Freiberg University of Mining and Technology
Faculty of Business Administration and Economics

KEY FACTORS INFLUENCING THE COMPETITIVENESS OF WIND ENERGY IN THE ELECTRICITY MARKET

(Master Thesis)

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"The Mill" by Rembrandt (1650)

"This paper is dedicated to my beloved parents."

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Glossary

AWEA	American Wind Energy Association
BOOT	Build, Own, Operate and Transfer
BWE	Bundesverband Wind Energie e.V
CO_2	Carbon Dioxide
DtA	Deutsche Ausgleichsbank (DtA)
EEG	Erneuerbare Energien Gesetz
EFL	Electricity Feed Law
EPRI	Electric Power Research Institute
ERP	European Recovery Programme
EWEA	European Wind Energy Association
FERC	Federal Energy Regulatory Commission
GHG	Green House Gases
HAWT	Horizontal Axis Wind Turbine
IEA	International Energy Agency
ITC	investment Tax Credit
NO_2	Nitrogen Dioxide
O&M	Operation and Maintenance
PPA	Power Purchase Agreement
PTC	Production Tax Credit
PURPA	Public Utility Regulatory Policies Act
R&D	Research and Development
RD&D	Research, Development & Demonstration
RES	Renewable Energy Sources
RESA	Renewable Energy Sources Act
RPS	Renewable Portfolio Standard
VAWT	Vertical Axis Wind Turbine
VDEW	Verband der Elektizitätswirtschaft
WAsP	Wind Atlas Application Analysis Program

Conversions

Linear, Area and Speed Measures

1 kilometer	= 0.6214 mile
1 meter	= 3.281 feet
1 centimeter	= 0.3937 inch
1 square kilometer	= 0.386 square mile
1 meters/second	= 2.237 miles/hour
1 kilometers/hour	= 0.62137 miles/hour

Energy and Power Measures

1 J (joule)	= 1 Watt second
	= 0.2388 cal
1 kWh (kilowatt hour)	= 10^3 watt hours
	= 3.6 x 10^6 Joule
	= 3,413 BTU (British Thermal Unit)
1 GWh (gigawatt hour)	= 10^9 watt hours
1 TWh (terawatt hour)	= 10^{12} watt hours
1 watt	= 3.4129 BTU per hour
	= 1.341 x 10^{-3} HP (horsepower)
	= 1 Joule per second
1 kW (kilowatt)	= 1.359 HP

Preface

The rapid evolution of the modern wind energy industry has been an outstanding sign of mankind's effort to achieve sustainable development. This success has been a concrete example of what wind industry can accomplish when governments provide adequate supports for research and development combine with renewable energy policies that provide an attractive and secure market for investors to invest in this new technology.

Assessing the level of technology advancement, and the continuous cost competitiveness of wind power utilization for electricity generation, there is a great hope that wind energy will be able to serve a significant portion of world electricity need. However, to achieve this future goal the existing barriers that can hold back its rapid development should be overcome.

From the technical point of view, further cost reductions in manufacturing and operating wind turbines can be achieved, including improving reliability and efficiency of their performance. However, these improvements require continues support from governments, which encourage the development of renewable energy in general and wind energy in particular. At the same time, governments should also eliminate subsidies that benefit fossil fuels by recognizing the environmental externalities costs that are associated with them to their electricity prices. These energy policies will be particularly crucial in creating a new competitive market for electricity.

It should be pointed out that the scope of this thesis is narrow to Germany and the United States wind energy markets as the two largest markets in the world, including the energy policies that these countries have adopted to increase their wind energy development.

Acknowledgement

Firstly, I would like to thank Lord Jesus Christ, for all of His blessings throughout my life. Secondly, I owe special thanks to Prof. Jan C. Bongaerts, the Director of the International Management of Resources and Environment program, for his supervision and invaluable guidance during my study and work in finishing my thesis. I gratefully acknowledge his dedication and tenacity in keeping this program alive. I believe that without his supports, IMRE will not experience such tremendous improvement that now it benefits from.

I wish to acknowledge all of the lecturers for the valuable learning experience that I obtained. I would also like to thank the entire staff of IMRE program and TU-Freiberg for their assistance during my study in Freiberg, especially Stefan Dirlich for his hard work and assistance in coordinating the IMRE program. And finally, I would like to thank for all of support and love from my wonderful parents who have inspired my life.

Freiberg, December 12, 2002

Felicia Elena Kurniadi

Chapter 1 Introduction

There are many renewable energy sources that might solve the world's energy and environmental problems, offering the potential of virtually infinite and pollution-free energy. The initial interest in renewable energy was driven by the oil crises of the 1970s, followed by fears of resources depletion and political uncertainty. The next driver is the growing concern over global climate change resulting from greenhouse gases emissions.[1] This concern has initiated the commitment[2] of industrialized countries to a binding reduction of their greenhouse gases emissions, which is expressed in the Kyoto Protocol in December 1997, another momentum that accelerates the implementation of renewable energy.

Various research and development efforts including various governments' energy policy experiments have continuously enhanced the development of renewable energy technologies.[3] In spite of these advancements, they remain relatively expensive to date. However, there is one particular renewable energy technology, the wind turbine, showing an astonishing progress. With continuous improvements in reliability, efficiency and reductions in investment cost, currently the utilization of wind power for electricity generation has become roughly competitive in many cases against conventional fuels.

Several investigations on the world's technical and exploitable wind resource potential conclude that the energy potential of wind is enormous.[4] An estimation done by Grubb and Meyer reported that the exploitable potential of wind energy appears to be

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[1] A Global Overview of Renewable Energy Sources (AGORES), "Global Warming and Climate Change," available at: http://www.agores.org/General/Climatehome.htm, April 16, 2002

[2] United Nations Framework Convention on Climate Change (UNFCCC), "A Guide to the Climate Change Convention and Kyoto Protocol," available at: http://unfccc.int/resource/guideconvkp-p.pdf, April 16, 2002

[3] Burton, T., Sharpe, D., Jenkins, N., and Bossanyi, E., "Wind Energy Handbook," Chichester, John Wiley and Sons, 2001, pp. 1-6

[4] European Wind Energy Association (EWEA), "Wind Force 12: A Blueprint to Achieve 12% of The World's Electricity from Wind Power By 2020," available at: http://www.ewea.org/doc/WindForce12.pdfm, September 20, 2002

approximately four times the current global electricity consumption.[5] In theory, up to 100% of electricity demand could be met from this source.

Another global trend, which has emerged over the past decade, has been the move towards privatization, non-utility electricity generation and competition. This new trend has become the opportunity for niche players such as wind power plants to enter the electricity market and in certain cases, provides specialized high value-added services such as sales to a 'green' power market.

Currently wind energy has shown a spectacular average annual growth rate in installed generation capacity of 40 percent over the last five years worldwide,[6] which makes it the world's most rapidly growing energy source, whether conventional or renewable. Recognizing the above-mentioned driving factors, it is believed that over the next ten years, wind energy could complete its transition from an 'alternative' to a fully competitive 'mainstream' energy source.[7] However, the success of this future scenario will highly depend on a complex interaction between the key factors influencing the competitiveness of wind energy in the electricity market, including technological development, economics, finance, environment and policy aspects.

One can summarize the advantages of wind-generated electricity as follows; wind energy is a free, renewable resource, so no matter how much is used today, there will still be the same supply in the future. Wind energy also provides clean and non-polluting electricity, unlike conventional power plants that emit air pollutants and greenhouse gases. Beside these environmental protections that it offers, wind energy also improves economic development, reduces dependency on energy imports, increases security of supply and contributes to job creation, which predominantly is seen as a key aspect in regional development.

The aim of this thesis is to provide an in-depth analysis of wind energy's progress to date, its likely future evolution and to discuss the key factors that will impact its competitiveness in the electricity market. Particular focus in this thesis is given to

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[5] Grubb, M.J., and Meyer, J.J., "Wind Energy: Resources, Systems, and Regional Strategies," 1993, can be found in Johansson, T.B., Kelly, H., Reddy, A.K.N., and Williams, R.H (editors), "Renewable Energy: Sources for Fuels and Electricity, Washington DC, Island Press, 1993, pp. 157-212

[6] Gipe, P., "Wind Booming Worldwide: A review of BTM Consult's World Market Update," can be found in Chelsea Green, available at: http://www.chelseagreen.com/Wind/articles/BTMUpdateRev.htm, September, 10, 2002

[7] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 2

Germany and the United States, which account for a major portion of the global wind energy market.

This paper is structured as follows; Chapter 2 presents an overview of the global wind resource potential. It demonstrates that a serious consideration of wind energy is only justified if the available wind resource potential is sufficient to fulfill a significant portion of countries' electricity demands. This chapter also introduces important aspects of wind resource assessment, which is a critical factor in projecting turbine performance at a given site since the proper siting of a wind turbine at windy locations, away from large obstructions, enhances a wind turbine's performance.

Chapter 3 describes the development of modern wind turbine technology as well as the fundamental principles of wind power generation. It also draws attention to the likely evolution of wind turbine designs that are essential to further reduce costs of manufacturing wind turbines and to improve their performance. This chapter also introduces the interest in developing offshore wind power plants and provides a discussion on the grid-connection issues of wind turbines.

Chapter 4 presents a global overview of both supply and demand sides of the wind energy market. Further emphasis in this chapter is also given to the development of the wind energy markets in Germany and the United States as the two largest wind markets in the world. On the supply side, the evolution of wind turbines manufacturers is discussed, including their strategies to compete in the growing market.

Chapter 5 elaborates the progress of important wind energy costs such as capital cost, operation and maintenance cost and other related costs that influence the economics of both onshore and offshore applications. A comparison between the economics of wind energy and conventional fossil fuels based electricity is provided. This chapter limits the discussion to the economics of grid-connected wind turbines.

Chapter 6 deals with environmental and social considerations associated with wind energy. Wind energy offers significant environmental benefits as mentioned previously; however, it also has environmental drawbacks that need careful attention, such as noise, bird kills, and visual intrusion including conflicts with nature conservations or tourism. Such conflicts should be tackled in a constructive manner that appreciates the perspective counter position for instance through a careful site planning.

In spite of the great advances in wind energy technology and economics, the driving force that can further its development is the right government support through energy policies. Each country adopts different policies and shows different levels of interest in the development of wind energy. Chapter 7 discusses various policies that are available to stimulate the wind energy development with particular emphasis on Germany and the Unites States.

Chapter 8 concludes the discussion presented in this thesis and identifies key factors influencing the future development of the integration of wind energy into the electricity market.

Chapter 2 Wind Resource Potential

This chapter attempts to provide a better understanding of the size and potential of the world's wind energy resource, answering the question of fundamental importance how much of the world's electricity needs can actually be met using wind energy. A general discussion of wind resource characteristics is provided since an understanding of wind resource characteristics is critical to all aspects of wind energy exploitation, from the identification of suitable sites and predictions of the economic viability of wind farm projects through the design of wind turbines themselves, and understanding their effect on electricity distribution networks which are discussed in subsequent chapters. At the end of this chapter, an overview of a wind resource assessment, which is important to estimate the average wind speed at a specific location, is given.

2.1 Wind Resource Characteristics and Potential

Wind energy is created by energy from the sun that reaches the lower atmosphere. Differences in atmospheric temperatures and the Earth's rotation cause cooler dense air to circulate to replace the lighter warmer air, generating the wind. The most striking characteristic of the wind resource is its variability. Depending on climatic conditions and surface topography such as height above ground, and type of terrain; wind varies significantly in intensity over a day, a season, or a year.[8] In other words, a wind potential is area-specific and geographically uneven;[9] therefore, a country's decision to opt for wind energy is only justified if the available wind resource potential is sufficient to meet a substantial portion of its electricity needs. A number of scientific assessments have been done thus far to better understand the size and potential of wind energy resource on the global and regional basis. For example, Grubb and Meyer,[10] the

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[8] SEDA website, "Wind Energy," available at: http://www.seda.nsw.gov.au/ren_wind.asp, June 13, 2002

[9] United Nations Department of Economic and Social Affairs (DESA), "Renewable resources energy, with special emphasis on wind energy," *Report of the Secretary General: E/C.13/1998/4*, available at: http://www.uccee.org/WindEnergy/UNreportwind.pdf, August 20, 2002

[10] Grubb, M.J., and Meyer, J.J., "Wind Energy: Resources, Systems, and Regional Strategies," 1993, can be found in Johansson, T.B., Kelly, H., Reddy, A.K.N., and Williams, R.H (editors), "Renewable Energy: Sources for Fuels and Electricity, Washington DC, Island Press, 1993, pp. 157-212

International Institute of Applied Systems Analysis[11] and the World Meteorological Organization have estimated the total global wind energy resource to be in order of 60 TW-yr/yr (approximately 500,000 TWh/yr).[12] Of this theoretical potential, Grubb and Meyer estimate the exploitable worldwide wind potential to be approximately 6 TW-yr/yr, after accounting for social, aesthetic, land use and environmental factors, which will ultimately limit total wind power development.

The International Energy Agency (IEA) has estimated the world's total demand for electricity to achieve 25,800 TWh (25.8 trillion kWh/year) by the year 2020.[13] In comparison to this, the world's wind energy resources are abundant. The total technically recoverable is estimated to be 53,000 TWh/year (53 trillion kWh/year). This is over twice as large as the projection for the world's entire electricity demand in 2020.[14] All other comprehensive investigations of the world's wind energy potential also conclude that the world's wind resources are extremely large and well spread throughout the six continents.[15] Thus, wind energy's potential contribution to the world's overall electricity supply is not limited by resource availability, but by economic and social factors.

2.2 Wind Resource Assessment

Wind resource assessment is usually defined as the calculation of the average wind speed over 10 to 20 years at a specific site or area.[16] These assessments are usually performed by national meteorological offices in cooperation with wind energy consultants. Despite the fact that the global wind resource potential is immense, due to the variability characteristics of wind resource, an accurate determination of the average wind speed at a certain site is crucial in planning a wind energy project.

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[11] Heifele, W., et al., "Energy in a Finite World," International Institute of Applied System Analysis, Cambridge, Massachusetts, 1981

[12] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 21

[13] International Energy Agency (IEA), "World Energy Outlook 2000," available at: http://www.worldenergyoutlook.org/weo/pubs/weo2000/weo2000.asp, August 20, 2002

[14] European Wind Energy Association (EWEA), "Wind Force 12: A Blueprint to Achieve 12% of The World's Electricity from Wind Power By 2020," available at: http://www.ewea.org/doc/WindForce12.pdf, September 20, 2002

[15] Greenpeace, "Wind Force 10: A Blueprint to Achieve 10% of The World's Electricity from Wind Power By 2020," available at: http://archive.greenpeace.org/~climate/renewables/reports/windf10.pdf, September 20, 2002

As a rule of thumb, a wind turbine's power output increases by the cube of the wind speed, and thus the cost of wind energy decreases drastically with increases of wind speed.[17] Wind speed generally increases with height above ground. Careful attention to the siting of wind turbines in windy locations, away from large obstructions, can optimize a wind turbines' performance.[18] Detailed principles of wind turbine power generation are discussed in Chapter 3.

Generally minimum annual average wind speeds of 6 m/s (meters per second) or 13 mph (miles per hour) are required for grid-connected applications. Annual average wind speeds of 4 m/s (9 mph) are required for small wind electric turbines and less wind suffice for mechanical applications, such as battery charging and water pumping.[19]

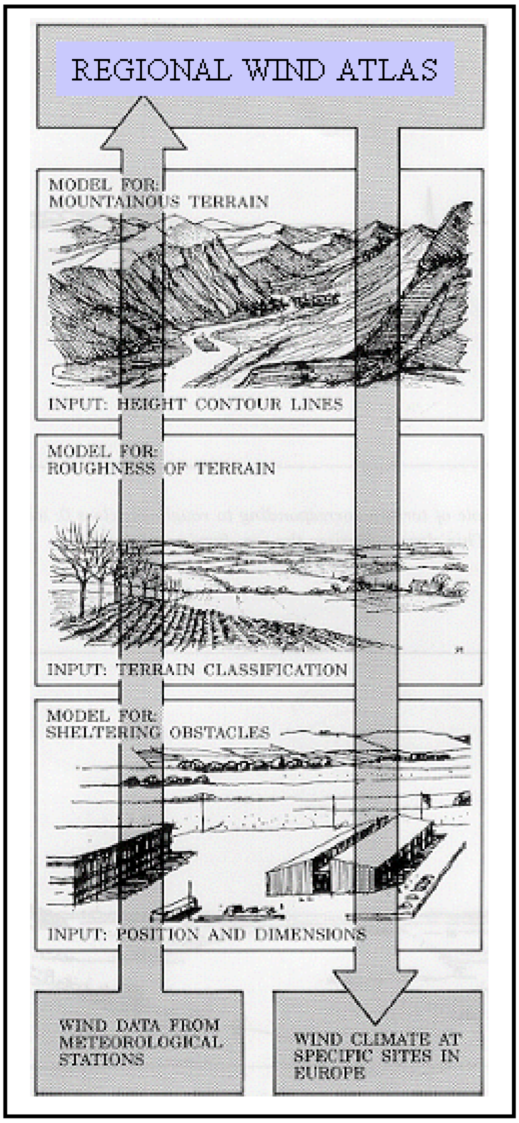
Ideally the simplest way to collect wind data is by taking actual measurements on-site because these measurements can provide high-quality data; however, these measurements involve the high time and cost. As a result, "micro-siting models", simulation codes based on theoretical and empirical results are used to estimate wind at all wind turbine locations based on wind measurements made at reference locations.[20] An example of such a simulation tool, developed by the Wind Energy Department at Risø National Laboratory (Denmark), is presently recognized as an industry standard worldwide, i.e., the Wind Atlas Application Analysis Program (WAsP). This program has been extensively used to estimate regional wind climate,[21] analyze data, and site of wind turbines at many locations in Europe with good accuracy.

The wind atlas model takes into account: terrain roughness (for example, desert surface, farmland, and water surface), sheltering effects (due to buildings and other

[16] National Renewable Energy Laboratory (NREL), "Estimating the Economic Value of Wind Forecasting to Utilities," available at: http://www.nrel.gov/wind/TP-441-7803.pdf, June, 14, 2002
[17] Danish Wind Industry Association, "Selecting a Wind Turbine Site," available at: http://www.windpower.org/tour/wres/siting.htm, September 8, 2002
[18] American Wind Energy Association (AWEA), "Basic Principles of Wind Resource Evaluation," available at: http://www.awea.org/faq/basicwr.html, September 8, 2002
[19] American Wind Energy Association (AWEA), "The Most Frequently Asked Questions about Wind Energy," available at: http://www.awea.org/pubs/documents/FAQ2002%20-%20web.PDF, September 7, 2002
[20] GIS Development, "Wind resource assessment using map info GIS software tool," available at: http://www.gisdevelopment.net/application/utility/power/utilityp0004.htm, September 8, 2002
[21] Wind climate: the distributions of wind speed/direction for a number of uniform surface roughness and heights above ground level.

obstacles, and orography (terrain heights variations such as hills and escarpments).[22] For instance, Figure 2.1 illustrates[23] the wind atlas method as developed during the preparation of the European Wind Atlas.

Figure 2.1 Input and output data of the WAsP program



Source: *http://www.wasp.dk/WindAtlasMethod.htm*, September 8, 2002

The left arrow in this figure illustrates the analysis of measured wind data at reference locations, resulting in a regional wind climate. Then, these regional wind

[22] Chadwick, H., "Module 1 (Meteorology): Section 5: The Wind Resource at a Potential Wind Turbine Site," *De Montfort university – Wind Energy Training Course*," available at: http://www.iesd.dmu.ac.uk/wind_energy/wetc154.html, September 8, 2002

climate data can be used to estimate the wind climate at a certain site for a wind turbine after being combined with the site-specific data, as shown with the right arrow in Figure 2.1.[24]

The flow of input and output data of the WAsP program[25] can be summarized as follows:

Analysis: meteorological data + site description → wind atlas data

Application: wind atlas data + site description → estimated wind climate

Chapter 2 has demonstrated that a serious consideration of wind energy is justified due to the abundant wind resource potential worldwide. Meanwhile, the prediction that electricity generation will be one of the world's largest industries in the future is also justified from the profitability point of view, since a small fraction of the global electricity market amounts to a major industry in terms of both investment and annual revenue. For instance, if wind energy supplies only 1 percent of this demand (assuming a wholesale electricity price of 0.03 US$/kWh), wind energy's annual electricity production would still be worth US$ 7.5 billion per year, more than many other industries.[26] Furthermore, with an installed capacity of 24,900 MW in 2001 and assuming a capital cost of 1,000 US$/kW, the world's investment in installed wind capacity was already worth approximately US$ 24.9 billion in 2001.

This chapter also pointed out that the importance of wind resource assessment in determining the precise site for a wind turbine. Careful evaluation and realizing the limitations of the available wind resource data will help to reduce uncertainties in the prediction of a wind turbine's annual output at a specific site.

[23] Risø, "Wind Atlas Method," available at: *http://www.wasp.dk/WindAtlasMethod.htm*, September 8, 2002

[24] Roughness, topography effects and the effect of shelter from obstacles at the reference sites are all removed from the data, before they can be applied to estimate the wind climate at the turbine site where local roughness, orography and shelter effects are added and the wind climate is computed at hub height.

[25] Risø, "Wind Atlas Analysis and Application Program: The Standard in Wind Resource Calculation and Micro-siting," available at: http://www.wasp.dk/structure.htm, September 8, 2002

[26] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 6

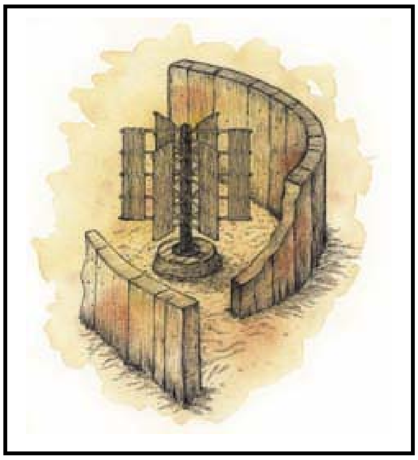
Chapter 3 Wind Turbine Technology

This chapter provides an overview of modern wind turbine technology, a discussion of its likely future development and an introduction to the fundamental principles of wind turbine power generation. At the outset, it is useful to start with a brief history of wind energy utilization, as this demonstrates the issues that wind energy system still face today, and provides insight into why wind turbines now look the way they do.

3.1 A Brief History of Wind Energy Utilization

People have used technologies to transform the power of wind into useful mechanical energy since antiquity such as propelling boats, pumping water and grinding grains. The use of wind energy is said to have its root from the Asian civilization of China, Tibet, India, Afghanistan and Persia.[27] The earliest known windmill design is the vertical axis system developed in Persian (Figure 3.1). These windmills were constructed indoors, with slots in the walls to allow the wind to enter and push the sails made of bundles of reeds or wood, which rotated like revolving doors.[28]

Figure 3.1 The Persian windmill



Source: http://www.purewind.net/historymills.html, September 5, 2002

[27] U.S. Department of Energy, "Wind Energy Program: History of Wind Energy Use," available at: http://www.eren.doe.gov/wind/history.html, September 5, 2002

[28] Purewind, "History of Windmills," available at: http://www.purewind.net/historymills.html, September 5, 2002

The returning European merchants and crusaders carried the windmill technology to Europe and by the 11th century windmills had spread throughout Europe and all had horizontal axes.[29] The reason for the sudden evolution contrasting with the vertical-axis Persian design approach is unknown; however, the fact that European water wheels also had a horizontal-axis configuration and apparently served as the technological model for the early windmills may provide part of the answer. Another reason may have been the higher structural efficiency of drag-type horizontal machines over vertical ones, which lose up to half of their rotor collection area due to shielding requirements.[30]

The early North European mills were built on posts, so that the entire mill could be turned to face the wind when its direction changed (Figure 3.2). These windmills normally had four blades. The number and size of blades presumably was based on ease of construction as well as an empirically determined efficient solidity (ratio of blade area to swept area).[31]

Figure 3.2 Post windmill

Source: http://etext.virginia.edu/flowerdew/mWind.html, September 5, 2002

Later the post mill evolved into the "smock" windmill (the name derived from the fact the windmill tower resembled a farmer's smock). In a smock windmill, only the

[29] Look Learn and Do, "A History of Windmills," available at: http://www.looklearnanddo.com/documents/history_windmills.html, September 5, 2002

[30] Telosnet, "Early History through 1875," available at: http://telosnet.com/wind/early.html, September 5, 2002

[31] Manwell, J.F., McGowan J.G., and Rogers, A.L., "Wind Energy Explained: Theory, Design, and Application," Chichester, John Wiley and Sons, 2002, pp. 11

very top of the windmill, or cap, revolved with the sails, like a turret. This innovation allowed the mills to be much larger and contain more powerful machinery, as well as allowing higher and larger sails to be deployed, to catch more wind (Figure 3.3).[32]

Figure 3.3 Smock windmill

Source: http://www.dartmouth.edu/alumni/ cont-ed/ace2002.html, September 5, 2002

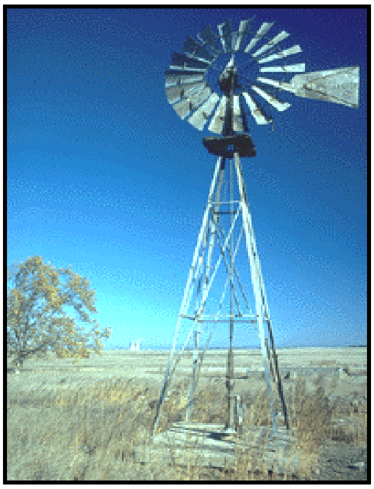
Wind energy continued to be a major source of energy in Europe through the period just prior to the Industrial Revolution. The industrialization era spread from Europe to America, led to a gradual decline in the use of windmills due to the invention of steam engines, which offered more advantages over wind in delivering power on a much larger scale, especially with the introduction of fossil fuels such as coal, oil, and gas. Moreover, the non-dispatchability[33] and non-transportability characteristics of wind energy gave a major drawback of its application.[34]

Prior of its demise, the European windmill reached a high level of sophistication. Meanwhile, in the United States, another variant of windmill came into widespread use most particularly for pumping water. These windmills were distinctive for their multiple-blades. One of its most significant features was a simple but effective regulating system that allowed the turbines to run unattended for long periods. Such regulating systems foreshadowed the automatic control systems, which are now an

[32] Purewind, "History of Windmills," available at: http://www.purewind.net/historymills.html, September 5, 2002
[33] Dispatchability: the ability to control generation output.
[34] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 42-43

integral part of modern wind turbines. Then, further development and refinement of the multi-bladed wind turbine used on farms throughout the world led to a replacement of the wood used in most parts of these machines by iron and steel. Lattice steel towers were introduced, and even steel lades came into use as shown in Figure 3.4.[35]

Figure 3.4 Multiple-blades windmill



Source: http://www.consumerenergycenter.org/renewable/basics/wind/wind.html, September 5, 2002

However, the industrialization also sparked the development of larger windmills to generate electricity. For example, Charles Brush[36] built the first automatically operating wind turbine for electricity generation in Cleveland, Ohio in 1888. Meanwhile, the development of larger wind turbines appeared in Denmark as early as 1890 and substantially influenced the development of today's wind turbines technology. For example, the Gedser turbine was erected in southeastern Denmark immediately after World War II. This three-bladed turbine was particularly innovative since it employed aerodynamic stall for power control[37], and used an induction generator that is much simpler to connect to the grid rather than a synchronous generator. These two concepts

[35] Manwell, J.F., McGowan J.G., and Rogers, A.L., "Wind Energy Explained: Theory, Design, and Application," Chichester, John Wiley and Sons, 2002, pp. 13

[36] Danish Wind Industry Association, "A Turbine Pioneer: Charles F. Brush," available at: http://www.windpower.org/pictures/brush.htm, September 5, 2002

[37] Aerodynamic stall is a type of aerodynamic braking system applied for stall controlled wind turbines, which have the rotor blades bolted onto the hub at a fixed angle. The geometry of the rotor blade profile has been aerodynamically designed to ensure that the moment the wind speed becomes too high, it creates turbulence on the side of the rotor blade, which is not facing the wind. This stall prevents the lifting force of the rotor blade from acting on the rotor.
Details can be found in Danish Wind Industry Association, "Power Control of Wind Turbines," available at: http://www.windpower.org/tour/wtrb/powerreg.htm, September 5, 2002

formed the core of the strong Danish presence in wind energy technology development. In the 1940's, the U.S largest two-bladed wind turbine at that time with a capacity of 1.25 MW began operating on a Vermont hilltop known as Grandpa's Knob that fed electricity power to the local utility network.

Consequently, wind turbine technology research and development did not disappear because of competition from fossil fuels, but rather made steady progress over the time. The re-emergence of wind energy can be considered to have started following the oil embargoes in the 1970s where new ways of converting wind energy into useful power were being introduced. Many of these approaches have been demonstrated in "wind farms" or wind power plants (groups of turbines that feed electricity into the utility grid) in the United States and Europe.

Today, the lessons learned from more than a decade of operating wind power plants, along with continuing R&D, have made wind-generated electricity come very close in cost to the power from conventional utility generation in some locations.[38]

3.2 Modern Wind Turbine Technology

A modern wind turbine is a machine that converts the power in the wind (kinetic energy) into electricity. Electricity generated by wind turbines can be either stored in batteries, or used directly.

There are two basic designs[39] of wind turbine: the horizontal axis wind turbine (HAWT), which has a rotating axis parallel to the ground and blades appear similar to airplane propellers, and the vertical axis wind turbine (VAWT), which its blades rotate on an axis perpendicular to the ground. However, nowadays virtually all existing wind turbines use the horizontal axis concept. Therefore, from now on this report focuses only on the technology of horizontal axis wind turbines.

[38] U.S. Department of Energy, "Wind Energy Program: History of Wind Energy Use," available at: http://www.eren.doe.gov/wind/history.html, September 5, 2002
[39] Iowa Energy Center, "Wind Energy Systems," available at: http://www.energy.iastate.edu/WindManual/Text-systems.html, September 7, 2002

3.2.1 How Do Wind Turbines Generate Electricity? [40]

In order to generate electricity, wind turbines commonly capture the wind's energy with two or three propeller-like blades, which are mounted on a tower. At 100 feet (30 meters) or more aboveground, they can take advantage of the faster and less turbulent wind.

The blades act much like airplane wings. As the wind blows, a pocket of low-pressure air forms on the downwind side of the blade, which then pulls the blade toward it, causing the rotor to turn (this process is called *lift*). The force of the lift is actually much stronger than the wind's force against the front side of the blade, which is called *drag*. The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity. Then, wires running down the tower carry electricity to the grid, batteries or other appliances, where it is stored, and/or used.

3.2.2 Main Components of A Wind Turbine

The horizontal axis wind turbines usually are either two- or three-bladed, these blades appear like airplane propellers. The three-bladed wind turbines are operated "upwind," with the blades facing into the wind, while the two-bladed wind turbines are operated "downwind"(Figure 3.5).

Figure 3.5 Two- and three-bladed modern HAWT

Source: http://www.memagazine.org/backissues/dec99/features/cells/cells.html and http://www.ata.org.au, September 5, 2002

[40] National Renewable Energy Laboratory (NREL), "Clean Energy Basics: Introduction to Wind Energy," available at: http://www.nrel.gov/clean_energy/wind.html, June 13, 2002

The main components[41] of the upwind HWAT are explained as follows (Figure3.6):

- ***Rotor***;

  The rotor includes the blades and hub. These are often considered to be the wind turbine's most important components both from a performance and an overall cost standpoint. The rotor can rotate either at near-fixed speed, or at variable speed, depending on its design. The blades of the rotor are designed to spin in the wind, driving the turbine generator. Sometimes gearing is used to increase the frequency for electricity generation. The blades are attached to the hub, which connects it to the low-speed shaft.

- ***Drive train;***

  It consists of the rotating parts of the wind turbine, which includes a low-speed shaft (on the rotor side), a gearbox, and a high-speed shaft (on the generator side). Other drive train components include the supporting bearings, one or more couplings, and a brake. The gearbox is used to increase the rate of rotation of the rotor from a low value typically below 100 rpm to a rate between 1200 – 1800 rpm[42], suitable for driving a standard generator. The rotor turns the low-speed shaft at about 30 to 60 rotations per minute and the high-speed shaft drives the generator.[43] A disc brake can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.[44]

- ***Generator;***

  All wind turbines use either induction or synchronous generators. The majority of wind turbines installed in grid connected application use the induction type, operating at near-fixed rotational speed. The main advantage of induction generators is that they are rugged, inexpensive, and easy to connect to an electrical network.

- ***Nacelle and yaw orientation system;***

  Nacelle is a box-like structure located behind the rotor blades, and its function is to protect the drive train components, and the generator from the weather. A yaw orientation system is required to align the nacelle so that the rotor axis points as

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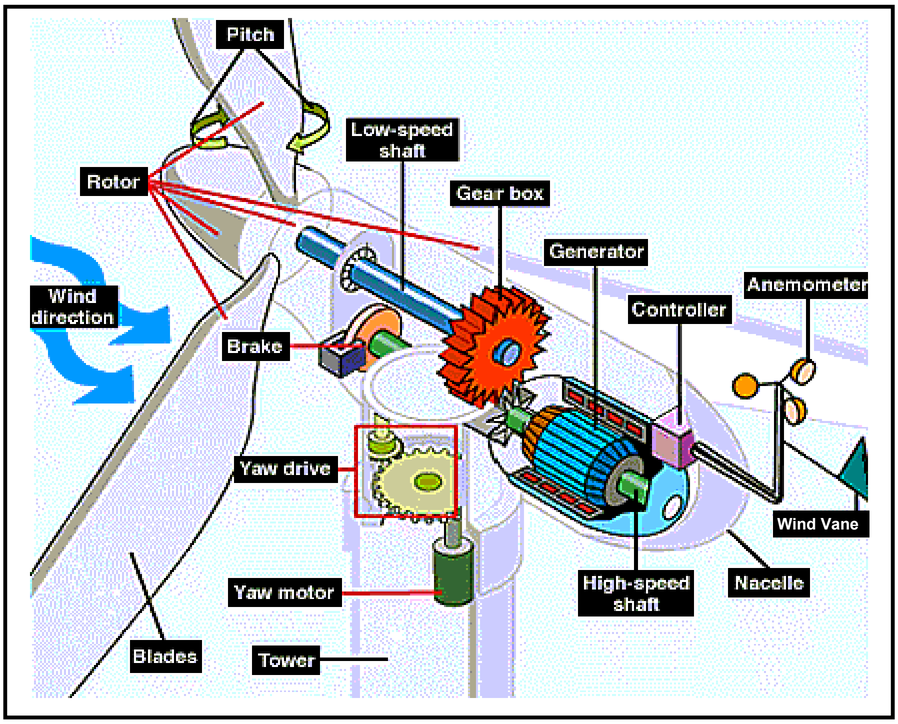
[41] Manwell, J.F., McGowan J.G., and Rogers, A.L., "Wind Energy Explained: Theory, Design, and Application," Chichester, John Wiley and Sons, 2002, pp. 3-7

[42] Iowa Energy Center, "Wind Energy Systems," available at: http://www.energy.iastate.edu/WindManual/Text-systems.html, September 7, 2002

[43] U.S. Department of Energy, "Wind Energy Program: How the Turbine Works?," available at: http://www.eren.doe.gov/wind/feature.html#drawing, September 7, 2002

accurately as possible towards the wind. Since upwind turbines need to face the direction where the wind comes, the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. The yaw drive is powered by a yaw motor. Downwind turbines do not require a yaw drive since the wind blows the rotor downwind.

Figure 3.6 Main components of the wind turbine



Source: http://www.eren.doe.gov/wind/feature.html#drawing, September 7, 2002

- ***Tower and foundation;***

  Towers are made from tubular steel or steel lattice. Since wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity. Tower height is typically 1 to 1.5 times the rotor diameter, but in any case is normally at least 20 m. Supporting foundations are usually made from concrete (for on-shore wind turbines). The stiffness of the tower is a major factor in wind turbine dynamics because of the possibility of coupled vibrations between the rotor and tower.

[44] There are also direct drive (without gearbox) wind turbines, see page 23.

- ***Control system;***

  The computer-based central control panel of the wind turbine is typically mounted inside the tower. This control system monitors gearbox and generator temperature, wind speed (if wind speed is above some set limit, the wind turbine may be stopped for safety reasons), vibration, and so on. If the wind turbine is part of a wind farm, the turbine is connected to a central monitoring computer.
- ***Transformer***

  The low voltage electricity output from the generator is stepped up to grid level through the transformer. From the transformer, the electric current that is carried through the high voltage cable feeds into the main grid.

3.2.3 Fundamental Principles of Wind Turbine Power Generation

The power output[45] of a wind turbine varies with the wind speed that goes through its rotor. Power is usually expressed in terms of work per unit time, or in other words, the change in kinetic energy per unit time, as shown in the following equation.

$$Power = \frac{1}{2} \rho \cdot A \cdot v^3$$

where,

P power (kW)

ρ air density (kg/m^3)

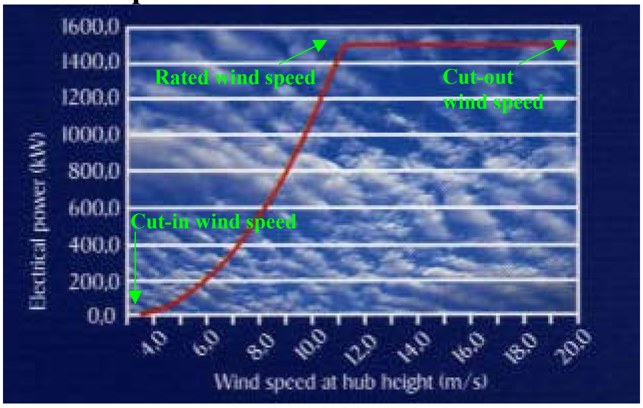
A swept rotor area (m^2)

v wind speed (m/s)

Since each wind turbine is designed to work between certain wind speeds, its power generation range can be obtained from its characteristic power performance curves that can be obtained from the manufacturer (usually derived from standardized field tests). A power performance curve shows the relationship between the electrical power output as a function of the hub height wind speed. The next figure, Figure 3.7, gives an example of a 1.5 MW wind turbine power performance curve.

[45] American Wind Energy Association (AWEA) website, "Basic Principles of Wind Turbine Energy Generation," available at: http://www.awea.org/faq/basicpp.htmlhttp://www.awea.org/faq/basicpp.html, September 7, 2002

Figure 3.7 Power performance curve for a 1.5 MW wind turbine



Source: Repower systems, November 6, 2002

There are three[46] wind speed terms that determine the performance of a wind turbine as explained below:

- ***Cut-in wind speed*** is the minimum wind speed at which the machine will deliver useful power. For example, Figure 3.7 shows 3.5 ms^{-1}, and there is insufficient energy below this speed to overcome system losses.
- ***Rated wind speed*** is the wind speed at which the "rated power" (generally the maximum power output of the electrical generator) is achieved, i.e.12 $ms^{-1.}$ Above this speed, it may have mechanisms that maintain the output at a constant value with increasing wind speed to ensure a stable system.
- ***Cut-out wind speed*** is the maximum wind speed at which the particular turbine is allowed to deliver power (usually limited by engineering design and safety constraint), i.e. 20 ms^{-1}. It also determines the ability of a particular machine to endure high wind.

Despite the fact that wind turbines are most commonly classified by their rated power at a certain rated wind speed, annual energy output is actually a more important measure for evaluating a wind turbine's value at a given site.[47] It can also be predicted

[46] ACRE, "How Do Wind Turbines Work?" available at: http://acre.murdoch.edu.au/refiles/wind/text.html, September 7, 2002
[47] American Wind Energy Association (AWEA), "How Does A Wind Turbine's Energy Production Differ from Its Power Production?" available at: http://www.awea.org/faq/basicen.html, September 7, 2002

from its power performance curve without considering the technical details of its various components[48], as proved by the following formula:

Energy = Power x time

There are three basic physical laws governing the amount of energy available from the wind:[49]

- ***The maximum power generated by the turbine is proportional to the wind speed cubed***
  For example, if the wind speed doubles, the power available increases by a factor of eight; if the wind speed triples then twenty seven times more power is available. Conversely, there is very little power in the wind at low speed. This law indicates that accurate and detailed local wind speed data is essential to determine the likely energy yield from a given site; therefore, generators should be designed for that particular site. Average wind speed information alone is often of limited value.
- ***The power available is directly proportional to the swept area of the blades***
  That is the power is proportional to the square of the blade length. For example, doubling the blade length will increase the power by four times, and tripling the blade length will increase the power by nine times.
- ***The maximum theoretical efficiency of wind generators is 59%***
  Wind turbines can utilize up to a theoretical maximum of 59% of the kinetic energy passing through its swept rotor area.[50] Currently, modern wind turbines[51] have efficiencies of about 45 - 50%.

[48] McGowan, J.G., "Wind Power," can be found in Bisio, A. and Boots, S. (editors), "Encyclopedia of Energy Technology and the Environment – Volume 4," New York, John Wiley & Sons, 1995, pp. 2908
[49] ACRE, "How Do Wind Turbines Work?" available at: http://acre.murdoch.edu.au/refiles/wind/text.html, September 7, 2002
[50] Swept rotor area: the area of the circular disc 'drawn' by the blade tips.

3.3 Wind Turbine Applications[52]

Currently, there are three categories of wind turbines applications: small stand-alone turbine systems, intermediate-sized turbines in hybrid systems, and large grid-connected turbine systems.

Small "stand-alone" wind turbines of less than 25 kW are used for various applications such as generating electricity, charging batteries, pumping water, or communications for homeowners and remote villages. They are often the most inexpensive source of power for remote sites. These turbines are very simple and can operate unattended for long periods at harsh sites.[53]

Intermediate-sized wind power systems (with capacity ranges from 25 to 150 kW) often incorporate additional generating systems for instance, photovoltaic, small-scale hydro, diesel, and/or storage systems. These "hybrid" systems provide improved reliability of power supply and operational flexibility. When the power from the wind turbine is not sufficient to operate the load, the alternate power source comes on-line. These systems have significant potential for rural electrification. In areas with good wind resources and no utility grids, a single wind turbine can provide electricity at lower cost than diesel. These systems can also be more cost-effective than transmission line extension for communities in remote, but windy regions.[54]

Nowadays, large and modern wind turbines (with capacity ranges between 150 kW to 3 MW) are usually built and operated close together forming "wind power plants" or "wind farms" to supply electricity for large grid-connected systems. Wind power plants are "modular", which means they consist of small individual modules (the turbines) and can easily be made larger or smaller as needed. Turbines can be added as electricity demand grows.[55] This large grid-connected wind turbines category accounts

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[51] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 43
[52] Natural Resources Defense Council (NRDC), "Wind Power," available at: http://www.nrdc.org/air/energy/fwind.asp, September 8, 2002
[53] National Renewable Energy Laboratory (NREL), "Clean Energy Basics: Introduction to Wind Energy," available at: http://www.nrel.gov/clean_energy/wind.html, June 13, 2002
[54] National Wind Technology Center (NWTC), "Small wind turbines and hybrid power systems," available at: http://www.nrel.gov/wind/smalltur.html, September 10, 2002
[55] American Wind Energy Association (AWEA), "The Most Frequently Asked Questions about Wind Energy," http://www.awea.org/pubs/documents/FAQ2002%20-%20web.PDF, available at: September 7, 2002

for by far the largest market value among the previous categories.[56] The subsequent chapters of this report focus only on subjects related to large grid-connected wind turbines.

3.4 Technological Trend

The technology of wind turbines has evolved a great deal over the last 25 years. The most significant technological trend is the continuing up-scaling of machines, now available with machines' capacity of up to 3 MW for offshore machines[57], while larger ones up to 5 MW are under design (Figure 3.8). There were only a few technical barriers to further up scaling of size, including transportation and availability of large cranes near the site. Electricity production efficiency is also rapidly improving, owing to higher towers, larger rotors and design improvement. This increased size and efficiency lead directly to increased annual energy output per square meter of land occupied, which is important in regions with limited land availability.

Figure 3.8 Representative size, height, and diameter of wind turbines

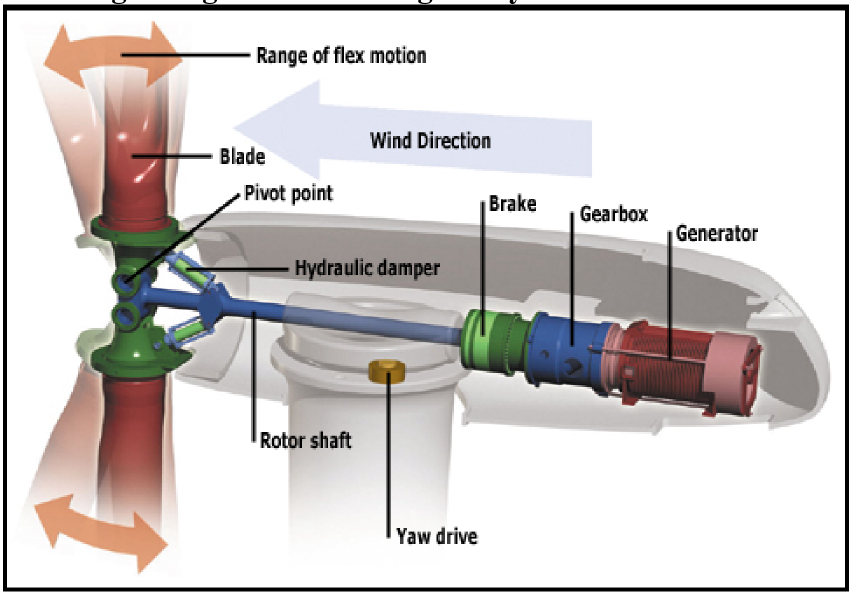
September 9, 2002 (designed by author)

It is also important to notice the possible future state-of-the-art of wind turbine concept that leads to a highly flexible machine, which is generally recognized through

[56] U.S. Department of Energy, "Wind Energy Topics," available at: http://www.eren.doe.gov/RE/wind.html, June 15, 2002

lightweight designs with high structural flexibility. Theoretically, these designs are more cost-competitive that the heavier and more rigid turbines of today. A successful example is the newest wind turbine prototype designed by Wind Turbine of Bellevue – WA (US) that has operated for two years at Rocky Flats in Colorado. This prototype is a downwind turbine with flexible and hinged blades. In strong winds, its two-propeller blades bend back slightly while spinning. The bending is barely perceptible to a casual observer. The flexibility in its blades enables the turbine to be 40 percent lighter than today's industry standard but just as capable of surviving destructive storms. This lighter weight could also decrease the cost of today's large turbines up to 25 percent. [58]

Figure 3.9 The lightweight turbine designed by Wind Turbine of Bellevue



Source: http://www.technologyreview.com/articles/fairley0702.asp, August 6, 2002

Higher structural flexibility also means higher drive train flexibility that includes variable speed, direct drive design and so on. Such improvements will have two primary advantages: increased electricity output and hence greater cost efficiency, and improved power quality and grid interaction.

Variable speed wind turbines can use more wind, due to the fact that they adapt to the particularity of the wind power itself - the changeable force of the wind. They start

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[57] World Energy Council, "Survey of Energy Resource," available at: http://www.worldenergy.org/wec-geis/publications/reports/ser/overview.asp, September 24, 2002
[58] Fairley, P., in Technology Review, "Wind for Pennies," can be found in Planetark, available at: http://www.technologyreview.com/articles/fairley0702.asp, August 6, 2002

at lower wind speeds, and increase the power with speed. The design itself may be more demanding than classic, constant-speed turbine; an energy increase of up to 10% is reported.[59]

The R&D focus on "direct drive" machines[60] has increased significantly, although it is not reflected in commercial sales, other than those from two wind turbine companies from Germany: Enercon and Lagerwey.[61] The direct drive wind turbine has an electromechanic system without gearbox. It utilizes a generator that rotates with the same speed as the rotor of the wind turbine, so that the gearbox is not necessary. Table 3.1 contains some examples of various R&D focuses of major wind turbine manufacturers.

Table 3.1 The Various R&D focuses of major wind turbine manufacturers

Company	Research & Development Focus
Bergey WindPower (United States)	Small (one-kilowatt to 50-kilowatt) turbines for distributed-power applications
Enercon GmbH (Germany)	Large turbines and direct drive machines
General Electric Wind Energy (United States)	Improving existing large, heavy design
Mitsubishi Heavy Industries (Japan)	Large turbines for offshore applications
National Wind Technology Center (United States)	Cost-effective turbines for moderate-wind sites
Nordex AG (Germany)	Large turbines for onshore and offshore applications
Pfleiderer Wind Energy (Germany)	Simplifying gearbox with permanent-magnet generators
Risø National Laboratory (Denmark)	Improving existing large, heavy design; testing of small-scale, lightweight designs
Vestas Wind Systems (Denmark)	Improving existing large, heavy design
Wind Turbine (United States)	Large, lightweight flexible turbines

Source: http://www.technologyreview.com/articles/focuson0702.asp, September 10, 2002

[59] Schreiber, D., "State of the Art of Variable Speed Wind Turbines," *the 11th Symposium on Power Electronics – Ee 2001*, can be found in SEMIKRON, available at: http://www.semikron.com/pdf/ds_wind.pdf, September 12, 2002
[60] Dubois, M., "Direct Drive Generators for Wind Turbines," *Phd Project*, can be found in TU-Delft, available at: http://ee.its.tudelft.nl/epp/RePhD_b002.htm, September 12, 2002
[61] BTM Consult ApS, "International Wind Energy Development: World Market Update 2000," *Report*, available at: http://www.btm.dk, June 14, 2002

Another R&D improvement has been done in lowering wind turbine noise emissions through better-designed blades, improved manufacturing quality of mechanical parts and use of damper materials.[62]

Offshore wind energy systems are also under active development in Europe as suitable locations on land are becoming scare and offshore wind speeds are somewhat higher than those on land, providing more energy yield.

Current technology advancement has made wind turbines more reliable, more cost effective, and quieter; nevertheless, cost reduction is still the prime objective for industrial research and development (R&D) in wind turbine technology. There will be continuing pressure for the designers to improve the cost effectiveness of turbines for all applications. Improved engineering methods for the analysis, design, and mass-produced manufacturing will be required. Opportunities also exist for the development of new materials to increase wind turbine life. Wind turbine technology's *progress ratio* (the decline in costs each time the cumulative manufactured volume doubles) has been on the order of 10 – 15 percent. This development is expected to continue in the future, perhaps at a slightly slower pace. [63]

Moreover, the tremendous opportunities for offshore applications with their difficulties need to be overcome, and as wind energy takes a larger fraction of the world's electricity supply, the issues of intermittency, transmission, and storage must be re-examined.[64] Transport and installation of very large turbines is not a problem offshore because of the availability of floating construction cranes.

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[62] United Nations Department of Economic and Social Affairs (DESA), "Renewable resources energy, with special emphasis on wind energy," *Report of the Secretary General: E/C.13/1998/4*, available at: http://www.uccee.org/WindEnergy/UNreportwind.pdf, August 20, 2002

[63] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 56

3.5 Offshore Wind Turbines

The concept of developing offshore wind resources for electricity production goes back to the 1970s,[65] and studies in the 1980s[66] and 1990s.[67] The siting of wind farms has two intrinsic advantages. First, the wind speeds are somewhat higher than those on land and show less variability, providing a large potential resource. Second, the environmental restrictions are more relaxed than those for onshore locations, opening up large areas for potential development.[68] Today, one of the main reasons for the migration offshore is that on-land sites are limited and that utilization of these sites can provoke opposition from the local population, especially at highly populated areas or sites of tourists attraction, as discussed in Chapter 6. These constraints are already being experienced in countries such as the U.K., Denmark, Netherlands, and Germany.[69]

These two factors taken together given a large potential resource that can envisage significant renewable energy developments to reduce CO_2 production. For instance, the European Union[70] targets to achieve 230 GW of installed wind energy capacity by the year 2020; while this capacity may be difficult to achieve onshore, due to limited space and environmental restrictions, a study carried out in the scope of the European non nuclear energy research program "JOULE" shows that very large offshore resource are available.[71] This study concludes that in most states of Northern Europe a 10 percent increase in the mean wind speed can result potentially in 30 percent more energy yield. It is generally believed that the continental shelf with water depth up to

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[64] Manwell, J.F., McGowan J.G., and Rogers, A.L., "Wind Energy Explained: Theory, Design, and Application," Chichester, John Wiley and Sons, 2002, pp. 18-19

[65] Heronemus, W.E., "Power from the Offshore Winds," Proc. of the 8th Annual Conference of the Marine Tech. Soc., 1972 can be found in Harrison, R., Hau, E. and Snel, H., "Large Wind Turbines: design and economics," Chichester, John Wiley and Sons, 2000, pp. 167

[66] Dixon J.C., and Swift R.H., "Offshore wind power systems: a review of developments and comparison of national studies," Wind Engineering Vol. 10 No.2, 1986 can be found in the British Wind Energy Association (BWEA), "Prospects for Offshore Wind Energy," *Altener contract XVII/4.1030/Z/98-395 – a written report for the EU by the BWEA,* 2000, pp. 7

[67] Matthies, H.G., *et al*., "Study of Offshore Wind Energy in the EC –Joule 1 (Jour 0072), 1995, can be found in Grainger, W., Gammidge, A. and Smith, D., "Offshore Wind Data for Wind Farms," available at: http://www.owen.eru.rl.ac.uk/documents/bwea20_38.pdf, August 24, 2002

[68] This is the view of Harrison, R. *et al.*
Harrison, R., Hau, E. and Snel, H., "Large Wind Turbines: design and economics," Chichester, John Wiley and Sons, 2000, pp. 167

[69] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 229

[70] European Wind Energy Association (EWEA), "Wind Force 12,' available at: http://www.ewea.org/doc/WindForce12.pdf, September 20, 2002

[71] see footnote 67 (Matthies et al.)

some 30 m and distances from shore of up to about 30 km offer considerable economic advantages.[72] Figure 3.10 shows the Middelgrunden offshore wind farm, the world's largest offshore wind farm (40 MW), which was completed off the Danish coast in December 2000.[73]

Figure 3.10 Middelgrunden offshore wind farm

Source: http://www.wind-energie.de, October 3, 2002

Now, the current technology availability with the presence of MW commercial turbines and the opportunity that offshore applications offer through larger projects make offshore projects become more and more attractive. The challenge of future progress of offshore projects is the ability to keep the investment cost at a level that in economic terms can be justified by the resource available for the specific project. This challenge also includes on how to deal with the foundation and the electrical infrastructure cost for offshore applications, which are more expensive than those of onshore wind farms.[74]

The project "Concerted Action on Offshore Wind Energy in Europe (CA-OWEE)," which was funded by the European Commission to stimulate the development of offshore wind-energy into an important energy source also concluded that the technology for the construction and operation of offshore wind farms is ready for large-

[72] Geocities, "Large Wind Turbines – Wind Farms," available at: http://www.geocities.com/dieret/re/Wind/wind.html#LARGE%20TURBINES, September 11, 2002
[73] Knight, D. "Wind is the fastest growing power sector," can be found in Common Dreams, available at: http://www.power-technology.com/projects/middelgrunden/, September 11, 2002
[74] BTM Consult ApS, "International Wind Energy Development: World Market Update 2000," *Report*, available at: http://www.btm.dk, June 14, 2002

scale application.[75] The most important challenges lie in the reduction of costs, the building up of experience and confidence in the building and maintenance of large wind-parks, the connection of these parks to existing electricity networks and the consequences for the landscape and birds.

3.6 Grid Connection Issues of Wind Turbines

Power utilities must maintain enough power plant capacity to meet expected customer electricity demand at all times, plus an additional reserve margin. All other things being equal, utilities generally prefer plants that can generate as needed, such as conventional fuels power plants. Therefore, wind turbines, which are still considered as a new technology by power utilities, raise several questions regarding their behavior in relation to the general electrical grid due to the wind's intermittent nature although it is plentiful and free in nature.

In two separate studies,[76] researchers have found that despite its intermittent nature, wind can provide "capacity value" for utilities. The capacity value for a wind system can be defined as the amount of conventional capacity, which must be installed to maintain the ability of the power system to meet the consumer's demand if the wind power installation is deleted.[77] The studies, by the Tellus Institute of Boston, Mass., and the Prince Edward Island (Canada) Energy Corp., concluded that when wind turbines are added to a utility system, they increase the overall statistical probability that the system will be able to meet demand requirements. They noted that while wind is an intermittent resource, conventional generating systems also experience periodic outages for maintenance and repair. For a utility, the higher the capacity value of wind power plants, the less new generation capacity is required. In practice, the capacity value of a wind generating plant is somewhere between zero and its rated capacity. Most modern utility-scale wind turbines operate with a capacity value of 25% to 40%, although they may achieve higher capacity factors during windy weeks or months. The exact amount of

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[75] van der Sanden, M., "Offshore Wind Technology Ready for Application," can be found in Europhysics News, available at: http://www.europhysicsnews.com/full/14/article6/article6.html, September 28, 2002

[76] American Wind Energy Association (AWEA), "The Most Frequently Asked Questions about Wind Energy," http://www.awea.org/pubs/documents/FAQ2002%20-%20web.PDF, available at: September 7, 2002

[77] Tande, J.O.G., and Hansen, J. "Determination of the Wind Power Capacity Value," *Proc. EWEC'91*, can be found in Manwell, J.F., McGowan J.G., and Rogers, A.L., "Wind Energy Explained: Theory, Design, and Application," Chichester, John Wiley and Sons, 2002

capacity value that a given wind project provides depends on a number of factors, including average wind speeds at the site and the match between wind patterns and utility load (demand) requirements,[78] and also the percentage of total electricity demand that is covered by wind energy (the penetration level)[79].

Another concern has been expressed over wind energy's potential impact on power quality such as real time power demand, voltage level, voltage fluctuation, and so on); however, in real life grid operations power quality has not yet been shown to be significant problem, even in electrical grids with a high percentage of wind power.[80] For example, even if wind may occasionally account for up to 50 per cent of power generation in the western part of Denmark (on windy winter nights), the transmission grid operators have been able to cope with this.[81] Furthermore, technologies are available to correct energy's power quality impacts.

Issues such as voltage fluctuations in the grid because of the fluctuating wind turbines power output are considered of minor importance when the turbines are installed in large wind farms. In such farms, the fluctuations caused by any individual turbine are relatively small and are to some extent cancelled out by the out-of-phase fluctuations of other turbines.[82]

Chapter 3 has demonstrated that nowadays the most common modern wind turbine configuration is the horizontal axis with two or three blades. The dramatic improvement of the wind turbine technology has been in the increasing size and performance of wind turbines. These improvements have led to drastic reductions in wind energy's cost per generated kilowatt-hour; however, further cost reductions remain the prime objective of wind industry's R&D in making wind turbines cheaper, lighter, more flexible and more efficient. Meanwhile, the growing interest on developing offshore wind power plants will also challenge the wind industry to deal with various

[78] Culture Change, "The Most Frequently Asked Questions about Wind Energy," available at: http://www.culturechange.org/wind.htm, September 7, 2002
[79] Manwell, J.F., McGowan J.G., and Rogers, A.L., "Wind Energy Explained: Theory, Design, and Application," Chichester, John Wiley and Sons, 2002, pp. 445-446
[80] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 64-72
[81] Krohn, S., "Wind Energy Policy in Denmark – Status 2002," February 2002, can be found in Danish Wind Industry Association, available at: http://www.windpower.dk/articles/energypo.htm, November 6, 2002
[82] See footnote 80

issues in building and operating offshore power plants. In spite of the wind's intermittent nature that raises several questions regarding the behavior of wind power plants in relation to the general electrical grid, the Danish example mentioned previously has shown the ability of transmission grid operators to manage this issue. Chapter 4 will present an overview of the market potential of wind turbines as takes a larger portion of the world's electricity market.

Chapter 4 Market Assessment and Future Outlook

This chapter presents an overview of the wind power market development from both supply and demand sides. The demand side can be observed from the global trend of wind turbine installed capacity, and as the scope of this paper is limited to the two largest wind markets, Germany and the United States, details on their market features are presented. To evaluate the supply side, identifying wind power industry players and observing their evolution are essential to examine how do they cope with this rapidly growing market. At the end of this chapter, a future market outlook of wind power is summarized.

4.1 Market Development – Demand Side

The international wind power market experienced a dramatic growth rate of 52% in 2001. The cumulative installed capacity in the world is now 24,900 MW, with new installed capacity of 6,824 MW recorded at the end of 2001. There are over 55,000 wind turbines installed worldwide today.[83] With this installed capacity, wind power is estimated to deliver some 50 TWh/year (billion kWh per year), sufficient to meet the consumption of 11-12 million households in Western Europe.[84]

Table 4.1 World market growth rates: 1996-2001

Year	Installed MW	Increase %	Cumulative MW	Increase %
1996	1,292		6,070	
1997	1,568	21%	7,636	26%
1998	2,597	66%	10,153	33%
1999	3,922	51%	13,932	37%
2000	4,495	15%	18,449	32%
2001	6,824	52%	24,927	35%
Average growth – 5 years		**39.5%**		**32.6%**

Source: BTM Consult ApS, March 2002

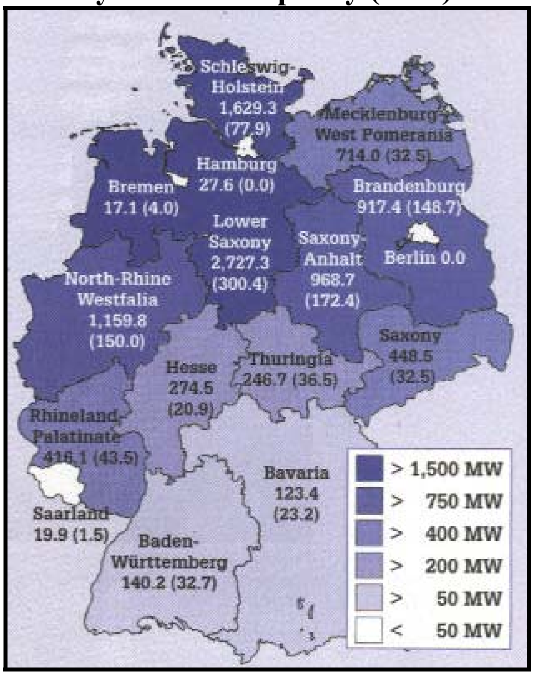
[83] European Wind Energy Association (EWEA), "Wind Force 12: A Blueprint to Achieve 12% of The World's Electricity from Wind Power By 2020," available at: http://www.ewea.org/doc/WindForce12.pdfm, September 20, 2002

Europe continues to lead the market, it accounts for two thirds of total installed capacity in 2001, followed by North America with 26% of new installed capacity. On a country basis, Germany as the perennial pacesetter continues to outdistance all other markets, followed by the United States in second place. Spain trailed the United States, while Denmark is confronted with limited transmission capacity.[85]

4.1.1 Germany

Germany leads the world in wind development, accounting for 40% of total installed capacity in 2001 (2,659 MW). According to the German Bundesverband Wind Energie (BWE) this is more than 60% greater than the year before providing total generating capacity of 8,750 MW for the nation at the end of 2001.[86] This remarkable achievement continues aggressively, as the latest news reports that it reached 10,000 installed MW on the 6th of August 2002 (Figure 4.1).

Figure 4.1 Germany Installed capacity (MW) – end of June 2002



Note: numbers in brackets show installed in 2002

Source: New Energy, August 2002

[84] BTM Consult ApS, "International Wind Energy Development: World Market Update 2001 – Record Growth," *Press Release on April 4, 2002*, available at: http://www.btm.dk, September 9, 2002

[85] Gipe, P., "Soaring to new heights: The world wind energy market," can be found in Renewable Energy World, available at: http://www.jxj.com/magsandj/rew/2002_04/wind_energy.html, September 10, 2002

[86] Bundesverband WindEnergie (BWE), "Informationen," available at: http://www.wind-energie.de/informationen/informationen.htm, August 11, 2002

Peter Ahmels, president of BWE, commented that with the capacity now in place more than 3.5% of Germany's electricity demand can be covered in a normal wind year. If the growth rate stays like this in the coming months, the wind power share of the supply will be more than 4% at the end of 2002.[87] In the past 10 years, this new industry has created more than 40,000 jobs. The German government's goal is to double the country's wind power capacity to 20,000 MW by the year 2010.[88]

Germany will have to take steps in tapping its offshore wind energy potential, as it has a long term target to achieve at least 25% of the country's electricity from wind by 2025. This figure can not be achieved without exploring its offshore potential due to the estimation that, by 2005, most sites suitable for wind energy facilities on land will already be developed and installations capacity will reach 16,000 MW. Therefore, to maintain the continuing expansion of the use of wind energy in Germany at a high level, focus on repowering[89] existing older machines onshore and rapid development of suitable offshore sites must be done, including offshore wind projects in the North and Baltic Seas. [90]

Currently there are already several offshore pipeline projects. A 350-MW offshore project "Nördliche Pommersche Bucht" is planned to be located east of the island of Rügen, where Nordex will deliver 70 5-MW turbines. Developers expect to complete the first construction phase by 2006. Two additional development stages of the same size are planned, which would bring the entire project to a capacity of nearly 1,000 MW, with electricity production of 3.6 billion kWh annually. Overall capital investment will amount to approximately EUR 1.53 billion (US$1.39 billion). Nordex is planning to construct the prototype as early as 2003, then intensively test the turbine for two and a half years, in preparation for delivering the machines in 2005. Developers are planning to locate the turbines at depths of 12 – 20 meters roughly 42 kilometers offshore.[91]

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[87] Bundesverband Wind Energie (BWE), "Through the 10,000 MW dream mark," *New Energy magazine No.4*, August 2002, pp. 14-19
[88] American Wind Energy Association (AWEA) eGroup, "Germany Passes 10,000 MW Mark," *Wind Energy Weekly magazine Vol. 21 No.1006*, August, 2002
[89] Repowering: installing larger wind turbines in existing wind farms to boost power production.
[90] Offshore-Wind, "Politics and wind: Wind energy on land," available at: http://www.offshore-wind.de/en/politics/po_200.html#Terawattstunden, October 7, 2002
[91] American Wind Energy Association (AWEA), "Global Wind Energy Market 2001," available at: http://www.awea.org/pubs/documents/GlobalWEMarket2002.pdf, September 7, 2002

4.1.2 The United States

In the United States, 1,695 MW of wind energy were installed in 16 states in 2001, bringing its nation's wind total capacity to 4,261 MW generated by installations in 26 states.[92] Wind farms in the U.S. now generate close to 10 billion kWh annually, enough to power one million average American households. This wind energy displaces 7.5 million tons of carbon dioxide, the leading greenhouse gas associated with global warming, which would be emitted if the same amount of power were generated from the average U.S. electricity fuel mix.[93]

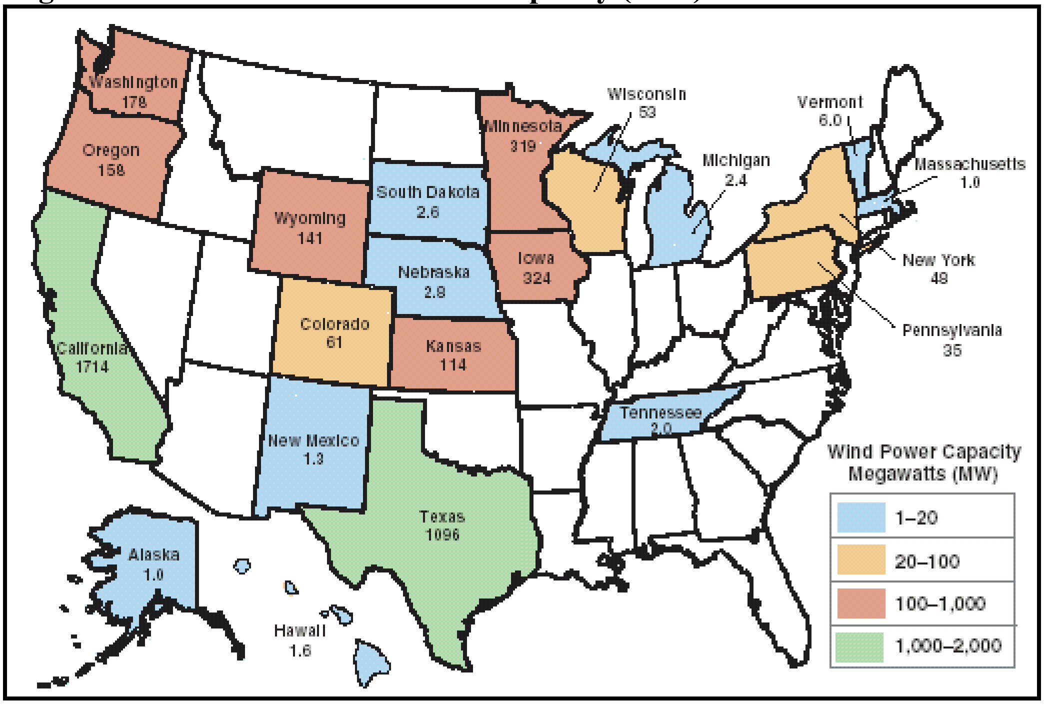
It is believed that excellent record that the U.S made in 2001 was driven by the expiration of the Production Tax Credit (PTC) at the end of 2001. The PTC is the U.S federal tax credit that lowers cost of electricity generated from wind power plants for sale at the wholesale (i.e., to a utility or other electricity supplier). The PTC is intended to encourage the development and utilization of wind energy.[94] Nevertheless, recent U.S. government announcements in March 2002 gives a hope for another booming of the U.S. wind market in the coming years, as the government approved a two years extension of the PTC.[95] The American Wind Energy Association's goal is to achieve at least 6% of the nation's electricity with wind by 2020, with the 100,000 MW installed capacity.[96]

In contrast to Germany, which is starting to explore its offshore potential, the U.S focus remains on onshore wind exploitation, since its massive wind potential onshore has not been exploited to the maximum. Two of the largest projects in the world at the time of construction went into operation in the western U.S.: the 278 MW King Mountain project was completed in West Texas and the 263 MW Stateline wind farm is

[92] U.S. Department of Energy, "Wind Industry Experiences Record Growth in 2001," *Wind Power Today magazine* – edition May 2002, available at: http://www.nrel.gov/docs/fy02osti/31583.pdf, September 20, 2002
[93] American Wind Energy Association (AWEA), "Global Wind Energy Market 2001," available at: http://www.awea.org/pubs/documents/GlobalWEMarket2002.pdf, September 7, 2002
[94] American Wind Energy Association (AWEA), "The Most Frequently Asked Questions about Wind Energy," available at: http://www.awea.org/pubs/documents/FAQ2002%20-%20web.PDF, September 7, 2002
[95] BTM Consult ApS, "International Wind Energy Development: World Market Update 2001 – Record Growth," Press Release on April 4, 2002, available at: http://www.btm.dk, September 9, 2002
[96] U.S. Department of Energy, "Wind Industry Experiences Record Growth in 2001," *Wind Power Today magazine* – edition May 2002, available at: http://www.nrel.gov/docs/fy02osti/31583.pdf, September 20, 2002

now operating along the Washington-Oregon border.[97] In addition, four other wind farms exceeding 100 MW in size were completed in Texas and Kansas. Additional projects throughout the U.S. amounting to 3000 MW have also been proposed.[98]

Figure 4.2 United States Installed Capacity (MW) - end of December 2001



Source: http://www.nrel.gov/docs/fy02osti/31583.pdf, September 20, 2002

4.2 Wind Energy Industry – Supply Side

During the last 20 years the wind turbine industry has developed into a professional high-technology industry. Generated revenues from equipment sales and installation in 2001 were reported more than US$ 5.2 billion,[99] while annual sales were even larger, approximately US$ 7 billion.[100] With an annual growth rate of about 40

[97] FPL Energy, "Wind Energy," available at: http://www.fplenergy.com/renewable/contents/wind.shtml, September 9, 2002
[98] American Wind Energy Association (AWEA), "Global Wind Energy Market 2001," available at: http://www.awea.org/pubs/documents/GlobalWEMarket2002.pdf, September 7, 2002
[99] Gipe, P., "Soaring to new heights: The world wind energy market," can be found in Renewable Energy World, available at: http://www.jxj.com/magsandj/rew/2002_04/wind_energy.html, September 10, 2002
[100] American Wind Energy Association (AWEA), "Global Wind Energy Market 2001," available at: http://www.awea.org/pubs/documents/GlobalWEMarket2002.pdf, September 7, 2002

percent for the past five years and similar growth rates expected in the foreseeable future, the wind power industry is one of the world's fastest growing business sectors.[101]

The international wind industry players are the major wind turbine manufacturers, most of whom are European large wind turbines companies. In Table 4.2 below, the ten largest wind turbine manufacturers are ranked by their sales (in MW) in 2001, including the sales from their majority-owned or fully-owned subsidiaries. Sales of turbines in 2001 were most likely higher than the amount actually installed, as the numbers in Table 4.2 include those turbines registered as sold but not yet installed at their destination. Table 4.2 also shows that the top ten suppliers provided 93 % of the new wind power capacity supplied during 2001.

Table 4.2 World's top ten wind turbine suppliers (ranked by MW sold in 2001)

Manufacturer	MW Sold (in 2001)	MW Sold (Total)
Vestas Wind Systems A/S (Denmark)	1,648	4,983
Enercon GmbH (Germany)	1,036	3,206
NEG Micon A/S (Denmark)	874	4,510
Enron Wind Corp (US)	865	2,288
Gamesa Eólica* (Spain)	648	2,125
Bonus Energy A/S (Denmark)	593	2,306
Nordex AG (Germany)	461	1,473
MADE Energías Renovables S.A. (Spain)	191	783
Mitsubishi (Japan)	178	558
REPower Systems AG (Germany)	133	379
Others	448	3,482
Total	7,075	26,092

* Gamesa sales are not included in Vestas sales above, as Vesta's share of Gamesa is only 40%.

Source: BTM Consult ApS, March 2002

For several years, the ten largest wind turbine manufacturers have been almost the same companies, although their internal position changed from year to year. Given their ability to maintain their individual market share in a rapidly growing market, it will be more difficult to become a new player in the wind industry. Possible new players may

[101] Gipe, P., "Wind Booming Worldwide: A review of BTM Consult's World Market Update," can be found in Chelsea Green, available at: http://www.chelseagreen.com/Wind/articles/BTMUpdateRev.htm,

come from conglomerates, which want to enter the industry. A recent example is the GE Power Systems, one of the world's leading supplier of power generation technology and energy services, which acquired Enron Wind Corp., a wholly owned subsidiary of Enron Corp in the first half of 2002.[102]

Several analysts also predict that major industrial groups are likely to diversify into the wind power industry. The arrival of these industrial giants will add lobbying power and political support for the wind market, which is forecasted by the European Wind Energy Association to be worth 80 billion Euros (US$ 71 billion) by 2020, up from seven billion today. [103]

The rapid growth rates of the wind energy industry have also necessitated changes within the wind manufacturing industry.[104] The first change concerns the ownership and capital base of the industry. Most modern wind turbine manufacturers started as privately owned small and medium-sized enterprises today, due to a higher capital base needed to fuel their current growth, some of them have accessed capital through public issues of equity. For example, NEG-Micon A/S and Vestas Wind Systems A/S are publicly owned companies whose shares are listed on the Copenhagen Stock Exchange. This approach gives a good opportunity for the public to invest in an environmental friendly business. Meanwhile, other companies have secured a larger capital base through acquisition by larger companies, the purchase of Enron Wind by GE Power can be used as an example here.

The second major change in the industry is the wave of mergers, which has occurred in recent years, such as NEG-Micon which was formed through a merger between two Danish companies, Nordtank Energy Group A/S and Micon A/S in 1997. Since then, NEG-Micon has gone on to acquire smaller wind turbine manufacturers and a number of vendors.

The third change is the globalization of the wind energy industry that has awaked the need of the major companies to establish production facilities and joint ventures in

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September 10, 2002

[102] GE Power Systems, "GE Power Systems signed agreement to acquire Enron's wind business," *News Release - February 2002*, available at: http://www.gepower.com/corporate/en_us/aboutgeps/releases/022002.pdf, October 3, 2002

[103] Dyrekilde, B., "Big players to spark wind power consolidation," can be found in Planetark, available at: http: //www.planetark.org/dailystory.cfm?newsid=1504&newsdate=18-Mar-2002, September 11, 2002

[104] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 59-64

many of the world's large wind turbine markets. For example, several Danish companies have established production sites in Germany, Spain and India. The Danish wind turbine manufacturers have successfully maintained their position conquering 50% of the world's market share in 2000 and almost 65% when foreign joint ventures are included.[105] European-designed turbines and key components are also manufactured under license through joint ventures in several developing countries, including India and China.

The establishment of local industrial capabilities takes many forms, ranging from the purchase of imported turn-key projects to the establishment of complete local wind turbine manufacturing capabilities. Typically, the first projects in a country are characterized by importation of wind turbines, including the towers, as turn-key projects or a BOOT (Build, Own, Operate and Transfer) projects. Usually local companies will be hired to build foundations and to establish grid connections, and the rest of the work will be foreign-based. Then, simple structures such as towers might also be purchased locally, reducing the amount of projects' total costs.

4.3 Future Market Outlook

It is forecasted that there will be approximately 60,000 MW of wind power capacity in place before the end of 2005 worldwide with an assumption of a 16% growth rate. A third of that will be in Europe alone. The wind power sector is thus one of the fastest growing industries in the world.[106] Meanwhile, the US market will show a significant increase in the coming years due to the impact of the PTC extension that helps to bring down the cost of wind-generated energy to a level close to traditional energy sources.[107] Asian markets - particularly India and Japan - will also show a promising future. Total turnover in the wind power industry will increase to approximately 10 $US billion per year in 2006.[108] Meanwhile the European Wind Energy Association (EWEA) along with Greenpeace sets ambitious targets: with the

[105] Danish Wind Industry Association, "Danish Wind Power 2001," available at: http://www.windpower.org/news/stat2001.htm, August 7, 2002
[106] Bundesverband Wind Energie e.V., "Wind Energie 2002: Marktübersicht," Osnabrück, Datahaus Publishing, 2002, pp. 1
[107] American Wind Energy Association (AWEA), "Wind Energy Production Tax Credit," available at: http://www.windenergyaction.com/facts/PTC_Fact_Sheet.pdf, September 9, 2002
[108] BTM Consult ApS, "International Wind Energy Development: World Market Update 2001 – Record Growth," Press Release on April 4, 2002, available at: http://www.btm.dk, September 9, 2002

current development trend wind energy will be able to provide 12% of world demand by the year 2020; therefore it needs to generate an output in the range of 3,000 TWh/year.[109]

The market survey concludes that the technological trend towards wind turbines with a higher rated power is continuing steadily. The range of large turbines, particularly those with an output of more than 1,000 kW, is increasing. This trend is also reflected clearly in the installation figures for 2001 in Germany; the average rated power for wind turbines erected last year was 1,280 kW. This year BWE also reported that the largest turbine that entered the market has a capacity of 3.6 MW. The market trend also shows that in general turbine manufacturers are continuing their efforts to lower manufacturing and transportation costs.[110]

Per Krogsgaard, wind energy expert at BTM Consult ApS, predicts offshore projects will comprise at most 10% of sales for major turbine manufacturers in the near future.[111] There are currently 9 offshore wind power projects worldwide. The trend began in the early 1990s with two farms in the Baltic off the coast of Denmark: the Vineby wind farm and the Tunø Knob. The last development is marked by the world's largest offshore project to date: the Middelgrunden wind farm (20 x Bonus Energy 2 MW) located 1.7 to 3.5 kilometers from Copenhagen. There are big plans for further projects. Applications for more than 50,000 MW have been submitted in Germany alone. Denmark aims to meet around half of its power requirement from wind by 2030, which most of that is to come from offshore turbines (4,000 MW planned).[112] There are also extensive plans for offshore installations in Sweden, the United Kingdom, Ireland, and the Netherlands.[113]

This chapter has shown a dramatic growth rate of the international wind power market that establishes the wind power industry as one of the fastest growing industries

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[109] European Wind Energy Association (EWEA), "Wind Force 12,' available at: http://www.ewea.org/doc/WindForce12.pdf, September 20, 2002
[110] Bundesverband Wind Energie e.V., "Wind Energie 2002: Marktübersicht," Osnabrück, Datahaus Publishing, July 2002, pp. 37
[111] Bundesverband WindEnergie e.V., "Wind Energie 2002: Marktübersicht," Osnabrück, Datahaus Publishing, July 2002, pp. 15
[112] British Wind Energy Association (BWEA), "Prospects for Offshore Wind Energy," *Altener contract XVII/4.1030/Z/98-395 – a written report for the EU by the BWEA,* 2000, available at: http://www.offshorewindfarms.co.uk/reports/prospects.html, September 15, 2002
[113] Bundesverband WindEnergie e.V., "Wind Energie 2002: Marktübersicht," Osnabrück, Datahaus Publishing, July 2002, pp. 15

in the world. The European countries will continually taking a big portion of capacity installed in the foreseeable future. Germany has started to focus on the exploitation of its offshore wind energy potential and the repowering its onshore sites, in order to meet its long-term goal in achieving 25% of its country's electricity from wind by 2025. Meanwhile, the United States will still focus on exploiting its vast onshore wind potential.

The excellent growth of wind industry necessitates the major wind turbine manufacturers to satisfy demand by establishing production facilities and joint ventures around the world. The generated revenues from wind business have also enticed other industry players to enter the wind business, providing more support on future development of wind energy. Efforts in bringing down costs of production and delivery of wind turbines are still becoming the main tasks to increase wind energy's market share in the electricity market. Chapter 5 will give a detailed of the various cost components that affect the overall cost effectiveness of electricity generated from wind energy.

Chapter 5 Economics of Wind Energy

Over the last 20 years, the cost of electricity from grid-connected wind systems has dropped by more than 80%. Now, state of the art wind power plants can generate electricity at prices that are in a competitive range with many conventional energy technologies.[114] This chapter focuses on the economics of wind energy primarily in relation to the grid-connected turbines, which account for the vast bulk of the market value of installed turbines.

The main parameters governing wind-power economics can be categorized as follows:

- investment costs, including auxiliary costs for foundation and grid connection;
- operation and maintenance (O&M) costs;
- financing costs;
- electricity production/average wind speed;
- availability;
- turbine lifetime.

Of these, the most important parameters are the turbines' electricity production and their capital costs. As electricity production efficiency is highly reliant on wind conditions, choosing the right turbine site is critical to achieve economic viability.[115] The following sections discuss each of the above parameters, which influence the cost effectiveness of wind power plant projects. Specific cost issues related with offshore wind turbines is also presented in a separate section. This chapter also compares the economic costs of wind power to conventional fuels.

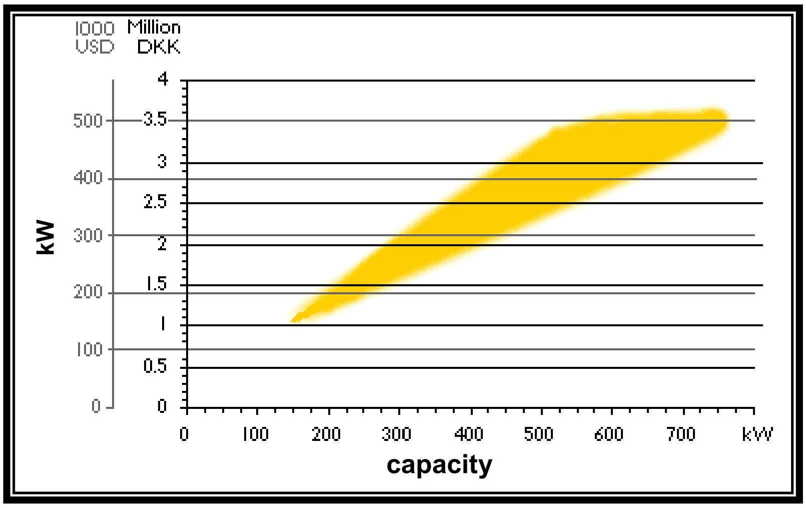
[114] American Wind Energy Association (AWEA), "The Most Frequently Asked Questions about Wind Energy," http://www.awea.org/pubs/documents/FAQ2002%20-%20web.PDF, available at: September 7, 2002

[115] Morthorst, P.E., "Wind Power: Status and Development Possibilities," can be found in Lund Institute of Technology, available at: http://www.ebd.lth.se/avd%20ebd/main/Summerschool/Lectures/lect-n-morthorst.pdf, September 28, 2002

5.1 Capital Cost and Efficiency Trends[116]

The determination of the capital cost (or total investment cost) generally involves the cost of the wind turbine and the cost of the remaining installation. Wind turbine costs can vary significantly. For instance, Figure 5.1 gives an idea of the production costs (excluding installation) of Danish grid-connected wind turbines as of February 1998. As shown, costs vary significantly for each rated generator size due to differing tower height and/or rotor diameter.[117]

Figure 5.1 Cost (1998) of Danish wind turbines



Source: http://www.windpower.org/tour/econ/index.htm, September 25, 2002

Capital costs of wind energy projects are dominated by the cost of wind turbines themselves (ex works)[118]. For a typical 600 kW wind turbine in Denmark, the turbine's share of total cost is approximately 80 percent, whereas grid connection and foundation account for approximately 9 percent and 4 percent, respectively. Other cost components, such as control systems and land, account for only minor shares of total costs as illustrated in Table 5.1.[119]

[116] Morthorst, P.E., "Wind Power: Status and Development Possibilities," can be found in Lund Institute of Technology, available at: http://www.ebd.lth.se/avd%20ebd/main/Summerschool/Lectures/lect-n-morthorst.pdf, September 28, 2002

[117] Manwell, J.F., McGowan J.G., and Rogers, A.L., "Wind Energy Explained: Theory, Design, and Application," Chichester, John Wiley and Sons, 2002, pp. 429

[118] Ex works means that no site work, foundation or grid connection costs are included. Ex works costs include the turbine as provided by the manufacturer, including the turbine itself, blades, tower and transport to the site.

[119] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 75

Table 5.1 Cost structure for a 600 kW wind turbine (1997 US$)

	Investment (US$ 1,000)	Share (%)
Turbine (ex works)	483	80
Foundation	23	4
Electric installation	9	2
Grid connection	53	9
Control systems	2	-
Consultancy	6	1
Land	10	2
Financial	8	1
Road	7	1
Total	**601**	**100**

Source: Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., 2002

In general, there are two trends that have dominated grid-connected wind turbine development:

1. The average size of wind turbine sold on the market has increased substantially;
2. The efficiency of electricity production has increased steadily.

The average size of a wind turbine sold in the Danish export market each year[120] has increased significantly from roughly 50 kW in 1985 to 944 kW at the end of 2001.[121] Turbines with capacities as high as 2 MW had already entered the market. Moreover, electricity production efficiency from a wind turbine has increased by almost 3 percent annually over the last 15 years, measured as annual energy production per swept rotor area (kWh/m^2). This progress is due to a combination of improved equipment efficiency, improved turbine siting, and higher hub height.

As shown in the next figure, Figure 5.2, there has been a substantial decline in per kW costs (approximately 4 percent per year) and auxiliary costs. Thus, overall investment costs per kW declined by more than 5 percent per year during the analyzed period.

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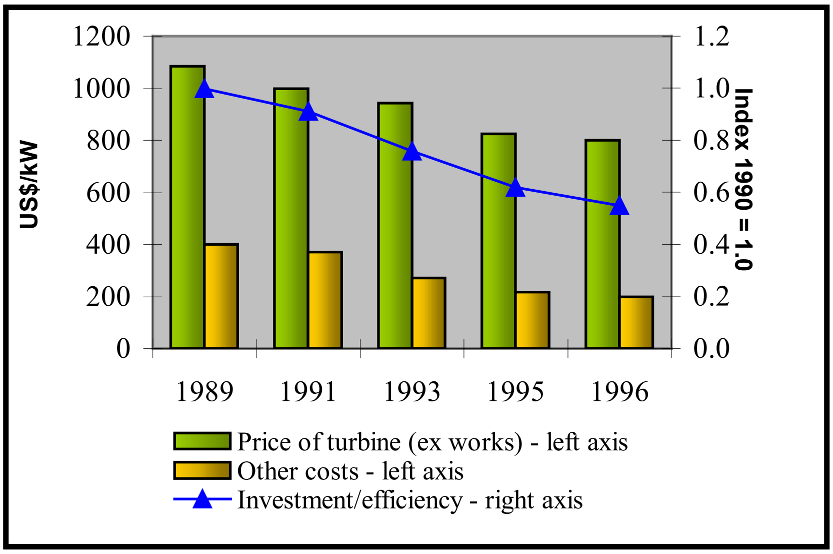
[120] Since Danish turbines have a total share of over 50 percent of the global wind turbine market since 1996, Danish turbines cost figures are assumed to be representative for worldwide trends.
[121] Danish Wind Industry Association, "Presentation 2001," available at: http://www.windpower.org/res/presnt01.pdf, September 25, 2002

Combining the efficiency improvement and the decline in investment costs per kW one sees that the ratio of total investment to annual production efficiency ($/kW divided by kWh/$m^2$) has improved by more than 45 percent since 1989, or more than 8 percent per year in real terms, shown in Figure 5.2 (right ordinate).[122] This improvement reflects not only declining turbine costs and improved efficiency, but improved turbine siting as well.

Figure 5.2 Wind turbine capital costs (ex works) and auxiliary costs (US$/kW in constant 1997 $); investment costs divided by efficiency (index 1990 = 1.0)



Source: Energistyrelsen, 1994 and Nielsen, P., 1997

An investigation made by the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) projected that capital cost for large-scale wind farms (in 1997 dollars) will decrease from US$ 1,000/kW in 1997 to US$ 635/kW in 2030.[123] A recent study conducted by Wind Force 12 of the European Wind Energy Association reported that the cost per unit of wind-powered electricity of a "state of the art" wind

[122] In terms of costs, only capital costs are reflected in this ratio. Any improvement in operation & maintenance (O&M) costs, equipment lifetime or equipment salvage values would not be reflected in the investment –per-production efficiency ratio.
[123] Electric Power Research Institute (EPRI), "Renewable Energy Technology Characterization," *EPRI Report: TR-109496*, available at: http://www.eren.doe.gov/power/techchar.html, September 26, 2002

turbine in 2001 in the most optimal conditions has an investment cost of US$ 765/kW and a unit price for its output of 0.036 US$/kWh.[124]

Wind energy project capital costs, as reported by the International Energy Agency, show substantial variations between countries, owing to factors such as market structures, site characteristics, and planning regulations.[125]

5.2 Operation and Maintenance Costs

Operation and Maintenance (O&M) costs comprise a substantial share of the total annual costs of wind turbine. O&M costs include the following typical components: insurance, regular maintenance, repair, spare parts, and administration.

O&M costs can be divided into two categories: fixed and variable costs.[126] Fixed O&M costs are yearly charges unrelated to the level of plant operation, which must be paid regardless of how much energy is generated (generally expressed in terms of US$/kW installed or percentage of turbine capital cost). Meanwhile, variable O&M costs are yearly costs directly related to the amount of plant operation, expressed in terms of US$/kWh.

Experience shows that O&M costs are generally very low while the turbines are brand new and they increase to some extent as the turbine ages. However, due to the newness of the wind energy industry, only a limited number of turbines have existed for the full-expected lifetime of 20 years. Consequently, estimates of O&M cost are highly uncertain, especially around the end of turbines' lifetimes.[127]

The Danish Wind Turbine Manufacturer's Association reported[128] that older Danish wind turbines' O&M costs (25-150 kW) account for approximately 3 percent of the original turbine investment per year. Newer turbines, which are on average substantially larger, have lower costs at the range around 1.5 to 2 percent of the initial

[124] European Wind Energy Association (EWEA), "Wind Force 12: A Blueprint to Achieve 12% of The World's Electricity from Wind Power By 2020," available at: http://www.ewea.org/doc/WindForce12.pdfm, September 20, 2002

[125] International Energy Agency (IEA), "R&D WTS Annex XV - Review of Progress in the Implementation of Wind Energy by the Member Countries of the IEA During 1996," July 1997

[126] Manwell, J.F., McGowan J.G., and Rogers, A.L., "Wind Energy Explained: Theory, Design, and Application," Chichester, John Wiley and Sons, 2002, pp. 441-443

[127] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 78

[128] Danish Wind Industry Association, "Operation and Maintenance Costs for Wind Turbines," available at: http://www.windpower.org/tour/econ/oandm.htm, September 26, 2002

turbine investment per year, or approximately 0.01 US$/kWh. The reasoning behind the preference to use a fixed amount per kWh of output in the calculations is that tear and wear on the turbine generally increases with increasing production. The California Energy Commission also predicted similar O&M costs for modern wind turbines in the range of 1.5 to 2 percent of the initial turbine investment per year.[129]

Another estimation demonstrates that for a new turbine, O&M costs might have a share of approximately 10 to 15 percent of total levelized cost per kWh produced, increasing to at least 20-30 percent by the end of the turbine's lifetime.[130] Based on actual field data, Table 5.2 gives results from the Danish Energy Association that show that wind energy systems O&M costs vary with turbine size and age (expressed as a percent of total wind farm installation cost). It is important to note the predicted rise in costs with turbine age.[131]

Table 5.2 Comparison of total O&M costs based on size & age of turbine

Turbine size	Years from installation				
	1-2	3-5	6-10	11-15	16-20
150 kW	1.2	2.8	3.3	6.1	7.0
300 kW	1.0	2.2	2.6	4.0	6.0
600 kW	1.0	1.9	2.2	3.5	4.5
Note: O&M costs are expressed as a percent of total wind farm installation costs					

Source: Lemming et al., 1999

5.3 Financing Costs

Wind energy project are capital intensive, and the majority of the costs must be borne at the beginning. For that reason, the purchase and installation costs are largely financed. The purchaser or developer will pay a limited down payment (perhaps 10 to 20%), and borrow the rest. The source of capital may be banks or investors. In either case, the lenders will expect a return on the loan, which is generated from the interest. Over the life of the project, the cumulative interest can add up to significant amount of

[129] California Energy Commission, "Economics of Owning and Operating DER technologies," available at: http://www.energy.ca.gov/distgen/economics/operation.html, September 25, 2002
[130] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 77
[131] Lemming, J., Morthorst, P.E., Hansen, L.H., Andersen, P., Jensen, P.H., "O&M Costs and Economical Life-time of Wind Turbines," *Proc. European Wind Energy Conf.*, pp. 387-390

the total costs. The interest rate has a significant influence on wind projects' financial viability. For example, changing the interest rate from 5 to 10 percent per year (in real term) increases the production cost of a 600 kW turbine by a little more than 30 percent.[132]

Although wind turbine technology has steadily progressed to a point where its reliability is today comparable to that of other energy technologies, it is still regarded as "novel" and "risky" by many members of the U.S. financial community; therefore, they offer less favorable financing terms and demand a higher return on investment than for more "conventional" energy sources. Meanwhile, most U.S. projects are still financed by European-based lenders.[133]

5.4 Availability

"Availability" is a measurement of the reliability of a wind turbine or other power plant. It refers to the percentage of time that the turbine is able to generate electricity. The times when a wind turbine is not available include downtime for periodic maintenance or unscheduled repairs. Recent data indicate that the availability for modern European machines is now in the order of 98% or more.[134]

5.5 Turbine Design Lifetime [135]

It is common practice to equate the design lifetime with the economic lifetime of a wind energy system. The Danish Wind turbine Manufacturers Association recommends that a 20-year design lifetime is a useful economic compromise that is used to guide engineers who develop components for wind turbines.

Following recent improvements in wind turbine design, an operating life of 30 years has been used for recent U.S. economic studies.[136] This assumption requires that adequate annual maintenance be performed in the wind turbines and that 10-year major

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[132] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 80-81
[133] American Wind Energy Association (AWEA), "Economic of Wind Energy," available at: http://www.awea.org/pubs/factsheets/EconomicsofWind-March2002.pdf, August 6, 2002
[134] European Wind Energy Association (EWEA), "The Economics of Wind energy," available at: http://www.ewea.org/src/economics.htm, September 24, 2002
[135] Danish Wind Industry Association, "Operating and Maintenance Costs for Wind Turbines," available at: http://www.windpower.org/tour/econ/oandm.htm#scaleop, August 7, 2002
[136] Electric Power Research Institute (EPRI), "Renewable Energy Technology Characterization," *EPRI Report: TR-109496*, available at: http://www.eren.doe.gov/power/techchar.html, September 26, 2002

maintenance overhauls be performed to replace key parts, such as rotor blades and gearboxes. However, the actual lifetime of a wind turbine depends both on the quality of the turbine and the local climatic conditions.

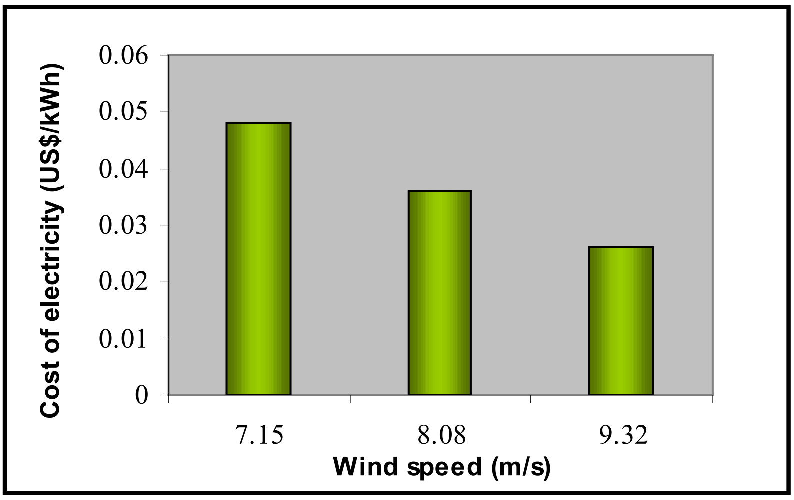
5.6 Electricity Production/Average Wind Speed

The average annual wind speed on the site is of paramount importance to the cost of energy. As discussed in Chapter 3, the energy that can be tapped from the wind is proportional to the cube of the wind speed. Thus, a slight increase in wind speed results in a large increase in electricity generation.

For example, consider two sites, one with an average wind speed of 14 miles per hour (6.25 meters per second) and the other with average winds of 16 mph (7.15 m/s). The second site will generate nearly 50% more electricity than the first location.[137]

Figure 5.3 also gives an idea of different costs per kilowatt-hour for a 51 MW wind farm in the United States at three different average wind speeds (expressed in meters per second) range from 0.048 to 0.023 US$/kWh (including the current wind production tax credit that is adopted in the U.S. market)

Figure 5.3 Cost of energy and wind speed



Source: http://www.awea.org/pubs/factsheets/EconomicsofWind-March2002.pdf, August 6, 2002

[137] American Wind Energy Association (AWEA), "Economics of Wind Energy," http://www.awea.org/pubs/factsheets/EconomicsofWind-March2002.pdf, August 6, 2002

5.7 Overall Cost Effectiveness

The total cost per produced kWh is calculated by discounting and levelizing investment and O&M costs over the lifetime of the turbine, divided by the annual electricity production. The unit cost of generation is thus calculated as an average cost over the turbine's lifetime. In reality, actual costs will be lower than the calculated average at the beginning of the turbine's life, due to lower O&M costs, and will increase over the period of turbine use.

The cost of wind energy[138] can be calculated by means of the following expressions:

$$c = \frac{a.I_{tot}}{A.E} + m$$

where,

c cost (US$ /kWh)

a annuity factor

I_{tot} total investment cost per m^2 swept rotor area

A availability

E annual energy output per m^2 swept rotor area (kWh/m^2)

m operation and maintenance cost

while,

$$a = \frac{i(1+i)^n}{(1+n)^n - 1}$$

where,

i interest rate

n amortization period

while,

$$E = 3.2\, v^3$$

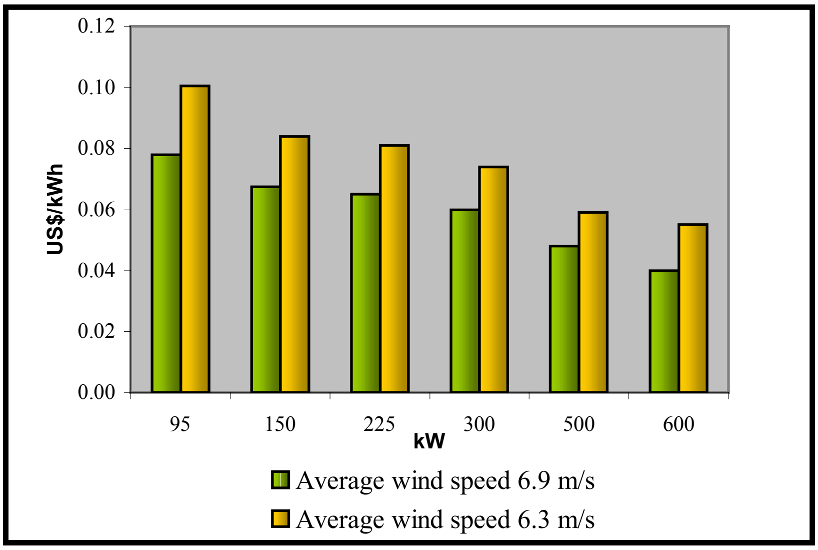
where,

v average annual wind speed at the hub height (m/s)

[138] Renewable Energy World, "Economics of Wind Energy: Prospect and Directions," available at: http://www.jxj.com/magsandj/rew/2001_04/economics_of_wind_energy.html, September 26, 2002

For example, Figure 5.4 shows the calculated unit cost for different sizes of turbines, based on the above-mentioned investment and O&M costs (refer to Figure 5.2 and Table 5.2), a 20-year lifetime, and a real discount rate of 5 percent per year. The turbines' electricity production is estimated for average wind speeds of approximately 6.9 m/s and 6.3 m/s, respectively, at a height of 50 meters above ground level. [139]

Figure 5.4 Total wind energy costs per unit of electricity produced, by turbine size, based on hub height of 50 meters (US cents/kWh, constant 1997 prices)



Source: Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., 2002

From the above figure, one can see the trend towards larger turbines and greater cost-effectiveness. For a site with the average wind speed of 6.9 m/s, for example, the average cost has decreased from over 0.078 US$/kWh for the 95 kW turbine to less than 0.045 US$/kWh for a 600 kW turbine, showing an improvement of almost 45 percent over a time-span of 9-10 years. Nevertheless, the improvement in $/kWh costs shown in Figure 5.4 is slower than that suggested in Figure 5.2 (45% in 7 years). This is largely due to the fact that Figure 5.2 includes improvements in turbine siting, while Figure 5.4 represents wind energy costs under fixed siting conditions.[140]

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[139] United Nations Department of Economic and Social Affairs (DESA), "Renewable resources energy, with special emphasis on wind energy," *Report of the Secretary General: E/C.13/1998/4*, available at: http://www.uccee.org/WindEnergy/UNreportwind.pdf, August 20, 2002

[140] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 80-81

5.8 Offshore Wind Turbines

Offshore wind energy costs depend on the wind resource, distance form shore, and water depth.[141] The major cost difference between onshore and offshore wind farms is that offshore wind projects require initially high investment to finance the cost of foundations and the grid connection (sea transmission cables).[142]

The cost of grid-connection to the shore is typically around 25%,[143] a much higher fraction than that for connection of onshore projects. Other, additional costs include foundations (up to 30%), operation and maintenance (with expected lower availability) and marinization of turbines.[144] An example of an offshore wind farm's cost structure is presented in Table 5.3.

Table 5.3 Investment costs of the Tuno Knøb in Denmark (1997 prices)

	Investment costs (million US$)	Share (%)
Turbine (ex works)*	4.8	40
Transmission cable (sea)		
to coast	1.5	13
between turbines	0.6	5
Transmission cable (land)	0.4	3
Electricity systems	0.5	41
Foundations	2.8	23
Operating and control systems	0.2	2
Environmental analysis	1.2	10
Total	**12**	**100**

Source: Fenhann et al, 1998

The cost of marinization of wind turbines involves costs spend for steel surface protections either by zinc coating or the use of non-corrosive materials. A closed nacelle

[141] Manwell, J.F., McGowan J.G., and Rogers, A.L., "Wind Energy Explained: Theory, Design, and Application," Chichester, John Wiley and Sons, 2002, pp. 409

[142] Renewable Energy World, "Offshore Wind ready to power a sustainable Europe," available at: http://www.jxj.com/magsandj/rew/2002_01/ca-owee.html#refs, September 26, 2002

[143] Wind Directions, "Offshore wind: the technical challenge," *EWEA Magazine Vol. XVIII No.6,* September 1999, can be found in Renewable Energy World, "Offshore Wind ready to power a sustainable Europe," available at: http://www.jxj.com/magsandj/rew/2002_01/ca-owee.html#refs, September 26, 2002

[144] Hartnell, G. and Milborrow, D., " Prospects for offshore wind energy," *BWEA report to the EU (Altener Contract XVII/4.1030/Z/98-395)*, 2000, can be found in British Wind Energy Association, "Offshore wind reports, studies and analyses," available at: http://www.offshorewindfarms.co.uk/reports/altreport.pdf, October 1, 2002

is a useful way of reducing corrosion and salt damage to rotating machines and electrical and electronic equipment. This requires the air conditioning of the nacelle including dehumification.[145]

5.9 Comparison with The Cost of Conventional Power

Now, state-of-the-art wind power plants can generate electricity for less than 5 cents/kWh in many parts of the U.S., a price that is in a competitive range with many conventional energy technologies.[146]

The traditional way to assess the values of wind energy is to equate it to the direct savings that would result due to the use of the wind rather than the most likely alternative. These saving are often referred to as “avoided costs”. The avoided costs are determined by three components: fuel costs, O&M costs, and capital cost.

It is generally accepted that implementing wind power avoids the full fuel cost and a considerable O&M costs of the displaced conventional power plant. The level of avoided costs depends on the extent to which wind power capacity can displace investments in new conventional power plants and is thus directly tied to the capacity value of wind plants. The capacity value will depend on several factors, as mentioned earlier in Chapter 3; however, the important factors in this assessment are the level of penetration of wind power and how the wind capacity is integrated into the overall energy system.[147]

Figure 5.5 shows the most recent data price comparisons between different generating technologies, an annual survey by Wind Power Monthly, published in January 2002. At current electricity prices, the cheapest wind plants, those with easy access and economies of scale are now fully competitive with gas, if sites have average good wind speeds of 7.5m/s. The price of electricity from new thermal plant is based on US and European data, and has changed little since 2001,with gas on an upward price trend. The costs of nuclear do not account for public sector liability, waste and decommissioning issues.

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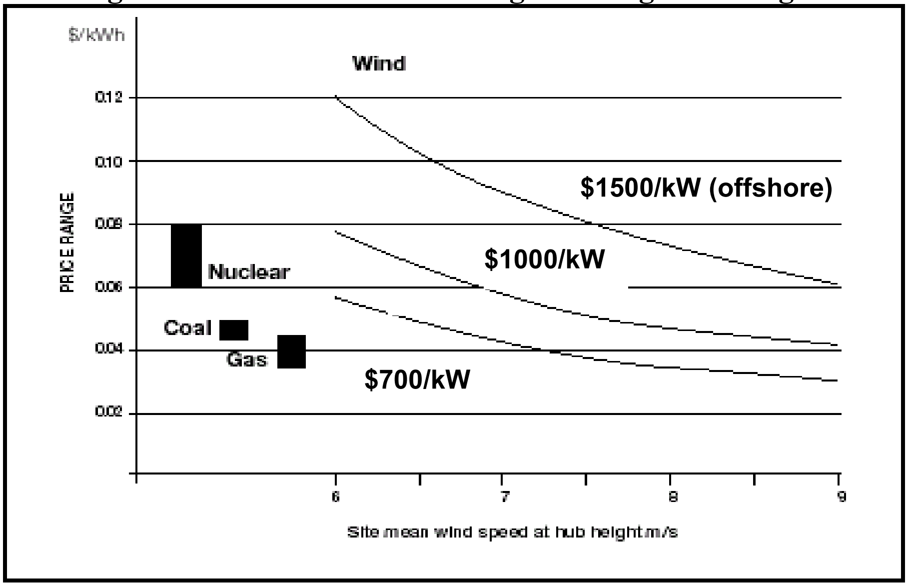
[145] Harrison, R., Hau, E. and Snel, H., “Large Wind Turbines: design and economics,” Chichester, John Wiley and Sons, 2000, pp. 167

[146] American Wind Energy Association (AWEA), “The Most Frequently Asked Questions about Wind Energy,” available at: http://www.awea.org/pubs/documents/FAQ2002%20-%20web.PDF, September 7, 2002

Figure 5.5 Prices for different generating technologies



Source: http://www.ewea.org/doc/WindForce12.pdf, September 20, 2002

If environmental costs were included in the calculation of the costs of electricity generation, wind energy's competitiveness would increase further because of its low environmental impacts. Wind energy produces no GHG emissions, so there is no damage to the environment or public health from emissions and wastes such as are associated with the production of electricity from conventional power plants (as illustrated in Table 5.4). Wind energy is also free of the environmental costs resulting from mining or drilling, processing, and shipping a fuel.[148]

Table 5.4 Stack emissions of coal, gas, and wind power plants (kg/MWh)

Pollutant	Conventional coal	Conventional gas	Wind
Sulfur oxides	1.2	0.004	0
Nitrogen oxides	2.3	0.002	0
Particulates	0.8	0.0	0
Carbon dioxide	865	650	0

Source: Manwell et al, 2002

[147] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 85-90
[148] American Wind Energy Association (AWEA), " Comparative Cost of Wind and Other Energy Sources," available at: http://www.awea.org/pubs/factsheets/Cost2001.PDF, August 6, 2002

According to a study by the European Union, the cost of producing electricity from coal or oil would double and the cost of electricity production from gas would increase by 30% if some external costs such as damage to the environment (not including that of global warming) and to health were taken into account.[149]

This chapter illustrates that the production cost of a kilowatt-hour of wind power has dropped dramatically; making electricity prices from wind energy are in a competitive range with many conventional technologies. Further cost reductions are still needed to stimulate wind market development to the point where a substantial industry can been established and to fix the historic distortion of the market in favor of fossil fuels because of their external environmental, health and social costs are not accounted in the costs of electricity generation. Chapter 6 will give more details on the environmental and social issues related with the exploitation of wind energy.

[149] European Union (EU), " New research reveals the true costs of electricity in Europe," available at: http://europa.eu.int/comm/research/press/2001/pr2007en.html, September 30, 2002

Chapter 6 Environmental and Social Considerations

This chapter reviews the environmental and social consideration associated with the deployment of wind turbines.

6.1 Environmental Impacts

Wind energy is considered a green power technology because it has only minor impacts on the environment compared to other conventional power plants. As discussed in the previous chapter, the stack or direct emissions of wind energy are essentially zero, showing that it generates no air pollutants or greenhouse gases, unlike conventional coal and gas-fired power plants. Nevertheless, there are indirect emissions associated with the production of wind turbines and the erection and construction of wind farms.

The various emission pollutants from a wide range of fuel cycles usually are manifested as human health impacts and ecological damage. Such damages are borne by the public rather than by the buyers and sellers of electricity themselves. These costs are known as "externalities" in the economic literature. Formally, externalities are defined as 'the costs and benefits which arise when the social or economic activities of one group have an impact on another and when the first group fail to fully account for their impacts'.[150]

A comprehensive study conducted by the European Commission in 1995, the so-called "ExternE - Externalities of Energy" quantifies monetary values of environmental externalities for a wide range of fuel cycles: coal, nuclear, oil, gas, hydro and wind. Regarding wind energy, the ExternE study characterizes the wind energy fuel cycles as including the following environmental impacts: noise, visual intrusion, global warming, acidification, public accidents, occupational accidents, land use, bird mortality and radio interference. Despite the fact that wind energy itself produces no air emissions, which would result in global warming or acidification, construction and installation of wind turbines do involve energy use that creates air emission impacts. Based on two wind

[150] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 149-163

farm sites in the United Kingdom, the ExternE study quantified the externalities of wind energy as shown in Table 6.1. [151]

Table 6.1 Environmental externalities values of wind-generated electricity

Category	External costs (m€/kWh)
Noise	0.07 – 1.1
Visual amenity	Not quantified
Global warming	0.15
Acidification	0.7
Public accidents	0.09
Occupational accidents	0.26

Source: ExternE, 1995

Noise values showed a wide variation depending on the population density surrounding the site. The study did not place a specific value on the visual impact but estimated it to be very small outside of important major recreational designated scenic areas, and most likely below 1.9 milli €/kWh (m€/kWh).

Land use impacts of wind energy were considered negligible because of the very small land area used by the actual wind turbines themselves and their compatibility with both agriculture and animal life. Bird mortality impacts were also estimated to be negligible in the United Kingdom and throughout Europe, though perhaps higher in other locations including the United States.

If one were to assume a median noise value of 0.6 m€/kWh and a visual amenity value of 1.0 m€/kWh, then summing the identified values in Table 6.1 would result in a total environmental externality value for wind energy of 2.8 m€/kWh (US$ 0.0032kWh). While the total wind externality value is not trivial, it is less than one-tenth of the conventional electricity generating cost.[152] Furthermore, the global warming and acidification are secondary impacts stemming from an assumption of fossil fuels use for turbine manufacturing. Though all fuel cycles such as coal, nuclear, oil and natural gas have such secondary impacts, the ExternE study included secondary emissions only for wind energy and did not analyze them for any of the other fuel cycles it studied. If

[151] ExternE, "Externalities of Energy," *European Commission Directorate General XII: Science, Research & Development - EUR 16520 EN*, available at: http://externe.jrc.es/publica.html#main_reports, October 5, 2002

therefore one were to exclude such secondary impacts for the purpose of comparison with other technologies, then the wind energy's externality value would be lower to approximately 2 m€/kWh (US$ 0.0025kWh).

The ExternE study also concludes that wind energy's environmental impacts appear to be no higher than those of any other fuel and considerably lower than those of fossil fuels. In addition wind energy's environmental impacts are local, relatively predictable and primarily aesthetic.

6.2 Social Considerations

As discussed above, visual and noise impacts are considered the most negative consequences of wind power. Since these impacts are entirely local in nature, the selection of locations of future plants is particularly important. The noise from a wind farm at a distance of 350 meters is of the order of 45 decibels, which is comparable to the noise from a car traveling at 40 miles an hour at a distance 100 meters. This noise level is less than the daytime rural background noise level and is only slightly greater than the night time level.[153] Nevertheless, concerns about the local environment impacts of wind turbines must be addressed directly. Openness and local public involvement throughout the planning and siting process are critical features in obtaining their consent to wind farms.

Job creation is another social consideration. The EWEA estimated 114,000 job-years in the global wind industry today.[154] As a result of the employment assessment for the implementation of the EWEA's targets in achieving 12% of global electricity demand from wind energy by 2020, it is predicted that a total of 1.475 million jobs will have been created around the world in manufacture, installation and other work associated with the industry.[155]

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[152] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 149-163

[153] United Nations Department of Economic and Social Affairs (DESA), "Renewable resources energy, with special emphasis on wind energy," *Report of the Secretary General: E/C.13/1998/4*, available at: http://www.uccee.org/WindEnergy/UNreportwind.pdf, August 20, 2002

[154] The 114,000 job-years is based on a statistical model comparing jobs, dollars and MW which would cover all wind-related employment.

[155] European Wind Energy Association (EWEA), "Wind Force 12: A Blueprint to Achieve 12% of The World's Electricity from Wind Power By 2020," available at: http://www.ewea.org/doc/WindForce12.pdfm, September 20, 2002

In general, wind energy provides additional economic benefits, where it ensures less dependence on imported fossil fuels, which can be subject to rapid price fluctuations and supply problems, and improves regional prosperity as local people earn more income from owning the land where wind farms are built or even from selling surplus electricity generated from their wind farms to local grid.

This chapter demonstrates that wind energy is one of the most environmentally benign electricity sources. Ignoring these environmental aspects in financial and economic analysis, results in a significant competitive disadvantage for wind energy. Moreover, wind energy's environmental impacts are local, and primarily aesthetic, while those of fossil fuels and nuclear energy involve long-term and large-scale impacts of things like global climate change and radioactive waste, whose overall impact on human health could be enormous. Close consultation and compensation from developers or opportunities for local community to profit from wind power projects could help to diminish the oppositions raised against wind power projects. It is even expected that the use of wind turbines can enhance local employment and prosperity.

Chapter 7 Incentive Mechanisms to Promote Wind Energy Development

Remarkable progress has been made over the last two decades in improving the technology, reliability, cost-effectiveness and overall understanding of wind energy. However, in spite of these significant improvements, there is a further need for supporting wind energy development. Consequently, various incentives mechanisms should be adopted and continue to be necessary for wind energy to penetrate the electricity market. For instance, environmental taxation is designed to correct existing market failures by recognizing the differing environmental impacts of technologies and taxing them accordingly. Other mechanisms, such as investment subsidies are to expand the market size and thereby stimulate technological development, economics of scale and overall cost reduction, with the eventual goal of eliminating the need of such subsidies. The various mechanisms are not mutually exclusive and are often used in combination.

This chapter gives a short overview of various incentives mechanisms, which have been used by countries to promote renewable energy in general and wind energy in particular. This chapter is not intended to provide full coverage of each policy. The only intention is to provide some good examples, for instance the German Electricity Feed-In Law (EFL) and the United States Production Tax Credit (PTC), which have supported their wind energy development.

7.1 Incentive Mechanisms: An Overview[156]

Examples of such incentive mechanisms that have been adopted to promote the development of wind energy projects and have led to the generation of considerable modern wind energy in a number of industrialized countries and developing countries are described as follows:

[156] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 171-178

Power Purchase Agreement (PPA)

A Power Purchase Agreement is a contract that ensures the power generated by an independent power producer (IPP) can be sold to the utility or a third party's transmission and distribution grid.

There is an opinion that reliable power purchase contracts are perhaps the single most critical requirement of a successful renewable energy project for selling the electricity produced. In a vertically integrated monopoly utility system, a utility that chooses to build wind power plants would of course have a guaranteed market. However, there are lots of wind power projects have been carried out by IPPs unaffiliated with any utilities. In this case, a mechanism is necessary to ensure that wind developers can sell their generated electricity to the utility. Creation of stable markets has thus been a prime objective of establishing PPAs.

Production subsidy

Where electricity generated by wind is more costly than that generated by conventional sources, wind energy may not be economically attractive at the going electricity rate. In that case, a production subsidy, paid per kWh of electricity generated, can reduce the cost of producing electricity from wind energy. However, as technology develops further and has the capability to make wind energy fully competitive in the marketplace, these production subsidies can be removed. Production incentives can be paid from the general tax base or through a surcharge or customer utility bills.

Tax credits

Tax credits can be provided based either on the capital cost of the project or on the kWh generated by the project. Investors prefer tax credits based on capital cost because the tax credit can be claimed regardless of the project's actual performance in generating electricity. For highly risky projects, investors might be willing to provide finance only under such generous conditions. However, the limitation with this scheme that it can be subject to abuse because investors simply interested in a tax shelter have little incentive to ensure that their projects actually produce electricity. Production tax credits, paid per kWh of electricity generated, reduce the scope for abuse by making payment contingent on project performance, thus increasing the risk to project investors.

Renewables set-aside

A renewable set-aside mandates that a certain percentage of total electricity generated must come from renewable sources. In some cases, this percentage can be further broken down into separate allocations for different technologies, such as wind, solar, and biomass. This policy provides a guaranteed market for electricity generated by renewable energy technologies, which might not otherwise be able to compete in the existing generation market.

Externalities adders

As traditional energy planning has largely ignored the environmental externalities of power production, some regulators have attempted to address this issue by increasing the hypothetical cost of conventional power plants through an environmental externality charge or "adder" in the planning stage. Such adders can improve the likelihood of wind energy plants being built by increasing the apparent cost of conventional technologies. For example, some US states have used externally adders for power project planning.[157]

Carbon tax

Like the externalities adder, a carbon tax adds to the cost of fossil fuel-based energy by imposing a per-kWh tax on the basis of the carbon contents of fuels and their likely impact on environment. Carbon-free energy sources such as wind energy can thus become more competitive against fossil fuels because of such a tax. This carbon tax involves actual payment of money and is not merely a hypothetical charge used for planning purposes only.

Preferential financing

The cost of raising capital is a major factor in all investment projects. In order to attract financial institutions to finance wind power generation projects, improved financial terms such as lowered interest rates or longer repayment period can significantly reduce project costs. Loan guarantees that reduce risks can also be another option to be offered.

[157] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 176

Research, development and demonstration grants (RD&D)

The RD&D grants can be used to improve the general technological and knowledge base necessary for more long-term stimulation of renewables; therefore, several governments such as the United States, Japan, Germany, and Spain have been providing RD&D grants to improve the development of wind energy technology, as well as for resource assessment, environmental considerations and other related areas.[158]

7.2 Germany's and the United States' Renewable Energy Policies

This section concentrates on the renewable energy policies which have been adopted by Germany, which has become the world leader in wind energy with its installed capacity record and the United States, which takes the second position.

7.2.1 Germany

Germany's success has been encouraged by the adoption of favorable national and regional policies since the early 1990s that support the development of renewable energy in general and wind energy in particular.

There are several primary components that have influenced its wind industry growth. The first breakthrough legislation that the German parliament passed is the Electricity Feed-In Law (EFL), the so-called "Stromeinspeisungsgesetz" in 1991.[159] This law specified the minimum price at which German utilities had to purchase all power from the renewable energy sources (RES) generators. This price was tied to the residential electricity tariff. Wind generators received a payment of 90 percent of the residential tariff.[160]

Another major stimulus to German wind energy development has been the '250 MW Wind Program", which was started in 1990 as a large-scale demonstration program which would pay developers for their output or for approved investment costs (for

[158] International Energy Agency (IEA), "Renewable Energy Policy in IEA Countries - Volume 1: Overview," IEA/OECD, 1997

[159] European Wind Energy Association (EWEA), "Wind Force 12: A Blueprint to Achieve 12% of The World's Electricity from Wind Power By 2020," available at: http://www.ewea.org/doc/WindForce12.pdfm, September 20, 2002

[160] Hoppe-Kilpper, M., Kleinkauf, W., Schmid, J., Stump, N., and Windheim, R. "Experiences with Over 1000 MW Wind Power Installed in Germany," *Proc. of 1996 European Union Wind Energy Conference*, Göteborg, May 1996, can be found in Institut für Solare Energieversorgungstechnik (ISET), available at; http://www.iset.uni-kassel.de/iset/owa/veroeff_kopf.show?p_veroeff_nr=401&p_lang=eng, August 5, 2002

certain cases, the maximum subsidy would amount to approximately 10 percent of capital cost).[161]

Germany's wind promotion program also comes in the form of preferential financing; such as below-market loans are available from the Deutsche Ausgleichsbank (DtA), a federal funding institution, which provides favorable financing terms for projects in areas such as environmental protection. DtA loans offer a fixed interest rate of 1-2 percent below commercial rates, and a maximum repayment grace period of five years is allowed to ease cash-flow constraints during projects' initial years. With such loans covering approximately 75 percent of the total project cost, combined with another 12 – 15 percent of project cost funded by bank loans, and approximately 5 percent of costs covered by grants, investor equity requirements are limited to a mere 5 to 8 percent of project cost.[162] These strong financial incentives have opened up the ownership and investment potential of wind power projects to a wide range of people that involve small businessmen and companies who in turn benefit from an investment tax rebate.[163]

Due to the liberalization of the German electricity market in the late 1990s,[164] greater competition among utilities has pushed electricity prices down below a viable level for RES power generators. Therefore, the German government persisted[165] on its commitment to support the RES by implementing new legislation, the so-called Renewable Energy Sources Act (Erneuerbare Energie Gesetz - EEG) that came into force in April 2000, to provide price supports that enable electricity generation from RES on an economically viable basis.

Under this new legislation, grid operators will continue to be obliged to buy electricity from producers employing RES, but, in contrast to the EFL, the minimum

[161] Hoppe-Kilpper, M., Kleinkauf, W., Schmid, J., Stump, N., and Windheim, R. "Experiences with Over 1000 MW Wind Power Installed in Germany," *Proc. of 1996 European Union Wind Energy Conference*, Göteborg, May 1996, can be found in Institut für Solare Energieversorgungstechnik (ISET), available at; http://www.iset.uni-kassel.de/iset/owa/veroeff_kopf.show?p_veroeff_nr=401&p_lang=eng, August 5, 2002

[162] Lindley, D. "A Study of the Integration of Wind Energy into the National Energy Systems of Denmark, Wales and Germany as Illustrations of Success Stories for Renewable Energy," *Proc. of 1996 European Union Wind Energy Conference*, Göteborg, May 1996

[163] European Wind Energy Association (EWEA), "Wind Force 12: A Blueprint to Achieve 12% of The World's Electricity from Wind Power By 2020," available at: http://www.ewea.org/doc/WindForce12.pdfm, September 20, 2002

[164] Erdmann, G., "Transformation in the German Electricity Market," can be found in Gesellschaft für Energiewissenschaft und Energiepolitik (GEE) available at: http://www.gee.de/mitglied/iaee_newsl2000.htm, September 20, 2002

price will no longer be calculated as a percentage of the average electricity price. There are set, cost-oriented rates that differentiate among RES. The grid operators then balance out the sum paid out to RES producers among each other so that there is no unfair burden on the grid companies that are active in regions with a high proportion of renewable power sources.

The tariff paid also varies according to factors such as the type of RES, quality of plant's location (the rate is reduced for well-situated producers), certain geographical conditions (e.g. along the coast and inland wind power plants) and size and age of the installation. This differentiation takes into account the objections raised by the European Commission which would otherwise have issued a warning that the more favorable sites were receiving too much assistance.[166] This legislation also recognizes wind's increasing competitiveness by introducing a decreasing output payment after five years of a turbine's operations.

In July 2002, Germany's power industry association (Verband der Elektizitätswirtschaft - VDEW) reported[167] that RES generators that supply to the German market earned 35% more last year than in 2000 under the new feed-in law (EEG). Total payments to RES power generators in 2001 is about €1.5 billion, for 18 billion kWh of power at 0.086 €/ kWh. In 2000, 13 billion kWh had been supplied at 0.085 €/kWh, while average wholesale power prices from traditional energy sources coal, oil, gas and nuclear energy in 2001 were just under 0.02 €/ kWh.

Support for wind power is also found in the strong political influence wielded by environmentalists, including the Green party, who currently lead the government together with the Social Democratic party. In September 1998, the government has also announced its intention to shut down 19 nuclear power plants presently providing 30% of the electricity within 30 years, at the end of their technical lifetime.[168] Other government support comes in the form of R&D funding in which wind energy programs

[165] Germany Info, "Background Papers: Promoting renewable Energy Resources," available at: http://www.germany-info.org/relaunch/info/archives/background/renewable.html, October 6, 2002
[166] Germany Info, "Background Papers: Promoting renewable Energy Resources," available at: http://www.germany-info.org/relaunch/info/archives/background/renewable.html, October 6, 2002
[167] Renewable Energy World, "German renewable revenues up 35% in 2001," available at: http://www.jxj.com/magsandj/rew/news/2002_05_03.html, October 5, 2002
[168] Masterman, S. and Reuters, "Shut Down," can be found in ABC News, available at: http://abcnews.go.com/sections/world/DailyNews/germany000614.html, October 5, 2002

receive one-third of the total government's funding while two-thirds is given to solar energy programs.[169]

It can be concluded that the excellent combination of guaranteed power purchase contracts, generous per-kWh payments, and favorable financing terms has made Germany a very attractive market for wind power projects, which resulted in the great success of its current wind power market.

7.2.2 The United States

The first U.S. renewable energy policies was passed during the energy crisis in 1978 known as the Public Utility Regulatory Policy Act (PURPA), as an action to reduce dependence on foreign oil, to promote alternative energy sources and energy efficiency, and to diversify the electric power industry. This law mandated that the public should purchase power from qualifying facilities (QFs) at power produced by qualifying facilities at the utility's avoided cost. Avoided cost is the incremental cost a utility would have to pay if the utility generated the electricity.[170]

Despite the fact that PURPA is a federal law its implementation is left to individual states, and different states acted with different levels of interest. For example, the state of California moved aggressively to implement PURPA due to serious power shortages, and its desire to promote resource diversity through small power plants and renewables.[171]

PURPA is the only existing federal law that requires competition in the utility industry and the only law that encourages RES. Despite its benefit, its role is no longer much help for RES due to low avoided costs in the 1990s, and many of the full range of benefits of RES are not accounted in the price, for instance reduced pollution, less global warming, domestic economic development, and reduced dependence on foreign energy sources.[172]

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[169] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 208-209

[170] Abel, A. and Shimabukuro, J., "CRS Report: Electricity Restructuring Bills: A Comparison of PURPA Provisions," *RS20146*, can be found in National Council for Science and the Environmental (NCSE), available at: http://www.cnie.org/nle/crsreports/energy/eng-50.cfm#N_9_, October 7, 2002

[171] Facts on File, "Renewable Energy: Key Federal Mandates," available at: http://www.facts.com/icof/key.htm, October 8, 2002

[172] Union of Concerned Scientists, "Public Utility Regulatory Policy Act," available at: http://www.ucsusa.org/energy/brief.purpa.html, October 8, 2002

In addition to PURPA, tax incentives have been the other driving force of renewable energy development in the U.S. For example, the Energy Tax Act of 1978 provided a business tax credit of 15 percent for certain technology investments including wind power and a generic business investment tax credit (ITC) of 10 percent. These credits were available until the Tax Reform Act in 1986 eliminated most tax advantages for renewables. Nevertheless, the Energy Policy Act in 1992 included the production tax credit (PTC) for wind energy. The PTC is a 0.015 US$/kWh (adjusted for inflation 0.017 US$/kWh in 2002)[173] business credit that applies to electricity generated from wind power plants during the first 10 years of a wind plant's operation and can reduce the levelized cost[174] of wind by about 0.007 US$/kWh over the plant's 30-year lifetime.[175]

The wind PTC is currently scheduled to expire on December 31, 2003 after it has experienced two extensions, in 1999 and March 2002. This "on-again, off-again" status of the credit is shuffling project development and the industry as a whole. Uncertainty also affects relationships with vendors and substantially increases costs as orders are rushed to meet PTC deadlines or as planning grinds to a halt and income is lost while the industry awaits an extension. In March 2002, AWEA reported the wind industry is seeking for a long-term extension through December 31, 2006, to provide a stable financial environment for the wind energy industry.[176]

In addition to the above-mentioned tax incentives provided by the federal government, various states also provided tax incentives. For example, the state of California offered a 25 percent investment tax credit available until 1995. On the one side, PURPA and state tax incentives resulted in many wind power plant developments in California during the mid-1980s. On the other side, these generous tax incentives combined with PURPA were misused by many projects (particularly wind) developers who developed their projects primarily for tax shelter purposes while their projects'

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[173] American Wind Energy Association (AWEA), "Economic of Wind Energy," available at: http://www.awea.org/pubs/factsheets/EconomicsofWind-March2002.pdf, August 6, 2002

[174] Levelized costing calculates in current dollars all capital, fuel, and operating and maintenance costs associated with the plant over its lifetime and divides that total cost by the estimated output in kWh over the lifetime of the plant.

[175] AWEA, "Comparative Cost of Wind and Other Energy Sources," available at: http://www.awea.org/pubs/factsheets/Cost2001.PDF, August 6, 2002

[176] American Wind Energy Association (AWEA), "Economic of Wind Energy," available at: http://www.awea.org/pubs/factsheets/EconomicsofWind-March2002.pdf, August 6, 2002

performance in terms of electricity generation were often far below expectation. Due to these experiences, tax incentives were changed from capital cost-based tax credits to production-based credits in 1992.[177] Policies described above were responsible for the establishment of the renewable energy industry in the U.S. and the state of California in particular. The state of California also adopts a new renewables support mechanism so called "system benefits charge" to provide funding to further develop renewables energy projects, which collected from electricity customers.[178]

In combination with the above-mentioned mechanism, another development in the state of California is the emergence of the "green" power market. This green power market gives customers the opportunity to buy electricity generated from environmentally friendly sources such as RES at higher electricity prices. Beside the Californian, there are also other states that have adopted green power marketing. Green power marketing has the potential to expand domestic markets for renewable energy technologies by fostering greater availability of renewable electric service options in retail markets. Surveys conducted also identified that customers have expressed a preference and willingness to pay more if necessary, for cleaner energy sources.[179]

In addition to those mechanisms, individual states policies have also played a significant role in fostering wind energy. For example, the state of Texas adopted the Renewables Portfolio Standard (RPS) which successfully experienced over 900 MW of new installed capacity from wind power plants in 2001.[180] The RPS can move large amounts of clean energy into the mainstream, as it requires utilities to use an increasing percentage of renewable energy over time. The RPS has also been credited as the driving force behind the United States' recent boom in wind development.[181]

Other government support also comes in the form of large R&D funding, however these findings are not translated into a successful commercial wind turbine

[177] Redlinger, R.Y., Andersen, P.D., and Morthorst, P.E., "Wind Energy in the 21st Century: economics, policy, technology, and the changing electricity industry," Basingstoke, Palgrave, 2002, pp. 186
[178] U.S. Department of Energy, "Policy Issues: System Benefits Charges," available at: http://www.eren.doe.gov/state_energy/policy_content.cfm?policyid=29, October 15, 2002
[179] Green Power Network, "Introduction," available at: http://www.eren.doe.gov/greenpower/intro.shtml, October 12, 2002
[180] European Wind Energy Association (EWEA), "Wind Force 12: A Blueprint to Achieve 12% of The World's Electricity from Wind Power By 2020," available at: http://www.ewea.org/doc/WindForce12.pdfm, September 20, 2002

industry in comparison with the Denmark's low R&D spending, where Danish wind turbine manufacturers have obtained more than 50% of global market share.

The U.S. will need a better law to replace PURPA, a legislation that must create an equal playing field for utilities and independent power generators, and must facilitate the unique characteristics of wind energy and recognize the environmental benefits of renewable energy in general.

This chapter has described that good policies can support a substantial growth of wind energy, taking Germany and the Unites States as case studies. Germany, which has adopted a minimum price schemes, combined with strong government commitment, exhibits a continuous extraordinary growth. Meanwhile, the U.S wind market has enjoyed the PTC in past few years; however, its further development will depend on the availability of stable long-term policies at a Federal and State level to provide a secure market.

[181] Laroi, V., "Wind energy future hinges on upgraded grid," can be found in Planet Ark, available at: http://www.planetark.org/dailynewsstory.cfm?newsid=16265&newsdate=05-Jun-2002, September 16, 2002

Chapter 8 Conclusion

With an average growth rate of 40% annually over the past five years, wind energy is the world's fastest-growing energy source, although it still accounts for a small portion of world electricity supply. This growth is expected to spread around the world, with major roles played by European countries, the United States, while the Asian market will be led by India, Japan and China.

The established commercial modern wind turbine designs have been the horizontal-axis machines with two or three blades, rotating at near fixed speed. Great advances were achieved in efficiency and reliability, as well as in economies of scale, both in terms of increased turbine size and increased manufacturing volume. These improvements have also led to drastic reductions in wind energy's cost per generated kilowatt-hour. However, wind turbine manufacturer will still be challenged to further reduce costs by focusing on various factors such as lowering capital and O&M costs, improving generation efficiency, reliability, and selecting the optimum siting for wind turbines.

Wind turbine manufacturers will also put efforts to manufacture higher capacity turbines for offshore applications as there is a market pressure from some European countries, which desire to meet significant amounts of their electricity supply from wind energy and their targets can only be accomplished by developing their offshore wind potential. Although the costs of offshore applications are still higher than those on land, they are expected to decline significantly as increasingly offshore wind farms are being developed in the future and more experience in operating them can be obtained.

In order to smooth the further penetration of wind energy as a new entrant in the electricity market despite its remarkable growth rate, and the profits that it can offer; support and commitments from all of actors in the wind energy industry are definitely needed. The governments are expected to design incentive mechanisms, which encourage the development of renewable energy in general and wind energy in particular, as evidenced by the U.S. and Germany examples. A reliable market is the most important factor for stimulating the further development of wind energy. Meanwhile, securing PPA has also become an important key success in Germany.

Without PPA, the current electricity market will not enable wind energy or other RES to compete fully with fossil fuels, since electricity prices do not entirely reflect the environmental costs of fossil fuels.

In the case of the U.S., though its wind energy potential is enough to meet more than twice its total current electricity consumption and the technology is proven and reliable; its policies have not sufficiently helped new entrants to overcome market barriers. The rate of its wind market growth will definitely depend to a large extent on policy decisions that it adopts in the next several years. A continuation of its renewables portfolio standards (RPS) where a minimum renewable energy requirement grows over time, and a long term PTC combined with stronger federal laws that support RES would sustain the wind industry’s grow in the U.S.

There is a need to design a new electricity pricing rule that recognizes the environmental externalities costs associated with fossil fuels. Examples include taxes/fees on emissions and pollution from conventional electricity generation or, conversely, economic incentives for renewables to help the market capture their environmental and public health benefits. The higher the air quality and other environmental standards adopted in a country the more competitive wind energy in the marketplace.

Besides government commitment, the wind industry and education institutions also have a social responsibility to educate and promote wind energy to society, which includes information and technology transfer at all relevant levels. Government incentives programs that help finance public wind farm projects will also enhance the interest of the public to obtain a direct benefit from owning and operating their own wind farms.

Overall, wind energy represents a great success in which, over a brief span of time, wind power is on the threshold of making the transition from an alternative energy source to an integral part of the mainstream electricity industry. Nevertheless, this transition is not yet complete, and the coming years will represent a crucial time in the wind industry’s maturation. Therefore, wind energy continues to require a favorable policy environment to encourage additional implementation, continued technological advancement and further cost effectiveness.

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