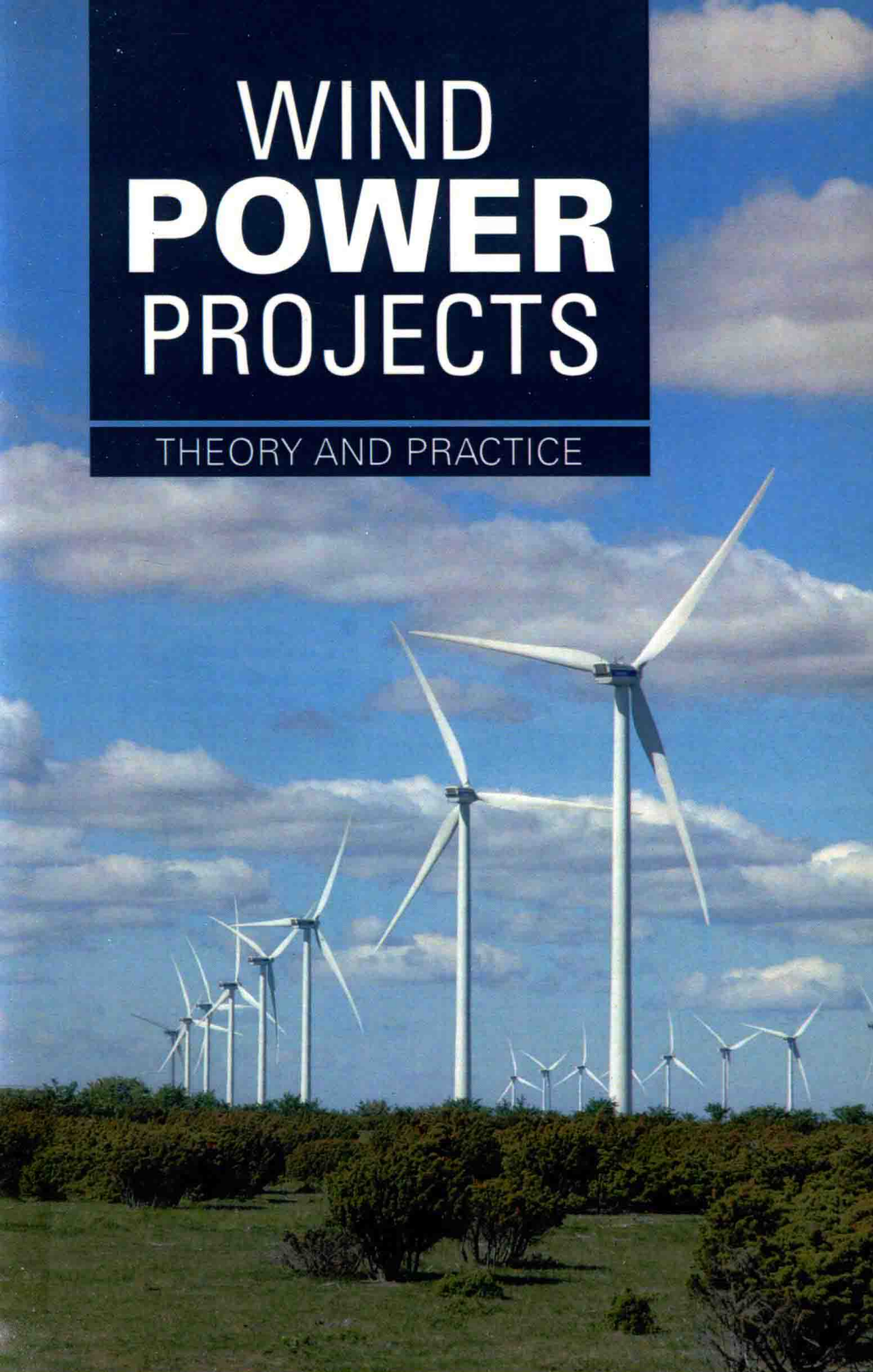
WIND POWER PROJECTS

THEORY AND PRACTICE



TORE WIZELIUS

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Theory and practice

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Wind Power Projects

Wind power has developed rapidly in terms of the number of new wind power plants now installed in more than one hundred countries around the world. This renewable energy source has become competitive, and to be able to combat climate change much more has to be installed in coming years. This also makes it necessary for policy makers, NGOs, research scientists, industry and the general public to have a basic understanding of wind power.

The majority of texts on wind power are written primarily for engineers or policy analysts. This book specifically targets those interested in, or planning to develop wind power projects. It can be understood by both specialists and non-specialists interested in wind power project development.

Having outlined the background of wind power and its development, explained wind resources and technology, the author explores the interactions between wind power and society and the role of wind power in the electric power system. Finally the main aspects of project development, including siting, economics and legislation, are explained.

This book will be an essential reference, or even a manual, for professionals developing new sites and for government officials and consultants involved in the planning or permission process. It can also be used as a textbook on wind power at schools and universities.

Tore Wizelius is a writer who has authored eight books on wind power. He was a lecturer on wind power at Gotland University, Sweden, from 1998 to 2008 and is now working as a wind power developer in Sweden.

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1 Development of wind power

Wind power has grown rapidly since the end of the 1970s. In these few decades wind power has developed from an alternative energy source to a new fast-growing industry, which manufactures wind turbines that produce power at competitive prices.

Wind turbines take kinetic energy in the wind and transform it into mechanical work (in water pumps and windmills) or electric power (in modern wind turbines). The wind is a renewable energy source; the wind is set in motion by the differences in temperature and air pressure created by the sun's radiation. Wind turbines do not require any fuel to be transported – a hazard to the environment – don't create any air pollution and don't leave any hazardous waste behind. Wind turbines produce *clean* energy.

The sun, the wind and running water are all renewable energy sources, in contrast to coal, oil and gas, which depend on fossil deposits from mines, oil- or gas-fields. In most countries, hydropower has already been fully developed. The technology to use direct solar radiation with solar collectors and photovoltaic (PV) panels has had a commercial breakthrough, but development is still about 10 years behind. The new renewable energy source that has the most successful development so far is wind power, but during 2014 more PV-cells are expected to be installed than wind power.

Modern wind turbines are efficient, reliable and produce power at reasonable cost. The wind power industry is growing very fast; the leading companies have, in the first years in this decade, increased their turnover by 30 to 40 per cent per year. Simultaneously the cost per kWh of electicity produced has been lower for each new generation of wind turbines that has been introduced on the market.

From the early 1980s the size of wind turbines has doubled approximately every four years. The current generation of wind turbines has a rated power of 3–6 MW, rotor diameters of 120 metres or even more, and towers up to 140 metres in height. New prototypes are even larger and mainly intended for the offshore market.

The technology in the wind turbines has developed in several ways. The control systems have become cheaper and more advanced. New profiles for the rotor blades can extract more power from the wind, and new electronic

power equipment makes it possible to use variable speeds and to optimize the capacity of the turbines.

In the same way as the wind turbines have grown in size, the installations have become larger and larger. In the early days of wind power development, the turbines were installed one at the time, often next to a farm. After a few years they were installed in groups of two to five turbines. Today, large wind power plants are built, on land and offshore, with the same capacity as conventional power plants. The largest wind power plants consist of hundreds of wind turbines and such large projects have now been developed in many parts of the world.

A challenge with the wind as an energy source is that the wind always varies. When the wind slows down or stops, power has to be produced by other power plants. This could lead to the conclusion that it will be necessary to have backup capacity with other power plants with the same capacity as the wind power connected to the power system. If this were true, wind power would be very expensive. Since wind power only constitutes one part in a large power system, this is, however, not necessary at all. A moderate proportion of wind power in a system does not need any backup capacity at all, since it already exists in the power system. In Scandinavia the power companies can simply save water in hydropower dams when the wind is blowing, and use this saved hydropower when the wind slows down.

In a power system, the power consumption varies continually, during the day as well as seasonally. Every power system has a regulating capacity to adapt power production to actual power consumption. This can be used to adapt the system to the variations in the wind – and the output of wind turbines – as well. When wind power penetration (that is the proportion of electric power produced by wind in a power system) increases to 10–20 per cent, it may be necessary to regulate the wind power as well, by reducing the power from wind turbines in situations with low loads (consumption) and high production, or by keeping a power reserve that can be used to balance power production with consumption at short notice. Few countries have however reached such penetration levels yet.

During the development from single small wind turbines connected to farms, to large wind power plants with the capacity of utility-scale power plants, wind power has become more competitive. The power produced by wind turbines has become cheaper. Today the cost of power produced by wind turbines (in places with good wind conditions) is competitive with the cost of power produced with oil, coal, gas or nuclear fuel in *new* power plants. In this decade wind power has become one of the cheapest energy sources available.

During the last few years, the market in China has expanded most and at the start of 2015 China had most installed capacity, followed by the USA where large wind power plants are installed on the plains of the Midwest and on the west coast. In Europe, Germany passed pioneering Denmark in 1994 with respect to installed wind power capacity, followed by Spain where

Table 1.1 Global wind power 2014/15 (MW)

Country	*Installed 2014*	*Total 2014/15*
China	23,351	114,763
USA	4,854	65,879
Germany	5,279	39,165
Spain	28	22,987
India	2,315	22,465
UK	1,736	12,440
Canada	1,871	9,694
France	1,042	9,285
Italy	108	8,663
Sweden	1,050	5,425
Denmark	67	4,845
Others	7,203	43,883
Total	51,477	369,553

Sources: GWEC, 2015; EWEA, 2015

a massive development of several thousand megawatts took place during the first decade of the twenty-first century (see Table 1.1 and Figure 1.4). There is still an immense potential for market growth in countries where development recently has taken off, like Australia, Brazil, Ireland, Canada and Poland, just to mention a few.

There are also ambitious plans to develop wind power plants offshore. Several offshore wind farms are already installed, in Denmark, Great Britain, the Netherlands and Sweden. Denmark has decided that wind power shall produce 50 per cent of the electric power in the country by 2030, and by the development of large offshore wind power plants this ambitious target is already within reach. Great Britain has also implemented an ambitious plan for offshore development.

In 2014 a further 51,500 MW of wind power was connected to the electric power grids around the world, and total installed capacity increased to 370 GW, an increase by 16 per cent from 2014. These 370 GW wind power produce around 755 TWh a year, which supplies some 170 million households with electricity. In Denmark wind power supplied 39 per cent of the total electric power consumption in 2014.

If this power had been generated by coal-fired power plants, some 255 million tons of coal would have been used, 255,000 railway wagons or 12,000,000 road transport lorries and some 530 million tons of carbon dioxide emitted.

Wind power has developed very quickly during the last 30 years. In the late 1970s and early 1980s wind turbines were small, manufactured in

Box 1.1 Wind power statistics

To indicate how much wind power there is in a country, the total installed capacity is used as a measure. Every wind turbine has a rated power (maximum power) that can vary from a few hundred Watts to 5,000 kW (5 MW). The number of turbines does not give any information on how much wind power they can produce. How much a wind turbine can produce depends not only on its rated power, but also on the wind conditions. To get an indication of how much a certain amount of installed (rated) power will produce, this simple rule of thumb can be used; 1 MW wind power produces 2 GWh/a (gigawatts per annum) on land and 3 GWh/a offshore. For the multi-MW turbines introduced during the last years these rules of thumb must be updated to: 1 MW produces 2.5 GWh/a on land and 4 GWh/a offshore.

1 TWh (terawatt hours) = 1,000 GWh (gigawatt hours)
1 GWh = 1,000 MWh (megawatt hours)
1 MWh = 1,000 kWh (kilowatt hours)
1 kWh = 1,000 Wh (watt hours)

International information on wind turbine installations is available at www.wwindea.org, www.ewea.org, www.gwec.net and on www.ieawind.org

smithies and small workshops and installed next to farms. Thirty years later wind power plants on land and offshore are integrated parts of the dominant energy system, and are manufactured by industrial giants such as General Electric in the United States, Siemens in Germany and their counterparts in India and China. In 2014, around 5 per cent of all electric power in the world was produced by wind turbines (WWEA, 2015) a share that will grow for many years ahead.

The power in the wind has been utilized by sailing ships and for different kinds of windmills for thousands of years (Hills, 1996). Wind turbines for electric power production were developed in Denmark by Paul laCour, and the first commercial grid-connected wind turbine started operating in Askov, Denmark, in 1902. From the 1920s battery-charging wind turbines were in common use in the countryside in the United States until the power grid was extended to these areas some decades later. This kind of small wind turbines were quite common also in Europe.

In the 1950s a wind turbine which delivered power to the AC grid was developed, the so-called Gedser-möllan, which gave valuable experience to Danish researchers and electrical engineers when it was in operation in the 1950s, but the abundance of fossil fuels that flooded the market at that time made it difficult for wind power to be competitive.

The modern wind power industry was developed in Denmark, starting in the late 1970s and it has been growing ever since. This was the start of the Danish success story in the wind power industry, which some 40 years later has spread across the globe.

Ever-growing wind turbines

Commercial wind turbines for grid connection, which are the focus of this book, were rather small when development started in the late 1970s and early 1980s. At that time the typical wind turbines had hub heights of about 20 metres, and on these lattice towers there was a nacelle with a 20–40 kW generator, a rotor with a diameter of around 15 metres and a swept area of 175 m^2 (see Figure 1.1).

In 2010 the largest wind turbines had hub heights of up to 160 metres, nominal power up to 7.5 MW, and rotor diameters close to 130 metres (see Figure 1.2). The industry is now developing wind turbines with a nominal power of 10–15 MW.

Beginning in the late 1970s wind turbine sizes have doubled on average every three to four years, if size is measured as the most common nominal power of the turbines during a specific year. When nominal power is increased, hub heights and rotor sizes increase as well (see Figure 1.3).

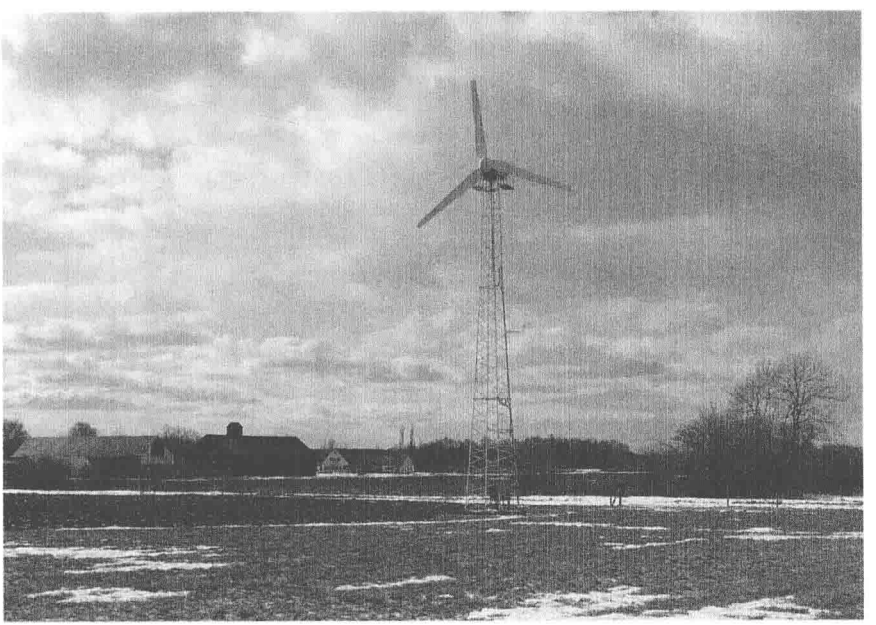

Figure 1.1 Typical wind turbine from early 1980s. A Vestas V15 with 35 kW nominal power and 18 m hub height installed at Lövsta Agricultural School on Gotland (photo: Tore Wizelius)

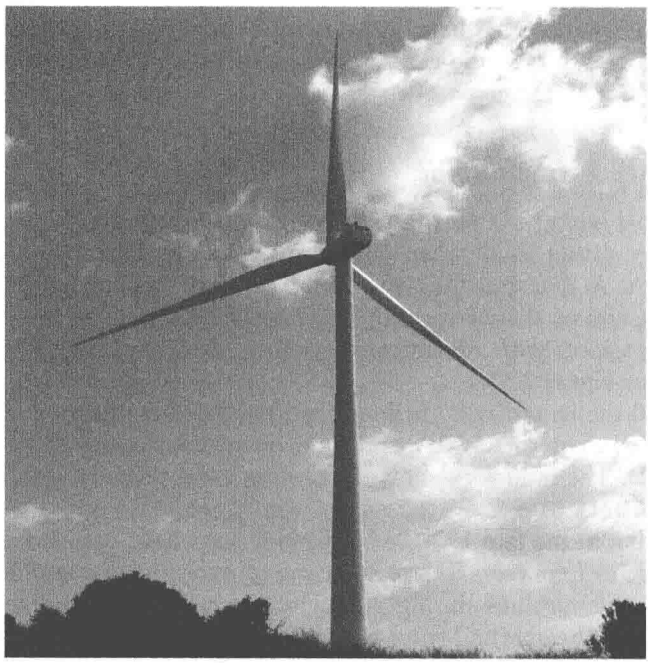

Figure 1.2 Gamesa G128 with 4.5 MW nominal power, 120 metre hub height and 128 metre rotor diameter is a new large wind turbine from the Spanish manufacturer Gamesa (photo: Tore Wizelius)

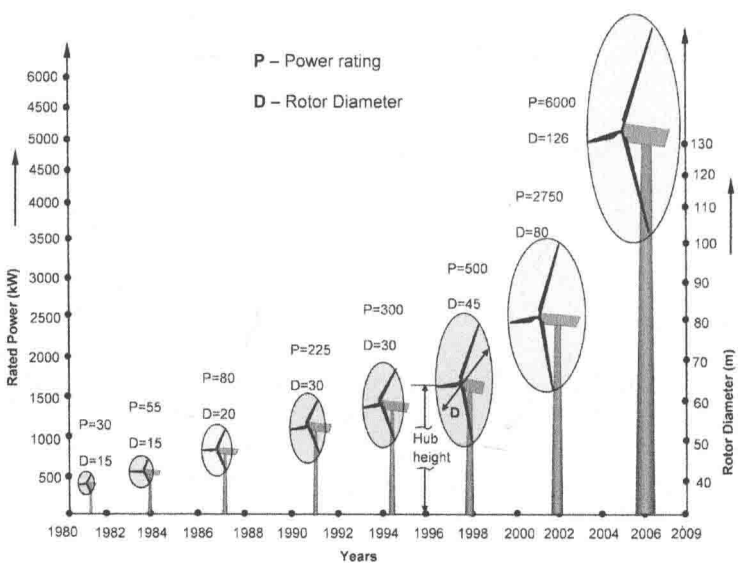

Figure 1.3 Development of wind turbine size. The size of wind turbines has increased quickly, with a doubling each three to four years (Earnest & Wizelius, 2011)

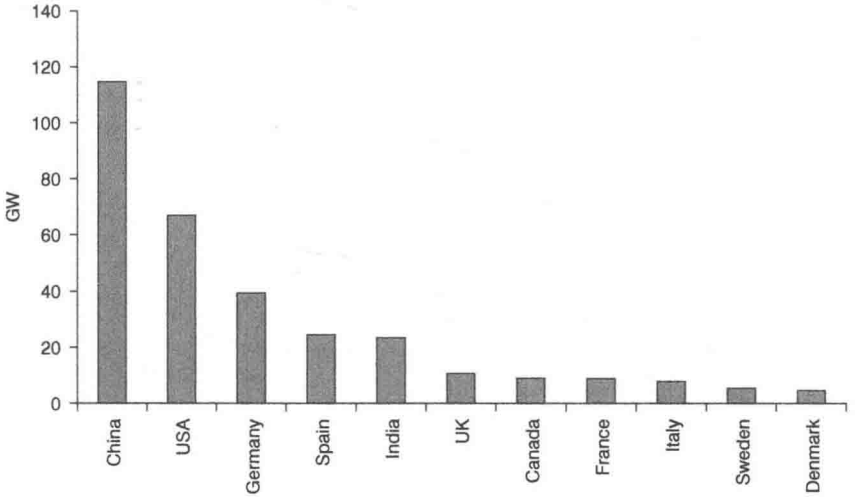

Figure 1.4 Installed capacity (GW) by country in 2014/15 (source: author's elaboration, based on data from GWEC 2015)

Early starters and late boomers

Denmark, a rather small country in northern Europe, has been at the forefront of the technical development of wind turbines as well as the actual installation of wind power connected to the power grid. An historical overview of the installed capacity of wind power in the electric power system shows that Denmark was in the lead from the 1970s and up to the early 1990s, except during the short wind power boom in California in the 1980s.

In 1994 Germany overtook Denmark and kept the lead position for a decade, with Spain in second place in the early years of the twenty-first century, the US taking the lead in 2007 and China, with an annual growth rate of more than 100 percent per annum for several consecutive years, taking over the lead position in 2010 (see Figure 1.4).

It may not be fair to compare a small country like Denmark with giants like India, China and the United States; a better measure for comparison is the wind power *penetration*, which means the proportion of electricity supplied by wind power to the national electric power system. In this respect Denmark was still in the lead in 2014. China and the United States, with most installed capacity, are below Sweden on this list (see Table 1.2).

Other measures are wind power capacity per capita and wind power capacity per land area in different countries (see Figures 1.5 and 1.6).