WIND POWER

Case Studies: Germany, The United Kingdom, and China

Nathan Fleming
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EXECUTIVE SUMMARY

Rising costs of conventional electricity production and the associated environmental, social, and economical effects are experienced worldwide. Many nations are turning to renewable fuel sources to provide more sustainable methods of generating electricity. Wind power is one of fastest growing renewable energy technologies in the world, but capturing energy from the wind is hardly a new concept. Human beings have utilized wind energy for millennia. Today's use of wind, however, provides nearly 60,000 MW of electricity worldwide.

This report explores wind turbine site factors and power system design. Site quality is determined by the availability of a wind resource and the level of difficulty in distributing the power generated from that resource to an electricity grid. Further considerations include public opinion and ecological effects. The economics involved with implementing wind power into a power system are largely characterized by the efficiency of the electricity market, costs of grid connection, costs of operation and maintenance, and the other grid-connected power sources.

Three case studies are provided: Germany, the UK, and China. These nations are among the world's leading developers of wind energy and each has optimistic goals for future use of wind power resources. All three nations have implemented policies to increase production of electricity from wind power, but the development of an efficient market for this technology has varied in each case. Developing effective wind energy policy has proven to be a dynamic learning process from which important conclusions are drawn.

HISTORY OF WIND TECHNOLOGY

Throughout history, different cultures have discovered many ways to harness wind and use the energy it provides. The earliest recorded use of windmills takes place in the Afghan highlands during the seventh century BC in which vertical axis mills acted as simple drag devices for grinding grain (Ackermann, 2005). By 3100 BC, Egyptians built wind powered sailboats to navigate the Nile River (NEED Project, 2007). Historical documents show that horizontal axis windmills existed in Persia, Tibet, and China by 1000 AD. These windmills made use of a shaft and blades revolving in the vertical plane (Ackermann, 2005). This technology spread throughout Europe during the twelfth and fifteenth centuries. Different variations of windmills developed from region to region. The most culturally recognizable windmill is the Dutch version, which makes use of fabric-covered propellers with the ability to pivot in relation to the changing wind direction (Redlinger et al., 2002). By the seventeenth century, Holland was one of the most industrialized nations in the world because of its windmill capacity (NEED Project, 2007).

Between the twelfth and nineteenth centuries, windmill performance had improved with constant technological advancements. By the end of the nineteenth century, some rotors reached up to 25 meters in diameter and the uses of windmills ranged from grinding grain to pumping water to drain lakes and marshes (Ackermann, 2005). American colonists utilized windmills for grinding wheat and corn, pumping water, and cutting wood (NEED project, 2007).

With the development of the fossil fuel powered steam energy, the Industrial Revolution saw a decrease in the use of windmills. Machines based on the thermodynamic process of steam engines were more compact and powerful, less site specific, and more reliable (Redlinger et al., 2002). Windmill use in rural America, however, continued throughout the nineteenth and early twentieth centuries. By the 1930s nearly 600,000 units were installed across the American countryside (Ackermann, 2005). Various agricultural uses of windmills continue to this day.

As industrialization increased, electrification also increased. Despite the ability of fossil fuel to provide cost-effective electricity on a large-scale, interest in wind was not lost (Redlinger et al., 2002). In 1891, Poul la Cour, a Danish scientist, built the world's first electricity generating wind turbine. Funded by the Danish government, he established a wind turbine testing station (Ackermann, 2005). Various advancements in wind energy technology developed throughout the early and mid-twentieth century. J. Juul, a student of la Cour, pioneered the basis for modern turbine design. His 200 kW Gedser turbine operated between 1957 and 1967 (Redlinger et al., 2002). The United Nations Conference on New Sources of Energy held in Rome in 1961 documented all the key information regarding the development of wind energy technology during the first half of the twentieth century (Redlinger et al., 2002). When renewed interest in wind energy sparked during the 1970s energy crises, published reports from the Rome conference provided a solid foundation of knowledge.

The first large developments of wind energy were established in the mountains of California in the late 1970s and early 1980s. These efforts resulted from special tax credits and the Public Utility Regulatory Policies Act (PURPA) which encouraged domestic energy conservation while decreasing dependence on foreign oil. As a result, individual turbine capacity grew from 50 kW to 200 kW by the end of the 1980s (Ackermann, 2005). Eventually, the initial push for US wind energy slowed down. Throughout the early 1990s, turbines in the US were dismantled at faster rates than they were installed. However, wind energy capacity in other parts of the world, especially Europe, expanded. Between 1995 and 2003, 76% of all new turbines were installed in Europe (Ackermann, 2005). The rapid growth of European wind energy largely resulted from feed-tariff laws in which utilities are required to pay a set price for renewable power generation fed into the network (Wustenhagen and Bilharz, 2006).

Today, about 60,000 MW of wind energy capacity is installed worldwide (National Research Council, 2007). Energy independence and environmental concerns such as air quality and global climate change are among main reasons nations throughout the world are investing in wind energy. In addition to wind power's low environmental impact, its market competitiveness makes it an attractive renewable energy resource (Soderholm and Klaassen, 2007). Nations with the most successful wind energy programs include Germany, Denmark, and Spain. Their use of energy policy promotes advancement in wind power technology (Ackermann, 2005). At the same time, these nations have seen the development of a green energy market driven by customer demand (Wustenhagen and Bilharz, 2006).

WIND TURBINE SITING

Transmission Capacity

Wind turbines consist of three main parts: the blades, the gearbox, and the tower. Working together, these parts convert the kinetic energy of wind into mechanical energy that produces electricity (NEED, 2007). Most turbines have three aerodynamic blades. Wind rotates the blades, which causes torque on the axis. The axis turns the generator gears and creates electrical energy for distribution to the transmission grid (National Research Council, 2007).

Wind is not distributed uniformly and consistently throughout the world. Often times, areas with high electricity demands are far from areas with highest possible production yields. Offshore and rural areas sometimes provide the best wind for electricity production, but transmission availability can be a barrier to development (IEA/OECD, 2005). Because of the need for a greater amount of installed transmission lines, costs increase at longer distances

(Redlinger et al., 2002). When choosing a site, not only does wind quality need consideration but so does the level of existing infrastructure.

Not in my Backyard (NIMBY) vs. Local Acceptance

Public opinion towards proposed wind turbine projects is often characterized by a “not in my backyard” attitude (NIMBY). NIMBYism creates juxtaposition between the support for wind technology at a general level and frequent opposition at a local level (Devine-Wright, 2004). Wolsink suggests that a “positive attitude towards the application of wind power, combined with the intention to oppose the construction of any wind power scheme in one’s own neighborhood” (2007, p. 1201) characterizes NIMBY-motivated opposition. This phenomenon is not unique to wind power. Conventional power plants, schools, prisons, among other public and private projects are subject to a NIMBY attitude.

Studies show that there is increasing public support world-wide for shifting from conventional energy sources to wind energy. For example, general opinion polls indicate 79%, 80%, and 82% of the populations in Canada, the UK, and Denmark, respectively, support the development of wind energy technology (Devine-Wright, 2004). Despite popular support for wind power, negative perceptions of wind energy often emerge on a local level. Visual impacts and noise concerns are the most common complaints. Apprehensions about reliability, high cost, impact on birds and wildlife, inefficiency, developer motivations, and idle turbines are frequently cited as local concerns (Devine -Wright, 2004). Offshore wind development includes further concerns such as, the effects on marine life, tourism, recreation, and the aesthetics of the ocean view (Firestone and Kempton, 2007).

Overtime, public attitude towards a wind energy project tend to become more accepting after the completion of a project (National Research Council, 2007). Some communities may even utilize a wind farm as an eco-tourist attraction. Local acceptance of a project is increased when the industry involves the community in a transparent planning process (Wolsink, 2007). Top-down planning tends to initiate public hostility towards a project.

ECOLOGICAL EFFECTS

Development of wind power can affect ecological systems, individual organisms, and ecosystem structure and function in positive and negative ways. The positive effects that result from wind power development include the simple fact that it displaces the environmental ills of fossil fuels. Mining, air pollution, green house gases, and global climate change are side effects of conventional coal based power systems (National Research Council, 2007). On the other hand, the effects of wind power on local and global environmental quality are very minimal.

Although wind farms account for only 0.003% of all anthropogenic bird fatalities, the most commonly discussed negative effect of wind power in scientific research literature is the risk it poses to bird populations (National Research Council, 2007). The degree to which wind power sites impact bird populations result from the number of collisions, habitat loss, and displacement (Drewitt and Langston, 2006). Considering bird behavior, migration, and breeding patterns when planning a turbine site can mitigate the effect turbines may have on bird populations.

Turbine sites pose a risk to individual organisms because of the possibility of collision. Even though turbine collision is most widely recognized, other site features may cause collision. For example, features such as towers, FAA (Federal Aviation Association) lights, rotors, guy wires, meteorological masts, and other structures create additional collision risk (Drewitt and Langston, 2006). In fact, even the vortex created by moving rotors can be powerful enough to force birds to the ground. Collision risk depends on bird species, bird numbers and behavior, weather conditions, topography, wind farm design, and the use of lighting (Drewitt and Langston, 2006).

Some birds are more threatened by wind turbine sites than others as a result of various levels of abundance and behavior. Birds most threatened by turbines are nocturnal migrating passerines (because of abundance) and raptors (National Research Council, 2007). Large birds with poor maneuverability such as geese and swans risk collision as well (Drewitt and Langston). Raptor species, which favor wind for soaring, occur in most areas with a potential for producing wind electricity. Effects of a decline in a single species are often felt by a whole ecosystem and alter the way it functions. This is especially true for keystone organisms that have a disproportionally large function, such as raptors that have a top down role as predators (National Research Council, 2007).

Some weather conditions combined with topographical features alter bird flight and influence collision risk. Studies show that bird collisions increase with poor weather conditions such as fog, rain, or wind. For example, strong head winds along with precipitation force birds to lower flight altitudes. This holds particularly true for migratory birds (Drewitt and Langston, 2006). Also, migratory birds often follow a river or a mountain ridgeline (especially in poor weather). Many times these areas offer a great wind resource, but the risk to birds may be high.

ECONOMICS

The 1990s saw the emergence of a global trend of privatizing electricity markets. With privatization, markets are not solely controlled by large electric utilities; however, utilities are still responsible for system planning and act as purchasing agents. This trend has enabled independent power producers (IPPs), such as wind-farms, to enter the energy market with greater ease (Redlinger, et al., 2002). The re-regulated system holds the 'market' responsible for providing adequate power. Power systems were traditionally designed with the intention of integrating only conventional power sources. Large integration of wind energy, in many cases, requires redesign of the network (Ackermann, 2005). With the integration of wind power, conflicts often arise between network operators/owners and wind project developers. For the most part, these conflicts are not over the technical aspects of integrating a project but the economic aspects.

Costs of grid connection, costs of operation and maintenance, and the overall cost-effectiveness should all be evaluated when determining the feasibility of a project. In some power systems, the system regulator charges the investor for connection at a rate which disregards the actual connection costs. In most re-regulated systems, however, the charges to the investor reflect the costs of connection. According to Ackermann (2005), there are three ways to determine the connection charges: shallow connection charges, deep connection charges, and shallowish connection charges.

1. *Shallow connection charges* reflect only the direct costs of connecting a wind farm to a power grid. These charges include the costs of new service lines and the partial cost of a transformer needed to raise the voltage from the wind farm to transmission network voltage. Nations that utilize shallow connection charges include Denmark, Germany, and Sweden.
2. *Deep connection charges,* on the other hand, include the costs of service lines, transformers, and all or some of the costs at the transmission and distribution level. Certain problems are associated with this particular system. For example, difficulty arises when trying to determine which costs result from connecting another generator (i.e. wind farm) and which

costs result from increased load or aging, less efficient equipment. These questions of costs often cause conflict between network owners/operators and wind farm developers.

3.*Shallowish connection charges* systems implement a combination of shallow and deep connection charges. Under this system, network owners/operators and developers contribute a portion of the reinforcement costs required for the integration of a wind project. Contributions are based on the proportion of the project's required increased capacity. The U.K. employs a shallowish connection charges system.

The capital costs of a wind energy project are most significantly affected by the costs of the turbine itself. On average, turbines account for nearly 80% of the total capital cost. Grid connection and the foundation account for about 9% and 4% respectively of the total capital cost (Redlinger et al., 2002). Other auxiliary costs such as land, components, and controls account for a minute share of the total capital cost.

Operation and maintenance costs of a turbine have about a 10%-15% share of the total cost of each kWh produced. As a turbine ages, these costs may be as high as 20% to 30% (Redlinger et al., 2002). Operation and maintenance costs can be attributed insurance costs, regular maintenance, repair, spare parts, and administration. Insurance and maintenance costs are estimated with some ease. The costs of repair and spare parts, on the other hand, are more difficult to estimate, because so many turbine projects are still rather young (Redlinger et al., 2002).

The intermittent nature of wind influences the costs associated with system operation. Because system operators schedule a specific amount of production hours to days in advance to meet forecasted demand, intermittency issues are a concern on multiple timescales (DeCarolis, 2006). In addition, determining operation costs can be rather difficult considering the influence of system transmission and generation infrastructure (DeCarolis, 2006). This is for two reasons. First, wind power is often connected to large energy pools that serve as back up reserve. Second, wind energy has associated entanglements with subsidies.

Balancing wind power to meet the supply and demand needs in a power system is split into primary control and secondary control (Ackermann, 2005). Primary control is responsible for the short term minute by minute needs of a power system. Secondary control is responsible for capacity tasks demanded ten to thirty minutes later. System operators use an automatic generation control (AGC) to manage primary control imbalances (DeCarolis, 2006). Any outages or fluctuations in the intra-hour load are responded to within minutes and an operating reserve is dispatched to meet the energy system's needs.

Primary control costs are difficult to allocate because the contribution of wind on a short term frequency is usually low. Also, a single turbine's output variations are usually smoothed over when aggregated amongst a number of turbines or if wind farms are distributed over a wide geographical range (Ackermann, 2005). Secondary control capacity is usually made available within fifteen minutes to free up the capacity used by primary control. The difference between forecasted wind power production and actual production is assigned to secondary control (Ackermann, 2005). Demand on secondary control is a matter of forecast precision and production error. Wind forecasts made further ahead of time are usually less precise. As a result, production calculations comprise a certain degree of error.

Furthermore, utility grids are often large integrated regional energy pools comprised of many power stations. Grid operation is based on statistical experience with the aim of meeting customer demand at minimal cost. Power stations are divided into three levels (Hau, 2006):

1. *Base-load power stations* are those with highest capacity and permanently function at their rated power output. Nuclear and large thermal plants are base-load power stations. These power stations are considered to have slow ramp rates because their control period is over a span of days.
2. *Medium-load stations* have a lower capacity level than base-load stations. These stations are operated and controlled on the basis of a daily expected demand curve. Control periods usually have a range of several hours. Coal is the most widely used fuel for medium-load stations. These stations have medium ramp rates.
3. *Peak-load stations* make up for short-term variations in grid load and demand. Gas, oil, and hydropower are examples of peak-load stations. These stations have very short control periods (often times, minutes) and are considered to have fast ramp rates.

Overall, cost-effectiveness is increased when wind energy is integrated into conventional energy systems that utilize gas turbine or hydropower (fast ramp rates), rather than nuclear or coal (slow and medium ramp rates) (DeCarolis, 2006). During peak demand times, or when wind becomes intermittent, fast ramp rates allow a back up source to dispatch with greater ease. Slow ramp rate power sources, on the other hand, take a longer period to ramp up and dispatch energy (National Research Council, 2007). Ackermann (2005, p. 409) states, “In general, the costs of integrating wind energy into the power system depends on the amount of wind power in relation to the overall power market and the design of the power exchange, which can also significantly influence the requirements for secondary control.” The cost-effectiveness of a wind project results from the quality of a wind resource, the difficulty level of grid connection, the type of connection charges, the existing and required infrastructure, and the primary/secondary control measures.

CASE STUDIES

Germany

Germany generates more wind power than any other country in the world (Strachen et al., 2006). Their installed wind power capacity accounts for 39% of the world total (Wustenhagen and Bilharz, 2004). Throughout the 20th century, Germany relied heavily on domestic coal. Since the 1960s nuclear power has also become an important energy source (Jacobssan and Lauber, 2006). Within the past decade, however, Germany's production of renewable electricity has more than doubled (Wustenhagen and Bilharz, 2006). By 2002, Germany owned more than one-third of the global reserve of wind turbines (Jacobssan and Lauber, 2006). Germany has set a goal to have renewables contributing 60% of their total electricity by 2050 with an 80% reduction in carbon dioxide emissions (Jacobsson and Lauber, 2006).

The creation of a successful wind power sector in Germany is attributed to institutional changes, market formation, the formation of technology-specific advocacy coalitions, and the entry of firms and other organizations (Jacobsson and Lauber, 2006). Policies such as the Renewable Electricity Fed into the Grid (StrEG), also known as the Feed-in Law, and its predecessor the Renewable Energy Act (EEG) of 2000 are the most significant economic incentives allowing such criteria to exist (Agnolucci, 2005).

Beginning in January 1991, the Feed-in Law required utilities to open the electricity grid to renewable energy technologies. The law resulted from growing public concern about nuclear technology in the late 1980s—initiated by the Chernobyl disaster of 1985. Also, the German Physical Society warned of catastrophic climate change caused by unwise energy production. As a response to growing political pressure, the German parliament effectively passed the law with nearly unanimous support despite opposition from electric utility companies (Wustenhagen and Bilharz, 2006). Under the Feed-in Law, electricity was to be purchased by the utilities at a rate of 90% of the cost to the final customer (Jacobssan and Lauber, 2006). The law also provided federal, regional, and local support to renewable energy investors via subsidies, tax incentives, and soft loans (Wustenhagen and Bilharz, 2006). Utility company-owned plants, however, were not qualified to participate in these schemes (Agnolucci, 2006). Despite the great appeal to financial investors, Jacobssan and Lauber (2006, p. 276) clarify that, "One of the declared purposes of the law was to 'level the playing field' for renewables sourced electricity by setting feed-in rates at levels that took account of the external costs of conventional power generation." At the time, external costs to society of coal-based electricity were 3-5 Eurocents per kWh (Jacobssan and Lauber, 2006).

The Feed-in law had enormous impacts on wind energy markets in Germany. The 1989 capacity of 20 MW rapidly expanded to 490 MW capacity in 1995 (Jacobssan amd Lauber, 2006). With the emergence of a market, learning networks grew. As a result, an adequate knowledge base developed. For this reason, new entrants faced less risk and market growth perpetuated. Furthermore, the wind energy market gained political strength because suppliers and owners of wind turbines had favorable environmental *and* economic arguments (Jacobssan and Lauber, 2006).

Even though the Feed-in law successfully increased Germany's renewable sector throughout the 1990s, problems eventually began to arise. The Feed-in law was designed around local utility monopolies, but liberalization of the German energy sector in 1998 caused these monopolies to cease to exist. Furthermore, utilities in Northern Germany were increasingly burdened as wind energy generation grew in this area. The German parliament felt obligated to respond for fear of unemployment in the electricity-associated industries and decreased renewable energy investors (Jacobssan and Lauber, 2006). As a result, the Renewable Energy Act (EEG) replaced the Feed-in law in 2000. Under the Renewable Energy Act, "local grid operators can transfer the cost of their EEG payments to the next higher grid level, and at the high voltage transmission line level, costs are balanced out across Germany" (Wustenhagen and Bilharz, 2006, p.1685). This nationwide equalization scheme allows operators who purchase more than an average amount of renewable electricity to sell the difference until all operators buy equal shares. Under the Renewable Energy Act, grid operators must connect and give priority to renewable energy generators. Also, if it can be done at reasonable costs, operators must update their grids (Agnolucci, 2006). Costs of upgrading the grid can be considered when determining charges to power generators.

The Renewable Energy Act is more explicit in its purpose than the original Feed-in law. Whereas the Feed-in law, was too vague in its promotion, the Renewable Energy Act explicitly states that its purpose is to "facilitate a sustainable development of energy supply in the interest of managing global warming and protecting the environment" with plans to "double the share of renewable energy sources in total energy consumption by the year 2010" (Wustenhagen and Bilharz, 2006, p.34). An amendment to the Renewable Energy Act in 2004 further clarifies its purpose of internalizing external costs, reducing contribution to geopolitical fossil fuel conflicts, promoting renewable energy technology, and increasing renewables to a minimum of 12.5% of the electric supply by 2010 and a minimum of 20% by 2020 (Wustenhagen and Bilharz, 2006).

The United Kingdom

The UK's domestic wind power generation ranks eighth in the world (Strachen et al., 2006). By 2004, the UK had developed a wind power capacity of nearly 2,500 MW, of which

50% was on-shore and 50% was off-shore (Toke, 2005). Established goals include: doubling the 2010 renewable energy capacity by 2020 and a 60% reduction of carbon dioxide emissions by 2050 (Toke, 2005, Mitchell and Connor, 2004). Unlike Germany, the UK’s early policy towards wind generated electricity and other renewable energy technologies appear to have led the initial market development through a rough beginning by applying “an approach that stimulated adverse developments or impeded actors that were eager to invest in wind power” (Breukers and Wolsink, 2007, p. 2741). The recent energy policy has, to a certain degree, rehabilitated the UK’s renewable energy market and deployment of wind power.

In 1990, the Renewable Non-Fossil Fuel Obligation (NFFO) was adopted by the Government of the UK. 1989 saw the liberalization of the energy sector, but nuclear power generators proved difficult to privatize. As a result, “the NFFO was primarily set up as a means to subsidize nuclear generation” (Mitchell and Connor, 2004, p. 1936). The government had to request the European Commission’s permission to support ‘non-fossil fuel.’ The 1990 Electricity Act allowed the government to collect a fossil fuel levy in support of NFFO but required the support of certain renewables including wind power generation (Breukers and Wolsink, 2007).

The NFFO was sanctioned by the European Commission to assign contracts to independent bidders between 1990 and 1998 with a total of five bid sessions—NFFO-1, 2, 3, 4, and 5 (Mitchell and Connor, 2004). Originally, these government subsidy contracts were designed to end in 1998. NFFO-1 contracts called for 600 MW of renewable energy capacity, but two-thirds of this was already commissioned. Owners of the already existing renewable energy generators were already receiving government support, so very little market competition took place. NFFO-2 contracts required 1000 MW of installed ‘new’ renewable capacity. NFFO-

2 bidding proved to be almost “too competitive.” Subsidies were to begin when a renewable plant was commissioned and were valid through the 1998 end date. Bidders recognized the small time frame for guaranteed revenue and often under bid the actual costs of their projects. As a result, many projects were not completed (Mitchell and Connor, 2004).

Beginning with NFFO-3 in 1993 (and later, NFFO-4 in 1997 and NFFO-5 in 1998), the 1998 contract end date was nullified for the development of renewable energy generators. NFFO-3 set a goal of 1500 MW installed renewable energy capacity. Under these contracts, bidders were allowed a five year grace period followed by a fifteen year period of subsidization (Mitchell and Connor, 2004). Initially, NFFO-3 was viewed with optimism, but 1994 through 1997 saw very little deployment of renewables. A low cost cap for investors resulted in under bidding and no penalty system was in place to reprimand investors that did not complete their contracted projects (Mitchell and Connor, 2004). As a result of the low cost concern, a domestic turbine manufacturing industry was disadvantaged, and better turbines from abroad were imported at a lower price. In addition, local site planning and landscape issues were often ignored and many NFFO projects were never completed (Breukers and Wolsink, 2007). Investors would bid on contracts without considering local planning issues, so a majority of projects were delayed or never implemented at all.

In 1997, NFFO-4 provided contracts for 1700 MW of renewable energy. The new to power Labor Party, highly supportive of renewable energy technology and industry, also set a goal of 10% of electricity coming from renewable sources by 2010. The following year, NFFO-5 contracted 261 projects for an additional installation of 1177 MW (Mitchell and Connor, 2004). As of 2005, only 14% of the projects contracted under NFFO-3, 4, and 5 were completed (Toke, 2005). Again, the low bidding pattern and lack of consideration of local planning procedures have inhibited a majority of the projects.

In general, the NFFO resulted in a confused and disorganized UK wind energy market between 1990 and 1998. Under the NFFO, the government set the 1993 goal of achieving 1500 MW of renewable energy capacity by the year 2000, but it was not met until 2002 (Toke, 2005). The NFFO system did not operate efficiently for a variety of reasons. Mitchells and Connor (2004, p. 1936) argue that "an opportunity arose to support renewable energy, as a result of another policy. The justification behind the support of renewable energy was never clarified or widely agreed." In other words, the initial push for wind energy policy was the result of a scheme to subsidize nuclear power. The lack of clarity and goals led to an opposition of the NFFO, especially among economists who felt that the policy confined itself to carbon reduction, in which case a tax on carbon emissions or a carbon trading scheme would have proven more efficient. On the other hand, those in support of renewable energy policies recognized possibilities of technological innovation, providing diverse energy option, broadening the energy industry, and proving local benefits (Mitchell and Connor, 2004).

Recognizing the need for a more effective renewable energy policy the UK government established the Renewables Obligation (RO) in 2002 (Mitchell and Connor 2004). Under the RO, electricity suppliers are to provide 10% of their electricity from renewable energy sources (Toke, 2005). Based on the feed-in policies of Germany and the Netherlands, this system puts the responsibility on the grid operators to provide electricity from renewable energy sources. Mitchell and Connor explain (2004, p. 1939) that with the RO "the obligation is on suppliers to purchase and supply a certain amount of *generated electricity* not a contract for generation from specific projects." Overall, the RO has shown more success than the NFFO. In 2004 alone, 184

MW of wind electricity generation capacity was installed, this is significant compared to the 100 MW installed capacity achieved by 1998 under the NFFO (Breukers and Wolsink, 2007).

China

China’s domestic wind power generation market is ranked fifth in the world (Strachen et al., 2006). Wind power is the fastest-growing electricity generation technology in China. As a result of the installation of 1,450 turbines, China’s wind power capacity more than doubled in 2006 (Martinont and Junfeng, 2007). The Chinese government has established goals of 5,000 MW wind power capacity by 2010 and 30,000 MW wind power capacity by 2030 (Martinont and Junfeng, 2007).

Starting in the late 1970s, China underwent major open-door policy and economic reformations. The Chinese government relied (and still does) heavily on the burning of coal to fuel a growing economy and raise their people out of poverty (Zhang, 2007). In 1986, China initiated a policy to connect wind generated electric sources to the grid under the Seventh 5-year plan. Under this plan, four 55kW imported turbines were established in the Rongsheng province (Lema and Ruby, 2007). Small-scale demonstration farms such as this were funded by international donor countries and government investments (Junfeng et al., 2007). Despite these early attempts to foster a wind energy market in China, efforts to develop successful policy suffered from “inter-ministerial competition and disjointed policy making because ministerial units” had “separate missions and equal level of authority” (Lema and Ruby, 2007, p. 3880). The Chinese energy sector was dominated by thermal plants under “fragmented authoritarian” control. Electricity generation was under the control of the Ministry of Water Resources and Electric Power, but electricity prices were set by The State Planning Commission.

Until 1987, private investment was not permitted in China’s energy sector, but with the central government’s abandonment of its electricity generation monopoly, sub-national governments, and foreign businesses gained rights to construct and possess electric generating facilities (Lema and Ruby, 2007). The need for an overhaul of the energy sector was initiated by power shortages that put nearly one fifth of China’s industrial capacity to a standstill. The principal government organization responsible for oversight was renamed the Ministry of Electric Power, but regional governments were allowed to initiate projects up to 50 MW without involving central authorities. However, a private wind power market failed to develop. Potential investors saw no incentive to enter a market where no clear development initiatives existed and where wind power would probably not be able to compete with subsidized coal. Furthermore, the utilities lacked much needed knowledge about connecting wind energies to the electricity grid (Lema and Ruby, 2007).

In response to the failure of establishing a successful wind energy market, the Eigth 5-year Plan of 1991 set out to increase research and development (R&D) efforts. The Chinese Academy of Meteorological Science performed an assessment of China’s various regions and discovered a vast wind potential of 253 GWs at full capacity (Lema and Ruby, 2007). Installed wind capacity increased during the mid 1990s as a result of R&D efforts and growing concern about burning coal and its ill effects on the environment and human health (Lema and Ruby, 2007).

In 1994, the Chinese wind energy market gained some strength with the decision that “the grid utility should facilitate the connection of wind farms to the nearest grid and all the electricity generated by wind farms should be purchased” (Junfeng et al., 2007, p. 5). Earlier that year, the Ministry of Electric Power released the *Strategic Development Plan for Generation* *of Wind Energy in China 2000 and 2020*. The plan set a goal to install 1000 MW wind capacity by the year 2000 (Lema and Ruby, 2007). Later, the *Program for development of New and Renewable Energy sources in China 1996-2010*, developed by the State Planning Commission, the State Science and Technology Commission, and the State Economic and Trade Commission lowered the optimistic goal to 300-400 MW (Lema and Ruby, 2007). This was another case in which coordination between different authorities involved with the Chinese energy bureaucracy did not operate effectively. There was "no clearly defined division of labor between the…agencies;" as a result, "they were competing for authority to allocate funds for renewable energy projects and only loosely coordinated their policies towards the emerging sector" (Lema and Ruby, 2007, p. 3883).

Coordination problems, unstable demand, and lack of technology plagued the Chinese wind market of the 1990s; initiatives have been taken throughout the early 2000s to address these failures (Lema and Ruby, 2007). In 2003, the Chinese government implemented its Wind Power Concessions Program (Martinot and Junfeng, 2007). Under this program, the government auctions the rights to wind power development (Zhang, 2007). Investor and developers are selected through a bidding process with the goal to "expand the rate of development and improve the manufacturing capacity of domestically made parts on the one hand, and to lower power generation costs and reduce electricity prices on the other" (Junfeng et al., 2007, p. 5). With this program, 4,000 MW of wind power capacity should be installed by 2010 (Lewis, 2007). The National Renewable Energy Law of 2005 gives further support to the Concessions Program by stating that it should be utilized for a majority of wind projects in China (Lewis, 2007).

CONCLUSIONS

These case studies illustrate the learning processes that policy makers undergo when implementing wind energy into electricity grids. Energy markets are dynamic systems involving various economic concerns that influence policy. The relationship between governments, utility operators, investors/developers, and ultimately the customer, determine the ease of implementing wind and other renewable energies into a power system.

Comparing the three nations studied, Germany demonstrates the most successful use of wind energy policy. Their initial push for renewable energy, in 1991, resulted from clear environmental and economical concerns. Strong central support for a policy that allowed relatively equal access for investors led to the development of the Feed-in Law. Under this law, utilities were obligated to buy and supply a specific amount of electricity from renewable energy sources. After privatization of the energy sector in 1998, the Renewable Energy Act of 2000 readjusted the original policy to maintain an efficient market and further clarify its purpose of developing a sustainable electricity supply.

The UK, on the other hand, initialized their renewable energy policy after the privatization of their energy market in 1989. The NFFO policy was originally designed to subsidize energy from non-fossil fuel sources including nuclear. Combining nuclear and renewable energy under the same policy resulted in a lack of direction and varying support among policy makers. From 1990 to 1998, NFFO contracts were made between the government and investors under an intensive bidding process, but a majority of these contracts were never implemented as a result of low bidding, low cost cap, lack of local site considerations, and no penalty system in place for breach of contract. In 2002, the UK implemented the Renewables Obligation, a feed-in system similar to Germany’s. Under this policy, the UK has experienced a more efficient implementation of wind energy.

China’s development of wind energy policy also illustrates a lack of clarity. Conflicts between government organizations have inhibited an efficient implementation of wind energy into the power sector. Their initial drive for renewable energy sources resulted from large power shortages in the late 1980s. With little prior investment in renewable energies, the Eighth 5-year Plan of 1991 expanded China’s R&D efforts. Various coordination conflicts cursed policy and implementation efforts throughout the 1990s. Under the Wind Power Concessions Program of 2003, a bidding process similar to the UK’s NFFO was implemented. China’s optimistic goals for wind energy development under the concessions program suggests the expectation of a more positive outcome than experienced in the UK. This may be related to differing systems of government.

Overall, successful implementation of wind power and other renewables into an energy system is largely a result of policy makers providing clear goals and direction. Environmental and economic concerns may be among the greatest considerations, but many other factors also play critical roles in the renewable energy planning process. Other key considerations include the existing power sector infrastructure and system operation, ease of transmission, the concerns of local communities, and ultimately customer demand.

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