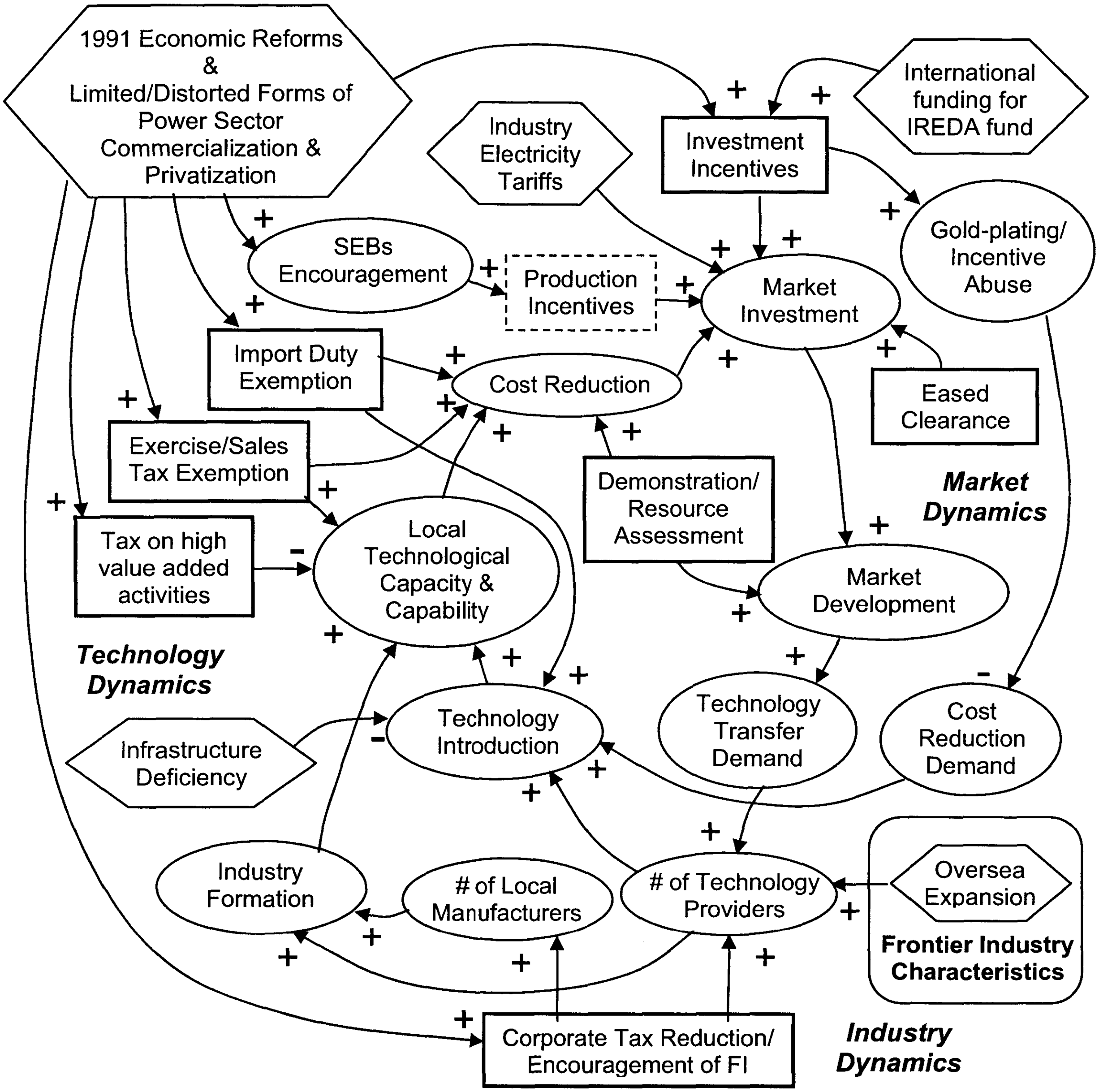

Figure 6-13: Causal Loop Diagram of India before Structural Break

The technology dynamics was also stimulated by the import duty and exercise/sales tax exemption, which increased the technology introduction and local technological capacity/capability building. Then, the increased technology introduction and local technological capacity/capability generated positive links to the cost reduction. However, there were several negative links created by the infrastructure deficiency, the tax on high value added activities, and the diminished cost reduction demand by the gold-plating/incentive abuse.

Overall, during this period, the positive links from the market dynamics through the industry dynamics created the positive feedback loops that go through the technology dynamics and reached to the cost reduction, coming back to increasing the market investment. On the other hand, the powerful negative links created by the gold-plating/incentive abuse and the infrastructure deficiency offset the positive influences on the technology introduction and local technology capacity and capability, hence the cost reduction. The cycles including market, industry, and technology were generated, but they did not reach the level to influence the policy variables, as seen at the frontier, because in reality the technology efficiency increase did not happen and the cost reduction effects were overshadowed by the gold-plating.

Structural Characteristics of Causal Loop Diagram of India after Structural Break

Figure 6-14 shows the causal loop diagram of India after the structural break.

The structural break was caused by both the internal policy variables (the MAT/income tax, the turbine certificate/quality standards variables, and the new import duty measures) and the external variables (the SEBs financial troubles, the transformed frontier technology characteristics into systemic/high-tech/science-based technology, the frontier industry consolidation, and the technology provider characteristics).

The new variables that triggered the structural break changed the market dynamics greatly. The gold-plating/incentive abuse variable induced the introduction of a new policy variable, the MAT/income tax, which returned a negative link to the abuse variable, hence reducing its effect, but it also generated a negative link to the market investment. Another new variable, the SEB financial trouble, generated a negative link to the production incentive variable by increasing the SEB resistance to wind energy development. The SEBs financial troubles also created positive links to the industrial electricity tariffs and to the 2003 Electricity Act through the SEB reform efforts, but the latter was introduced with a great time delay. These new policy and SEB variables increased negative influences on the market investment, hence the market development and the technology transfer demand, until the 2003 Electricity Act began outweighing their negative effects.

The industry dynamics was greatly influenced by new variables as well. However, unlike the market dynamics, the new variables in the industry dynamics were external, coming from the frontier. First, without the innovation capacity and capability, whether the technology transfer demand creates positive or negative link depended very much on the technology provider characteristics. Yet, the competitive strategy modification at the frontier changed the technology provider characteristics in terms of technology control, mostly toward its tightening, and created a strong negative link to the technology introduction variable. The technology introduction variable also got another negative link due to the industry consolidation at the frontier, which reduced the number of technology providers. Only a small number of technology providers with technology transfer willingness could positively influenced the technology introduction variable.

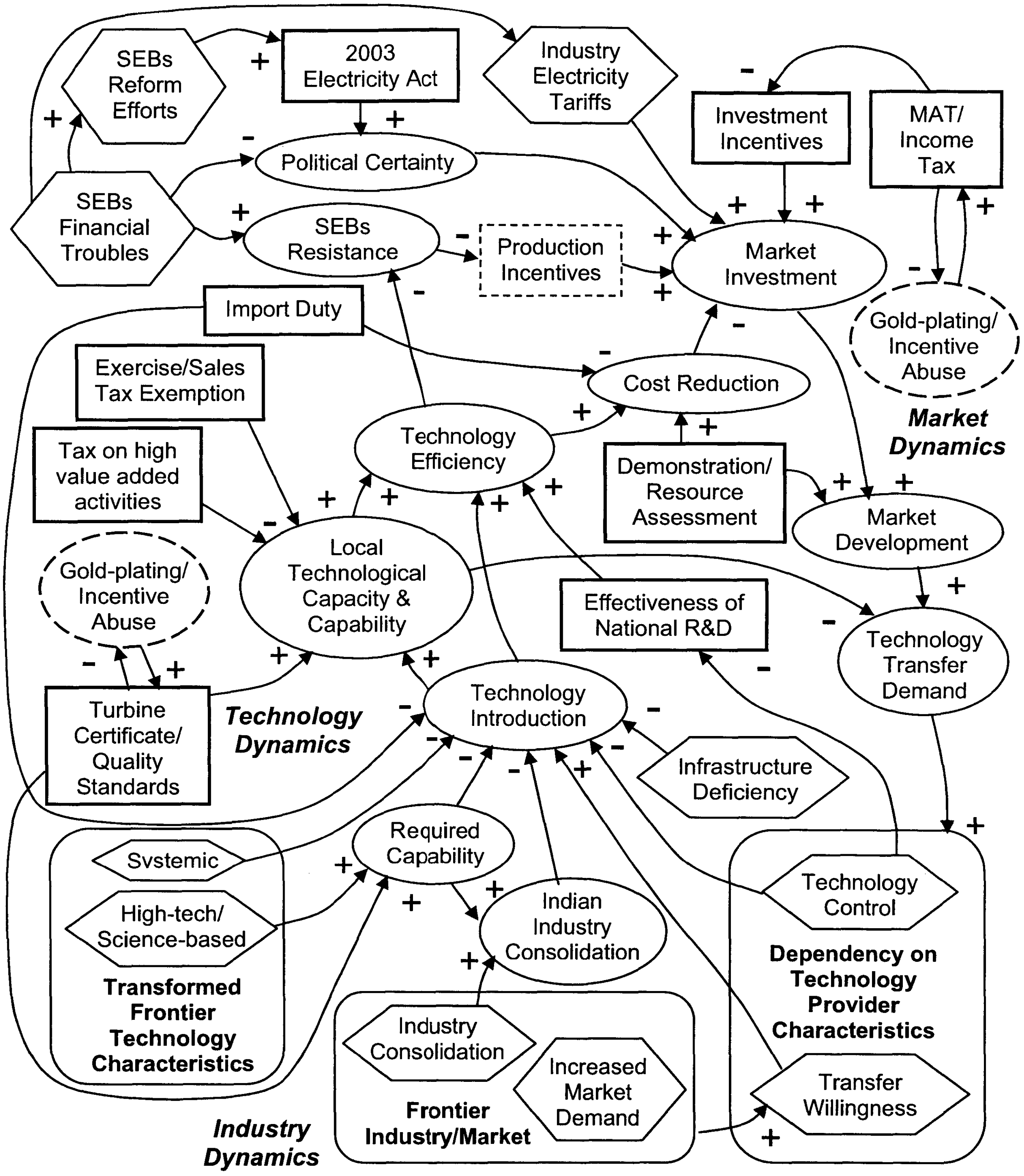

Figure 6-14: Causal Loop Diagram of India after Structural Break

A different external variable created at the frontier changed the technology dynamics too; the transformed technology characteristics (high-tech, systemic, science-based) generated negative links to the technology introduction variable. The internal and external domestic variables were also the cause of negative links; the continuous infrastructure deficiency and the newly imposed import duty did influence the technology introduction variable negatively. Thus, most of the new variables created negative links and reduced the technology introduction, which then decreased the local technological capacity/capability building and technology efficiency variable. The technology efficiency variable was also negatively influenced by the tighter technology control by technology providers, which also decreased the effectiveness of the national R&D. Only the technology certification/quality standards variable created a positive link to local capacity/capability building and counteracted the gold-plating/incentive abuse variable, contributing to the elimination of the phenomenon.

Overall, negative effects increased in all the market, industry and technology dynamics in the new diagram. In particular, the number of negative links that influenced the technology introduction variable has greatly increased. However, their effects were not reversed by any counteracting variables. As a result, all of the technology introduction, the local technological capacity/capability building, the technology efficiency increase, and the cost reduction as well as the links between them ended weak, creating the loop structures far from virtuous cycle. This was the structure that increased the technology gaps with the frontier.

Indian Policy Evaluation

Policy Evaluation based on Effectiveness

The policy measures that targeted the project investment activity and the project development and execution activity in the market development/investment cluster stimulated the investment in the beginning, hence were effective in this sense. However, all the investment incentives generated the gold-plating/incentive abuse variable in the first boom years, which was the exactly opposite that they intended to do. In terms of policy measures after the structural break, the MAT/income tax measure created the desired effects by eliminating the gold-plating/ incentive abuse phenomenon, but at the same time outweighed the effects of other original investment incentives, greatly reducing the market investment. The effectiveness of the production incentives, in particular, the feed-in tariffs, have been weak because the market investment was rather induced by a strong external variable, the high electricity tariffs to the industry sector. Overall, the effectiveness of policy measures in this cluster has been greatly mixed.

The effectiveness of policy measures in the technology development/investment cluster is also mixed. The demonstration and wind resource assessment measures increased the information necessarily for project development. And the exercise/sale tax exemption measures as well as the technology certification/quality standards measures were effective in increasing the local technological capacity and capability. On the other hand, the R&D measures did not produce any positive or negative links in the first boom years, and its existence was faded out by the tight technology control posed by technology providers after the mid 1990s. Also the exercise tax on high value added activities has continuously worked as a variable producing negative link.

The policy measures in the industry structure/development cluster had been effective for the industry formation in the beginning. On the other hand, the two measures in the cross-border transaction/investment cluster, the IREDA Manufacturing Equipment Loan and the MNES Consulting, have not been creating links to the dynamics.

In terms of import duty policy, which targeted different value chain activities in different policy cluster, the duty exemption in the early years as cross-border transaction/investment policy was effective by positively influencing the technology introduction. Also it was effective as market development/investment policy by reducing the cost. However, the increased duty after the structural break diminished both the effects. As a result, it was not effective to increase the local technological capacity and capability building as it targeted. Thus, the Indian import duty showed the ineffectiveness of inconsistent use of one policy measure targeting different value activities in different policy cluster in wrong timing.

In overall structure, the Indian policy measures were not constructed effectively to reinforce positive influences and counteract negative influences created in the loop structures. Although there was difficulty of influencing the external variables by the domestic wind energy policy alone, some of the negative loops were generated by the policy measures themselves. The policy measures could have been constructed to avoid such effects.

Difficulty of Replicable Cross-border Energy Technology Transfer and Role and Effects of Policy

Fragile Balance, Incomplete Loop Structure, and Strong External Variables

Compared to the virtual cycle and co-evolution of policy, market, industry, and technology dynamics created at the frontier, the Indian causal loop structures were the complex system of negative and positive links, which resulted in fragile balance of the system.

A significant contributing factor to the fragile dynamics was the large number of strong external variables. The frontier technology and industry characteristics and the infrastructure deficiency in India were the ones directly influenced the technology introduction, while the financial problems of SEBs and the industry electricity tariffs created links connected to the market investment. Those strong external variables increased the complexity of the system by adding many links. However, many of them were negative links, in particular, to the technology introduction. More importantly, because these external variables could not be easily and directly influenced by the Indian wind energy sector, the loops were not closed, resulting in many incomplete loops. All of the market, industry, and technology dynamics, hence the entire Indian system, were left to the mercy of the external factors.

Role and Effects of Policy in Cross-border Wind Energy Technology Transfer

Thus, the causal loop diagram analysis of India illustrates a difficulty of replicable cross-border technology transfer of distributed power generation technology under many external variables. In the internally closed structure such as the frontier dynamics, the properly functioning market dynamics can start rippling effects in technology and industry dynamics, spurring technology development and diffusion and reaching to the stage of virtuous cycle. However, the Indian structure cannot be enhanced by the improved market dynamics alone, because the Indian structure and dynamics are not closed internally and there are external variables that dictate the

Indian industry and technology dynamics from the frontier. Moreover, these external variables posed by the frontier technology and industry are constantly transforming themselves, creating the illusive, moving targets.

How to deal with such external variables strategically is an important agenda for energy technology development and diffusion involving cross-border technology transfer between developed and developing countries, along with the question of how to improve internal dynamics. Such strategic dealing can happen both at firm/business level and policy level. Making and implementing effective policy that turns negative links into positive ones and reduces the effects of negative loops is a key strategy at policy level. However, this is not an easy task by any means. Policy may not be able to interfere external variables directly, because they can be only dealt with strategically at business/firm level and/or because possibly effective policy measures may not conform the international rules of cross-border transaction/investment policy that are changing constantly.

The next chapter tries to form the findings of this chapter into more theoretical thinking of cross-border transfer of climatc friendly energy technology and consider the role of policy, taking the international climate change mitigation mechanisms such as the Kyoto Protocol into consideration.

Chapter 7: Conclusion

Chapter 6 examined the causal factors and processes that created the similarities and differences in technology development and diffusion between the technology frontier of Denmark/Germany and India, and their effects on technology transfer results. .

This chapter concludes the research. The chapter consists of two parts. The first section reviews the key findings according the conceptual focus and theoretical and practical contexts of the research introduced in Chapter 1. The second section draws some practical implications for future climate change mitigation technology transfer based on the research findings.

Section 7.1: Key Findings

7.1.1 Direct Role of Policy and Institutional Settings

Technology Frontier - Denmark and Germany

Market Development

- The monetary value creation and rewarding policy, which creates favorable policy/ institutional sensitivity factors (revenue sources, fiscal measures, cost of financing, purchase agreements) in project finance mechanism, served the market development, hence technology inducement, most effectively in the case of wind energy.[109], [110] Direct environmental policy or direct technology forcing measures such as energy consumption/emission restriction requirements have not been the market driver.
- The sequencing and combination of monetary value creation and rewarding policy incentives was the critical factor of the market size expansion.
  - The production incentives (feed-in tariffs) were the most important factor for market development. At the frontier, their legal guarantees were especially important to provide the certainty of investment by reducing the risks and showing the continuity of political

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[109] Sawin (2001) very clearly articulated the effectiveness of demand-pull policy in her detailed comparative study on wind energy technology development and diffusion in Denmark, Germany, the United States as a whole, and the state of California, from 1970 through 2000. Her dissertation research particularly focused on the role of government policy and their effectiveness. Unlike the conventional economic theory, which insists that renewable energy will achieve greater market penetration once it is cost-effective with conventional generation, her research concluded the government policy is the most significant causal factor in determining the diffusion of wind energy technology, and the priority should be given on demand creation rather than government R&D to achieve the competitiveness. Sawin also lists the importance of turbine certifications as well as political certainty as significant success factors (Sawin 2001). This research confirms her findings again in many areas.

[110] Also a series of publications by Norberg-Bohm and her colleagues stress the importance of demand-pull policies and the existence of sustained markets, along with supply-push policies, for innovations and deployment of newer energy technologies in developed countries including wind. See (Norberg-Bohm. 1996, Banales-Lopez, and. Norberg-Bohm. 2002, and Loiter and Norberg-Bohm. 1999).

will, although the links of the feed-in tariffs to market retail electricity price often created investment uncertainty.

  - The investment subsidies in early years can be effective means to kick-start the market. However, it was their gradual retreat and shift toward the production incentives that contributed to strengthening the cost reduction demands and successfully establishing sustainable market and competitive sector growth at the frontier.

  - The fiscal and financial incentives were also effectively used to increase the competitiveness of technology and support the market growth.

- The ownership regulations (Denmark) as well as the availability and types of fiscal and financial incentives shaped the investor profile in great deal.

- The spatial planning regulations and the ownership regulations contributed to the local acceptance of wind energy technology, the prevention of the government incentive abuse, and the orderly market growth greatly. However, the process of their establishment and refinement took time.

- Timely manner of effective policy implementation to replace obsolete technology is important. In particular, the Danish experiences showed that the use of long-term production incentives (reduction of monetary reward for production from obsolete technology) was more effective than the use of one-time only investment subsidies (capital subsidies for replacement of obsolete technology).

- Long-term certainty of policy and institutional supports is essential for sustainable market development. Stability and continuity of governmental supports and showing the political will are critical, even if the policy mixture itself is changed over time.

  - Shift of timing from one policy mechanism to another, e.g., the feed-in tariffs to the support mechanisms based on free market mechanism such as green certificates, needs to be carefully examined, as the Danish experience since 2000 showed the difficulty of such shifting under the uncertainty of transition to liberalized market and energy sector reform.

  - Under the market liberalization process, legal measures that separate policy measures from the uncertainty of the market, e.g., the EEG of Germany, can be effective and are often necessary to support environmental technologies that are not fully competitive. Their supports are well-justified on externality ground.

Industry Development

- The direct roles of industry structure-related regulations and industrial policy interventions on the wind industry development were limited in the well-established institutional environments of Europe. The indirect influences of the market and technology development and investment policy incentives were the main forces that shaped industry development and structure. However, the governments did still play significant roles as coordinator and initiator of industry collaborations and networks at both international and national levels for industry-wide competitiveness building.

Technology Development

- The supply-push policy for technology development in supporting incremental innovations based on the market and industry experiences have been timely and cost effective for wind. Pushing radical innovations without the backing of market and industry knowledge accumulation have been far less successful and created the costly failures.

- The distinction of the roles of regional/international bodies and the national governments in R&DD (the EU efforts in the grand scheme of turbine upscaling and the national R&DD programs in basic science, commercialization and technology analysis of components and system) successfully reduced the redundancy but created an effective synergy. The effectiveness of international R&DD networks was amplified by the capability of national governments in coordinating such networks.

Technology Transfer

- The developmental and financial assistance tied with donor-country technology can help the infant industry's oversea expansion strategy and transfer of technology. The Danish supports tied with the Danish technology/enterprises gave the first mover advantages to the Danish industry.

Policy that played Multiple Roles

- There are the measures that directly influenced multiple policy clusters beyond the originally targeted one. At the frontier, the technology development measures played this role by influencing the market and industry dynamics.

    - The turbine testing and certification requirements, which originally targeted to support high-quality technology development, have played significant multiple roles. In Denmark, they have been effective in: 1) eliminating the abuse of the government incentives; 2) deterring the entry of low quality firms into the industry by working as institutional-technical barrier for business entry as well as eliminating the existing low quality firms; 3) creating de facto international standard, giving the first mover advantage to the Danish industry as well as containing the regional competitiveness within the limited areas of Europe with higher capacity and capability.

    - The public R&DD programs have played dual roles in sorting out the competitive firms as well as coordinating the industry collaboration efforts and projects, strengthening the industry competitiveness as a result, while supporting technology development.

Technology Receiver - India

Market Development

- The creation and implementation of policy measures that increase the certainty and controllability of the market is critical. Although the Indian policy incentives look similar to those at the frontier at a glance (investment, production, fiscal and financial incentives), they have had great difficulty in developing stable and sustainable market due to the following reasons:
    - The entire market growth has been supported by an external factor, i.e., high electricity tariffs posed on the industry sector, which made the production incentives totally ineffective regarding the control of market development.
    - The heavy reliance on the above external factor and on the short-term fiscal incentives made the Indian wind energy investment one-time tax planning and management tool for industry investors. Such mechanism does not contribute to competitive market development due to the lack of performance-oriented characteristics and cost reduction demands, and the market cannot engage in sunset-clause of investment and fiscal measures as it deeply depended on those non-performance-oriented measures.
    - The difficulty of policy management for market development has been further increased by the strong fluctuation and geographical segmentation of the market caused by the federal structure, along with intense local political uncertainty under the unhealthy financial conditions of state utilities and the controversial sector restructuring process. The weak policy and infrastructure coordination between states also contributed to the segmentation.
    - Implementation of the incentive-abuse prevention measures from the beginning is critical in order to create the orderly and continuous growth of new market and its certainty. The lack of quality assurance measures in early years in India caused the abrupt policy change that created the sudden market recession, but the trust of investors could not be easily regained.
- Showing a clear national direction and strong political will for the sector development by national legislations, e.g., the Electricity Act of 2003, was important for the market, especially under the strong political uncertainty due to the sector transition and the segmented institutional structure in India.
- The procedure and methods of the power sector reform and restructuring are very important. The hasty and mishmash procedure and methods of the power sector liberalization can pose larger costs later by creating self-contradictory mechanisms and increasing political uncertainty, affecting the market negatively.

Technology Development

- The most significant technology support measures have been the National Wind Assessment Program and the MNES demonstration program, as they have reduced the resource costs greatly.

- On the other hand, the public R&D program has been ineffective due to the limited financial sources and the restricted business practices on R&D posed by most of technology providers.

Policy that played Multiple Roles

- The industrial policy measures played multiple roles at the technology receiver side. India has used more industrial policy measures, in particular targeting manufacturing activities, than the frontier governments. However, their records are mixed; they were both effective and counter-effective. The effective sequencing of those measures requires high capability of policy makers in grasping the conditions surrounding the industry and the technology in timely manner.

    - The industrial policy interventions played the direct role of establishing the wind energy industry and technology transfer in early years. The supportive FDI policy, the favorable trade policy, and the rules on prohibiting foreign manufacturers to set up a shop independently played important roles in industry formation by encouraging joint ventures and license agreements with foreign manufacturers. They also actively supported technology transfer through foreign collaborations, but their effectiveness has lessened over the years, as individual technology providers began taking control over technology transfer contents. FDI and other forms of technology partnerships do not automatically guarantee the continuous technology upgrading and replicable technology transfer.

    - Both the import duty and the exercise duty have mixed records as manufacturing incentives. Frequent changes in the import duty without the stable and sizable market and enough technological capability as well as the exercise duty on high value added activities disrupted the targeted technology development as well as contributed to the market recession by increasing the costs. The lack of political capacity and capability to make appropriate assessments and policy measures in appropriate timing was an important factor behind the failure.

- The establishment of the national level revolving fund and its continuous usage can not only be a cost effective way of utilizing international public lending to support private market development, but also contribute to effectively eliminating the danger of bilateral concessionary financing and avoiding potential technology-lock-in situation.

- The quality assurance measures such as turbine certification and project guidelines contributed to increasing technological capability building greatly as well as induced the industry structural adjustment by eliminating low quality firms.

7.1.2 Co-evolution of Policy, Market, Industry and Technology

In the process of wind energy technology development and diffusion, the whole ensemble and the co-evolution of policy, market, industry, and technology was critical. While their ensemble successfully created virtuous cycle of technology development and diffusion at the frontier, this research highlighted the difficulty of creating such cycle in India.

Frontier – Virtuous Cycle of Policy, Market, Industry and Technology Development

Central Role of Policy in Creation of Virtuous Cycle

- The virtuous cycle creation among policy, market, industry, and technology development was critical for competitive wind energy technology development, as it effectively reduced the cost of power generation and increased the competitiveness of technology, which in turn reduced the necessity and amounts of policy supports. Their dynamics determines the direction and speed of technology development and diffusion. The establishment of such cycle has been successful at the frontier.

- Policy has been central in the process of making the virtuous cycle by: 1) triggering new dynamics; and 2) reducing the negative effects by introducing new measures that create the counteractive positive effects for them. The starting point of the cycle was the creation of market dynamics by market value creation and rewarding policy measures, because they generated the rippling effects on technology and industry development by creating strong synergy for technology improvement. The performance-oriented market development policy (feed-in tariffs) was very effective measures, creating the similar effects with what technology forcing standards could have achieved.

    - The policy measures that corrected the negative effects were mainly in place in the market dynamics, indicating the importance of creating the effective market dynamics in virtuous cycle creation.

    - At the frontier, other factors such as land development pressures reinforced by the wind turbine zoning and noise regulations in Germany fortified the technology efficiency improvement demands. In addition, the competition with other investments was successfully created by not giving too generous policy incentives to wind.

    - The German EEG has further fortified the technology forcing demands as dynamic performance measures by its formulation of feed-in tariffs as a function of time.

- The frontier cycle creation showed that the indirect effects of policy are also important due to the interaction among factors in the whole system dynamics. Continuous adjustment and overall coordination of policy according to the evolution of other aspects of the sector are, therefore, essential.

Market, Industry, and Technology Interaction

- Both supply and demand factors played important roles in wind energy innovations as the sources of technological change. However, the main role in technological change was played by the demand-pull factors; both the market size and demand characteristics were necessary. They were collectively the driver of technology development and the determinant of technological characteristics.

  - The market with size and continuity matters, as only the sizable and continuous market can have enough power to justify all technology development investments and determine the speed of technology development. At the frontier, several local markets with similar characteristics (Denmark, Germany, and Spain, etc.) contributed to create the stable and sizable regional market.

  - The market demand characteristics determined the direction of wind energy technology development. Technology development and diffusion at the frontier has been very much demand-pull, as almost every technology can be traced back its origin to a certain market demand and/or the combination of them. In particular, technology efficiency improvement demands created by the investment economic pressure and various policy measures were most important for leading tremendous wind turbine upscaling in size and capacity as well as various innovative features of wind energy technology.

  - Technology supply by exogenous innovations outside the wind energy industry worked as effective support-factors to satisfy the market demands, but they also determined the speed and direction of wind energy technology development as pacing technologies. The exception was blade technology innovations that are specific and endogenous to the wind energy industry.

- Technological characteristics/specificity and industry competitiveness management strategy were deeply related to each other. The strong and continuous technology upgrading market demands were the modification driver for both. Technological characteristics determined by the market demands greatly influenced the necessity of capacity and capability management, hence the transformation of various firm-level competitiveness strategies.

  - The market demands for technology efficiency improvement transformed wind energy technology into high-tech integration of increasingly specialized components/value chain activities with stronger science-based innovation focus and increased technological complexity since 1990.

  - In the process of technological transformation, the wind industry was forced to modify various competitiveness management strategies (business entry, organizational growth, innovation network building, and geographical management of capacity and capability procurement and sourcing) in order to manage the required technological capacity and capability. However, the strategies have been specific to component and value activity; management strategy is closely related to technological specificity. This co-evolving technology-management transformation process cumulatively increased the technical barriers, which in turn contributed to consolidating the industry by eliminating less capable firms and containing the industry competitiveness within the region with high technological capacity and capability.

  - The close networks of government organizations, academics and researchers, manufacturers, sub-suppliers, and users amplified the effectiveness of capacity and capability management of firms and the industry as a whole on technology development.

India - Difficulty of Virtuous Cycle Creation

Market, Industry and Technology Interaction

- Replicable technology transfer is process-oriented. Unsuccessful virtuous cycle creation interrupted the replicable technology transfer from the frontier to India and contributed to the increase of technology gaps after the initial strong transfer trend.

- Installed capacity and new technology introduction through new turbine introduction have very strong structural relationship. The domestic market factors as well as both internal and external industry and technology factors are closely intertwined with the development and transformation of the structural relationship.

  - The structural relationship between installed capacity and new technology introduction changed after the 1996-97 year to the one that requires more installed capacity for the introduction of the same number of new turbine models to the market. This type of transformation is neither necessarily harmful nor something should be avoided, because installed capacity is not only indicating the amount of investments made but also related to the size/capacity of models used in the projects. To a certain degree, it is the natural transformation created by turbine upscaling. However, the problems in India was that this structural change accompanied the reduction of both installed capacity and the number of new turbine introduction, and contributed to the increase of technology gaps with the frontier greatly.

- The development of the initial structural relationship that spurred the strong technology transfer and new turbine introduction from the frontier was supported by positive interactions among the strong market growth, the industry formation through foreign collaborations, and the existing technological capability that were suited to small-capacity, mid-tech wind turbines at the time.

- The transformation of the structural relationship between installed capacity and new technology introduction had the complex causal factors, which were caused both internally and externally. Coincidentally, all the internal and external negative events occurred during a short period of time, amplifying the damaging effects further, interrupting replicable transfer, and contributing to the increase of technology gaps with the frontier.

  - The market-related causal factors were that: 1) the sudden and severe market slowdown, which was mainly caused by the abrupt policy change and happened to be coinciding with the frontier trend towards large-capacity turbines, amplified the negative side of the structural transformation by reducing the investments necessary to introduce those new and larger models; and 2) the market recession also contributed to the slowdown and termination of many technology collaborations with foreign technology providers.

  - The technology-related causal factors were that: 1) the increased systemic integration characteristics of wind energy technology at the frontier have made partial transfer of newer technology without the introduction of the entire models very difficult; 2) the increased technological complexity and high-tech characteristics required higher technological capacity and capability, which many Indian collaboration partners could not offer, and this has made the Indian manufacturers outside the global value chain and sourcing/production networks of technology providers, further deterring the opportunities of capacity/capability upgrading; and 3) the weakness in infrastructure in both electricity grid and transportation interrupted the introduction of larger-capacity turbines.

  - The industry-related causal factors were: 1) the industry consolidation at the frontier as well as various troubles in business relationships between technology providers and receivers during the first boom years reduced the number of technology providers in India; and 2) the tightened technology control as a result of the transformed competitiveness management strategies by technology providers deterred the introduction of newer and upgraded technologies.

Role of Policy in Technology Transfer

- The policy and institutional settings is central in both development and transformation in the structural relationship between capacity development and new technology introduction by influencing market-, industry-, and technology-related factors.

- The process-oriented nature of replicable technology transfer requires continuous and simultaneous demand-pull forces and supply-push forces. Policy plays a vital role in both aspects. However, the combination and sequencing of policy measures in India were not powerful and effective enough to induce both demand-pull and supply-push technology transfer.

  - Performance-oriented market development policy formulation and policy adjustment without abrupt change are vital for demand-pull technology transfer through sizable and continuous market growth with strong technology upgrading and cost reduction demands. This creates replicable technology transfer demands. The market demand characteristics are a necessary but not sufficient condition for inducing technological change, which requires the sizable market too. The demand-pull policy measures are also important because domestic market can be more easily controlled than industry- and technology-related factors that are more strongly influenced by external factors.

  - Technological capacity and capability and its relationship with technological characteristics are very important for managing supply-push technology transfer. Technology receivers have vulnerability to external factors due to the lack of technology ownership and control and the inherently lower technological capacity and capability than the frontier. In this regard, policy formulation for supply-push technology transfer is trickier and more difficult than demand-pull policy, because it requires flexible adjustment of policy incentives to manage and enhance technological capacity and capability at firm level in line with the industry and technology transformation happening on both technology provider and receiver sides, while not intervening and distorting free business activities and competition among firms in the industry.

- Industrial policy measures, especially manufacturing incentives such as import duty and exercise duty, can create controversial effects as supply-push technology transfer policy. Their formation and implementation as cost and technology management policy require careful consideration because both cost reduction and technological capability building may not be accomplished simultaneously.

- Infrastructure development policy is crucial not only for technology transfer of distributed power generation technologies such as wind but also for other sector business activities. Hence, prioritizing its early development and the necessary political coordination are vital.

7.1.3 Application of Theories of Technological Change on Wind Energy Technology Development and Diffusion

This part examines the mechanisms of wind energy technology development and diffusion at the frontier and India against the neo-classical theories and the evolutionary theories, and evaluates the adequacy of policy approaches related to these theories.

Technology Frontier

As easily seen, the analysis of technology innovation at the frontier, in particular the early Danish success by many other researches (see Chapter 4) as well as the technology advancement since 1990 by this research, strongly support the evolutionary theories in: 1) path-dependent technology development at firm level; 2) appropriateness and effectiveness of the evolutionary policy measures related to industrial network building (initiating and supporting interactions among various economic actors and providing coordination mechanisms) and related to the system of innovation (maintaining the institutional knowledge infrastructure, stimulating interactive learning among various actors presented in the national or regional innovation system, monitoring the innovation system, creating complementary links between public and private actors, creating and facilitating access to knowledge, and matching the supply and demand for knowledge within the system) at industry level, regarding wind energy technology.

The incremental and evolutionary nature of wind energy innovation since the 1970s showed strong path dependence; the wind turbine manufacturers innovated along certain familiar and known paths, their technological learning has been costly, and they coped with uncertain and risky business environments by developing and adapting organizational and managerial routines. This strong path-dependent process also showed the importance of technology development continuously backed and inspected by the market; the constant market trials are a cost effective way of developing technology. The technologies developed without going through such constant market trials were doomed to fail, as many radical attempts during the 1970s and the 1980s failed quickly despite their enormous consumption of time and financial resources because they never faced market trials in the process and lost the opportunities of continuous improvements.

The wind energy innovations since 1990 also have shown the increased importance of exogenous science-based innovations and pacing technologies, which the mainstream traditional neo-classical models argue as the sources of technical change taking the form of shifts of production function. However, it is important to recognize that these supply-side factors did not work in the way that the mainstream neo-classical theories indicate; their contribution was closely intertwined with endogenous firm innovations and industry dynamics, and the sources of technological change are far more complex and comprehensive than the neo-classical theories assume. Yet, the wind energy innovations also have shown the importance of expanded pool of design knowledge as public goods, which the new growth models argue important for firms to stimulate the interaction with human capital to shift production function by optimizing R&D choices. A large amount of scientific codified information created by international R&D networks created the level playing field for industry players at the frontier and became the sources of competitiveness for each manufacturer.

In terms of policy aspects, it is true that the frontier governments of Denmark, Germany and the EU covered some of the neo-classical policy measures to address the market failures of under-investments of R&DD (stimulating R&DD and expanding/accumulating the pool of design knowledge as public good), market imperfections (the EU antitrust measures), and information asymmetries (gathering and providing data/information). Yet, their effectiveness largely depended on the fact that many of these neo-classical measures were formulated and provided along the line of evolutionary support measures (formulating/stimulating R&DD and expanding the knowledge base through the national/regional system of innovation, and gathering and disseminating the information based on the data gathered through the government-industry network), because the links between exogenous innovation/knowledge base and technological change are not instantaneous and costless. The evolutionary ways of thinking played the decisive roles in policy formulation and they contributed to increasing the effectiveness of basic neo-classical policy measures at the frontier.

Thus, both the neo-classical and evolutionary policy measures played important roles in wind energy technology innovations, as both the movements of and along the production functions have happened. The frontier governments successfully supported both aspects. Incorporating the evolutionary policy measures contributed to amplifying the power and effectiveness of some of the neo-classical policy measures. And all these were possible with the strong market base.

India

On the other hand, the Indian side of wind energy development and diffusion showed clear inadequacy of addressing the assimilation aspects of the evolutionary theories.

As the evolutionary theories suggest, the assimilation of technology was time-consuming and costly and the Indian firms were not permitted to select technology freely. Each of them spent time and resources to build skillful entrepreneurship and technological capacity and capability by learning to build their own original production lines. However, the gaps in productivity with the frontier have increased overtime; during the Indian firms were struggling mastering the technology on old production functions of smaller-capacity turbines, the frontier shifted to newer production functions of larger-capacity turbines with various innovative features; the simple transfer of technology and capital was not enough to overcome the difference of productivity level.

In terms of policy aspects, the Indian governments have tried to correct market failures created by the externalities caused by costly technological learning and capability building through some evolutionary policy measures (e.g., technology acquisition through the new FDI and trade policy that induced foreign technology collaborations in the early years). However, the market development measures, other measures such as several manufacturing incentives, and the attempt to create generic knowledge base through C-WET have been rather indecisive and ineffective, in terms of creating scale and opportunities necessary for learning-by-doing and learning-by-searching (R&D). The restricted business practices posed by technology providers have also intervened policy measures in addressing the externalities created by cost of technological learning and capability building in India; the system of innovation and the knowledge network building within India regarding both med-tech and more advanced level technologies were weak.

From the neo-classical and "accumulation" perspectives, it is difficult to evaluate the Indian wind energy policy incentives because India has been engaging in policy measures involved in industrial activity and providing protections, and intervening free international flows of capital and technology. Certainly, the stagnation of introducing and mastering technology was intensified by the lack of physical and human capital accumulation aspects; in particular, the lack of physical capital investments on infrastructure (both the electricity grid and transportation) was one of the reasons that prevented India from shifting to newer and more efficient technologies.

However, it is clear that the assimilation aspects have been very important for wind energy technology development and diffusion in India due to its direct influences on mastering technology from the outside sources, and the policy measures have not been fully effective in correcting the market failures associated with technology assimilation.

7.1.4 Application of International Technology Transfer Theories on Wind Energy Technology Transfer from Denmark/Germany to India

This part tries to apply some of the existing international technology transfer theories on the wind energy case examined by this research.

Determinants of Entry Mode of Wind Energy Technology Transfer to India

The initial entry mode of wind energy technology transfer to India was mostly determined by the GOI restriction on building manufacturing facilities by foreign firms without the collaboration with local firms. Local manufacturing was necessary in order to reduce the costs. Therefore, all foreign entries in the early years chose joint ventures and license agreements over FDI. The location advantages advocated by Dunning were high in India at that time; the market prospect was strong and the availability and cost of labor input and transportation were satisfactory. However, due the above government restriction, foreign technology providers did not fully exercise the privilege to choose among the options stemming from internalization and ownership advantages; the choice between higher entry mode such as FDI and intermediate mode such as joint ventures/license agreements were not strategically made in this regard. The choice between joint ventures and license agreements was made by: 1) initial capacity and capability of the

Indian sides (higher original capital and capacity/capability firms such as Suzlon and BHEL cases for license agreements); and 2) ownership restrictions of SOE (BHEL case). This supports the organizational capability perspectives on determinant factors on technology receiver side.

The removal of the GOI entry mode restrictions contributed to the emergence of FDI as entry mode since the late 1990s (NEG-Micon and GE cases); they could exercise their strategies freely. One of the important backgrounds that made both the firms to decide to take FDI was, however, their business troubles with the former Indian partners (Micon with NEPC and Tacke/ GE with Flovel) during the mid 1990s; as a result, after their bitter court disputes, Micon lost its rights of manufacturing their turbines under 400kW in India and Tacke was also restrained its business activities in India. Therefore, ownership advantages (controlling firm's specific assets) by FDI were considered very high for both the firms at that time. As for location advantages (market attractiveness), the conditions were somewhat in question. NEG Micon remained in business in India after the break-up with NEPC during the severe market recession, solely in order to replace the bad quality turbines and projects built under Micon's name during the first boom years. Location advantages for GE are also unknown: GE has not been extensively installed its turbines in India, and the extent of export by the Indian subsidiary to other markets has not been so strong, considering the small amount of total export figures by the Indian wind industry. The Indian market entered to the recession and the technological capability supply from India began showing inadequacy for newer and more high-tech turbines. As for internalization advantages (transaction and coordination costs through internalization), the exact assessments are difficult due to the lack of data, comparing with other joint venture firms.

Thus, the existing theoretical frameworks regarding the choice of entry mode can be only partially applied to the wind energy technology transfer from Denmark/Germany to India, although the inadequacy of some data made full examination difficult. The O-L-I framework by Dunning as well as transaction cost theories cannot fully explain the choice of mode by technology providers, although parts of their arguments fit. This is largely because these frameworks mainly concern the factors from technology provider side. As many empirical studies have suggested, the factors that influence the mode of transfer are far more complex than any of the existing theories suggest, and more considerations on internal and external factors on technology receiver side need to be incorporated.

Mode of Transfer and Technology Transfer Results

As for the relationship between the mode of transfer and the transfer results, FDI have shown the introduction of more advanced technologies. However, in terms of developmental effects, the difference between FDI and joint ventures are ambiguous, as technology transfer itself has not been very active in recent years, compared to the initial stage by the mid 1990s. In addition, the results of technology transfer can greatly differ even among the same mode of transfer, depending on the detailed ownership structure and the willingness of technology providers for sharing advanced technology and business activities, as seen various cases of joint ventures in Chapter 6. The most thriving case in creating developmental effects and technological capacity/ capability building was the case of fully independent ownership, which could take an advantage of technological advancements at the frontier while overcoming technology control by technology providers, as seen in the Suzlon's case, but this requires the strong capital base.

The research indicates that more in-depth analysis and empirical data from other country and/or other technology cases can be useful to explore the relationship between equity share structure and transfer results as well as the difference in developmental effects between the modes, for wind energy technology.

Importance of Evolutionary Process of Partner Relationships on Transfer Results

Although the importance of the relationship between mode of transfer and transfer results should not be diminished, this research found that the evolutionary process of technology collaborations is another very important element to determine the technology transfer results and developmental effects of the transfer. Market, industry, firms, and technology are alive and evolve constantly; as a result, the dynamics of technology partnerships change. Technology transfer is a reciprocal process. Therefore, the mode of transfer alone cannot determine the evolving transfer results.

As for the forms of technology transfer, both the Indo-Danish and Indo-German technology transfers have the elements of horizontal technology transfer, as the production of similar goods for the local Indian market by multiple firms using local labor force has occurred. Also, the partnership cases have shown the mode of technology diffusions beyond learning-by-doing and training of fragmented production activities, i.e., backward and forward linkages formation and demonstration effects. However, there have been also the elements of vertical technology transfer at the same time; the production of high value goods has never occurred in many partnership cases. In addition, the export of lower value goods from India to other markets has not been strong either. Thus, the forms of transfer to India have been quite mixed; although technology transfer potentials have been stronger than a pure from of vertical technology transfer, they have never been fully realized and the technology gaps have increased over the years. The original reason for creating more of horizontal technology transfer elements was the initial strong market prospect and the cost reduction demands in India. However, all the factors analyzed in Chapter 6, the prolonged market recession, the lagged technological capability building, and the tightened technology control by the providers hindered the realization of larger potentials by strengthening the horizontal transfer elements.

This also shows that the importance of evolutionary dynamics of technology partnerships on the extent of transfer potential realization; initiating and sustaining the higher transfer potentials do not automatically happen and both strong demand-pull and supply-push efforts are necessary.

Future Research Needs

Thus, this research found that the importance of incorporating more factors on technology receiver side into the theoretical frameworks of the mode of international technology transfer. As mentioned in Chapter 1, many empirical studies have enhanced the knowledge regarding the factors on the technology receiver side and this research backed up those findings.

The research also found that the importance of factors and processes beyond those which determine the mode of transfer for the ultimate and long-term results of technology transfer; all domestic and external factors of market, industry, firms, and technology and their interactions change the transfer outcomes greatly. In particular, 1) the role of local market size and demand characteristics in technology inducing replicable transfer; 2) the implications of technological characteristics on technology transfer decision, subsequent technological capacity and capability building, and firm management of competitiveness; and 3) their dynamic changes, are all important to determine the outcomes. Due to the limitation of the scope of this research, which was confined within the wind energy sector of limited countries in a limited timeframe, it is inappropriate to generalize the results too widely. However, the future research on international technology transfer should, therefore, take more of dynamic interactions among various factors into consideration, especially for their long-term effects.

7.1.5 Role of Industrial Competitiveness Management on Wind Energy Technology Transfer Outcomes

The role of firm competitiveness management of technology providers is considered as the central element as the determinant of the mode of transfer in various international technology transfer theories; all transaction-cost-related arguments as well as Dunning's ownership advantages are about the competitiveness management by technology providers. Although this research showed that other factors happened to be more important as the determinant of entry mode in the wind energy technology transfer case to India, the firm competitiveness management by technology providers through technology control has increased its importance in determining the process and outcomes of technology transfer over the years, along with the market and infrastructure factors.

Simultaneous Transformation of Firm Competitiveness Management and Technological Characteristics

The research showed that the increased intensiveness of firm competitiveness management has derived from its strong relationship with technological characteristics and their transformation. Within the relatively short research timeframe, the wind energy industry grew from an emerging industry to a maturing but still growing industry and wind energy technology has become more complex with high-tech and science-based components. The importance of science-based innovations as the sources of competitiveness has increased, although the competitiveness continuously comes from all activities of value chain. Firm competitiveness strategies have been transformed tremendously not only to survive but also to thrive in the fast-evolving technology environments. As the technology intensiveness increased, so did the intensiveness of firm competitiveness management. The process of acquiring technology became more difficult and demanding for technology receivers, as a result.

Firm Competitiveness Management and Technological Specificity

This research also demonstrated that the firm competitiveness management and its strategies are very component/value activity specific. Technological characteristics and their evolution, which are technology-specific, greatly influence how to build technological capacity and capability. The development of innovation/production/project execution capacity and capability and their sources of knowledge creation and accumulation, i.e., learning mechanisms (e.g., R&D or learning-by-searching, learning-by-doing, learning-by-interacting), greatly differ in different science/engineering disciplines as well as technological levels and maturity (low-, med-, and high-tech) which each component/value activity relates to, even within one technology system.

The frontier players took very different competitiveness management approaches for different components and value activities according to their technological specificity. While the industry players took the tight R&D cooperation tactics to increase the entire industry competitiveness in generic knowledge accumulation in components with very strong basic science nature such as blade materials and aerofoil technology, technology improvement and development in more conventional and mature engineering disciples such as mechanical/structural/electrical/ transportation engineering components and value activities are carefully handled at firm level R&D and cooperation with sub-suppliers. More mature-level applied R&D in blade technology is also undertaken at firm level. In conventional and mature components/value activities, the knowledge creation and accumulation largely depends on the existing firm capacity and capability, while technology components in newer scientific disciplines require strong governmental and industry-level efforts to reduce the risks and costs. Thus, the roles of government and firms in technology development at the frontier are well-separated, according to technological specificity of components/value activities within the technology system, according to the required knowledge creation and accumulation mechanisms.

Firm Competitiveness Management at Technology Receiver Side

On the contrary to the active and intensified firm competitiveness management at the frontier, the management practices at the Indian side are largely passive, except a couple of cases. The firms which were able to take more active competitiveness management and/or roles in the collaborations with technology providers, such as Enercon and Suzlon, could engage more deeply in technological capacity and capability development. Although those cases showed the importance of willingness of transfer from the frontier and technology control by the receiver itself, working hard to cultivate the capacity and capability necessary to be a part of global management and sourcing of the collaborations is also essential. Thus, the firm level efforts on technology receiver side are very important for breaking a hole in the intensifying firm competitiveness management by technology providers.

Future Research Needs

The research tried to examine the relationships between technology transformation and firm competitiveness management as well as the effects of the relationships on technology transfer outcomes as much as possible from the available data sources. However, the unavailability of the first-hand data from technology provider firms regarding their competitiveness management strategies and the lack of data regarding wind R&D expenditures, export values, and manufacturing value added in India made it impossible for this research to take quantitative examinations in this area. The availability of these data could have strengthened the research substantially.

Although these data will be continuously difficult to obtain especially for the one from private firms, strengthening the statistical data base, in particular in developing countries, regarding monetary value data related to various climate change mitigation technology development and diffusion will definitely support more of both quantitative and qualitative analytical measures and deepen our understanding of the role and effects of firm competitiveness management on transfer of climate change mitigation technologies.

7.1.6 Sector Specific Aspects of Wind Energy Technology Transfer

There are some sector specific factors and processes regarding wind energy technology transfer that are different from more general technology transfer.

The most significant sector specific aspect derives from its strong relationship with government policy. The entire sector development is strongly policy-driven; hence, cross-border technology transfer has been also driven by policy, compared to the transfer of other commercial products.

Another important sector aspect relates to its infrastructure technology characteristics; specifically, the quality and characteristics of local electricity grids and the integration with them were the important factors that greatly influenced the technology transfer results.

The other aspect that was specific to wind energy was probably the speed of the industry and technology transformations. Their tremendous changes happened during a relatively short-amount of time was a part of the reasons that contributed to the increased technology gaps between the frontier and India.

7.1.7 Enabling Environments and Wind Energy Technology Transfer

This part re-examines the wind energy technology transfer from the perspectives of enabling environments and their ten dimensions defined by IPCC (2000) introduced in Chapter 1. Table 7-1 summaries the strength of such environments on both the technology provider and receiver sides as well as between them, based on the research findings.

At a glance, it is very clear that the frontier has developed the strong enabling environments for wind energy, addressing all of ten dimensions by some kinds of public and/or private measures and efforts. However, it is important to note that enabling environments at the frontier, in particular many elements and dimensions specific to wind energy, are the product of various public and private efforts over the years, being built and re-shaped as the technology progressed and reaching gradually to the current stage.

Meanwhile, the strength of enabling environments in India varies, depending on different elements of the dimensions, but in general they are more problematic or weak compared to the frontier. Although enabling environments have also progressed in India over the years, building better enabling environments has been difficult, as expected. In the Indian wind energy development,

- The market-specific dimensions such as the Sustainable Markets dimension and the Macroeconomic Policy Frameworks dimension have been problematic, weakening the demand-pull force for replicable technology transfer. The former as sector-specific dimension cannot be built without the favorable latter as generic dimension. Various elements in the Macroeconomic Policy Frameworks dimension still need to be strengthened.

- The technology-related dimensions such as the National Systems of Innovation and the Research and Technology Development interrelate to each other but are significantly weak in both generic and technology-specific aspects. The weakness has been partially caused by both the fragile vertical connections between technology providers and receivers and by the inadequate horizontal connections among the fellow Indian players, both of which are restricted by technology provider controls. However, generic technological capacity/ capability developments that can be enhanced by various educations and training, independent of technology provider controls, have been also inadequate, contributing to the weakness of entire supply-push forces.

- In terms of the Codes, Standards, and Certifications dimension, the Indian case demonstrated their strong necessity and effectiveness for healthy market and technology development in new and developing country markets from the beginning.

Table 7-1: Enabling Environments at Frontier, India and In-between

Dimensions of Enabling Environments	Frontier	Cooperation	India
National Systems of Innovation	Strong at all levels	Some generic supports but weak in general	Progressed with C-WET, but still weak at all levels
Social Infrastructure and Participatory Approaches	Strong in innovation/project development	Weak	Weak in technology selection/project development, but has been low relevance
Human and Institutional Capacities	Strong at all levels	Firm – vary Political – weak	Firm – vary Political – need to improve Financial – good
Macroeconomic Policy Frameworks	Capital/financial – strong Fiscal – good Interest rates - low Risks – lower today Energy price - liberalized Stability - strong	Capital/financial – strong in international lending Other areas - weak	Capital/financial – strong Fiscal – strong Interest rates –high Risks – medium today Energy price – subsidized Stability – getting stronger
Sustainable Markets	Strong with technology upgrading demands	----	Weak with replicable transfer demands
National Legal Institutions	Risk reduction – strong Governance - strong Corruption – very low	----	Risk reduction – weak Governance – good today Corruption – high in early
Codes, Standards, and Certifications	Strong	Getting stronger	Getting stronger
Equity Considerations	Gradually developed with Zoning/Ownership laws	----	Weak, but relevance is low
Rights to Productive Resources			
Research and Technology Development	Strong	Vary at firm level, but weak in general	Weak

- As for the National Legal Institutions, although the IPR regime was not so important for wind energy technology because patent activities in Europe were generally weak especially in early years,[111] more informal restricted business practices have been used by many

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[111] The Danish Patent Office publicly warned the country's wind industry of its vulnerability to aggressive business tactics by overseas competitors in 1998. A Danish patent investigation revealed that none of the global wind

providers, in particular for technology adaptation and innovations within India. In addition, other aspects of this dimension were especially weak in early years, interrupting the healthy development of market and technology.

- The technology-specific development of the Human and Institutional Capacities dimension vary, depending on firms and partnerships. However, more generic development of this dimension needs to be strengthened significantly in order to support both market-related and technology-related dimensions.

- The relevance of the Social Infrastructure and Participatory Approaches, the Equity Considerations, and the Rights to Productive Resources dimensions has been weak so far. This is because the sector development has progressed without the inclusion of a large number of different social groups. The relevance may grow as the wind energy sector development grows further and increases the contact with diverse social groups regarding both production and consumption of wind power.

In terms of cooperation between the two sides, the international lending and its use as the revolving funds have been very effective to advance financial elements in the Macroeconomic Framework for wind in India greatly. The sharing of technology codes/standards/certification with the frontier has also contributed to the enhancement of enabling environments. However, the cooperation activities have been weak or sporadic in general. The firm competitiveness management is the key for both enhancement and interruption for the National Systems of Innovation, the Research and Technology Development, and the Human and Institutional capacities dimensions.

Thus, reorganizing the research findings according to the dimensions of enabling environments showed the importance of such environments in supporting technology development and diffusion on both technology provider and receiver sides. However, it also showed the difficulty of technology receiver countries to build such environments in a short amount of time, in particular in the dimensions that concern firm-level activities under the restrictions posed by technology providers. Replicable technology transfer can only happen when both demand-pull and supply-push forces are strong; enabling environments can be only effective if they are concerted and well-balanced.

The research also found a missing dimension, the importance of "physical infrastructure," in terms of development and diffusion of distributed power generation technologies such as wind. This dimension should be considered as a part of enabling environments, as it is very important to support various economic activities in general.

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industry's best-known names on the top 20 list of companies were most active within wind industry patent applications between 1985 and 1996 (Wind Power Monthly. 1998a).

Section 7.2: Practical Implications of the Research

This section draws some practical implications for the future climate change mitigation efforts in terms of technology transfer, based on the findings of this research.

7.2.1 Specific Implications for the Indian Wind Energy Sector

The Indian wind energy sector has been experiencing the second boom years since the enactment of the 2003 Electricity Act. However, the technology gaps with the frontier have not been closed. The following recommendations can be made for the future, based on the research findings.

- Engaging in market transformation toward more performance-oriented market with replicable technology transfer demands is necessary to encourage stronger technology improvement and upgrading. In order to do so, it is essential to separate the wind energy market investment mechanism from the industry electricity tariffs, the external factor that wind energy policy cannot control, and reinforce the feed-in tariffs that make wind project economics profitable without fiscal subsidies. State feeds-in tariffs can also reflect more of the conditions of resource availability of sites in terms of wind resources and infrastructure, like dynamic performance standards such as the German EEG.

- It is important to create the stronger cost reduction demands to stimulate transfer and indigenization of higher value technologies. While keeping the robust market demands with performance-oriented incentives, the implementation of sunset-clause of investment subsidies is recommended.

- Advancing the entire electricity sector reform and restructuring further and correcting the mistakes already made are still very important. Although the privatization has already made, SEBs and SERCs have to make further efforts to remove cross-subsidy policies, while requiring full recovery of capital, operation, and maintenance costs.

- India will experience the needs of replacement of old technologies within several years. This can be a big opportunity to effectively reduce the technology gaps and increase power production and efficiency by implementing replacement policy, coupling with performance-oriented production incentives and fortification of the infrastructure.

- Strengthening infrastructure development in the electrify grid system and interface as well as in transportation by putting more national and international resources is urgent, in order to receive larger benefits through future wind projects including the CDM projects.

- GOI, state governments, and the wind energy industry need to explore more active supply-push measures in technological capacity and capability building, while eliminating ineffective manufacturing incentives. They can try to fortify or create stronger networks that contribute to the generic problem solving as well as the industry-level competitiveness creation. Although there are always the needs to avoid the conflict with firm business practices, the industry can involve generically in many areas.

    - In order to reduce the number of low quality products, policy measures that penalize them can be fortified, e.g., increasing penalties on repeated component failures.
    - Industry-level data gathering and analysis on the existing manufacturing problems, collaborative training on high-tech component manufacturing, and fortification of science-related education can be attempted.
    - Industry-level collaborative R&D of interface technology between weak grid and high-tech wind turbines with technology providers can be another important supply-push support. GOI can initiate the collaborative programs with the frontier governments and developmental agencies as well as various industry associations.

- The CDM can provide great opportunities to bring technology and practices beyond the existing Indian regulations/policy require due to its additionality requirement. There are also possibilities of south-south technology transfer and market-base expansion to other developing countries through collaborations with technology providers by utilizing the CDM. GOI and the wind industry should actively explore such opportunities. In either case, creating stronger backward and forward linkages through the CDM is a key.
- In order to identify the existing market failures and formulate effective policy, further reinforcement of capacity and capability of policy markers and collaborations with the industry players are recommended.

7.2.2 Practical Implications on Climate Change Mitigation Efforts

Enabling Environments - Role of Government and Role of Firms in Light of Intensifying Industrial Competitiveness Management

Building and re-shaping enabling environments in keeping with the evolution of the technology and industry is very important but difficult. The frontier has done this well over the years by clearing various obstacles one by one, while enabling environments in India still show many deficiencies, as this research has shown. The tasks to build and fortify each dimension are more demanding for technology receivers due to the lack of various capacity and capability.

Enabling environments and the elements in each dimension can be largely divided into the ones that can be built by more generic policy- and institutional-level activities and the ones that concern more of firm- and technology-specific activities. The balance between the two is dimension-specific; the technology-related dimensions such as the National Systems of Innovation, the Research and Technology Development, and the Human and Institutional Capacities, concern more deeply both firm-level and generic policy-level activities than the Macroeconomic Policy Frameworks, the Sustainable Markets, and the National Legal Institutions dimensions, which are far more generic and hence can be dealt with the efforts to improve government policy and institutional settings.

The technology-related dimensions are directly influenced by more complex issues of firm competitiveness management. This research actually showed that various restricted business practices and technology controls by technology providers, along with the unsustainable market, have significantly reduced the opportunities to build the strength of these technology-related dimensions. Even if the generic macroeconomic and market-related dimensions were fortified in technology receiver countries, the weak technology-related dimensions can reduce the effectiveness of the entire enabling environments by interrupting the transfer of more advanced or locally suitable technologies.

The centrality of firms in the current and future technology development will continue, as the global business environments and practices have been already shaped to empower private sector. Therefore, in these technology-related dimensions, it is important to consider how to incorporate private firms into development of enabling environments in light of competition, because technology provider firms can be the force of strengthening such environments through technology transfer; their role and responsibilities are quite substantial. However, this centrality of firms may dictate both generic and technology-specific capacity and capability development in the technology-related dimensions, if active policy measures are not taken to incorporate them into the development of enabling environments.

The research findings on the strong relationship between firm competitiveness management and technological evolution/specificity indicate that: 1) the role of government and the role of private firms in the development of technology-related dimensions of enabling environments strongly depend on technological characteristics and specificity, i.e., science/engineering disciplines, technological levels and maturity, and factor intensity of components/value activities; and 2) both firm strategies and government policy need to evolve dynamically along with the environments surrounding technology, market and industry. Both policy developers and firm managers need to understand the component/value activity-specific sources of knowledge creation and accumulation (learning mechanisms) for effective policy formulation and implementation.

Role of Firms - Value Creation at Firms and Partnerships

In order to gain the long-term and continuous developmental effects by transfer of fast-evolving technology, technology receiver firms need to engage very actively in competitiveness management to enhance technology-specific capacity/capability and to be continuously a part of the global capacity/capability management of technology providers. And their technology management and development strategies need to be carefully constructed, depending on component/value activity characteristics, the level of existing technological capacity/ capability, and factor intensity.

At firm level, ideally, both technology provider and receiver firms should engage in more strategic value creation and value finding activities through active exchanges with each other, in order to increase the competitiveness together. For example, technology receiver firms need to generate strong sale points to their technology providers continuously to induce replicable technology transfer. Cost advantages due to low cost labor and resources of developing countries cannot be the only factor; technological advantages are necessary to be provided simultaneously for long-lasting relationship.

At the same time, technology provider firms can also try to find more vigorous roles of the technology receiving partners in their global competitiveness management, not as mere sale and/or production agent for the local market. Initial technology transfer can be induced by the sector-specific improvement in the Macroeconomic and Market dimensions of enabling environments, as it happened in India in the early 1990s. However, continuous and replicable transfer strongly depends on the process after the initial activities. At firm level, it depends on building good business relationships and trust between technology providers and receivers, because technology transfer is a reciprocal process, as the Enercon owner Aloys Wöbben mentioned.

Role of Government- Generic Capacity and Capability Building

On the other hand, the role of government is also quite significant in terms of building generic capacity and capability through policy and institutional support measures. However, the difficulty of formulating and implementing effective industrial and technology development policy is increasing today, as many products and services have increased technological intensiveness as well as complexity and their targets are always shifting in the fast-moving technology fields such as wind; fragmented and static industrial and technology development policy has not been effective in the past but will be much less effective in the future. In addition, the evolving global rules of private capital movement and trade have reduced the efficacy of the knowledge accumulated for effective policy measures in the past.

For capacity and capability building, policy incentives need to address various generic aspects of technology acquisition, capacity/capability building, and development of market and business environments simultaneously. For example, the import/export incentives should be constructed together with the strong domestic market growth policy in order to generate good learning opportunities through large production scale, while technical training and science education being provided to increase generic capacity/capability for different specificity of components/ value activities and to become a base of continuous learning and backward linkages at firm level. This is important for both technology provider and receiver sides.

Meanwhile, the intensifying firm competitiveness management by technology providers will increase the roles of firm and government simultaneously in technology receiver countries in the fast-moving and complex technology fields, in order to develop and supply technical capacity and capability to satisfy the replicable technology transfer demands. In addition, for highly integrated technology system such as wind which requires the entire system transfer for new technology introduction, a well-concerted capacity/capability building and import policy for different components are important for replicable technology transfer.

In terms of development of generic dimensions of enabling environments as well as generic elements in the technology-related dimensions in technology receiver countries, they can be supported by more of international developmental assistance and/or NGO activities, neutral to technology origin. Such international supports and cooperation can be most effective in strengthening the Human and Institutional Capacities, because this dimension concerns all other dimensions and becomes the base for technology-specific capacity development.

Further Business Involvement and Role of Government - Market Value Creation

Along with capacity/capability development policy and business strategies, continuous value creation at the market is the central factor in incorporating private sector firms into technology development, replicable technology transfer, and development of enabling environments. The key for the private sector involvement is the stimulation of firm motivation through new value creation and rewarding activities and fortification of existing value activities in the market. Both need to be initiated by policy and the international mechanisms in the climate change mitigation efforts due to market externalities that are not incorporated into the current market mechanism.

Many countries have engaged in individual market value creation efforts in various climate change mitigation technology areas. Wind energy development in the European countries is an excellent example of the monetary value creation and rewarding efforts as the central success factor. Once policy triggers the performance-oriented market dynamics, technology and economics are improved by private businesses that try to maximize the gaining from the market .

On top of the individual market value creation efforts, another important success factors in wind energy development at the frontier was its regional European market, as mentioned in Chapter 6. The wind energy development history showed that simultaneous international business expansion opportunities are very important to increase learning opportunities by providing larger production and innovation scale and to reduce the risks involved in different political markets.

The current climate change regime took these points and has created the carbon finance mechanism under the Kyoto Protocol. The carbon finance mechanism created a new international currency of carbon credits and links it to the existing monetary system to stimulate the further private sector firm involvements in the climate change mitigation and adaptation efforts. Although such an additional value creation has certainly the potentials that can override the technology control issues by expanding the investment recovery opportunities, in reality there are still many practical issues remained and the effectiveness of the mechanism yet to be seen. Each country, therefore, still needs to provide as much as value creation and rewarding policy, sometime in combination with environmental tax and technology/emission requirements, in order to foster wider and more advanced technology development and diffusion.

CDM and Technology Transfer

As mentioned in Chapter 1, the CDM is one of the three carbon finance mechanisms under the Kyoto Protocol. One of the important purposes of the CDM is to spur technology transfer by encouraging private sector in developed countries to engage in the clean development projects that reduce emissions in developing countries, where the costs of the GHG emission reductions are lower, and generate the emission reduction credits that can be applied toward their emission targets under the Kyoto Protocol. The potentials of technology transfer through the CDM can be influenced by the following factors.

Carbon Price

The monetary value of the CDM projects is linked to the price of carbon (the CER price), which is decided by supply and demand of carbon in the carbon market. The global carbon market can be divided into: 1) project-based system or baseline and credit system such as CDM and JI; and

2) allowance market or cap and trade system such as the Emission Trading under the Kyoto Protocol (global), the European Union Emissions Greenhouse Gas Trading Scheme (EU ETS, regional), the British and the Danish trading systems (national), and BP ands Shell internal trading (firm). Such fragmented nature of the global carbon market generates no single carbon price but creates differentiated prices for emission reductions.

There are many market, policy, and technology variables that determine the carbon price in the market.[112] Several economic models forecast low carbon prices with the absence of the United States in the market, since the demands from the largest emitter of GHGs of the world will be non-existent. Also, if the so-called "hot air" allowances from the former Soviet Blocks such as Russia and Ukraine are used in the market, it also greatly lowers the carbon price as a result of carbon oversupply. If the price of carbon is too low, the value of engaging in the CDM will decrease tremendously, and so will the potentials of technology transfer through the CDM. The impacts of CER price on IRR also vary by project (technology) type.

Transaction Costs

The CDM has very complicated and lengthy procedures in order to avoid the abuse of the mechanism. With all requirements and procedures for the CDM projects to be officially registered and implemented, upfront transaction costs (search cost, negotiation costs, costs for CDM due diligence, baseline determination, documentation, approval, validation, review, and registration) as well as implementation transaction costs (costs for monitoring, verification, review, certification, enforcement) are very high. These high transaction costs have been considered harmful for the CDM to be widely utilized.

Although transaction costs of the CDM will likely decrease over time due to learning curve, some early evidences suggest that the magnitude of absolute transaction costs depend on factors such as project complexity, the economic condition of host country (EcoSecurities 2002; Michaelowa and Steonzik 2002; PriceWaterhouseCoopers 2000), and the host country capacity to competently address the issues relating to project approval and coherently articulate national sectoral priorities and transparently define sustainable development criteria (UNDP Energy & Environment Group 2003). One empirical study on the 65 CDM already-approved projects in India found that the higher the emission reduction of a project, the higher the probability that the transaction costs do not impact the project's viability (Krey 2004). This means that the project using more advanced mitigation technology may have more advantages in terms of reducing the effects of transaction costs. However, it is also all relative to the CER price, project complexity, and human and institutional capacities and the economic condition of host country as well.

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[112] For example, the EU ETS has the market variables such as : 1) the national allowances (the currency of the EU ETS) traded in the scheme; 2) the linkages with other domestic trading schemes (e.g., Canada and Japan), and other carbon commodities created by the Kyoto Protocol's market mechanisms, such as the CDM; 3) the potential addition of other gases and sectors into the EU ETS; 4) the quantity of cost-effective abatement options within Europe available to participants in the carbon market; and, 5) the surplus allowances (e.g., hot air), particularly from Russia and Ukraine entering the market. In particular, the latter two variables are considered to have large influence on the carbon price. For example, if Russia and Ukraine hot air allowances are used in combination with the available abatement options, there is a potential to meet all demand requirements, which lower the carbon price due to oversupply. However, without the use of hot air allowances, the price of carbon would increase considerably and creates the possibilities of the increased use of CDM credits (ICF Consulting. 2005).

Additionality Requirements and Baseline Methodologies

The additionality requirement is the central element of the CDM that can contribute to newer and more advanced technology development and diffusion in host country, which will be difficult under the normal circumstances due to high performance uncertainty and/or various investment and technical barriers. The additionality requires the GHG emissions to be reduced below those that would have occurred in the absence of the CDM project activity (a business-as-usual-scenario, which is the baseline for the project); hence, the additionality is relative to the baseline of the project.

The baseline development is conceptually and technically the most difficult phase in developing a CDM project. Using different baseline methodologies can generate different results in the GHG emission estimates; hence, it can greatly influence project economics of the CDM project as well as the advancement level of the technology used in the project, e.g., most updated technology or technologies that are one or more generations older. However, the baseline methodologies have evolved greatly in recent years and many are submitted to and approved by the CDM Executive Board. As a result, the uncertainty regarding the baseline methodologies have been significantly reduced, for example for wind energy technology CDM, though there are many rooms for improvement.

Sustainable Development Criteria

On the other hand, the other central element of the CDM, the sustainable development criteria are left open to the host country of the CDM and far more ambiguous. Although this means that what the host country wants determine the long-term developmental effects and the incorporation of any of social, economic and environmental criteria to the CDM can have a certain level of long-term benefits, the depth of developmental effects will change tremendously, depending on the type of technologies and the ways of their transfer. For example, building a clearer energy plant will definitely bring environmental and health benefits and conserve local resources (environmental criteria) and it can improve quality of life (social criteria) and/or provide financial returns to local entities (economic criteria) to the host country. However, the developmental benefits beyond such contributions, e.g., building production capacity and capability of energy equipment and plants beyond mere project execution capability, require different commitments from both technology providers and receivers.

Each country needs to choose what kinds of capability in which technology to be built based on its own developmental goals. In addition, the sustainable development criteria do not guarantee to bring what the host country wants; it also strongly depends on technology provider control and willingness. Therefore, the balance between the host country sustainable development criteria and the provider willingness determines the direction and depth of long-term developmental effects brought by the CDM technology transfer.

Geographical Distribution of the CDM Projects

Another issue, which is drawing a growing attention, is the geographic distribution of the CDM projects. As of September 2006, the vast majority of the approved CDM projects are in large countries such as China, India, and Brazil, and only a handful in Africa (CD4CDM 2006). Various reasons are considered for this divide; for example, these rapidly industrialized countries already have better macroeconomic environments and human and institutional capacity/

capability to increase project viability and provide better business and market expansion potentials and lower risks than least-developed countries in Africa. However, the existence of such divide means that the CDM can be a new development divider among developing countries in the future, and this can bring some detrimental effects on both global sustainable development and climate change mitigation.

Uncertain Potentials of the CDM Technology Transfer and Policy Focus

Due to the above factors that influence the value (project viability) and the contents of the CDM projects greatly, it is very difficult to estimate the effectiveness of the CDM on technology transfer at this moment. Whether the CDM can really spur the private sector technology transfer and whether the CDM will bring the long-term sustainable developmental benefits are strong concerns in light of intensifying global competition. There are also concerns over the possibilities that technology providers and the CDM developers may be seeking for not long-term developmental benefits but just quick profits.

At the same time, there is one significant advantage of the CDM over non-CDM projects. That is its strong mechanism of governance; the UNFCCC and the CDM Executive Board oversee the whole process of the projects and this can contribute to reducing various potentials of corruptive business practices. Many international organizations and agencies are also watching and lending their hands on building capacity for the CDM, which can be utilized for other developmental activities. Inadequacy that derives from actual implementations is necessary to be corrected as the commitment period of the Kyoto Protocol progresses, which will give the mechanism itself various learning opportunities.

Some suggestions can be made to increase the effectiveness of the CDM on technology transfer.

- Developed country governments and NGOs as well as international organizations should engage in more vigorous support activities for generic human and institutional capacity and capability building and the creation of macroeconomic environments in developing countries through ODA to reduce transaction costs of the CDM and encourage more even geographical distribution of the CDM projects by creating more level playing fields.

- Potential host countries of the CDM projects should use their national policy wisely, in order to utilize both the additionally requirements and the sensitivity factors of project economics.

    - National policy should create performance-oriented market mechanism and/or environmental/technology requirements that generate technology efficiency demands, which make the higher additionality requirements and induce more emission reductions and project revenues by bringing more advanced technologies.

    - National policy also should work on policy/institutional sensitivity factors as well as technology-related sensitivity factors of project economics, e.g., offering investment and financial incentives to reduce cost of financing and investment costs, and utilizing land use policy and/or other measures to create economies of scale to reduce transaction costs of the CDM projects.

- Higher carbon price is a key to generate stronger interests in the CDM. Carbon market design to suppress carbon oversupply becomes very important.

Replicable Technology Transfer, CDM and Beyond the Kyoto Mechanisms

In terms of replicable technology transfer, whether the CDM can initiate such transfer depends on what kind of mechanisms will be in place after the first four-year period of the Kyoto Protocol.

Taking the importance of replicable technology transfer for the advancement of both climate change mitigation and sustainable development into account, however, the efforts beyond the Kyoto Protocol should consider the mechanisms that induce replicable technology transfer. If the CDM or similar mechanisms continue, the research findings suggest that the fundamentals of initiating replicable technology transfer are the same with the non-CDM projects; strengthening both demand-pull (continuous and sustainable market value creation and rewarding with performance-oriented characteristics through carbon price) and supply-push forces (technological capacity/capability building and management at both national and firm levels for reducing costs and attracting more carbon investors) continue to be fundamental for the future mechanism, in order for more advanced technologies to be continuously introduced to the host countries.

Suggestions for Future Distributed Power Generation Technology Development and Transfer

The followings are suggested for the future distributed energy generation technology development and transfer, based on the research findings.

Policy-driven Virtuous Cycle Creation

- Global climate change is a result of the externality associated with the GHG emissions, which has not been corrected through any institutions or market. Hence, policy intervention is well justified. Virtuous cycle creation in both technology provider and receiver countries is very important for international technology development and diffusion of climate change mitigation technologies, and it needs to be driven by simultaneous demand-pull and supply-push policy incentives.

Sustainable Market Development Policy

- Market development policy needs to be formulated to stimulate the demand-pull, replicable technology upgrading and transfer forces with performance-oriented incentives, targeting both continuous expansion of market size and technology inducing/forcing by emphasizing technology improvement and cost reduction market demands.

- Policy options are not limited to feed-in tariffs and investment subsidies. Various policy options including power demand-pull measures such as CO_2 tax are also available. Appropriateness and sequencing of policy incentives should be considered well by each country, based on the criteria such as cost effectiveness, certainty for industry and consumers, market efficiency, transparency, equity, and transaction costs and administrative capacity.

- International lending is better utilized as revolving financial resources, which create a sustainable financial basis for continuous market development, rather than one-time subsidies.

Technological Characteristics and Technological Capacity/Capability Development

- In building technological capacity and capability, the role of firms and their competitiveness management and the role of government differ greatly according to technological specificity. It is important that the roles also evolve and change overtime, according to technological transformation as well as capacity/capability advancement.

    - The component/value activity-specific sources of knowledge creation and accumulation (learning mechanisms) should be well-understood by both policy developers and firm managers, not only to devise R&D responsibility and projects but also to satisfy the replicable technology transfer demands in timely manner.

    - Government policy makers should contact industry players as well as independent analysts periodically to gain the fair industry data and to formulate and sequence supply-push policy that supports generic aspects of learning mechanisms of each technology component through training and education and fortifies the basis of backward linkage formation and development.

    - The technology receiver side needs to continuously evaluate technological transformation that is constantly happening at the frontier and their position in technology provider firm's global capacity/capability management strategy and to create/adjust their own strategy to upgrade their capacity/capability to induce replicable technology transfer through both cost and technological advantages. Meanwhile, the technology provider firms also can try harder to find the ways to incorporate the technology receiver sides into their global strategy by finding the potentials of cost and technological advantages. This links up simultaneous enhancement of competitiveness for both sides.

Infrastructure Aspects and "Enabling Technologies" for Distributed Power Generation Technologies

- For distributed power generation technologies, infrastructure technology aspects (the electricity grid system and quality, in particular for incorporation of high-tech power generation equipments, and transportation infrastructure for large equipments such as more updated wind turbines) are extremely important as they can determine the types of technologies that can be transferred and incorporated into the national system.

- Development of so-called "Enabling Technologies" can spur more transfer of advanced distributed power generation technologies. "Enabling Technologies" are an interface technology, which can manage the local grid management system to make it workable with high-tech distributed power generation equipment regardless of the original grid quality. Because they enable to bring high-tech power plants such as multi-MW wind turbines as a black box and connect to the local, even weak, grid system, they can satisfy the competitiveness protection needs by technology providers while bringing higher economic and environmental benefits to technology receivers (Danish Wind Industry Association 2005b).[113] This type of interface technology can be developed in order to spur technology transfer of high-tech distributed power generation equipment. The collaboration between countries is essential.

Risk Reductions

- The role of codes/standards/certifications is large in high-risk new technology and market development. It is extremely important to implement high-quality assurance measures with high-level governance from the beginning, in order to create continuous market confidence and guarantee high-quality industry and technology development and transfer. Early development and constant upgrading of international quality measures/systems can benefit all aspects of market and technology development.

- National macroeconomic framework and national legal institutions are very important for general investment risk reduction. However, in order to reduce the risks, various elements within these dimensions need to be all well-functioning; strengthening only parts of these dimensions can create the unbalanced environments, which can generate undesirable effects in governance and growth pattern, e.g., strong fiscal elements without sound governance can invite corruptive business practices.

- International/regional collaborations and network building in R&D should be utilized well in order to share risks and high-costs, in particular in basic research area, as done in wind energy at the frontier.

Electricity Sector Reform and Restructuring

- Under the global trend of the electricity sector reforms and restructuring, the priority between the free market principle and the environmental interests that can permit the state supports needs to be clarified in order to determine the types of policy incentives used in each country.

- In developing country context, the necessity and timing of embarking on such reforms and restructuring should be cautiously considered. The procedure and methods of the reforms and restructuring need to be carefully constructed, and the step-by-step approach of commercialization and privatization is recommended. Hasty process only creates conflicting outcomes.

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[113] This is a part of public technology. DWIA considers that how to move to this type of technologies, which are not the equipment of wind turbines that are privately owned and fiercely protected, is the future theme of wind energy technology transfer. "This type of technology is what we are willing to transfer, not the core sources of competitiveness of wind turbine technology. Keeping competitiveness is bringing a black box of wind turbine technology after transferring technology of how to make it work as power plant locally. There are huge opportunities in this type of transfer." (Danish Wind Industry Association. 2005b)

Overall Human Capacity and Capability Building

- Every economic development activity ultimately depends on human capacity and capability, building of which requires strong initiatives of those who are really engaging in the activity itself; no outside assistance guarantees the development of such human capacity and capability. However, it is also true that the outside assistance can be a great support. The role of international and national developmental agencies and organizations including NGOs can be further fortified to provide genuine support from neutral perspectives. In this sense, developing countries should utilize ODA and the CDM as great opportunity provider to obtain neutral supports in capacity and capability building that can be used for other economic activities.

Remaining Deep Chasms

The research showed the importance of enabling environments in developing countries, as insisted by developed countries for climate change mitigation technology transfer. This research also confirmed the gaps between the immediate technology transfer needs and the long-term process of sustainable development remains strong, and the materialization of replicable technology transfer is very important to reconcile them.

However, it could not answer the question whether or not fortifying enabling environments of developing country alone can effectively solve the issues of industrial competitiveness management and control between technology providers and receivers and the issues of immediate technology transfer and long-term sustainable development needs, because the technology receiver country of India in the research still have many deficiencies in its enabling environments. There is no doubt that enabling environments are a necessary condition for initiating technology transfer. However, whether or not they are also a sufficient condition to induce technology transfer that remove technology gaps remains unanswered.

This study was a research on cross-border technology transfer involving a developing country that had basic med-tech technological capability and capacity and were begun engaging in the rapid industrialization in the beginning of the process. Also, this was the research that strongly concerns manufacturing capability and industrialization. However, the path for sustainable development will differ among countries due to the differences in country sizes and locations, populations, resource types and intensities, cultures, and histories, and this is why the selection of the sustainable development criteria in the CDM is left open to the host country choice, although the ultimate goals of sustainable development will be the same for all nations and people on this planet. There is no universal answer to the path of development. The forms of technology transfer, therefore, vary as well.

The perennial debate over technology transfer between developed country parties and developing country parties continues today, and many issues in the north-south divide remain unsolved. The most recent debate in COP12 at Nairobi, Kenya, in November 2006 was over the development of a standing body with strong role in promoting the transfer of technologies from developed countries. Proposals from developing countries included the creation of a Technology Development and Transfer Board with decision-making powers and the establishment of a

Multilateral Technology Acquisition Fund to make technologies available to developing countries by "buying out" IPRs. However, these proposals were firmly opposed by developed countries. Also the gaps between the immediate technology transfer needs and the long-term process of sustainable development are increasing under the intensifying global competition and the growing climate change threats as seen in the rising number of severe natural disasters in recent years. However, technology transfer activities still remain weak, compared to the gravity of the issue.

The deep chasm among the countries may not be diminished until all nations recognize the urgency and gravity of global climate change and begin seriously work together toward the common solutions. The surrounding global business environments with the intensifying competition that is accompanying strong exploitative characteristics are one of the largest obstacles for the cooperation. Tough roads are ahead, in order to further incorporate the private sector into cross-border transfer of climate change mitigation technologies while avoiding unfair exploitation of people and resources everywhere.

At the same time, however, those who take climate change and sustainable development seriously have made progresses in many areas. Many international efforts on capacity building and development and implementation of the carbon financing mechanisms, including diverse international carbon funds, have advanced since 1992. The first commitment period of the Kyoto Protocol will begin in 2008 and new activities are added toward the global efforts everyday. The global community building is in progress; our colleagues are all over the world. We simply need to add success stories one by one, one place after another.

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Appendix A: Policy Instruments

Appendix A-1: Government Wind Energy R&DD Budget in Denmark 1975-2002 (Million USD)

Year	Wind Energy R&DD*	Total RE R&DD*	Total Energy R&DD*	Wind/Total RE R&DD	Wind/Total Energy R&DD	Annual Growth of WE R&DD
1975	0.090	0.540	22.539	16.7%	0.4%	---
1976	0.247	0.907	24.749	27.2%	1.0%	174.4%
1977	2.677	5.315	36.982	50.4%	7.2%	983.8%
1978	4.426	10.190	46.766	43.4%	9.5%	65.3%
1979	3.093	19.100	59.309	16.2%	5.2%	-30.1%
1980	4.158	9.052	35.502	45.9%	11.7%	34.4%
1981	2.303	5.758	19.069	40.0%	12.1%	-44.6%
1982	3.027	4.552	16.707	66.5%	18.1%	31.4%
1983	2.452	3.936	17.883	62.3%	13.7%	-19.0%
1984	2.999	4.255	16.337	70.5%	18.4%	22.3%
1985	3.345	4.243	14.381	78.8%	23.3%	11.5%
1986	4.879	5.699	21.761	85.6%	22.4%	45.9%
1987	4.081	5.051	21.600	80.0%	18.9%	-16.4%
1988	NA	NA	NA	NA	NA	NA
1989	8.448	11.035	26.475	75.6%	31.9%	---
1990	4.132	8.759	35.533	47.1%	11.6%	-51.1%
1991	8.362	17.689	42.132	47.2%	19.8%	102.4%
1992	7.813	18.750	48.438	34.6%	16.1%	-6.6%
1993	6.937	20.040	46.553	33.9%	14.9%	-11.2%
1994	5.908	17.421	39.234	34.5%	15.1%	-14.8%
1995	5.614	16.276	36.498	41.3%	15.4%	-5.0%
1996	5.419	13.119	31.612	48.8%	17.1%	-3.5%
1997	8.249	16.911	36.737	39.1%	22.4%	52.2%
1998	7.277	18.593	44.504	43.3%	16.3%	-11.8%
1999	6.911	15.947	42.863	39.5%	16.1%	-5.1%
2000	6.308	15.975	43.258	36.3%	14.6%	-8.7%
2001	6.474	17.838	42.215	36.3%	15.3%	2.6%
2002	8.498	9.158	20.241	49.7%	42.0%	31.3%
Average Annual Growth Rate				47.8%	16.0%	16.5%

* Million USD (2002 prices and exchange rates)
RE = renewable energy WE = wind energy

Source: IEA

Appendix A-2: Transitional Rules for Green Electricity between 2000 and 2003 in Denmark

Programs	Contents	
Interim Tariff Rules applied between January 2000 and March 2001	For turbines built before January 2003 DKK 0.33/kWh for at least the first ten years of their operation, or until a well functioning market for renewables credit trading is established plus DKK 0.10/kWh, a refund of CO_2 tax. Production incentive of DKK 0.17/kWh will be added as follows: ▪ for 25,000 full load hours for turbines under 200kW; ▪ for 15,000 full load hours turbines rated at 201-599 kW; ▪ for the first 12,000 full load hours for turbines over 600 kW	
	Turbines bought before 1/1/2000	**Turbines bought after 1/1/2000**
Interim Tariff Rules applied from April 2001 to 2002	DKK 0.60/kWh: ▪ for the first 25,000 full load hours for turbines up to 200kW; ▪ for the first 15,000 full load hours for turbines rated at 201-599kW; ▪ for the first 12,000 full load hours for larger turbines Then, DKK 0.43/kWh Purchase obligation.	DKK 0.43/kWh for the first 22,000 full load hours with purchase obligation. Then, income from sale of certificates plus DKK 0.10/kWh that has price cap of DKK 0.36/kWh with no purchase obligation.
Interim Tariff Rules applied from 2003	DKK 0.60/kWh until end of assigned full load hours, then DKK 0.43/kWh until age ten years with purchase obligation. For turbines with age 10 to 20 years, market price plus DKK 0.10/kWh that has price cap of DKK 0.36/kWh with no purchase obligation.	For turbines bought before 1/1/2003, DKK 0.43/kWh for the first 22,000 full load hours with purchase obligation. Then, market price plus DKK 0.10/kWh that has price cap of DKK 0.36/kWh with no purchase obligation.
		For turbines bought after 1/1/2003, market price plus DKK 0.10/kWh that has price cap of DKK 0.36/kWh with no purchase obligation.

Source: (IEA 2003a; IEA 2004; IEA 2005; Meyer and Koefoed 2003)

Appendix A-3: Danish Wind Power Tariffs as of May 30, 2005

Turbine Type	Contents
Turbines connected to the grid from 1/1/2005	A fixed premium of DKK 0.10/kWh for 20 years and an allowance of DKK 0.023/kWh for offset costs, etc.
Turbines connected to the grid 2003-2004	A premium up to DKK 0.10/kWh for 20 years with price cap of DKK 0.36/kWh*, plus an allowance of DKK 0.023/kWh for offset costs, etc.
Turbines connected to the grid 2000-2002	A tariff of DKK 0.43/kWh for the first 22,000 full load hours for turbines on land and 10 years for offshore turbines.** A premium up to DKK 0.10/kWh until the turbine is 20 years old with price cap of DKK 0.36/kWh*, plus an allowance of DKK 0.023/kWh for offset costs, etc.
Turbines bought prior to the end of 1999	A tariff of DKK 0.60/kWh until full load hours are used up and subsequently DKK 0.43/kWh until the turbine is 10 years old. Full load hour allowance is: ▪ 25,000 hours for turbines of 200 kW or less; ▪ 15,000 hours for turbines of 201-599 kW; ▪ 12,000 hours for turbines of 600 kW and over If the turbine is more than 10 years old but has not used its full load allowance up yet, it is eligible for a premium of DKK 0.27/kWh with price cap of DKK 0.60/kWh* A premium up to DKK 0.10 /kWh until the turbine is 20 years old with price cap of DKK 0.36/kWh*, plus an allowance of DKK 0.023/kWh for offset costs, etc. for turbine is over 10 years old and its full load allowance is used up**.
Turbines financed by electricity utilities (All land-based turbines connected before 4 June 2002 and offshore wind farms at Horns Rev and Nysted)	Turbines on land or offshore connected to the grid no later than 12/31/1999: ▪ Plant owners are responsible for the sale of production on the electricity market and for related costs. Turbines on land connected to the grid from 1/1/2000: ▪ Plant owners are responsible for the sale of production on the electricity market and for related costs. They are eligible for a subsidy that combined with the market price comprises DKK 0.43/kWh for 10 years from the grid connection. When the turbine is over 10 years old, a premium up to DKK 0.10/kWh until the turbine is 20 years old with price cap of DKK 0.36/kWh*, plus an allowance of DKK 0.023/kWh for offset costs, etc. Offshore turbines connected to the grid after 1/1/2000 ▪ Plant owners are responsible for sale of production on the electricity market and for related costs. They are eligible for subsidy that combined with the market price comprises DKK 0.453 /kWh for 42,000 full load hours. If production is subject to a grid tariff, it is eligible for compensation up to DKK 0.007 /kWh. After all full load hours are used up, a premium up to DKK 0.10/kWh until the turbine is 20 years old with price cap of DKK 0.36/kWh*, plus an allowance of DKK 0.023/kWh for offset costs, etc

* The premium is regulated in accordance with the market price. The price cap is applied to the total of the premium and market price.

** Once the full load hours are used up, turbine owners are responsible for the sale of production on the electricity market and for related costs.

Source: DEA, www.ens.dk data as of May 30, 2005

Appendix A-4: Selected R&DD Programs by BMWi in Germany

Wind Power R&D and WMEP Phase II, Phase III (July 1996-June 2000) and Phase IV (July 2000-June 2004)

Subject	R&D Contractor	Period	Cost (Million EUR)	BMWi (%)
Wind measurement data processing up to 150m for planned achieve of wind data		4/92-1/98	607 (MDEM)	100
250MW wind measurement and evaluation program		7/96-6/00	13.683.5 (MDEM)	100
Special wind data and programs for complex terrain	German weather service	7/93-6/97	0.84 (1641.9 MDEM)	100
Early recognition of turbine failure	ISET/Industry	1/94- 12/97	0.732 (1431.8 MDEM)	50
Fatigue loads WECS	VDMA/DEWI	7/95-6/97	0.227 (443.6 MDEM)	50.
MW WECD inland	RWE Enertgie	6/95-9/99	2.502 (4893.6 MDEM)	20.43
Control LS WECS	ISET/Industry	7/95-6/99	0.61 (1192.6 MDEM)	40
Active stall rotor blade	A&R Rotec	8/96-7/98	1.281 (2505.98 MDEM)	50
Lightening protection WECS	Fordegesellschaft Windenergie	10/96-9/99	0.307 (600 MDEM)	50
Development of a 3-4MW WECS	Enercon	8/98-6/02	5.113 (10000 MDEM)	35
Decentralized electrical power plants for grid; voltage fluctuation	Windtest KW.koog	8/99-1/02	0.416 (813 MDEM)	50
Integration of decentralized electrical power plants for grid	Engineering high school Wilhelmshaven	8/99-1/02	0.445 (870 MDEM)	100
Phase IV, WMEP	ISET	7/00-6-04	5.85 (11450 MDEM)	100
Forecast wind electricity for medium and large utility regions	Fordegesellschaft Windenergie	5/00-10-01	0.332 (650 MDEM)	94.31
Aspects of construction and environment of offshore WECS	University Hannover	10/00-9/03	0.854 (1670 MDEM)	100
Advanced drive train for LS-WECs	Fr. Flender AG	1/01-12/03	0.941 (1840 MDEM)	40
Advanced life time analysis of WECs	Germanischer Lloyd Windenergie	12/99-11/02	0.481	50
Drivetrain for offshore WECs	MULTIBRID entwicklungsgesellschaft mbh	5/01-4/05	16.617	25
3-4 offshore wind power measurement platforms	Germanischer Lloyd Windenergie	4/01-9-03	15.33	100

Source: (IEA 2001; IEA 2002a)

Appendix A-5: Government Wind Energy R&DD Budget in Germany 1974-2002 (Million USD)

Year	Wind Energy R&D)	Total RE R&D*	Total Energy R&D*	Wind/Total RE R&D	Wind/Total Energy R&D	Annual Growth of WE R&D (%)
1974	0.000	1.110	953.079	0.00%	0.00%	NA
1975	0.000	10.15	1142.857	0.00%	0.00%	0.00%
1976	0.000	17.722	1100.564	0.00%	0.00%	0.00%
1977	5.346	26.727	1246.340	20.00%	0.43%	0.00%
1978	8.552	45.324	1336.653	18.87%	0.64%	59.97%
1979	15.756	99.069	1462.444	15.90%	1.08%	84.24%
1980	29.947	104.028	1489.482	28.79%	2.01%	90.07%
1981	36.191	109.327	1586.104	33.10%	2.28%	20.85%
1982	27.378	165.708	2007.163	16.52%	1.36%	-24.35%
1983	11.795	79.560	1220.830	14.83%	0.97%	-56.92%
1984	12.670	96.973	1197.295	13.07%	1.06%	7.42%
1985	16.406	86.448	1137.208	18.98%	1.44%	29.49%
1986	7.846	53.948	831.864	14.54%	0.94%	-52.18%
1987	11.341	75.946	640.575	14.93%	1.77%	44.54%
1988	10.045	80.856	566.055	12.42%	1.77%	-11.43%
1989	7.791	79.384	490.231	9.81%	1.59%	-22.44%
1990	13.014	94.250	508.690	13.81%	2.56%	67.04%
1991	10.385	105.252	503.504	9.87%	2.06%	-20.20%
1992	14.278	111.007	394.525	12.86%	3.62%	37.49%
1993	27.970	121.152	383.602	23.09%	7.29%	95.90%
1994	20.019	80.022	306.716	25.02%	6.53%	-28.43%
1995	19.932	70.625	262.669	28.22%	7.59%	-0.43%
1996	32.815	87.641	282.704	37.44%	11.61%	64.63%
1997	20.551	68.653	255.372	29.93%	8.05%	-37.37%
1998	19.683	76.938	272.971	25.58%	7.21%	-4.22%
1999	20.237	67.769	182.034	29.86%	11.12%	2.81%
2000	14.608	71.050	260.997	20.56%	5.60%	-27.82%
2001	16.858	67.527	280.164	24.96%	6.02%	15.40%
2002	14.420	54.571	262.017	26.42%	5.50%	-14.46%
Average Annual Growth Rate				18.60%	3.52%	4.05%

*Million USD (2002 prices and exchange rates)
RE = renewable energy WE = wind energy

Source: IEA

Appendix A-6: Energy-related Ministry Budget in India in INR. Crore

	Energy Total	Power	Petroleum	Coal & Lignite	MNES	MNES/ TOTAL
1992-93	20289.8	12157.4	5698.5	2276.5	157.4	0.78%
1993-94	26909.0	14773.1	9589.3	2293.1	253.5	0.94%
1994-95	27482.0	16346.4	8643.6	2238.7	253.3	0.92%
1995-96	26893.3	16511.4	8123.5	1948.3	310.2	1.15%
1996-97	27330.4	16937.5	8007.6	1958.6	426.7	1.56%
1997-98	31792.7	19396.3	9682.7	2212.7	501.0	1.58%
1998-99	35572.4	21159.0	11213.6	2540.2	659.5	1.85%
1999-2000	35809.6	21327.4	9953.2	3719.1	809.9	2.26%
2000-2001	40893.4	28015.4	9867.2	2093.5	917.3	2.24%
2001-2002	37145.4	25180.0	8702.1	2106.8	1156.5	3.11%
2002-03	44709.99	25280.77	15805.67	1911.31	1712.24	3.82%
2003-04 (RE)	57926.04	30725.99	23892.72	2378.62	928.71	1.60%
2004-05(BE)	46788.21	19112.94	23575.80	3073.62	1025.85	2.19%
1 crore = 10 million						

Source: Eighth plan outlay, Ninth plan outlay, and Tenth plan outlay by heads of development: centre, states and union territories in (Economic Division Ministry of Finance 2005)

Appendix A-7: Support Policy in Other States in India

State	Time Period	Wheeling Charge	Banking	Feed-in Tariffs	Third-Party Sales
Kerala	**1994-3/1998***	2% of power generated	Six months w/ 2% charge	To be decided by SEB	Not allowed
	4/2000 - Present	5% of power generated	Nine months (June – February)	INR 2.8/kWh 5% annual escalation based on 2000-01 tariffs for five years	
* In addition, capital subsidy of 15% of installation cost with a ceiling of INR 5 lakh was available.					
Madhya Pradesh	**1994 - 1999***	2% of power generated	Not Allowed	INR 2.25/kWh	Allowed
	2002 – 6/2004**				
	6/2004 – Present ** and ***			INR 3.97/kWh in 2004-05, INR 0.17 annual reduction for 20 years	
* In addition, land lease for a period of 5 years at a token rent of INR 1/per annum and thereafter on government prescribed rates and capital subsidy same for other industries were available. Exemptions of electricity duty for 5 years, of state sales tax on plant & machinery, and from power cut to the extent of 30% were available. ** Exemption of electricity duty for 5 years and capital subsidy same for other industries were available. Reactive power charge of INR 0.27 per consumed power was applied. *** In addition, infrastructure development charge of 50% of the cost of grid extension, application/processing fee of INR 50,000/MW, and reactive power charge of INR 0.27 per consumed power are applied.					
Utter Pradesh	**1994 – 3/2000***	2% of power generated	One year	INR 1.75/kWh in 1994-95 INR 2.25/kWh in 1995-97 5% annual escalation based on 1995-96 tariff	Allowed w/ 2.5% wheeling charges
* land lease for a period of 35 years and capital subsidy same for other industries were available					
West Bengal	**1995 - Present**	2% of power generated	Six months	To be decided by SEB	Not allowed

Sources: (Consolidated Energy Consultants Ltd. 2002; Consolidated Energy Consultants Ltd. 2005; MNES 1995a; MNES 1996a; MNES 1997a; MNES 1998; MNES 1999a; MNES 2000a; MNES 2001a; MNES 2002a; MNES 2003; MNES 2004; MNES 2005)

Appendix B: Summary Statistics

Appendix B-1: Regression Result for Equation 1

```
Dependent Variable: TNUMBER
Method: Least Squares
Sample: 1992-93 2004-05
Included observations: 13
==========================================================================
       Variable        Coefficient    Std. Error    t-Statistic     Prob.
==========================================================================
           C             3.081062      1.761609      1.749005      0.1081
       CAPACITY          0.004246      0.004481      0.947606      0.3637
==========================================================================
R-squared                0.075472    Mean dependent var           4.230769
Adjusted R-squared      -0.008577    S.D. dependent var           4.585373
S.E. of regression       4.604994    Akaike info criterion        6.032798
Sum squared resid        233.2656    Schwarz criterion            6.119713
Log likelihood          -37.21319    F-statistic                  0.897957
Durbin-Watson stat       1.077026    Prob(F-statistic)            0.363683
==========================================================================
```

Appendix B-2: Regression Results for Equation 2

```
Dependent Variable: TNUMBER1
Method: Least Squares
Sample(adjusted): 1992-93 2002-03
Included observations: 11 after adjusting endpoints
==========================================================================
       Variable        Coefficient    Std. Error    t-Statistic     Prob.
==========================================================================
           C             2.091142      0.721831      2.896997      0.0231
       CAPACITY          0.035875      0.003095      11.59197      0.0000
     D1*CAPACITY        -0.021578      0.005358     -4.027391      0.0050
          D1            -2.353188      1.059676     -2.220668      0.0618
==========================================================================
R-squared                0.974720    Mean dependent var           4.363636
Adjusted R-squared       0.963885    S.D. dependent var           4.884112
S.E. of regression       0.928169    Akaike info criterion        2.964082
Sum squared resid        6.030488    Schwarz criterion            3.108772
Log likelihood          -12.30245    F-statistic                  89.96535
Durbin-Watson stat       2.254958    Prob(F-statistic)            0.000006
```

Appendix B-3: Regression Results for Equation 3

Dependent Variable: TNUMBER1
Method: Least Squares
Sample(adjusted): 1992-93 2002-03
Included observations: 11 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.999245	0.645379	1.548307	0.1601
CAPACITY1	0.039461	0.003224	12.23844	0.0000
D1*CAPACITY1	-0.031506	0.003606	-8.736294	0.0000

R-squared	0.956910	Mean dependent var	4.363636
Adjusted R-squared	0.946138	S.D. dependent var	4.884112
S.E. of regression	1.133515	Akaike info criterion	3.315525
Sum squared resid	10.27885	Schwarz criterion	3.424042
Log likelihood	-15.23539	F-statistic	88.82961
Durbin-Watson stat	1.583928	Prob(F-statistic)	0.000003

Appendix B-4: Regression Results for Equation 4

Dependent Variable: TNUMBER2
Method: Least Squares
Sample(adjusted): 1996-97 2004-05
Included observations: 9 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.262046	0.818388	-0.320197	0.7618
CAPACITY	0.014297	0.004614	3.098965	0.0269
D2*CAPACITY	-0.004490	0.005354	-0.838636	0.4399
D2	-4.564145	2.542814	-1.794919	0.1326

R-squared	0.840222	Mean dependent var	2.333333
Adjusted R-squared	0.744355	S.D. dependent var	1.936492
S.E. of regression	0.979116	Akaike info criterion	3.096770
Sum squared resid	4.793343	Schwarz criterion	3.184425
Log likelihood	-9.935463	F-statistic	8.764466
Durbin-Watson stat	2.348092	Prob(F-statistic)	0.019563

Appendix B-5: Regression Results for Equation 5

Dependent Variable: TNUMBER
Method: Least Squares
Sample: 1992-93 2004-05
Included observations: 13

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.091142	1.089067	1.920122	0.0870
CAPACITY	0.035875	0.004669	7.683131	0.0000
D3*CAPACITY	-0.032026	0.004893	-6.545396	0.0001
D3	-0.957571	1.269533	-0.754270	0.4700

R-squared	0.930047	Mean dependent var	4.230769
Adjusted R-squared	0.906730	S.D. dependent var	4.585373
S.E. of regression	1.400381	Akaike info criterion	3.759026
Sum squared resid	17.64961	Schwarz criterion	3.932857
Log likelihood	-20.43367	F-statistic	39.88610
Durbin-Watson stat	1.792238	Prob(F-statistic)	0.000016

Appendix B-6: Regression Results for Equation 6

Dependent Variable: TNUMBER
Method: Least Squares
Sample: 1992-93 2004-05
Included observations: 13

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.386462	0.547478	2.532450	0.0297
CAPACITY	0.038189	0.003443	11.09100	0.0000
D3*CAPACITY	-0.034736	0.003249	-10.69144	0.0000

R-squared	0.925625	Mean dependent var	4.230769
Adjusted R-squared	0.910750	S.D. dependent var	4.585373
S.E. of regression	1.369865	Akaike info criterion	3.666476
Sum squared resid	18.76531	Schwarz criterion	3.796849
Log likelihood	-20.83210	F-statistic	62.22715
Durbin-Watson stat	1.777284	Prob(F-statistic)	0.000002

Appendix B-7: Regression Results for Equation 7

```
Dependent Variable: CAPACITY
Method: Least Squares
Sample(adjusted): 1993 1996
Included observations: 4 after adjusting endpoints
===========================================================================
        Variable        Coefficient    Std. Error    t-Statistic     Prob.
===========================================================================
           C            -254.4447      105.1005      -2.420965      0.1365
       TAXSAVING         2.62E-05      6.03E-06       4.338232      0.0492
===========================================================================
R-squared                0.903940    Mean dependent var            178.6425
Adjusted R-squared       0.855910    S.D. dependent var            173.1523
S.E. of regression       65.72729    Akaike info criterion         11.51576
Sum squared resid        8640.153    Schwarz criterion             11.20891
Log likelihood          -21.03152    F-statistic                   18.82026
Durbin-Watson stat       2.134351    Prob(F-statistic)             0.049243
===========================================================================
```

Appendix C: Summary of Cash Flow Analysis

Appendix C-1: Assumption for Cash Flow Calculations

1) Average Turnkey Capital Cost and Average Project Size

Year	Average Capital Cost (INR Million per MW)
1992-93	29
1993-94	35
1994-95	40
1995-96	45
1996-97	52
1997-98	40
1998-99	42
1999-00	43
2000-01	44
2001-02	45
2002-03	45
2003-04	45
2004-05	45

Sources: Based on data from (Consolidated Energy Consultants Ltd. 2002; Consolidated Energy Consultants Ltd. 2005; Rajsekhar, Van Hulle, and Jansen 1999; Wind Power Monthly 1999d)

2) Majority Turbine Size, Wheeling Charges, and Capacity Utilization Factor (CUF)

CUF = Energy generated per year (kWh)/[Installed Capacity (kW) * 8760 (hours)].
2% of wheeling charge is deducted from generated power, as all generated electricity is used as captive use and wheeled.

Year	Majority Turbine Size	CUF	Wheeling Charge	Net CUF
1992-93	150kW ≤ X < 500kW	18%	2%	16%
1993-94				
1994-95				
1995-96				
1996-97				
1997-98				
1998-99				
1999-00				
2000-01		20%		18%
2001-02				
2002-03	500kW ≤ X < 1000kW	22%		20%
2003-04				
2004-05				

3) System/Economic Lifetime

Economic lifetime and system lifetime are both considered 20 years.

4) O&M Cost

1.5% of capital cost for the first two years and subsequently 2% of capital cost per year with 5% annual escalation.

5) IREDA Financing Term

Year	Interest Rate	Loan Repayment Schedule	Equity-Debt Ratio
1992-93	12%	Eight years with one year moratorium	40:60
1993-94	12%		
1994-95	14.5%		
1995-96	15%		
1996-97	18%		
1997-98	15.5%	Ten years with one year moratorium	25:75
1998-99	14%		
1999-00	16%		
2000-01	13.5%		
2001-02	13.5%		
2002-03	12.5%		
2003-04	11.5%		
2004-05	10.5%		

6) Tax Conditions

	Return on Equity	MAT and Income Tax (IT) Rate	Corporate Tax Rate	First-year Tax Depreciation
1992-93	16%*	0%	46%	100%
1993-94				
1994-95				
1995-96				
1996-97				
1997-98		12.9%	35%	
1998-99			30%	
1999-00		11.4%		
2000-01		8.4%		
2001-02				
2002-03				
2003-04				80%
2004-05				

* According to the minimum rate of return by the GOI guideline private sector participation.

7) National Average of Industry Electricity Tariffs

	Industry Power Tariff	Expected Annual Raise
1992-93	1.72	7%
1993-94	1.98	7%
1994-95	2.21	10%
1995-96	2.20	8%
1996-97	2.76	10%
1997-98	3.13	10%
1998-99	3.29	8%
1999-00	3.51	7%
2000-01	3.59	5%
2001-02	3.67	3%
2002-03	3.46	3%
2003-04	359.7 (ES)*	3%
2004-05	374.4 (ES)*	3%

* estimated based on available data.

Sources: (Central Electricity Authority 2003; Lok Sabha 2001; Planning Commission 2001 and 2002)

8) De-rating by Aging

Generated wind power will be reduced 5% every five year due to aging of wind turbine.

Appendix C-2: Base Case Cash Flow Calculations (All in INR)

1) 1992-93 Year

Average project size 650kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	18850000	0	0				0	18850000		-18850000	-18850000
1	0	282750	0	1206400	0	8671000	1727605	1489150	10398605	8909455	7954871
2	0	282750	2276735	1206400	0		1848538	3765885	1848538	-1917348	-1528498
3	0	377000	2276735	1206400	0		1977935	3860135	1977935	-1882200	-1339713
4	0	395850	2276735	1206400	0		2116391	3878985	2116391	-1762595	-1120161
5	0	415643	2276735	1206400	0		2264538	3898778	2264538	-1634240	-927311
6	0	436425	2276735	1206400	0		2423056	3919560	2423056	-1496504	-758176
7	0	458246	2276735	1206400	0		2592669	3941381	2592669	-1348712	-610089
8	0	481158	2276735	1206400	0		2774156	3964293	2774156	-1190137	-480676
9	0	505216	2276735	1206400	0		2968347	3988351	2968347	-1020004	-367824
10	0	530477		1206400	0		3176132	1736877	3176132	1439255	463402
11	0	557001		1206400	0		3228538	-1763401	3228538	1465137	421192
12	0	584851		1206400	0		3454535	-1791251	3454535	1663285	426924
13	0	614093		1206400	0		3696353	-1820493	3696353	1875860	429899
14	0	644798		1206400	0		3955098	-1851198	3955098	2103900	430500
15	0	677038		1206400	0		4231954	-1883438	4231954	2348517	429065
16	0	710890		1206400	0		4528191	-1917290	4528191	2610902	425895
17	0	746434		1206400	0		4845165	-1952834	4845165	2892330	421252
18	0	783756		1206400	0		5184326	-1990156	5184326	3194170	415369
19	0	822944		1206400	0		5547229	-2029344	5547229	3517885	408450
20	0	864091		1206400	0		5935535	-2070491	5935535	3865044	400677

First-year Tax Saving = INR 8,671,000
IRR = 1.44%

2) 1993-94 Year

Average project size 900kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	31500000	0	0				0	31500000		-31500000	-31500000
1	0	472500	0	2016000	0	14490000	2753660	2488500	17243660	14755160	13174250
2	0	472500	3804624	2016000	0		2946417	6293124	2946417	-3346707	-2667974
3	0	630000	3804624	2016000	0		3152666	6450624	3152666	-3297958	-2347421
4	0	661500	3804624	2016000	0		3373352	6482124	3373352	-3108771	-1975680
5	0	694575	3804624	2016000	0		3609487	6515199	3609487	-2905712	-1648779
6	0	729304	3804624	2016000	0		3862151	6549927	3862151	-2687776	-1361711
7	0	765769	3804624	2016000	0		4132502	6586393	4132502	-2453891	-1110016
8	0	804057	3804624	2016000	0		4421777	6624681	4421777	-2202904	-889716
9	0	844260	3804624	2016000	0		4731301	6664884	4731301	-1933583	-697269
10	0	886473		2016000	0		5062492	2902473	5062492	2160019	695468
11	0	930797		2016000	0		5146024	2946797	5146024	2199227	632225
12	0	977337		2016000	0		5506245	2993337	5506245	2512908	645001
13	0	1026204		2016000	0		5891682	3042204	5891682	2849479	653027
14	0	1077514		2016000	0		6304100	3093514	6304100	3210586	656950
15	0	1131389		2016000	0		6745387	3147389	6745387	3597998	657341
16	0	1187959		2016000	0		7217564	3203959	7217564	4013605	654706
17	0	1247357		2016000	0		7722794	3263357	7722794	4459437	649492
18	0	1309725		2016000	0		8263389	3325725	8263389	4937665	642092
19	0	1375211		2016000	0		8841827	3391211	8841827	5450616	632853
20	0	1443972		2016000	0		9460754	3459972	9460754	6000783	622082

First-year Tax Saving = INR 14,490,000
IRR = 0.50%

3) 1994-95 Year

Average project size 1100kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	44000000	0	0				0	44000000		-44000000	-44000000
1	0	660000	0	2816000	0	20240000	3756537	3476000	23996537	20520537	17921866
2	0	660000	5786831	2816000	0		4132190	9262831	4132190	-5130640	-3913457
3	0	880000	5786831	2816000	0		4545410	9482831	4545410	-4937421	-3289150
4	0	924000	5786831	2816000	0		4999950	9526831	4999950	-4526880	-2633765
5	0	970200	5786831	2816000	0		5499946	9573031	5499946	-4073085	-2069646
6	0	1018710	5786831	2816000	0		6049940	9621541	6049940	-3571601	-1585003
7	0	1069646	5786831	2816000	0		6654934	9672476	6654934	-3017542	-1169540
8	0	1123128	5786831	2816000	0		7320427	9725958	7320427	-2405531	-814267
9	0	1179284	5786831	2816000	0		8052470	9782115	8052470	-1729645	-511337
10	0	1238248		2816000	0		8857717	4054248	8857717	4803469	1240224
11	0	1300161		2816000	0		9256315	4116161	9256315	5140154	1159086
12	0	1365169		2816000	0		10181946	4181169	10181946	6000777	1181794
13	0	1433427		2816000	0		11200141	4249427	11200141	6950713	1195523
14	0	1505099		2816000	0		12320155	4321099	12320155	7999056	1201606
15	0	1580354		2816000	0		13552170	4396354	13552170	9155817	1201198
16	0	1659371		2816000	0		14907387	4475371	14907387	10432016	1195310
17	0	1742340		2816000	0		16398126	4558340	16398126	11839786	1184815
18	0	1829457		2816000	0		18037938	4645457	18037938	13392482	1170475
19	0	1920930		2816000	0		19841732	4736930	19841732	15104803	1152951
20	0	2016976		2816000	0		21825905	4832976	21825905	16992929	1132814

First-year Tax Saving = INR 20,240,000
IRR = 5.23%

4) 1995-96 Year

Average project size 1100kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	49500000	0	0				0	49500000		-49500000	-49500000
1	0	742500	0	3168000	0	22770000	3739539	3910500	26509539	22599039	19651338
2	0	742500	6618648	3168000	0		4038702	10529148	4038702	-6490446	-4907709
3	0	990000	6618648	3168000	0		4361798	10776648	4361798	-6414850	-4217868
4	0	1039500	6618648	3168000	0		4710742	10826148	4710742	-6115406	-3496503
5	0	1091475	6618648	3168000	0		5087601	10878123	5087601	-5790521	-2878912
6	0	1146049	6618648	3168000	0		5494609	10932696	5494609	-5438087	-2351035
7	0	1203351	6618648	3168000	0		5934178	10989999	5934178	-5055821	-1900670
8	0	1263519	6618648	3168000	0		6408912	11050166	6408912	-4641254	-1517234
9	0	1326695	6618648	3168000	0		6921625	11113342	6921625	-4191717	-1191548
10	0	1393029		3168000	0		7475356	4561029	7475356	2914326	720377
11	0	1462681		3168000	0		7669715	4630681	7669715	3039034	653220
12	0	1535815		3168000	0		8283292	4703815	8283292	3579477	669030
13	0	1612606		3168000	0		8945955	4780606	8945955	4165350	676986
14	0	1693236		3168000	0		9661632	4861236	9661632	4800396	678433
15	0	1777898		3168000	0		10434562	4945898	10434562	5488665	674527
16	0	1866793		3168000	0		11269327	5034793	11269327	6234535	666252
17	0	1960132		3168000	0		12170873	5128132	12170873	7042741	654453
18	0	2058139		3168000	0		13144543	5226139	13144543	7918404	639848
19	0	2161046		3168000	0		14196107	5329046	14196107	8867061	623047
20	0	-2269098		-3168000	0		15331795	5437098	15331795	9894697	604569

First-year Tax Saving = INR 22,770,000
IRR = -0.79%

5) 1996-97 Year

Average project size 1200kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	62400000	0	0				0	62400000		-62400000	-62400000
1	0	936000	0	3993600	0	28704000	5117914	4929600	33821914	28892314	24485012
2	0	936000	9181949	3993600	0		5629706	14111549	5629706	-8481843	-6091528
3	0	1248000	9181949	3993600	0		6192676	14423549	6192676	-8230872	-5009563
4	0	1310400	9181949	3993600	0		6811944	14485949	6811944	-7674005	-3958166
5	0	1375920	9181949	3993600	0		7493138	14551469	7493138	-7058330	-3085261
6	0	1444716	9181949	3993600	0		8242452	14620265	8242452	-6377813	-2362543
7	0	1516952	9181949	3993600	0		9066697	14692501	9066697	-5625803	-1766080
8	0	1592799	9181949	3993600	0		9973367	14768348	9973367	-4794981	-1275648
9	0	1672439	9181949	3993600	0		10970704	14847988	10970704	-3877284	-874157
10	0	1756061	9181949	3993600	0		12067774	14931610	12067774	-2863836	-547177
11	0	1843864	9181949	3993600	0		12610824	15019413	12610824	-2408589	-389996
12	0	1936058		3993600	0		13871907	5929658	13871907	7942249	1089832
13	0	2032860		3993600	0		15259097	6026460	15259097	9232637	1073642
14	0	2134504		3993600	0		16785007	6128104	16785007	10656904	1050226
15	0	2241229		3993600	0		18463508	6234829	18463508	12228679	1021291
16	0	2353290		3993600	0		20309859	6346890	20309859	13962968	988247
17	0	2470955		3993600	0		22340844	6464555	22340844	15876290	952259
18	0	2594502		3993600	0		24574929	6588102	24574929	17986826	914278
19	0	2724227		3993600	0		27032422	6717827	27032422	20314594	875085
20	0	2860439		3993600	0		29735664	6854039	29735664	22881625	835308

First-year Tax Saving = INR 28,704,000
IRR = 2.69%

6) 1997-98 Year

Average project size 1250kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	50000000	0	0				0	50000000		-50000000	-50000000
1	0	750000	0	2000000	258000	17500000	6045845	3008000	23545845	20537845	17781684
2	0	750000	7614863	2000000	258000		6650430	10622863	6650430	-3972433	-2977780
3	0	1000000	7614863	2000000	258000		7315473	10872863	7315473	-3557390	-2308796
4	0	1050000	7614863	2000000	258000		8047020	10922863	8047020	-2875843	-1615985
5	0	1102500	7614863	2000000	258000		8851722	10975363	8851722	-2123641	-1033168
6	0	1157625	7614863	2000000	258000		9736894	11030488	9736894	-1293593	-544886
7	0	1215506	7614863	2000000	258000		10710584	11088369	10710584	-377785	-137775
8	0	1276282	7614863	2000000	258000		11781642	11149145	11781642	632498	199712
9	0	1340096	7614863	2000000	258000		12959807	11212959	12959807	1746848	477548
10	0	1407100	7614863	2000000	258000		14255787	11279963	14255787	2975824	704348
11	0	1477455	7614863	2000000	258000		14897298	11350318	14897298	3546979	726870
12	0	1551328		2000000	258000		16387027	3809328	16387027	12577699	2231605
13	0	1628895		2000000	258000		18025730	3886895	18025730	14138835	2171940
14	0	1710339		2000000	258000		19828303	3968339	19828303	15859964	2109378
15	0	1795856		2000000	258000		21811133	4053856	21811133	17757277	2044780
16	0	1885649		2000000	258000		23992247	4143649	23992247	19848598	1978874
17	0	1979932		2000000	258000		26391471	4237932	26391471	22153540	1912271
18	0	2078928		2000000	258000		29030619	4336928	29030619	24693690	1845484
19	0	2182875		2000000	258000		31933680	4440875	31933680	27492806	1778940
20	0	2292018		2000000	258000		35127049	4550018	35127049	30577030	1712993

First-year Tax Saving = INR 17,242,000
IRR = 10.11%

7) 1998-99 Year

Average project size 1100kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	46200000	0	0				0	46200000		-46200000	-46200000
1	0	693000	0	1848000	238392	13860000	5592310	2779392	19452310	16672918	14625367
2	0	693000	6642874	1848000	238392		6039695	9422266	6039695	-3382571	-2602779
3	0	924000	6642874	1848000	238392		6522871	9653266	6522871	-3130395	-2112928
4	0	970200	6642874	1848000	238392		7044701	9699466	7044701	-2654766	-1571834
5	0	1018710	6642874	1848000	238392		7608277	9747976	7608277	-2139700	-1111293
6	0	1069646	6642874	1848000	238392		8216939	9798912	8216939	-1581973	-720726
7	0	1123128	6642874	1848000	238392		8874294	9852394	8874294	-978100	-390885
8	0	1179284	6642874	1848000	238392		9584237	9908550	9584237	-324313	-113691
9	0	1238248	6642874	1848000	238392		10350976	9967515	10350976	383462	117918
10	0	1300161	6642874	1848000	238392		11179054	10029427	11179054	1149627	310105
11	0	1365169	6642874	1848000	238392		11469710	10094435	11469710	1375275	325414
12	0	1433427		1848000	238392		12387287	3519819	12387287	8867467	1840524
13	0	1505099		1848000	238392		13378270	3591491	13378270	9786779	1781873
14	0	1580354		1848000	238392		14448531	3666746	14448531	10781786	1721959
15	0	1659371		1848000	238392		15604414	3745763	15604414	11858650	1661355
16	0	1742340		1848000	238392		16852767	3828732	16852767	13024035	1600545
17	0	1829457		1848000	238392		18200988	3915849	18200988	14285139	1539934
18	0	1920930		1848000	238392		19657067	4007322	19657067	15649745	1479858
19	0	2016976		1848000	238392		21229632	4103368	21229632	17126264	1420596
20	0	2117825		1848000	238392		22928003	4204217	22928003	18723786	1362375

First-year Tax Saving = INR 13,621,608
IRR = 6.92%

8) 1999-2000 Year

Average project size 1500kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	64500000	0	0				0	64500000		-64500000	-64500000
1	0	967500	0	2580000	294120	19350000	8135815	3841620	27485815	23644195	20382927
2	0	967500	10008840	2580000	294120		8705322	13850460	8705322	-5145138	-3823676
3	0	1290000	10008840	2580000	294120		9314695	14172960	9314695	-4858265	-3112485
4	0	1354500	10008840	2580000	294120		9966723	14237460	9966723	-4270737	-2358690
5	0	1422225	10008840	2580000	294120		10664394	14305185	10664394	-3640791	-1733428
6	0	1493336	10008840	2580000	294120		11410901	14376296	11410901	-2965395	-1217123
7	0	1568003	10008840	2580000	294120		12209664	14450963	12209664	-2241299	-793038
8	0	1646403	10008840	2580000	294120		13064341	14529363	13064341	-1465022	-446869
9	0	1728723	10008840	2580000	294120		13978845	14611683	13978845	-632838	-166407
10	0	1815160	10008840	2580000	294120		14957364	14698119	14957364	259245	58766
11	0	1905918	10008840	2580000	294120		15204160	14788877	15204160	415283	81153
12	0	2001213		2580000	294120		16268452	4875333	16268452	11393118	1919317
13	0	2101274		2580000	294120		17407243	4975394	17407243	12431849	1805435
14	0	2206338		2580000	294120		18625750	5080458	18625750	13545293	1695807
15	0	2316655		2580000	294120		19929553	5190775	19929553	14738778	1590712
16	0	2432487		2580000	294120		21324622	5306607	21324622	16018014	1490325
17	0	2554112		2580000	294120		22817345	5428232	22817345	17389113	1394735
18	0	2681817		2580000	294120		24414559	5555937	24414559	18858622	1303966
19	0	2815908		2580000	294120		26123578	5690028	26123578	20433550	1217985
20	0	2956704		2580000	294120		27952229	5830824	27952229	22121405	1136718

First-year Tax Saving = INR 19,055,880
IRR = 5.43%

9) 2000-01 Year

Average project size 1500kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	66000000	0	0				0	66000000		-66000000	-66000000
1	0	990000	0	2640000	221760	19800000	9245830	3851760	29045830	25194070	22197418
2	0	990000	9305355	2640000	221760		9708121	13157115	9708121	-3448994	-2677323
3	0	1320000	9305355	2640000	221760		10193527	13487115	10193527	-3293588	-2252588
4	0	1386000	9305355	2640000	221760		10703203	13553115	10703203	-2849912	-1717307
5	0	1455300	9305355	2640000	221760		11238364	13622415	11238364	-2384052	-1265716
6	0	1528065	9305355	2640000	221760		11800282	13695180	11800282	-1894899	-886361
7	0	1604468	9305355	2640000	221760		12390296	13771584	12390296	-1381288	-569263
8	0	1684692	9305355	2640000	221760		13009811	13851807	13009811	-841996	-305734
9	0	1768926	9305355	2640000	221760		13660301	13936042	13660301	-275740	-88214
10	0	1857373	9305355	2640000	221760		14343316	14024488	14343316	318828	89867
11	0	1950241	9305355	2640000	221760		14307458	14117357	14307458	190101	47210
12	0	2047753		2640000	221760		15022831	4909513	15022831	10113318	2212806
13	0	2150141		2640000	221760		15773972	5011901	15773972	10762072	2074673
14	0	2257648		2640000	221760		16562671	5119408	16562671	11443263	1943604
15	0	2370530		2640000	221760		17390805	5232290	17390805	12158514	1819460
16	0	2489057		2640000	221760		18260345	-5350817	18260345	12909528	1702067
17	0	2613510		2640000	221760		19173362	-5475270	19173362	13698092	1591221
18	0	2744185		2640000	221760		20132030	-5605945	20132030	14526085	1486699
19	0	2881394		2640000	221760		21138632	-5743154	21138632	15395477	1388263
20	0	3025464		2640000	221760		22195563	-5887224	22195563	16308339	1295664

First-year Tax Saving = INR 19,578,240
IRR = 4.76%

10) 2001-02 Year

Average project size 1250kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	56250000	0	0				0	56250000		-56250000	-56250000
1	0	843750	0	2250000	189000	16875000	7876554	3282750	24751554	21468804	18915246
2	0	843750	7930701	2250000	189000		8112851	11213451	8112851	-3100600	-2406878
3	0	1125000	7930701	2250000	189000		8356236	11494701	8356236	-3138464	-2146494
4	0	1181250	7930701	2250000	189000		8606923	11550951	8606923	-2944027	-1774020
5	0	1240313	7930701	2250000	189000		8865131	11610013	8865131	-2744882	-1457285
6	0	1302328	7930701	2250000	189000		9131085	11672029	9131085	-2540944	-1188557
7	0	1367445	7930701	2250000	189000		9405017	11737145	9405017	-2332128	-961128
8	0	1435817	7930701	2250000	189000		9687168	11805517	9687168	-2118349	-769185
9	0	1507608	7930701	2250000	189000		9977783	11877308	9977783	-1899525	-607690
10	0	1582988	7930701	2250000	189000		10277116	11952689	10277116	-1675572	-472285
11	0	1662137	7930701	2250000	189000		10056158	12031838	10056158	-1975680	-490639
12	0	1745244		2250000	189000		10357843	4184244	10357843	6173599	1350791
13	0	1832506		2250000	189000		10668578	4271506	10668578	6397072	1233204
14	0	1924132		2250000	189000		10988636	4363132	10988636	6625504	1125322
15	0	2020338		2250000	189000		11318295	4459338	11318295	6858957	1026408
16	0	2121355		2250000	189000		11657844	4560355	11657844	7097488	935774
17	0	2227423		2250000	189000		12007579	4666423	12007579	7341156	852776
18	0	2338794		2250000	189000		12367806	4777794	12367806	7590012	776814
19	0	2455734		2250000	189000		12738841	4894734	12738841	7844107	707330
20	0	2578521		2250000	189000		13121006	5017521	13121006	8103485	643805

First-year Tax Saving = INR 16,686,000
IRR = 0.55%

11) 2002-03 year

Average project size 1300kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	58500000	0	0				0	58500000		-58500000	-58500000
1	0	877500	0	2340000	196560	17550000	8495175	3414060	26045175	22631115	20116546
2	0	877500	7924781	2340000	196560		8750030	11338841	8750030	-2588811	-2045480
3	0	1170000	7924781	2340000	196560		9012531	11631341	9012531	-2618810	-1839274
4	0	1228500	7924781	2340000	196560		9282907	11689841	9282907	-2406934	-1502637
5	0	1289925	7924781	2340000	196560		9561394	11751266	9561394	-2189872	-1215223
6	0	1354421	7924781	2340000	196560		9848236	11815762	9848236	-1967526	-970522
7	0	1422142	7924781	2340000	196560		10143683	11883483	10143683	-1739800	-762837
8	0	1493249	7924781	2340000	196560		10447993	11954590	10447993	-1506597	-587188
9	0	1567912	7924781	2340000	196560		10761433	12029253	10761433	-1267819	-439223
10	0	1646307	7924781	2340000	196560		11084276	12107648	11084276	-1023372	-315143
11	0	1728623	7924781	2340000	196560		10845964	12189964	10845964	-1343999	-367893
12	0	1815054		2340000	196560		11171343	4351614	11171343	6819729	1659346
13	0	1905807		2340000	196560		11506483	4442367	11506483	7064117	1527830
14	0	2001097		2340000	196560		11851678	4537657	11851678	7314021	1406115
15	0	2101152		2340000	196560		12207228	4637712	12207228	7569516	1293541
16	0	2206209		2340000	196560		12573445	4742769	12573445	7830676	1189485
17	0	2316520		2340000	196560		12950648	4853080	12950648	8097568	1093356
18	0	2432346		2340000	196560		13339168	4968906	13339168	8370262	1004601
19	0	2553963		2340000	196560		13739343	5090523	13739343	8648820	922697
20	0	2681661		2340000	196560		14151523	5218221	14151523	8933302	847152

First-year Tax Saving = INR 17,353,440
IRR = 1.77%

12) 2003-04 year

Average project size 1400kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	63000000	0	0				0	63000000		-63000000	-63000000
1	0	945000	0	2520000	211680	15120000	9518826	3676680	24638826	20962146	18800131
2	0	945000	8192073	2520000	211680	3780000	9804391	11868753	13584391	1715638	1379990
3	0	1260000	8192073	2520000	211680		10098523	12183753	10098523	-2085230	-1504283
4	0	1323000	8192073	2520000	211680		10401478	12246753	10401478	-1845275	-1193882
5	0	1389150	8192073	2520000	211680		10713523	12312903	10713523	-1599380	-928063
6	0	1458608	8192073	2520000	211680		11034928	12382361	11034928	-1347432	-701226
7	0	1531538	8192073	2520000	211680		11365976	12455291	11365976	-1089315	-508428
8	0	1608115	8192073	2520000	211680		11706956	12531868	11706956	-824912	-345310
9	0	1688521	8192073	2520000	211680		12058164	12612274	12058164	-554109	-208028
10	0	1772947	8192073	2520000	211680		12419909	12696700	12419909	-276790	-93197
11	0	1861594	8192073	2520000	211680		12152881	12785347	12152881	-632466	-190991
12	0	1954674		2520000	211680		12517468	4686354	12517468	7831114	2120924
13	0	2052407		2520000	211680		12892992	4784087	12892992	8108904	1969649
14	0	2155028		2520000	211680		13279781	4886708	13279781	8393074	1828407
15	0	2262779		2520000	211680		13678175	4994459	13678175	8683716	1696612
16	0	2375918		2520000	211680		14088520	5107598	14088520	8980922	1573704
17	0	2494714		2520000	211680		14511176	5226394	14511176	9284782	1459147
18	0	2619450		2520000	211680		14946511	5351130	14946511	9595381	1352429
19	0	2750422		2520000	211680		15394906	5482102	15394906	9912804	1253066
20	0	2887943		2520000	211680		15856753	5619623	15856753	10237130	1160596

First-year Tax Saving = INR 14,908,320
IRR = 3.08%

13) 2004-05 year

Average project size 1300kW

Year	Initial Cost	O&M Cost	Loan Payment	Return on Equity	MAT/IT	Saving on Tax Depreciation	Captive Use Saving	Gross Outflow	Gross Inflow	Net Inflow	PV of Cash Flow
0	58500000	0	0				0	58500000		-58500000	-58500000
1	0	877500	0	2340000	196560	14040000	9182645	3414060	23222645	19808585	17926322
2	0	877500	7294540	2340000	196560	3510000	9458125	10708600	12968125	2259525	1850515
3	0	1170000	7294540	2340000	196560		9741869	11001100	9741869	-1259231	-933294
4	0	1228500	7294540	2340000	196560		10034125	11059600	10034125	-1025475	-687822
5	0	1289925	7294540	2340000	196560		10335148	11121025	10335148	-785877	-477027
6	0	1354421	7294540	2340000	196560		10645203	11185521	10645203	-540318	-296808
7	0	1422142	7294540	2340000	196560		10964559	11253242	10964559	-288683	-143511
8	0	1493249	7294540	2340000	196560		11293496	11324349	11293496	-30854	-13881
9	0	1567912	7294540	2340000	196560		11632301	11399012	11632301	233289	94980
10	0	1646307	7294540	2340000	196560		11981270	11477407	11981270	503862	185647
11	0	1728623	7294540	2340000	196560		11723672	11559723	11723672	163949	54667
12	0	1815054		2340000	196560		12075382	4351614	12075382	7723768	2330676
13	0	1905807		2340000	196560		12437644	4442367	12437644	7995277	2183353
14	0	2001097		2340000	196560		12810773	4537657	12810773	8273116	2044548
15	0	2101152		2340000	196560		13195096	4637712	13195096	8557385	1913846
16	0	2206209		2340000	196560		13590949	4742769	13590949	8848180	1790843
17	0	2316520		2340000	196560		13998678	4853080	13998678	9145598	1675149
18	0	2432346		2340000	196560		14418638	4968906	14418638	9449732	1566385
19	0	2553963		2340000	196560		14851197	5090523	14851197	9760674	1464187
20	0	2681661		2340000	196560		15296733	5218221	15296733	10078512	1368204

First-year Tax Saving = INR 13843440
IRR = 4.37%