Wind Energy and Electricity Prices

Exploring the 'merit order effect'

A literature review by Pöyry for the European Wind Energy Association

Abbreviations

EUR	Euro
MOE	Merit order effect
MWh	Megawatt hours
RE	Renewable energy
RES	Renewable energy sources
GW	Gigawatts

EEX	European energy exchange
TSO	Transmission system operator
IPP	Independent power producer
EUA	European Union allowances
ETS	Emission Trading System
O&M	Operation and maintenance

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Authors:

- The section 'principles of the Merit Order Effect' is based on content written by Dr. Poul Erik Morthost, Risoe/DTU and published in 'The Economics of Wind Energy", section 3.5 (EWEA March 2009, available on www.ewea.org)
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Executive Summary

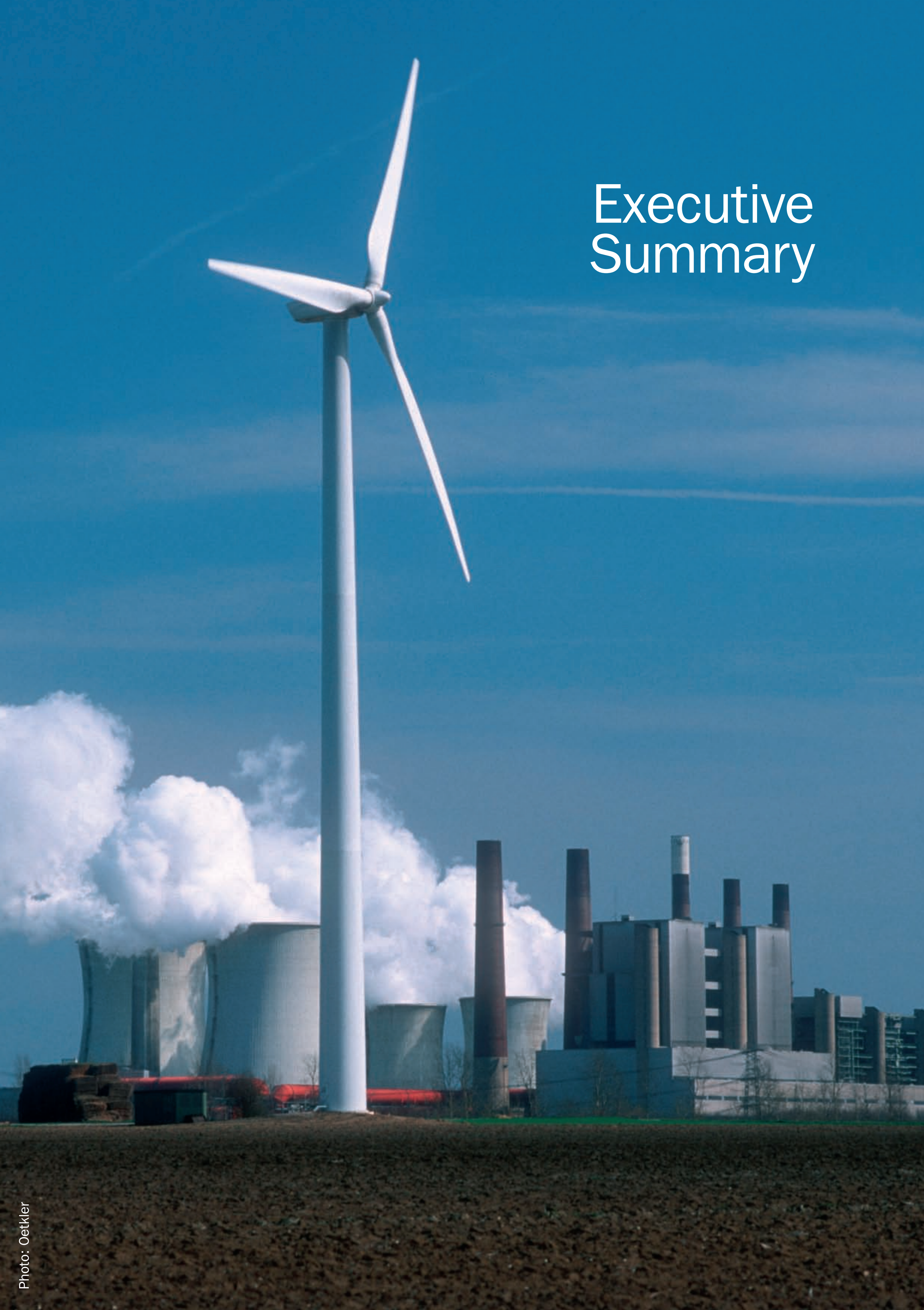


Photo: Oetkler

This report focuses on the effect of wind energy on the electricity price in the power market. As the report will discuss, adding wind into the power mix has a significant influence on the resulting price of electricity, the so called merit order effect (MOE).

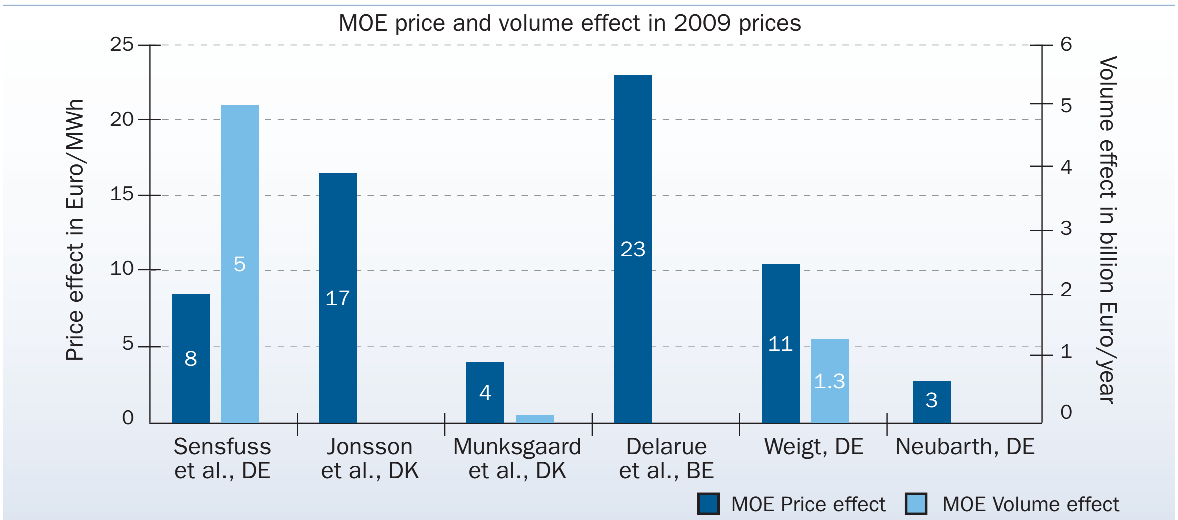
The merit order effect has been quantified and discussed in many scientific publications. This report ends the first phase of a study on the MOE carried out for EWEA by consultants Pöyry, evaluating the impact of EWEA's 2020 scenarios on future European electricity prices[1].

The basic principles of the merit order effect are provided in the first part of the document, which gives the reader the necessary background to follow the subsequent literature review. The literature review itself contains methods and tools not only to quantify the merit order effect but also in order to forecast its future range and volume.

The papers reviewed in this literature survey cover a wide range of aspects linked to the price and MOE of wind power penetration in each country. Although each paper in a specified category works with different sets of assumptions, they essentially draw similar conclusions:

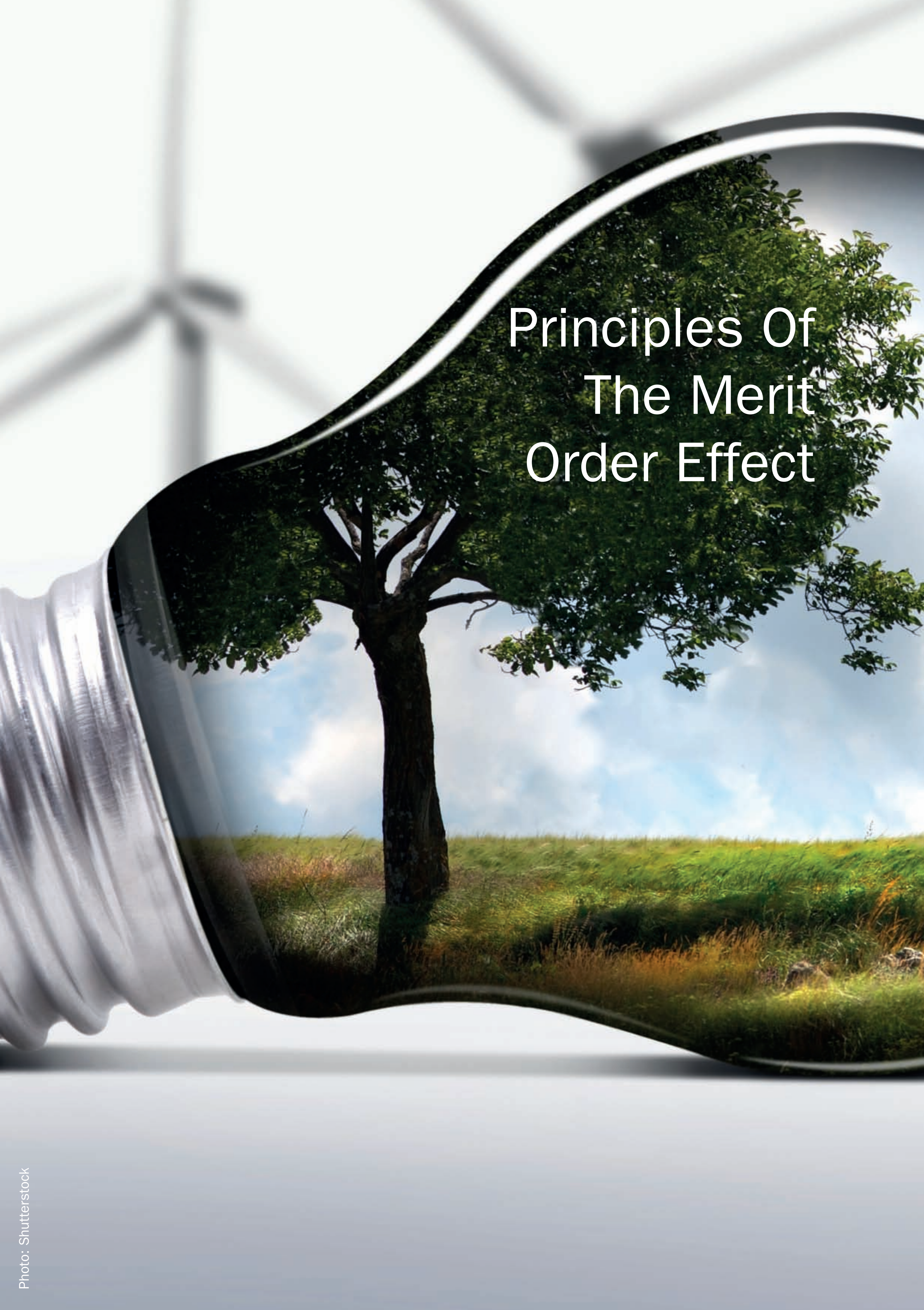
- **An increased penetration of wind power reduces wholesale spot prices.** There were instances of zero spot prices in the studies reviewed, part of which could be attributed to wind generation. Wind power also affects the merit order, resulting in MOE ranging from 3 to 23 €/MWh (see *Figure 1*).
- **Wind replaces CO_2-intensive production technologies.** The literature discusses the MOE of increased wind power in terms of the technology replaced by wind and its position in the merit order curve. During periods of low demand, the technology that sets the price in the wholesale market is usually hard coal in the countries reviewed in the papers. Wind replaces hard coal power plants during hours of low demand and gas fired power plants during hours of high demand in all these countries.
- **Wind can replace part of the base load[2].** Some of the papers discuss the potential of wind power to replace part of the base load in the respective countries or regions. The resulting argument was that wind power could replace a portion of the base load if there is a greater integration of wind producing areas such as Denmark, Germany and the Benelux into one power market.
- **Consumers pay lower prices.** The MOE and the subsequent effect of wind generation on prices was also analysed from the point of view of the end users. It shows that if both the direct and indirect cost savings from renewable energy generation were taken into consideration, the net effect of the RES support scheme would be negative, that is, the consumers would pay lower prices.

FIGURE 1: SUMMARY OF RELEVANT STUDIES AND THEIR ESTIMATED MERIT ORDER EFFECTS



Source: Pöyry

[1] For more on EWEA's 2020 scenarios, see the Pure Power report on www.ewea.org.
[2] Baseload is defined as the part of the load which is statistically guaranteed.



Principles Of The Merit Order Effect

Photo: Shutterstock

Power markets

As part of the gradual liberalisation of the EU electricity industry, power markets are increasingly being organised in a similar way. This applies to a number of liberalised power markets, including those of the Nordic countries, Germany, France and the Netherlands. Common to all these markets is the existence of five types of power market:

- **Bilateral electricity trade or OTC (over the counter) trading:** Trading takes place bilaterally outside the power exchange, and prices and amounts are not made public.

- **The day-ahead market (spot market):** A physical market in which prices and amounts are based on supply and demand. The resulting prices and the overall amounts traded are made public. The spot market is a day-ahead market where bidding closes at noon for deliveries from midnight and 24 hours ahead.

- **The intraday market:** There is quite a time difference between close of bidding on the day-ahead market and on the regulating power market (below). The intraday market was therefore introduced as an 'in between market', where participants in the day-ahead market can trade bilaterally. Usually, the one-hour long power contract is traded. Prices are published and based on supply and demand.

- **The regulating power market (RPM):** A real-time market covering operation within the hour. The main function of the RPM is to provide power regulation to counteract imbalances related to day-ahead planned operation. The demand side of this market is made up of transmission system operators (TSOs) alone, and approved participants on the supply side include both electricity producers and consumers.

- **The balancing market:** This market is linked to the RPM and handles participant imbalances recorded during the previous 24-hour period of operation. The TSO acts alone on the supply side to settle imbalances. Participants with imbalances on the spot market are price takers on the RPM/balance market.

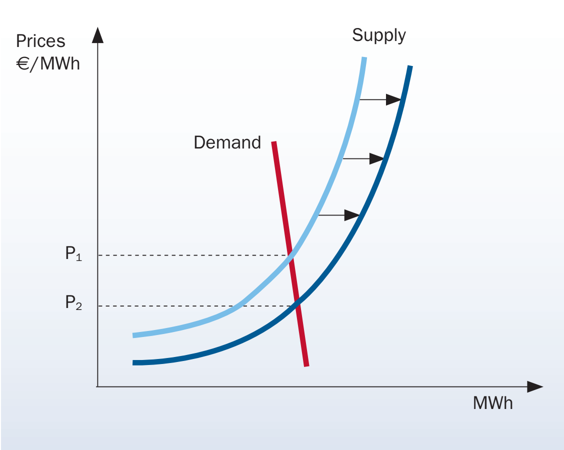
The day-ahead and regulating markets are particularly important for the development and integration of wind power in the power systems.

Supply and demand curves

The basic concept of determination of the price in a market is shown in *Figure 2*. The figure shows a demand curve and a supply curve and the point where they meet, which determines the price.

The demand curve in *Figure 2* is relatively steep. This means that the demand is inelastic, that is, it remains almost unchanged in spite of a change in price.

FIGURE 2: TYPICAL SUPPLY AND DEMAND CURVES



Source: EWEA

Inelastic demand is a characteristic of goods that are a necessity. The substitutes for these goods are few and difficult to obtain. Power and electricity fall into this category as they are vital goods seen as essential for the existence of modern civilisation.

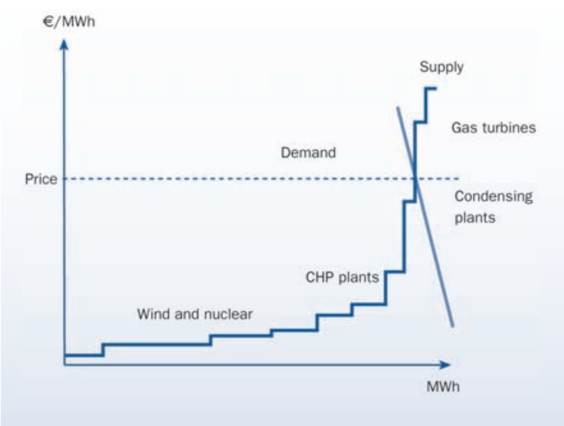
As demand is inelastic, minor changes in the supply can result in major price changes. Adding wind power into the generation mix will affect the supply curve, the supply curve will shift, and a new price will be determined as a result of market dynamics.

Supply and demand in the power market

The supply and demand curve in the power market is presented in *Figure 3*. Typically, the power portfolio is made up of a range of power technologies: wind, nuclear, combined heat and power plants, and condensing plants and gas turbines. The ordering of the power supply of each of these players depends on the amount of power they can supply and the cost of this power.

Figure 3 shows a typical example of an annual supply and demand curve. In a power market, the supply curve is called the 'merit order curve'. As seen in *Figure 3*, such curves go from the least expensive to the most expensive units and present the costs and capacities of all generators. Each unit is shown as a step in the 'curve'. The differences between costs are mainly due to the technology used and the fuel it consumes. As shown, the bids from nuclear and wind power enter the supply curve at the lowest level, due to their low marginal costs, followed by combined heat and power plants, while condensing plants are those with the highest marginal costs of power production. Note that hydro power is not identified in the figure, since bids from hydro tend to be strategic and depend on precipitation and the level of water in reservoirs.

FIGURE 3: ANNUAL SUPPLY AND DEMAND CURVES IN THE POWER MARKET



Source: EWEA Economics of Wind

How does wind power influence the power price on the spot market?

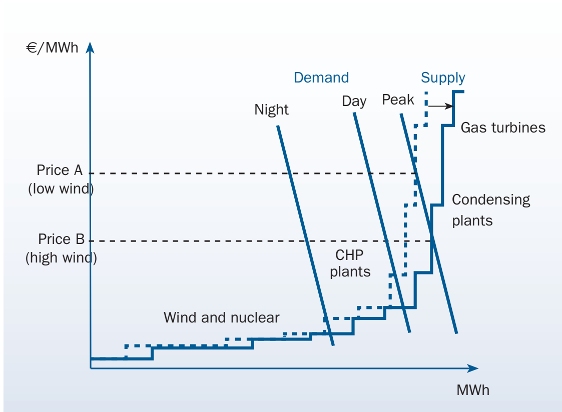
Wind power is expected to influence prices on the power market in two ways:

- Wind power normally has a low marginal cost (zero fuel costs) and therefore enters near the bottom of the supply curve. Graphically, this shifts the supply curve to the right (see *Figure 4*), resulting in a lower power price, depending on the price elasticity of the power demand. In the figure below, the price is reduced from Price A to Price B when wind power decreases during peak demand. In general, the price of power is expected to be lower during periods with high wind than in periods with low wind. This is called the 'merit order effect'.

- As mentioned above, there may be congestion in power transmission, especially during periods with high wind power generation. Thus, if the available transmission capacity cannot cope with the required power export, the supply area is separated from the rest of the power market and constitutes its own pricing area. With an excess supply of power in this area, conventional power plants have to reduce their production, since it is generally not economically or environmentally desirable to limit the power production of wind. In most cases, this will lead to a lower power price in the sub-market.

The way in which wind power influences the power spot price due to its low marginal cost is shown in *Figure 4.*

FIGURE 4: EFFECT OF WIND POWER AT DIFFERENT TIMES OF THE DAY



Source: EWEA Economics of Wind

When the supply of wind power increases, it shifts the power supply curve to the right of the figure. At a given demand, this implies a lower spot price on the power market, as shown. However, the impact of wind power depends on the time of the day. If there is plenty of wind power at midday, during the peak power demand, most of the available generation will be used. This implies that we are at the steep part of the supply curve

(see *Figure 4*) and, consequently, wind power will have a strong impact, reducing the spot power price significantly (from Price A to Price B in *Figure 4*). But if there is plenty of wind-produced electricity during the night, when power demand is low and most power is produced on base load plants, we are at the flat part of the supply curve and consequently the impact of wind power on the spot price is low.

Impact of wind power on spot prices

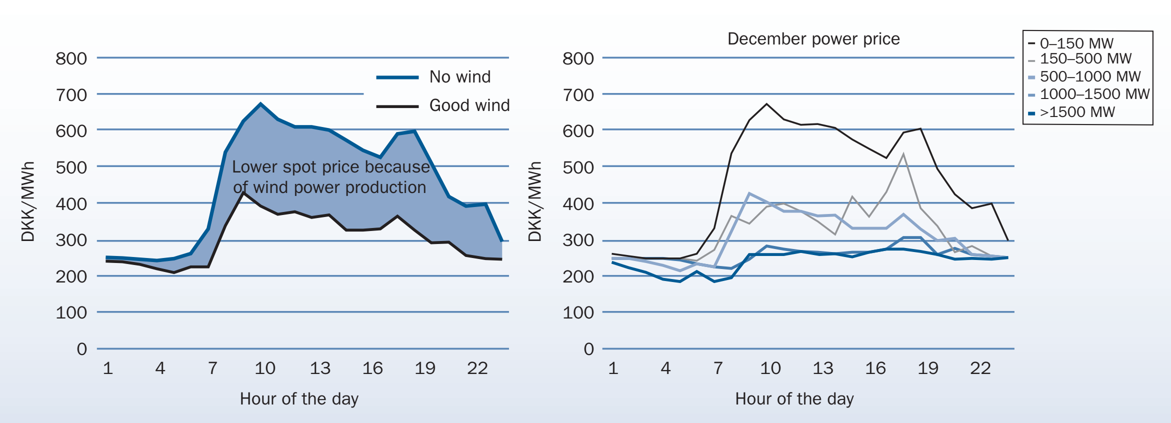
Structural analyses are used to quantify the impact of wind power on power spot prices. A reference is fixed, corresponding to a situation with zero contribution from wind power in the power system. As more wind comes onto the system the effect is calculated at different levels. This is illustrated in the left-hand graph in *Figure 5*, where the shaded area between the two curves gives an approximate value of wind power in terms of lower spot power prices.

The right-hand graph in *Figure 5* gives figures from the West Denmark area. Five levels of wind power production and the corresponding power prices are depicted for each hour of the day in December 2005. The reference is given by the '0-150 MW' curve, which includes those hours of the month when the wind was not blowing. Therefore, this line on the graph provides approximate prices for an average day in December 2005, in a situation with zero contribution from wind power.

The other lines on the graph show increasing levels of wind power production: the 150-500 MW curve shows a situation with low wind, increasing to storm levels in the >1,500 MW curve. As shown, the higher the wind power production, the lower the spot power price. At very high levels of wind power production, the power price is reduced significantly during the day, but only falls slightly during the night. Thus, there is a significant impact on the power price, which might increase in the long term if even larger shares of wind power are fed into the system. *Figure 5* is based on data from December 2005, but similar data is found for most other periods during 2004 and 2005, especially in autumn and winter, owing to the high production of wind power in these time periods.

Of course, 'noise' in the estimations does exist, as there is some overlap between curves for the different categories of wind power. Thus, a high amount of wind power does not always imply a lower spot price than low wind power production, indicating that significant statistical uncertainty exists. And of course, factors other than wind power production also influence

FIGURE 5: THE IMPACT OF WIND POWER ON THE SPOT POWER PRICE IN THE WEST DENMARK POWER SYSTEM IN DECEMBER 2005



Note: The calculation only shows how the production contribution from wind power influences power prices when the wind is blowing. The analysis cannot be used to answer the question 'What would the power price have been if wind power was not part of the energy system?'

Source: Riso DTU

prices on the spot market. But the close correlation between wind power and spot prices is clearly verified by a regression analysis carried out using the West Denmark data for 2005, where a significant relationship was found between power prices, wind power production and power consumption. When wind power reduces the spot power price, it has a significant influence on the price of power for consumers. When the spot price is lowered, this is beneficial to all power consumers, since the reduction in price applies to all electricity traded – not only to electricity generated by wind power.


Photo: de Beer

Literature Review

Photo: Faulkner/Benn

On behalf of EWEA, Pöyry analysed various studies on the impact of wind on power markets. Pöyry focuses on some key areas and topics related to the merit order effect and investigates how they are covered in the different studies.

The review talks about a "price effect". This refers to the MOE per megawatt hour (MWh). The "volume effect" is also mentioned, and refers to the total savings brought about by wind power penetration during a particular year.

As part of the review, a matrix was prepared (see Appendix), to highlight which issues are directly or indirectly addressed in the different studies, and to provide an overview. The key areas analysed in the review are:

a) Approach and model
b) Key assumptions
c) Actual MOE in terms of price and volume effect
d) Key parameters sensitivities analysed and their results
e) What kind of conventional technology wind capacities replace
f) Main conclusions
g) Pöyry's assessment

The selected papers deal with the impacts of increased wind power capacity and indicate the price or cost effect of increased wind power on the electricity market. However, only a few papers really focus on the effects on the electricity price, whereas others focus on related topics such as impacts on subsidy schemes or market design. In the matrix in annex, the papers are categorised into the following headings based on their core focus:

I. Effect of wind power on spot and wholesale prices, producing a merit order effect
II. Direct and indirect benefits of renewable energy support (RES) schemes for end users
III. Wind power and the power system infrastructure

I. Wind power's merit order effect on spot and wholesale prices

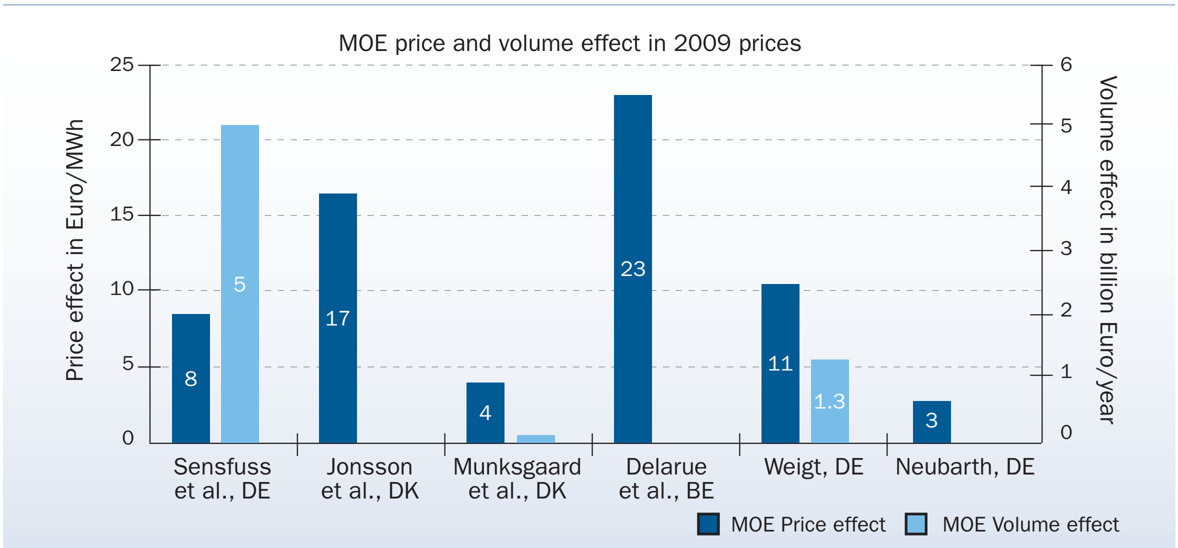
Literature

The papers reviewed cover a wide range of prices and MOE effects from wind power penetration in each country. Although each paper in each of the specified categories uses different sets of assumptions they essentially draw similar conclusions. The general conclusion in all of them is that there is a downward movement of wholesale/spot prices, due to increased wind power penetration. There were instances of zero spot prices, part of which could be attributed to wind generation. Wind power also affects the merit order resulting in a merit order effect. The papers specify, dependent on their main assumptions, an MOE range of 3-23 €/MWh.

Only a few of the studies indicate the total amount of savings made due to the wind power penetration during a particular year. For Germany, two studies evaluate the volume effect of increased wind power within a range of €1.3–5 billion per year. The Danish volume effect is put by one study at €0.1 billion for 2006. However, all these figures depend heavily on certain assumptions such as the assumed wind penetration level, the power generation mix and the marginal costs of the replaced conventional technology.

Figure 6 below summarises the results.

FIGURE 6: SUMMARY OF RELEVANT STUDIES AND THEIR ESTIMATED MERIT ORDER EFFECTS



Source: Pöyry

Moreover, the literature discusses the MOE of increased wind power in terms of the technology replaced by wind and its position in the merit order curve. During periods of low demand, the technology that sets the price in the wholesale market is usually hard coal in the countries reviewed. Wind replaces hard coal power plants during hours of low demand and gas fired power plants during hours of high demand in all these countries. Sensfuss et al. quantified the annual MOE for Germany based on spot price analysis. Some of the papers discuss the potential of wind power to replace a part of the base load in the respective countries or regions. They conclude that there is a possibility of wind power replacing a small portion of the base load if there is a larger integration of wind producing areas such as Denmark, Germany and Benelux.

The most important and relevant papers are summarised in the table provided in the Appendix to this report. These papers assess the merit order effect of wind on wholesale or spot prices.

The second group of papers, referred to in Section 2, analyse the MOE and the effect of wind generation on power prices from the point of view of the end users. The key question was whether the RES support schemes result in higher costs for the consumers? Studies by Bode et al. and Miera et al. conclude that, if both the direct and indirect cost savings from renewable energy generation are taken into consideration, the net effect of the RES support scheme would be negative, that is, the consumers actually pay lower prices. The main argument is that when wind power replaces high cost peak load plants (which are mainly hard coal and gas fired), savings are made in terms of fuel costs. Additional savings are made due to the reduction in compliance cost within the EU's ETS market mechanism – that is, having to buy the utilities having fewer carbon credits to buy because wind emits no CO_2.

The third group of papers reviewed mainly focused on the effect of wind power on the power system and carbon emissions as referred to in Section 3. It was observed by Goransson et al. that not only the variable costs but also the start-up and shut-down costs play a significant role in the dispatch of power in the system. Increased wind power penetration will cause the capacity factor of units with low start-up and shut-down costs to decrease more that those with high start-up and shut-down costs.

One observation that is common to all the papers reviewed here is that all the results and conclusions were based on past historic data and none on any forecasts for future years. Especially given the 2020 targets for renewable energy, it would be useful to have an idea of the possible price effects in 2020 or later years, when there will be even more renewables in the system. Also, the studies focus on single countries - there is a need for a study which encompasses all the wind generating countries in the EU, so that they can be analysed under the same set of assumptions and provide a picture of the future. This study will be carried out by Pöyry for EWEA in 2010.

Photo: GWEC

Wind power's merit order effect on spot and wholesale prices

1.1 *Sensfuss, Frank, Ragwitz, Mario and Genoese, Massimo. (2007). Merit Order Effect: A Detailed Analysis of the Price Effect of Renewable Electricity Generation on Spot Prices in Germany. Fraunhofer Institute Systems and Innovation Research. Energy Policy 36 (2008) 3086– 3094.*

Abstract

The paper measures the merit order effect (MOE) of renewable energy generation on German electricity spot prices in 2006. The key assumptions in the paper were as follows:

- Electricity demand in the short term is inelastic[3] with respect to day-ahead markets
- All electricity is traded on the simulated spot market
- Renewable energy generation had no major impact on the development of the power plant portfolio. This means the decision to invest in new RE capacity does not affect the decision to invest in conventional capacity.

Methodology

The bid price for power plants is based on variable cost and start up cost. A calibrated PowerACE[4] model was used to run simulations from 2001-2006. The simulations were run once with renewable electricity (RE) production supported by feed-in tariffs, and run a second time without them, in order to measure the MOE of the renewables.

Results

The results show that the impact of RE production in electricity spot prices during the low-load period is zero, while it reaches up to 36 €/MWh in hours of peak demand. However, this difference is attributed to the steepness of the German supply curve, which is higher in cases of high demand. The final results show a reduction in the average market price of 7.83 €/MWh in 2006 due to renewables – this is the MOE of renewable energy production. The total volume of the MOE in 2006 was €4.98 billion. The paper also uses another indicator from the consumer perspective, which is the ratio of the merit-order effect to the electricity generated by RE sources. This indicator reaches 95.4 €/MWh, while the average specific tariff for renewable electricity stood at 109 €/MWh in 2006. A few sensitivity analyses were also been carried out in the study:

- *Variation in fuel prices:* A range of fuel prices of +/- 20% were studied to capture their MOE. Lignite, nuclear and fuel oil plants had limited impact on the spot prices, while gas and hard coal price variation has the maximum impact. This is because the price setting units in Germany are mostly gas and coal. A gas price reduction by 20% caused a MOE of around 30% while hard coal had an opposite impact between 9-11% on the MOE.

- *Variation in RE capacity:* The RE capacity was varied in steps of 20% to capture the MOE and it was observed that when RE capacity grew by 40% the MOE grew by 31%.

- *Scarcity mark-up:* The scarcity mark-up is a premium that is added to the bid price. It is a quantitative representation of the scarcity value of a capacity and depends on the expected ratio of available generation capacity to demand. The lower the ratio, the higher the scarcity mark-up. In the simulations, the scarcity mark-up was added to the bid-price to capture its MOE. The scarcity mark-up increased the MOE by around €0.7 billion in 2005 and 2006.

- *Carbon prices:* Simulations were also run with varying carbon prices and it was observed that a rise in the daily carbon price from 0 to 40 €/tonne leads to a reduction of the MOE of around 16%. This phenomenon according to the paper is rather surprising at the onset. This is explained in the study by a separate simulation consider-

[3] Inelastic electricity demand implies that demand does not change with change in electricity prices.

[4] The PowerACE is a research project on effects of emissions trading and the increased use of renewable energy sources on power markets that was conducted from 2004-2007. Many research institutions were involved in the projects team and it was funded by Volkswagen Stiftung.

ing a hypothetical portfolio of five hard coal and six gas fired plants, showing the different effects of the change in carbon prices on the slope of the merit order curve. The study explains that the volume of MOE is largely dependent on the steepness of the merit-order curve[5].

For certain technologies, like gas turbines, the increasing carbon prices increase the slope of the merit-order curve since the impact of efficiencies on generation cost increases, which should increase the MOE of the RE generation. Another important aspect is the impact of switching fuels. Higher carbon prices move hard coal power plants up within the merit–order curve, decreasing the slope of the shoulder and peak load segment. As a result the MOE decreases. The extent of both these effects depends heavily on the position of the technologies within the merit-order curve, which is dependent on the hourly RE generation and the total electricity demand. In addition, the study states that the actual size of both effects depends on the relation of gas and coal prices and the carbon price. Therefore, the aim of this simplified analysis was to highlight the complexity of the effects determining the impact of carbon prices on the MOE.

Lastly, the paper examines the effect of RE generation on the overall power portfolio to measure the MOE with the assumption that with a new power portfolio the merit-order curve would be different, and as a result the volume of the MOE would also vary. The authors conclude that RE generation through feed-in schemes affected neither investments in new capacity up to 2006 nor the decommissioning and strong change of existing capacity between 2005 and 2006. However, the 'possible' impact of a modified power plant portfolio on the MOE was assessed by simulating a new portfolio taking into account the retirement of all decommissioned power plants with a life-time of less than 30 years and an adapted merit order curve due to addition of RE capacity. The result was a MOE of €2.1 billion in 2006.

1.2 Jonsson, Tryggvi, Pinson, Pierre and Madsen, Henrik. (2009). Day-Ahead Electricity Prices in Denmark: The Impact of Wind Power Forecasts, and On the Market Impact of Wind Energy Forecasts. Energy Economics (2009) 10.018.

Abstract

Both papers mentioned above are by the same authors and reach similar conclusions. The main difference between them is that the first paper provides quantitative results. Therefore, all quantitative results from these authors should be assumed to have come from the first paper. The results present an analysis of how the spot prices in West Denmark are affected by wind power forecasts. The analysis emphasises the effects of such forecasts on the mean behaviour of prices, the intra-day variations of these effects and their impact on the distributional characteristics of the day-ahead market.

Methodology

A non-parametric regression model was used for the analysis. In order to capture the MOE it assumes two scenarios, that is, the wind does not blow versus the wind does blow. The papers demonstrate that the ratio between the wind generation forecast and the load forecast has the strongest effect on the spot prices. The impact of wind power generation on the day-ahead spot prices is quite substantial. However, the report says that the extent of this impact is difficult to point out. The paper explains, using an example, that when the forecast wind penetration is under 4% there is little or no effect on spot prices, but with a forecast of 11% wind or more, the spot prices gradually decrease.

Results

Sensitivities were varied, simulating a RE penetration between 20%-80% of the total power demand. The effect on the price (that is, the difference between the no wind blows and the wind does blow scenarios) was 25-30 €/MWh for periods of predicted low wind penetration,

[5] When the merit order curve is steeper i.e., when the slope of the curve is increased, the MOE is higher as compared to a flatter merit order curve with reduced slope.

(40%) and 33- 35 €/MWh during periods for which high wind penetration was predicted (80%). During the night, the average price varies from around 30 €/MWh when low wind power production was forecasted down to around 18 €/MWh for hours with large amounts of wind power production forecast, while during the day the difference between the two extremes – low forecasts and high ones - is larger, as prices go down from 50-55 €/MWh down to 30 €/MWh. On average, prices drop by 17.5% when the wind power penetration exceeds 4%. In Denmark, where the target is to have up to 50% of electricity consumption from wind, there will be more instances of zero spot prices. This will make investment in future capacities less attractive. Wind power has non-linear effects on prices, which implies that the current market situation cannot be scaled directly in order to analyse future circumstances. The share of other RES (biomass, solar and wave) should also be monitored, as should their impact on the effect of wind power. They will play an important role in the future development of the market structure.

1.3 Bach, Paul Erik. (2009). Effect of Wind Power on Spot Prices. Renewable Energy Foundation. London, UK.

The volatility of the spot market prices is used as an indicator of the quality of the wind resource and the interconnector capacity available. There is no model in this paper. The approach is simplistic: only data from statistical graphs is analysed. This paper concludes that a definitive opinion cannot be given as to whether wind power contributes to higher or lower average spot prices. The argument given against the hypothesis that lower wind power penetration causes spot prices to increase, is that even if conventional capacity is available, it may take days to bring a unit from a state of long-term reserve into a state of operational reserve. Wind power does contribute to a reduction in prices, but interconnector capacities play a very significant role in bringing the price to zero at times. For example, the report claims that Swedish congestion policy is the reason for unstable prices in East Denmark. Sweden tries to maintain uniform prices in all price areas, which means internal bottle-necks are transferred into reduced trading capacity between East Denmark and Sweden. The cost of capacity reductions should be studied while considering the large-scale integration of wind power.

1.4 Nicolsi, Marco and Fürsch, Michaela. (2009). The Impact of Increasing the Share of RES-E on the Conventional Power Market - The example of Germany. Zeitschrift fuer Energiewirtschaft 03/2009.

Abstract

The paper analyses the short-term and long-term effects of wind power on the spot prices. The key assumption is that power demand normally stays around the same level.

The paper agrees that the variability of wind power leads to a drop in day-ahead spot prices. But it investigates the short-term price effect that could lead to an adaptation process in the conventional generation capacity mix in the long run. The paper demonstrates that in the long run a higher peak load plant share is required to cope with the increasing volatility of the residual demand[6]. The result is an adapted merit-order curve[7], which will intersect with an increasingly volatile residual demand curve and lead to higher price volatility in the power market. This will trigger further adaptations in the conventional generation capacity mix.

Methodology

The analysis does not make use of a specific model. Instead it shows, with the help of statistical historical data, that there is a negative correlation between the wind power in-feed and the power prices. Furthermore, it indicates that there is a strong correlation between the load and power prices. As a next logical step, the analysis combines these two parameters in order to receive the residual load and its price correlation.

[6] Residual demand: the difference between the total demand the total wind in-feed i.e., the demand that is left after part of the total demand is met by wind capacity.

[7] The variability of wind power brings about a drop in day-ahead spot prices. Data from Germany illustrates this effect and explains the underlying relationships. This short-term price effect leads to an adaptation process in the conventional generation capacity mix. In the long run, a higher peak load plant share is required to cope with the increasing volatility of the residual demand. The result is an adapted merit-order effect.

Results

The main conclusions of this paper are that the correlation between load and spot prices is much higher than the correlation between wind in-feed and spot prices. While the short-term effect of wind is the lowering of prices, in the long term there is an effect on the conventional capacity as well. Wind can make up a small amount of capacity credit[8] as a result of which some base load capacities will be displaced. However, this percentage is very small. The paper provides the example of Dena (2005), which showed that wind capacity of 14.5 MW in 2003 in Germany had a capacity credit of between 7% and 9%, meaning that between 1.0 and 1.3 GW of conventional capacities can be substituted. One important implication is that an increasing penetration reduces the relative capacity credit.

The study mentioned above also calculated that the 35.9 GW wind capacity considered in 2015 would be have a capacity credit of only 5-6%. The result of a high RES-E in-feed with a relatively low capacity credit is an increase in peak load capacity and a drop in base load capacity, and is not quantified in the paper. The steepness of the merit-order curve will also change in the long run due to this phenomenon. In 2008, the total load deviation was 42,451 MW, while the difference between the maximum and minimum wind power in-feed was only 18,911 MW during the year. It is the fluctuation in the residual demand that is greater than the deviation in total demand. This effect is expected to increase with the addition of 38 GW of wind power capacity by 2020 as the minimum residual demand (low load and high wind) will decrease with increasing wind capacity. The reasoning behind this is that certain RES-E, notably wind power, provide a relatively high energy amount, but contribute little to an adequate power system due to their low capacity credit. If the volatile wind power in-feed leads to an increasingly fluctuating inelastic residual demand curve, the power price becomes increasingly volatile.

1.5 Munksgaard, Jesper and Morthorst, Poul Erik. (2008). Wind Power in the Danish Liberalised Power Market - Policy Measures, Price Impact and Investor Incentives. Energy Policy (2008).07.024.

Abstract

This paper analyses the impact of wind on the spot market price on hourly basis with and without the wind power capacity included in the power system. The assumptions are not clearly specified in this paper, mainly because Munksgaard and Morthorst are referring to a study by Østergaard et al. from 2006. The main focus in the paper is on the redesign of wind power policy measures following the Danish electricity reform in 2000 and the impacts on incentives to invest in new wind power capacity.

Methodology

The paper analyses the economic impacts of the measures with regard to the wind power producer and the electricity consumer. This is done by comparing the payment to wind power producers with the spot-market price. First, the subsidy paid to wind power producers is evaluated and then the authors analyse whether larger amounts of wind power have an impact on the spot power price. Finally, the analysis compares the revenue from wind power production with the costs of production in order to assess whether an incentive exists to invest in wind power. No modelling tool is used. The analysis is based on a comparison between forecast data and actual data on subsidies and power price levels.

Results

The main conclusion of the paper is that the fact that Danish wind power tariffs were redesigned in 2000 does not by itself constitute a reason for the current Danish recession in new wind power installations. The main causes of the recession could include a combination of problems such as spatial planning, the high risk aversion of new investors and perhaps more favourable support schemes in other countries. On the merit order

[8] Capacity credit: The generation capacity which has guaranteed availability.

issue, the paper concludes that consumer electricity prices would have been 0.1-0.4 c€/kWh higher from 2004-6 if there had been no wind power production.

The paper also analyses some sensitivities at varying levels of wind power in MW on an hourly basis. The sensitivity results show that in a "no wind" situation (under 500 MW), prices can increase by up to 600 DKK/MWh (80 €/MWh) and in an "extreme wind situation"[9], spot prices on hourly basis are reduced to a range of approximately 250 €/MWh (34 €/MWh when wind power production exceeds 1,500 MW). These figures reflect price extremes which are very unlikely; nevertheless, the paper concludes that the extreme scenarios would lead to a decreased spot price of 12-14% in West Denmark and 2-5% in East Denmark.

1.6 Delarue, Erik. D., Luickx, Patrick J. and D'haeseleer, William D. (2009). The Actual Effect of Wind Power on Overall Electricity Generation Costs and CO_2 Emissions. Energy Conversion and Management 50 (2009) 1450–1456.

Abstract

The paper analyses the effect of wind power on the cost of power generation. It models the variable nature of wind power. The results of the paper are relevant for countries with a diverse mix of technologies, such as Belgium. The paper does note the effect on the merit order, since it discusses the technologies replaced; however, the effect is not been quantified.

Methodology

This paper uses an optimisation model to determine the effects of wind power on the cost of electricity generation and carbon emissions in Belgium. The model used is mixed integer linear programming (MILP) and has the characteristics of an advance unit commitment (UC) model[10]. In the first step a regular UC day-ahead optimisation is executed and in the second step a real-time dispatch is executed. The paper considers the gate closure time – assumed to be 24 hour ahead – to be an important determinant of the accuracy of wind power prediction. It also models the errors in wind power forecasts, which it assumes to be a key factor. Four kinds of wind profile are matched with four kinds of load profile to make 16 simulations in total.

Results

The paper concludes that assuming the price of coal to be 5.4 €/MWh and gas 11.5 €/MWh, the cost of electricity of a 35% efficient coal fired plant becomes 15.4 €/MWh and for a 50% efficient gas fired plants becomes 23 €/MWh. The total fuel cost reductions amount to 56,000 €/MW of installed wind capacity, which translates into 23.3 €/MWh. However, different forecast accuracies for wind power generation do not have any significant impact on generation cost and CO_2 reduction. In the case of low load levels and high wind output, coal-fired plants are replaced. In other cases, such as high wind, high load or low load, low wind, it is mostly gas fired plants that are replaced. But on average in this Belgian case study, electricity from wind replaces the equivalent of a 50% efficient combined cycle gas turbine (CCGT) plant.

1.7 Weigt, Hannes. (2008). Germany's Wind Energy: The Potential for Fossil Capacity Replacement and Cost Saving. Applied Energy 86 (2009) 1857–1863.

Abstract

This paper analyses the potential of wind energy to replace fossil fuel capacity and the eventual cost saving this would bring about. The paper discusses the MOE potential of wind power and this is tested in a three step process. First, the off-peak load segment is tested for potential replacement; second, the mid-load plants are estimated, and finally the peak segment is analysed[11].

[9] When wind power penetration exceed 1,500 MW.

[10] According to the paper the model takes into account a wide set of technical constraints of power plants. To take wind power and its limited unpredictable character into account properly, a specific algorithm has been developed. In a first step, a regular day-ahead unit commitment (UC) optimisation is performed, applying with a certain forecast of wind power. In a second step, the real-time dispatch is executed. Each hour of the day, the activated plants are dispatched, now taking the actual wind power output into account.

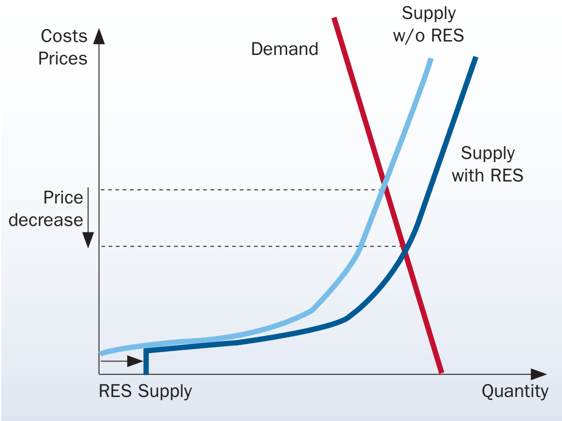
Methodology

To perform their analysis, the authors built a market model to estimate the differences in production costs and market prices caused by wind penetration. It is an optimisation model with the objective function of meeting the demand in a least-cost manner. The model is a static model with respect to the underlying parameters. The export and import of electricity and small scale generation from solar, biomass and other distributed generation have not been considered.

Results

The main conclusion of the paper is that wind generation has a downward impact on both prices and generation costs. During the observation period, a total saving of €4.1 billion is observed (€1.3 bn in 2006, €1.5 bn in 2007 and €1.3 bn in the first half of 2008). The significant increase in savings is due to the increase in EUA's prices in 2008. On average the price reduction is around 10 €/MWh, going up from 2006 to 2008. The price impact varies for different times (and different load levels). Whereas during off-peak hours the impact on increased wind generation is rather small, there is a significant reduction during peak hours. This can be explained by the impact of wind generation on the merit curve of electricity markets. Electricity markets typically face a relatively flat supply curve in the beginning and a rapid slope increase in peak-load levels. Given that wind has no fuel costs it is added at the left side of the merit order curve, shifting the whole curve to the right. During off-peak times this shift has little price impact due to the flat gradient. However, during peak times even a small shift can cause significant price differences. This is explained in *Figure 7*.

FIGURE 7: MERIT ORDER EFFECT OF RES



Source: Weigt

Savings from reduced market prices are roughly in the same range as the additional expenses that come from feed-in tariffs. However, the possible savings from reductions in emission allowance prices indicate that the overall impact would be to bring the price down. Besides the pure market effect, there is also an indirect effect in terms of saving on fuel costs. The conventional capacity replacement potential is not proven although there was reduction of 4 GW capacity observed during the period which could not be attributed to wind power. However, if a larger area such as Denmark, Benelux and Poland is integrated then it will increase the potential of wind generation to replace installed conventional capacity.

1.8 Neubarth, Jürgen. (2006). Influence of Wind Electricity Generation on Spot Prices (Beeinflussung der Spotmarktpreise durch Windstromerzeugung). Energiewirtschaftliche Tagesfragen 56. Jg. (2006) Issue 7.

Abstract

This study focuses on the role of the TSO and how it deals with uncertainties in wind generation, its forecasts and its related extra costs due to the need for balancing power. The MOE calculation is only a by-product of the analyses and does not relate to any future forecast. The analysis is made with actual and historical data. The study compares hourly forecasts for production by wind operators reported to the TSO from 1 September 2004 to 31 August 2005, with the corresponding spot prices at the EEX auction.

[11] The dataset is divided in time-of-day subsets: base (0am–12pm), off-peak (8pm–8am), mid-load (8am–8pm), noon (11am–1pm), and evening (5pm–7pm).

Methodology

The paper compares statistical data for wind prognosis and spot market prices. No specific modelling tool was used in the analysis, and only actual and historical data (2004 - 2005) were used.

Results

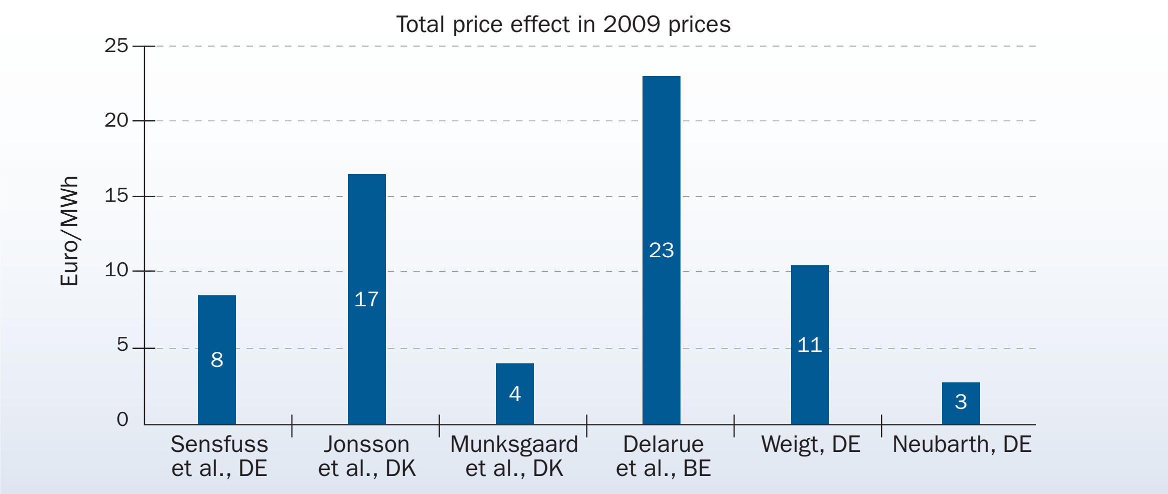
It was observed that, due to market dynamics and the lower marginal costs of wind power compared to conventional power, the spot electricity prices decrease by 1.9 €/MWh per additional 1,000 MW wind capacity in the system. This refers to the daily average values of market prices. The only sensitivity analysis is done by calculating a different "average value": annual averages show a MOE of 2.7 €/MWh. The main conclusion is that the uncertainty of wind prognosis is in the 5% range. Because of this, the TSO has an additional cost to balance differences of prognosis and obligations to the electricity traders. These costs are correlated to the wind generation volume but cannot easily be predicted. However, the TSO could be allowed to add these extra costs onto the grid fee.

Conclusions

The papers above have been categorised together as they all deal with the effect of wind power on the spot prices of a particular country. Four of the papers (Sensfuss et al., Jonsson et al., Munksgaard et al., Weigt and Neubarth) estimate the effect of wind power generation on the hourly spot prices in Germany and Denmark. Weigt's paper looks at the cost savings in conventional capacity due to wind generation, putting them at 11 €/MWh (converted to 2009 prices for comparability). However, this has still been included in Figure 8, with the assumption that the cost saving he describes is due to a reduction in price. Bach and Nicolsi et al. do not indicate any effect on the price. Although each of the papers has a different set of assumptions, it is still interesting to see the range of effects on the price they show. The following figure shows the effect on the price in €/MWh calibrated to 2009 prices[12].

Jonsson et al. give price effects separately for day time and night time. The average of the two prices has

FIGURE 8: PRICE EFFECT OF WIND CAPACITY PENETRATION – LITERATURE COMPARISON



Source: Pöyry

[12] The Euro Zone Consumer Price Index (HCIP) was used to calculate at 2009 prices.

TABLE 1: THE PRICE EFFECTS OF INCREASED WIND POWER AND ITS ASSUMPTIONS – LITERATURE REVIEW

Study	Country	Scenarios/Variables	Year of study	MOE Price effect	MOE Volume effect	Gross electricity production in the year	Percentage of electricity from Wind	Average spot price during the year
				EUR/MWh	Billion EUR	TWh	%	EUR/MWh
Sensfuss et al.	DE	Wind generation increase in 2006	2006	8	5	621	4.5	≈ 65
Jonsson et al.	DK	Per additional 1000MW	2004-05	17		36*	18.3*	≈ 35.5*
Munksgaard et al.	DK	A comparison with a no wind scenario	2004-06	4	0.1	45.6**	13.4**	≈ 46.5**
Delarue et al.	BE	Pure fuel cost saving	2008	23		95.6#	5.1#	≈ 65
Weigt	DE	Difference of 40% & 80% wind penetration	2008	11	1.3	633	6.4	≈ 44
Neubarth	DE	Increase in wind generation from 2006-08	2006-08	3		627	5.45	≈ 54

* for 2005 - ** for 2006 - # for 2007

Sources[13]

been taken for this graph. It can be observed that there is a wide variation in the effect on the price. One obvious reason is the differences in the assumptions but other reasons could be the different countries and regions analysed. While papers from Sensfuss et al. and Neubarth use German spot market prices, Munksgaard et al. refer to Danish spot prices and Jonsson et al. use the spot prices of West Denmark only. The most important variable for the determination of the effect on prices is the costs of the marginal conventional technology which wind is replacing.

In order better to understand the results from the different studies, we have summarised the main assumptions and results in the table below. It indicates which wind generation volume the price effect refers to and what the related average spot market price was in the year in question.

Furthermore, Sensfuss et al. also assume that the entire demand is traded on the spot market, which might be a possible reason why the effect on prices is lower than in Denmark. As explicitly mentioned in this paper, the extent of the effect largely depends on the steepness of the merit order curve, which differs from country to country.

Another aspect which is thoroughly analysed in *Sensfuss et al.* is the effect of fuel and carbon price changes on the MOE. A rise in the carbon prices of €40 has resulted in a reduction in the MOE of 16% in Germany. Similarly, gas and hard coal prices have the highest impact on the MOE. In Bach's paper, the key factor in causing extreme price fluctuations was considered to be the availability of interconnector capacities rather than wind power penetration. In most cases, wind displaces the technologies at the top of the merit order, which are the most expensive, but the paper of Nicolsi et al discusses whether wind can constitute a small amount of capacity credit in Germany. That is, whether wind could displace a tiny portion of the base load in the long run. In Belgium, it displaces CCGT capacity running at 50% efficiency level. The papers also mention occurrences of zero spot prices. The conclusion is that with increased capacity addition, there will be more instances of zero prices in the spot market. However, according to Bach and Weigt, as wind-producing regions are integrated into the European power market through new grid interconnectors, there will be minimal zero spot prices[14].

[13] Spot prices derive from Nordpool (http://www.nordpoolspot.com/reports/areaprice/Post.aspx) and the European Commission's Statistical Yearbook 2010; wind generation volumes derive from the Danish Energy Agency (2009), the German Environmental Ministry (2009) and the European Commission (2009).

[14] The occurrence of zero spot prices implies non intersection of the supply and demand due to over supply. Bach assumed such extreme spot prices as indicator of a poorly served market; however, Weigt does not provide any opinion.

II. Direct and indirect benefits of renewable energy support (RES) schemes such as feed-in tariffs for end users

Literature

2.1 Bode, Sven. (2006). Impact of Renewable Energy Support Schemes on Power Prices. Hamburger WeltwirtschaftsInstitute. HWWI Research Paper 4-7.

Abstract

This paper analyses the effect of RES support schemes on the net price of power paid by the consumer. It was shown that the net effect of RES support schemes on the price paid by the consumer is largely dependent on the slope of the supply curve.

Results

Taking only the power costs to be the main cost elements, in most of the cases the net effect is positive, which means that power costs for the consumers increase due to the implementation of RE support schemes. However, with steeper supply curves the net effect may become negative, which implies that the power costs paid by the consumers decrease. The sensitivities carried out in the paper are all price changes measured with changes in RE production with varying slope of the supply curve. With a slope of 0.0001, wholesale price decreased by 1 €/MWh (€20.96 to 19.96 or, 4.76%) with an increase in RE production from zero to 10,000 MWh. With a slope of 0.001, the price decreases by 9.8 €/MWh (€73.53 to €63.73 or 9.8%).

2.2 Miera, Gonzalo Sáenz, Del Río Gonzáles, Pablo, Vizciano, Ignacio. (2008). Analysing the Impact of Renewable Energy Support Schemes on Power Prices: The Case of Wind Energy in Spain. Energy Policy 36 (2008) 3345– 3359.

Abstract

This paper presents an analysis of the direct effect of wind power on wholesale prices in Spain. The key assumption is that there is a perfectly competitive electricity system, which is in equilibrium. The power system is exclusively based on thermal technologies – which is indeed the case in the Spanish system. The main hypothesis tested in this paper is that wind energy pushes down the wholesale electricity market for two reasons. Firstly, displacing marginal technology with higher marginal costs, such as gas and secondly, wind energy leads to lower electricity demand from conventional capacities, leading to reduced demand for CO_2 credit to meet compliance requirements. The paper tried to test the above hypothesis with the help of past data on wholesale prices and wind penetration levels.

Results

The paper concludes that wind power has a *direct effect* on wholesale prices, whereas RES support schemes result in lower wholesale power prices. Therefore there is a net reduction in the retail electricity price. However this is a short-term effect and a new higher equilibrium price is reached in the medium and long term. The ease with which the new equilibrium[15] between supply

[15] According to the paper, in equilibrium, the market price only depends on the relationship between the costs of the different conventional (thermal-based) technologies, which is unaffected by the penetration of wind electricity.

and demand is reached will determine the extent to which wind generation is able to reduce the market price. The *indirect effect* is a reduction in demand for CO_2 allowances, which are necessary to comply with the EU ETS targets and that those allowances cost less (since there a lower demand for them).

Conclusions

The two papers above mainly analyse the costs and benefits of RES support schemes from the point of view of the end user. According to them, the net effect of RES support schemes can cause the consumer to pay lower tariffs. This is mainly due to two things: firstly, the replacement of high cost conventional fuel generation by RE generation and the subsequent fuel cost reduction, and secondly, less expenditure on compliance with the EU-ETS targets. Bode's paper, however, mentions that the actual effect is largely dependent on the slope of the supply curve. With a steeper supply curve, the net effect might be negative – that is, the end users' tariff may decrease due to RES support schemes.

Photo: GWEC

III. Wind power and the power system infrastructure

Literature

3.1 *Goransson, Lisa and Johnsson, Filip. (2008). Dispatch Modelling of a Regional Power Generation System: Integrating Wind Power. Renewable Energy 34 (2009) 1040–1049.*

Abstract

The paper studies the effect of the large-scale integration of variable wind power into a power generation system, that is a system which includes large thermal plants normally used for base load operation. It demonstrates how the introduction of wind power production changes the dispatch order of the large thermal power plants in the West Denmark system so that the plant with the lowest running costs no longer has the highest capacity factor. The different power plant technologies used in most power generation systems exhibit large differences in production characteristics with respect to average load hours, generation costs, part load performance and controllability. In terms of these properties there is obviously a great difference between wind power plants and thermal power plants. While thermal power plants use an energy source which can be stored (fuel), wind power plants rely on the fluctuating wind speed for their electricity production. A thermal unit can reach rated power on demand whereas this is obviously not possible for a wind power plant. Thus, despite the high availability of the wind turbines (98%), the capacity factor (sometimes referred to as the load factor) rarely reaches beyond 30% for onshore wind power and 40% for offshore wind power. Therefore, one installed megawatt of wind power cannot replace 1 MW of thermal power. So, as low-cost wind power is introduced into a power system the capacity factor of the other units in the system will decrease. The extent of the drop depends on the ability of the unit to adjust its production pattern to the wind power production, relative to the ability of other units in the system to adjust their production and, to some extent, to export capacities to some region outside that of the system in dispatch. It is shown that this effect is only detected if start-up performance and minimum load level limitations are included in the optimisation.

Methodology

The paper uses Mixed Integer Programming (MIP)[16] to assess the impact of the variability of wind power on thermal power plants in the regional electricity grid system in West Denmark. The model evaluates which dispatch alternative is favourable from a systems perspective – that is, satisfying demand while minimising system costs. The optimisation considers the start-up and turn-down costs[17] as well as minimum load level for a large thermal plant. The running cost of the decentralised power units are broken down into three components - O&M, fuel and CO_2 costs, which have been taken as 20 €/tonne. Power demand is inelastic and there is transmission capacity constraint. 3,500 MW of wind capacity can be added to the system without any reinforcement of the electricity grid. For the sensitivity analysis, three wind power situations were considered:

- No wind
- Wind capacity of 2,375 MW (2005 levels) which

[16] Linear programming (LP) is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for a list of requirements represented as linear equations. If the unknown variables are all required to be integers, then the problem is called an integer programming (IP) or integer linear programming (ILP) problem. If only some of the unknown variables are required to be integers, then the problem is called a mixed integer programming (MIP) problem.

[17] Starting up a power plant causes costs even before the actual production of electricity starts. For example, the power plant's boiler has to be pre-heated and the plant has to be synchronised with the grid. These costs can be significant. Similarly, there are costs incurred for shutting down a power plant as well due to damage caused to the equipment.

corresponded to 24% of the yearly load
- 50% increase in the existing capacity from 2005, that is, 3,561 MW and 34% penetration

Results

The paper concludes that start up costs and a minimum load limit currently play a significant role in the dispatch of power. With increased power production and high-cost gas power plants in use, the difference in costs will increase and the difference in emissions will decrease in no wind and current wind situations. The costs and emissions at the current wind level (2005) will be 4% and 5% lower. In winter time, simulated power production in the centralised units is mainly due to heat demand, therefore wind power penetration has less of an impact on carbon emissions. This trend is reversed during the summer months. The paper concludes that an increase in the amount of wind power reduces the periods of constant production and the length of these periods. The capacity factor of units with low start-up and turn-down performances and high minimum load level will decrease more than the capacity factor of units with high start-up and turn-down performance and/or low minimum load level.

3.2 *European Wind Energy Association. (2009). TradeWind: Integrating Wind - Developing Europe's power market for the large-scale integration of wind power.*

Abstract

The long-term objective of TradeWind is to facilitate the dismantling of barriers to the large-scale integration of wind into European power systems on transnational and European levels. It aims to formulate recommendations for policy development, market rules and interconnector allocation methods in order to remove unjustifiable barriers to wind power integration. The area studied is the EU-27, and includes the transmission networks in the synchronous zones of UCTE, Nordel, GB and Ireland. The TradeWind analysis uses the simulation of cross-border power flows in European transmission systems with future wind power capacity scenarios, representations of present and future network configurations and simulation of market behaviour with different market rules. In this way, it can examine and quantify the effect of increasing wind power penetration on power flows in European grids.

Results

With the help of the WILMAR and PROSYM tools[18], the study evaluates system costs because the energy economic context sets the basis from which any further improvement of market rules leads to a reduction of operational costs of power generation. The macroeconomic cost savings of wind power replacing conventional sources are calculated at 42 €/MWh. This macro-economic cost saving represents the reduction in operational costs of power generation by adding more wind and also by adding more transmission. These are the estimated effect on the marginal costs of a fuel mix with less conventional power generation and more wind. These costs do not take account of the capital costs in power plants, wind plants and also not of the cost of the support schemes for renewables.

But along with this cost reduction, the study explains that wind power also contributes to a significant reduction of wholesale power prices in the different countries. The reduction in the average power price due to wind depends strongly on the country. Based on the wind power capacity installed in 2008, the study anticipates how much could be installed by 2020 and looks at the price reduction due to wind power in each country, which does not exceed 16 €/MWh.

In general, the TradeWind study focused on the benefits of improved interconnection assuming

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[18] WILMAR tool, see www.WILMAR.risoe.dk; PROSYM (Proprietary Hourly Power System Evaluation Model) see www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/TradeWind_Report_01.pdf, page 39.

that with greater transmission capacity it is easier to dispatch the economically optimised generation mix.

3.3 *Deutsche Energie Agentur (DENA). (2005). Integration into the national grid of onshore and offshore wind energy generated in Germany by the year 2020. Grid Study I*

Abstract

The study focuses on technical and organisational solutions which make 30% electricity from renewables possible in the period 2015 to 2020. It bases itself on the assumption that the grid enhancement and extension measures required for the integration of 20% renewables will have been implemented by then. First of all, the study drafts scenarios for the increased use of renewable energy sources. The primary element of the scenarios is a geographically differentiated scenario for wind power development onshore and offshore, with the assignment of wind power feed-in to particular network nodes. Based upon these scenarios, the effects of wind power feed-in on the transmission network and on generation mix are investigated. Weak points in the power system are identified and solutions developed. The following aspects are being examined in the second part of the study which will be published in 2010:

- Forecasting the quality of wind energy fed into the grid and future electricity consumption

- Flexible electricity supply mechanisms
- Demand-side management
- Wind turbines providing balancing and reserve power
- The use of storage technologies
- Comparing suitable means of transporting wind-powered electricity to load centres inland
- Reliability of the electricity supply, even under difficult conditions
- The current capacity of overhead lines depending on the ambient temperature and wind speeds (temperature monitoring), and the use of high temperature conductors.

Conclusions

The three studies above mainly focus on grid infrastructure, that is, on transmission capacities and dispatch mechanisms which are affected by wind power or which affect the transmission of wind power. There is not much discussion in these studies of the effect on prices or the MOE effect of wind power, but they throw light on the technical aspects of wind integration into the system.

Photo: Getty

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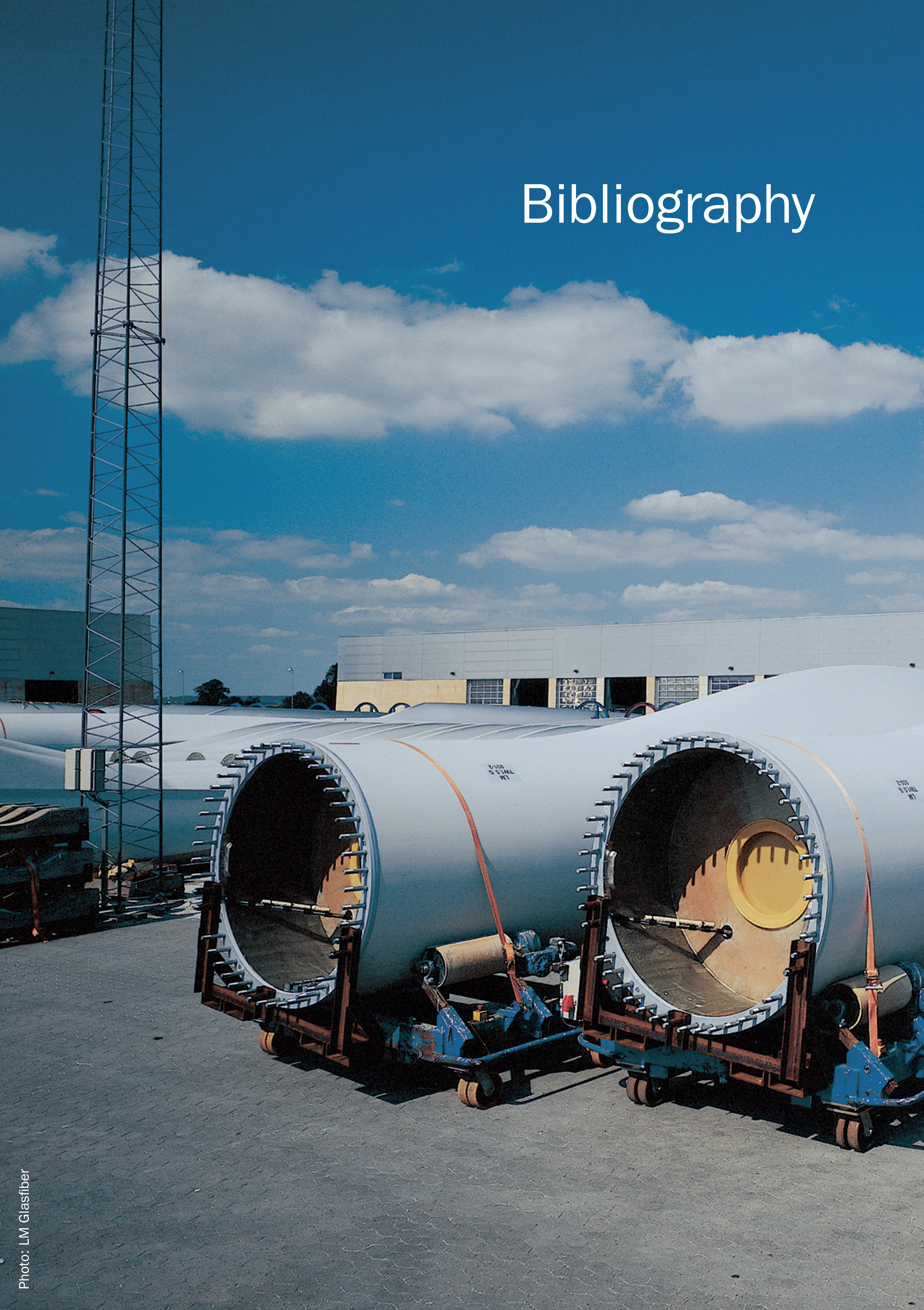

Photo: LM Glasfiber

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Nr.	Paper	Time period of study & country	Approach & model	Key assumptions	MOE - price effect (€/MWh)*	MOE - volume effect (billion €)*	Installed capacity of wind (GW)	Wind capacity as percent (%) of total capacity
1,1	The Merit Order Effect: A detailed analysis of the price effect of renewable energy generation on spot market prices in Germany - Frank Sensfuss	2006, Germany	Simulations with and without RE generation - PowerACE Model.	Assumes RE capacity supported by feed-in tariff exists in both simulations but does not produce in one of the scenarios to capture the MOE.	7,83	4,98	4.4 - 14.7 (varying RE load in selected periods of the year).	
1,2	Day-Ahead Electricity Prices in Denmark: The Impact of Wind Power Forecasts - Tryggvi Jonsson	Jan 2006 to Oct 2007, Western Denmark (DK1) price area	Assessment of effects of wind power forecasts on spot prices - Non-parametric regression model.	1) Assumes that wind capacity exist but does not produce i.e., wind does not blow vis-à-vis wind blows to capture MOE; 2) Ratio between the forecasts for wind generation and load has the strongest association with the spot prices.	Price effect of 25-30 for periods of low wind penetration forecasts (40%) and 33-35 during periods of high wind penetration forecasts (80%).	Not calculated.	Not mentioned.	Varied penetration between 20%-80% of the total power demand.
1,3	Effect of Wind Power on Spot Prices - Paul Erik Bach	2008, Denmark	There is no model run in this paper. The approach is simplistic with analysis of data from statistical graphs only.	Volatility of the spot market prices is used as an indicator of the quality of resource allocation and interconnector capacity availability.				
1,4	The Impact of increasing Share of RES-E on the Conventional Power Market - Marco Noclsi et al. 2009	2008, Germany	The paper analyses the short-term and long-term effects of wind power on the spot prices.	Demand is perfectly inelastic i.e., the demand curve is vertical.				
1,5	Munksgaard, J and P E Morthorst 2008: Wind power in the Danish liberalized power market–Policy measures, price impact and investor incentives. Energy Policy 2008	2006, Denmark	Impact on spot market price on hourly basis has been analyzed with and without actual wind power capacity included in the power system (Poul Erik: What kind of model has been used in the Østergaard et al 2006 study?)	Difficult to detect as the price impact analysis was made in Østergaard et al 2006.	2004: 1.0; 2005: 4; 2006: 2.5	Not calculated. However, total Danish consumption figures are included. In 2004: 35.3 TWh; in 2005: 35.5 TWh; in 2006: 36.1 TWh.		
1,6	The actual effect of wind power on overall electricity generation costs and CO_2 emissions - Erik. D Delarue et al.	2005 - Western Denmark	This paper uses a simulation model to determine the effects of wind power on cost of electricity generation and CO_2 emissions. The Model used is mixed integer linear programming (MILP) and has the characteristic of an advance unit commitment (UC) model. In the first step a regular UC -day-ahead optimization is executed and in the second step a real-time dispatch is executed.	1) The gate closure time has been considered as an important determinant of the accuracy of wind power prediction. This paper assumed 24 hr ahead gate closure time. 2) The error in wind power prediction has been modeled and it was assumed to be a key factor.	1) Cost effect - fuel cost reductions of 56 k€ per MW of installed wind capacity which translated into 23.3 €/MWh; 2) CO_2 emission reduction - 1.26 kton per MW.	The yearly volume effect was not estimated.	In this paper the wind power penetration level is considered up to 1500 MW. Results of many simulations have come out infeasible otherwise.	
1,7	Germany's wind energy: The potential for fossil capacity replacement and cost saving - Hannes Weigt	2006-08, Germany	First, the off-peak load segment is tested for potential replacement, second, the mid-load plants are estimated and finally the peak segment is analyzed. Based on the wind input data a market model has been constructed to estimate the differences in production costs and market prices caused by wind penetration. It is an optimization model with the objective function of meeting the demand in a least -cost manner.	1) The model is a static model with respect to the underlying parameters; 2) Export and import of electricity has not been considered in the model; 3) Small scale generation by solar, biomass and other distributed generation have not been considered.	10 €/MWh	During the observation period, a total saving of 4.1 billion € is observed (1.3 in 2006, 1.5 in 2007 and 1.3 in 2008 first half). The significant increase in saving is due to the re-increase in prices of EUA in 2008.	2006 - 30 TWh. 2007 -40 TWH and 22TWh in first half of 2008.	
1,8	Beeinflussung der Spotmarktpreise durch Windstromerzeugung - Neubarth	2004-2005 , publication in 2006 - Germany	No special modeling tool. The approach is to compare statistical data for wind prognosis and spot market prices.	The analysis is only done with actual and historical data. No forecasting! The study compared reported hourly forecasts for production by wind operators reported to the TSO in the time period 1 Sept 2004 - 31 Aug 2005 with the corresponding spot prices at the EEX auction.	1.9 -2.7 €/MWh		18 000 MW	13% of total German installed capacity.

Technology replaced by wind	Sensitivities	Sensitivity results	Do they meet the 2020 RE targets?	Main conclusion	Pöyry's comments
Hard coal during hours of low demand and gas during hours of high demand.	1) Varying fuel prices; 2) varying CO_2 prices; 3) varying RE capapcity; 4) varying scarcity mark -up, and 5) varying power plant portfolio.	1) Lignite, fuel oil and nuclear had no MOE. Gas and hard coal had the highest MOE; 2) Simulations were also run with varying carbon prices and it was observed that a rise in the daily carbon price from 0 to 40 EUR/ton leads to a reduction of the MOE by circa 16%.	Nothing mentioned	The slope of the merit-order curve is the most important factor behind the volume of the MOE.	The paper examines the impact of all RE technologies supported by feed-in tariff schemes. Thus the results do not capture the price effect of only wind power generation on the spot prices.
	Varying levels of wind power penetration.		Nothing mentioned	1) The impact of wind power generation on the day-ahead spot prices is quite substantial. In Denmark, where the target is to have up to 50% of the electricity consumption from wind, there will be more instances of zero spot prices. This will make investments in future capacities less attractive. 2) Since wind power has non-linear effects on prices, it implies that the current market situation cannot be scaled directly for analyzing future circumstances. The share of other RES (solar & wave) should also be monitored and whether they level out the effect of wind power or magnify them will play an important role in future development of the market structure.	The paper shows the non-linear relation between wind power generation and spot prices but it does not specifically study the MOE and as such does not discuss the technologies that are displaced by wind. It also does not mention the total wind capacity in the system but only the penetration percentage in a particular time in a day. On the whole, the effect on spot prices is the main focus and not the MOE i.e., the per MWh price change due to displacement of other technologies.
				1) Wind power does contribute to the reduction in prices but interconnector capacities play a very significant role in bringing the price to zero at times. For example, the Swedish congestion policy is the reason for unstable prices in East Denmark. Therefore the cost of capacity reductions should be studied while considering large scale integration of wind power.	1) The paper could not give a definitive opinion on whether wind power contributed to higher or lower average spot prices. This is due to several dependencies such as demand level, available interconnector capacities, congestion policies, bidding policies and uncontrollable generation; 2) There is no analysis of MOE or any quantification of the MOE or any other price effect in this study.
The technology replaced has not been mentioned in the paper, but it argues that in the long term some base load plants (which are coal, lignite & nuclear in Germany) will be replaced.			The paper assumed that the 2020 target will be met. But this does not have any impact on the conclusions since this assumption is not used in any statistical analysis or modeling.	1) The correlation between load and spot prices is much higher than the correlation between wind infeed and spot prices. 2) While the short term effect of wind is lowering prices, in the long term there is an effect on the conventional capacity as well. Wind can constitute a small amount of capacity credit as a result of which some base load capacities will be displaced. However, this percentage is very small. Therefore, the result of the RES-E infeed with a relatively low capacity credit is an increase in peak load capacity and decrease in base load capacity. 3) The slope of the merit-order curve will also change in the long run due to this. 4) In 2008, the total load deviation was 42,451 MW while the difference between the maximum and minimum wind power infeed was only 18,911 MW. It is the fluctuation in the residual demand that is greater than the deviation in total demand. This effect is expected to increase with 38 GW installation of wind power capacity by 2020 i.e., the minimum residual demand (low load & high wind) will decrease with increasing wind capacity.	This paper stresses that it is not wind, but the residual load (actual load minus the wind infeed) that affects the spot prices. If the volatile wind power infeed leads to an increasingly fluctuating inelastic demand curve, the power price becomes increasingly volatile. The difference from other papers is that, it claims that in the long run wind power will displace base load plants as it will constitute a (small) proportion of the capacity credit in Germany. Therefore the MOE is at the base load.
Hard coal during hours of low demand and gas during hours of high demand.	The impact on the spot market price of electricity from varying levels of wind power production in MW is analyzed on hourly basis for Western Denmark.	From approx. 600 DKK/MWh in situations with no wind, spot prices on hourly basis are reduced to a range of app. 250 DKK/MWh when wind power production exceeds 1,500 MW.	Nothing mentioned	Main conclusion of the paper is that the redesign of Danish wind power tariffs in 2000 does not by itself make evidence for the actual Danish recession in new wind-power installations after the electricity reform. The main causes could include a combination of problems in spatial planning, high risk aversion of new wind turbine investors and perhaps more favorable support schemes in other countries. On the merit order issue, the paper concludes, that consumer electricity prices would have been 0.1- 0.4 c€/kWh higher in the period 2004-06 if wind power production had been absent.	With regard to impact of wind-power production on spot market prices of electricity the study by Munksgaard and Morthorst is referring to a study by Østergaard et al 2006. Consequently, not much information is supplied on the approach for analysis. The reason is that main focus in the paper is on the redesign of wind power policy measures following the Danish electricity reform in 2000 and the impacts on incentives to invest in new wind power capacity.
In the case of low load level and high wind output, coal-fired plants are replaced. In other cases e.g., high wind high load or low load low wind, mostly gas fired plants are replaced. But on the average in this Belgian case study, electricity from wind on an average is equivalent in replacing a 50% efficient CCGT plant.	Four kinds of wind profile are matched with four kinds of load profile to make 16 simulations in total.	Not mentioned explicitly		1) Average savings in generation costs due to wind was estimated at 23.3 €/ MWh. Assuming the price of coal to be 5.4 €/MWh and gas 11.5 €/MWh, the cost of electricity of a 35% efficient coal fired plant becomes 15.4 €/MWh and for a 50% efficient gas fired plants it becomes 23 €/MWh. This in the Belgian case study, electricity from wind on an average is equivalent in replacing a 50% efficient CCGT plant; 2) Different forecast accuracies of wind power generation however do not have any significant impact on generation cost and CO_2 reduction.	This paper analyses the effect of wind power on cost of generation and not wholesale or spot prices. It models the intermittent nature of wind power. The results of the paper are relevant for countries with a diverse mix of technologies such as Belgium. It does capture the effect on the merit order in the form of discussion on technologies replaced; however, the effect has not been quantified.
				1) Wind generation has a decreasing impact on both the prices and generation costs. On the average the price reduction of 10 €/MWh with an increasing trend from 2006 to 2008. 2) The price effect is most prominent during peak hours than off peak hours since wind is added to the left of the merit-order curve where it is almost horizontal. 3) Saving from reduced market prices is roughly the same range as the additional expenses due to feed- in tariffs. However, when the possible savings from reduction in emission allowance prices indicated that the overall impact on the price is positive. 4) Besides the pure market effect there is also an indirect effect in terms of saving of fuel costs 5) The conventional capacity replacement potential is not proven although there was reduction of 4 GW capacity observed during the period but that could not be attributed to wind power. However, if a larger area is integrated such as Denmark, the Benelux and Poland then it will increase the potential of wind generation to replace installed conventional capacity.	This paper focuses on the reserve capacity and wind impact upon both generation costs and market prices. The potential of wind energy to replace installed conventional generation capacities is studied which shows that the existing data does not provide evidence for a significant capacity credit of wind energy.
	The only sensitivity is done by calculating a different "Average value": Annual average instead of daily averages indicate figures showing a MOE of 2.7 €/MWh.			Wind prognosis is uncertain and its average forecasting error lies at 5%. Because of this, the TSO has an additional cost to balance differences of prognosis and obligations to the el-traders. These costs are correlated with the wind generation volume but can hardly be forecasted. However, it should be allowed for the TSO to carry forward these extra costs to the grid fee.	This study is not 100% focused on the MOE. Instead, it focuses on the role of the TSO and how it deals with uncertain wind generation and its related extra costs. Hence, the MOE calculation is only a by-product of the analyses and does not relate to any future forecast.

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2,1	Impact of Renewable Energy Support Schemes on Power Prices – Sven Bode	Germany	Price changes measured with changes in RE production with varying slope of the supply curve.	1) Competitive market; 2) Linear aggregated supply & demand curve.	1) The price effect is dependent on the slope of the supply curve. With a slope of 0.0001, wholesale price decreased by € 1 (20.96 to 19.96€: 4.76%) with an increase in RE production from zero to 10,000 MWh. 2) With slope 0.001 price decreases by 9.8€ (73.53€ to 63.73€ - 9.8%).			
2,2	Analysing the Impact of Renewable Energy Support Schemes on Power Prices: The Case of Wind Energy in Spain - Gonzalo Sáenz Miera	2007, Spain	Analysis of the direct effect of wind power on wholesale prices has been based on the assumption of a perfectly competitive electricity system, which is in equilibrium and according to the conditions of the electricity market in Spain, is exclusively based on thermal technologies.	Wind energy pushes down the wholesale electricity market for two reasons: 1) displacing marginal technology having higher MC and 2) wind energy leads to lower electricity demand, leading to reduced demand for CO_2 credit to meet the compliance requirements.			In 2006 the installed capacity was 11,728 GW and total generation 22,941 GWh.	10% of the electricity demand in Spain in 2007.
3,1	Dispatch modeling of a regional power generation system - Integrating wind power - Lisa Goransson	Western Denmark	1)The paper uses the Mixed Integer Programming (MIP) to assess the impact of intermittency of wind power on thermal power plants in the regional electricity grid system; 2) The model evaluates which dispatch alternative is favorable from a systems perspective i.e., satisfying demand while minimising the system costs. The optimisation considers the start up and turn down costs was well as minimum load level for a large thermal plant.	1) The running cost of the decentralised power units are broken down into three components - O&M , fuel and CO_2 costs. The CO_2 cost has been assumed at 20 €/tonne; 2) power demand is inelastic; 3) There is in transmission capacity constraint and 3,500 MW of wind capacity can be added to the system without any reinforcement of the electricity grid.				
3,2	Trade Wind - Integrating Wind in Europe - EWEA	EU 27	The long-term objective of TradeWind is to facilitate the dismantling of barriers to the large-scale integration of wind into European power systems on transnational and European levels. It aims to formulate recommendations for policy development, market rules and interconnector allocation methods in order to remove unjustifiable barriers to wind power integration. The scoped area is the EU-27, and includes the transmission networks in the synchronous zones of UCTE, Nordel, GB and Ireland. The TradeWind analysis uses the simulation of cross border power flows in European transmission systems using future wind power capacity scenarios, representations of present and future network configurations and simulation of market behavior with different market rules. In this way, it can examine and quantify the effect of increasing wind power penetration on power flows in European grids.					
3,3	DENA Grid Study I	Germany, 2005	The study focuses on technical and organisational solutions which make a 30 per cent contribution by renewable sources to the electricity generated possible in the period 2015 to 2020. It builds upon the conclusions that the grid enhancement and extension measures required for the integration of 20% renewables have been implemented. First of all, the study drafted scenarios for the increased use of renewable energy sources. The primary aspect here was a geographically differentiated scenario for wind-power development onshore and offshore, with the assignment of wind-power feed-in to particular network nodes. Based upon these scenarios, the effects of wind power feed-in on the transmission network and on the power station park were investigated. Weak points in the power system have been identified and solutions developed.					
13	On the market impact of wind energy forecasts - Tryggvi Jónsson	Jan 2006-oct 2007, Western Denmark	This paper presents an analysis of how the spot prices in Western Denmark are affected by wind power forecasts. The analysis puts emphasis on the effects of such forecasts on the mean behaviour of prices, on the intra-day variations of these effects and impact on the distributional characteristics of the day-ahead market. A non-parametric regression model has been used for the analysis. For estimation, a least squares criterion is employed allowing for the mean effect of the forecasted wind power penetration on the prices to be extracted.	Considers wind power as a price -maker instead of a price taker.	12 €/MWh during low wind prediction and 20-25 €/MWh during high wind prediction.		2,400 MW of installed capacity with actual penetration of 1,500 MW.	

Technology replaced by wind	Sensitivities	Sensitivity results	Do they meet the 2020 RE targets?	Main conclusion	Pöyry's comments
				1) Even though support schemes are financed by consumers, in the long run power costs of consumers may decrease due to them. However, the net effect very much depends on the slope of the supply curve. In most of the cases (i.e., different slopes) the net effect has been positive, which means that power costs for the consumers increase due to the implementation of the of RE support Schemes. 2) With steeper supply curves the new effect may become negative.	This paper provides some analysis on the effect of the RES support schemes on the net price of power paid by the consumer. While it was shown that the net effect of RES support schemes on the price paid by the consumer is largely dependent on the slope of the supply curve, considering only the power costs as the main cost elements, the net effect is mostly positive. However, the author does not provide any definitive conclusion about the net effect of the RES schemes and mentions that it is largely dependent on the underlying assumptions. Therefore, the conclusion is quite ambiguous.
Gas and coal				1) Direct effect of wind power on wholesale prices - RES support schemes results in lower wholesale power prices. Therefore there is a net reduction in the retail electricity price- however this is a short term effect and a new higher equilibrium price is reached in the medium and long term. 2) The ease with which the new equilibrium is reached will determine the extent to which wind generation is able to reduce the market price. 3) Indirect effect: a reduction in the demand for CO_2 allowances, which are necessary to comply with the EU - ETS targets and a lower price for those allowances (given a lower demand for them)	The main focus of the paper was analyzing the costs and benefits of RES support schemes from the point of view of the consumers' prices. The overall conclusion was that Res support schemes which have eventually led to increased RES generation do results in lower wholesale prices and they also save the compliance costs of the utilities which then require led CO_2 credits. The paper does not provide any quantification of the price effects of RES and also does not provide any analysis of the MOE explicitly. It does mention the technologies displaced, indirectly implying a MOE of the RES.
	1) Three wind power situations have been considered - no-wind, current wind at 2005 of 2375 MW which corresponded to 24% of the yearly load and 50% increase in the existing capacity from 2005 i.e., 3561Mw corresponding to 34% of the yearly load.	1) Start up costs and minimum load limit play a significant role in the actual dispatch of power. With increased power production and high-cost gas power plants in usage, the difference in costs will increase and the difference in emissions will decrease in no wind and current wind situations. 2) The costs and emission at the current wind level (2005) will be 4% and 5% lower; 3) Winter time, simulated power production in the centralized units are mainly due to heat demand, therefore there is less reduction in CO_2 due to wind power penetration. This trend is reversed in summer time.		The simulations show that an increase in amount of wind power reduces the periods of constant production and the duration of these periods. The capacity factor of units with low start-up and turn down performances and high minimum load level will decrease more than the capacity factor of units with high start and turn down performance and/or low minimum load level.	The main focus of the paper is the physical properties of the power system rather than market implications, it is more appropriate for long term system planning than short term return calculations. This commercial gain or loss of the overall MOE has not been captured.
					The study is not relevant to be included in this literature survey since it does not investigate the merit order effect of increased wind power. All cost relevant analyses refers to costs for infrastructure development of the grid and dealing with challenges in regard to balancing.
		1) During the day the average spot price is around 55-60 €/MWh. With wind penetration of 20%, the av. price declines and there is a sharp decline when the penetration reaches 40% and when the penetration reaches 80% the spot prices decline to around 22-25 €/MWh. 2) Over 2% of times when the penetration level is 40% the spot price is zero.		1) During the night, the average price varies from around 30 €/MWh for forecasted low wind power production down to around 18 €/MWh for hours with forecasted large wind power production. 2) During the day the difference between the two extremes in forecasted quantities of wind power produced is larger as the prices go down from 50-55 €/MWh to 30 €/MWh 3) there is a MOE during the day time, replacement of the costly base load plants and shifting them to cover peak loads. 4) On the average, prices drop by 17.5% when the forecasted wind power penetration exceeds by 4%. 5) Effect on distribution of spot prices - Going from a low wind power penetration to high, generally leads to a lower skewness due to diminishing frequency of very high prices along with the increased probability of very low prices.	This paper once again analyses the effect of wind power prediction on spot prices in Western Denmark. The conclusions are similar to that of other papers that are in the area of spot price analysis . The additional information in the paper besides the impact analysis on spot prices, is the analysis if the distributional characteristic of the spot prices. The paper shows the possibility of the same results in other price areas as well such as Germany and the Netherlands. It also discusses the MOE but does not quantify the extent of cost savings due to the MOE.

Notes

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EWEA is the voice of the wind industry, actively promoting the utilisation of wind power in Europe and worldwide. It now has over 650 members from almost 60 countries including manufacturers with a 90% share of the world wind power market, plus component suppliers, research institutes, national wind and renewables associations, developers, electricity providers, finance and insurance companies and consultants.

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