The Effects of Wind Power on Spot Prices

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A study made for the Renewable Energy Foundation, London, UK[2]

Abstract

Do present power systems and market arrangements provide the proper framework for an efficient utilization of wind power? A statistical examination of wind power output and spot prices in Denmark has been conducted in order to shed light on this matter. The volatility of spot market prices is used as an indicator of the quality of resource allocation. The study stresses the importance of sufficient grid capacity and of efficient market arrangements for cross border trade and for local wholesale trade.

I. Observing Market and System Performance

In 2008 Danish wind energy was equivalent to 19.3% of the electricity consumption in Denmark. In Great Britain it has been a widely accepted assumption that this share of wind energy, at least, could easily be replicated by other countries.

In order to examine this assumption the Renewable Energy Foundation commissioned an analysis of the impact of wind power on the spot market in Denmark [1].

Data for the years 2006 to 2008 were downloaded from Energinet.dk's web site. A significant interaction with the German market was observed, and so additional wind power data from the German E.ON Netz control area were downloaded to permit comparative study.

The Nordic spot market, Nord Pool Spot, is the essential tool for the optimal allocation of resources in the Danish power systems. Cases of poor market performance have been identified and the corresponding operational conditions have been examined. Grid bottlenecks due to temporary reductions of transmission capacity seem to be of particular importance.

The study also demonstrates the importance of cross border trade for an efficient allocation of wind energy.

The combination of market statistics and operational properties is a recipe for understanding system behaviour and for preparing the power systems for an increasing share of renewable energy.

II. Data Collection and Transparency

Hourly statistical market data are available on Energinet.dk's web site [3]. Among available data are:

- Elspot price*
- Capacity on transmission lines*
- Scheduled trade
- Physical exchange*
- Nord Pool energy turnover
- Production and consumption*
- Real-time market*
- Auctions of transmission capacity across the Danish-German border (daily, monthly and annual)
- Total congestion income on interconnections
- Purchase of reserves, daily auctions

For the study a selection had to be made. Data marked with * were selected and downloaded as one spreadsheet for each of the years 2006 to 2008.

Wind power output from the German E.ON Netz control area (now known as Transpower Stromübertragungs GmbH) had to be downloaded in order to understand the apparent interaction with the German electricity market. On the Transpower web site[4] recorded physical data are available on a 15 minutes basis. Among the available data are:

- Vertical grid load
- Control zone balance
- Cross border flows
- Actual and forecast wind energy feed-in
- Preview of the cross border capacity assignment

Transpower offers no information on market prices. However, unlike Energinet.dk, Transpower publishes wind power forecasts.

The Transpower 15 minute data had to be downloaded as one spreadsheet per month and converted into hourly data for each year of the study.

A press release from the four German transmission system operators and the European Energy Exchange (EEX) from 15th June 2009 reports plans for a new transparency platform for the power market. This initiative is welcome.

An international harmonisation of selection and format of data could pave the way for better and more comprehensive studies of the European power markets. Hopefully the new European TSO association, ENTSO-E, will contribute to sufficient and uniform data access.

III. Criteria for Poor Market Service

The Nord Pool Spot is a day-ahead-market, and trades about 70% of all physical electricity in Norway, Sweden, Finland, and Denmark, and about 79% of all physical electricity in Denmark. Due to long distances and limited transmission capacity six bidding areas (or price areas) have been defined. In the absence of congestion the area prices are identical with the system price. Market players can trade physical electricity bilaterally within each of the two Danish bidding areas. The Nord Pool spot market must be used for physical trade across bidding area borders.

Nord Pool Spot is the most important electricity market in the Nordic countries. The spot price is the reference price for financial trade and for a considerable share of the bilateral trade.

Nord Pool determines the spot price by taking the intersection of the demand curve and the supply curve, both curves resulting from a bidding process.

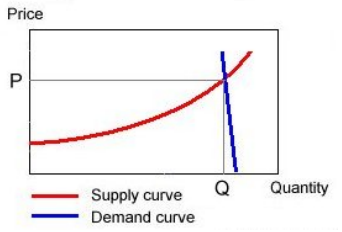

Figure 1 Normal spot price calculation

Sometimes the two curves have no intersection. The reasons can be:

1. Insufficient supply capacity
2. Surplus of wind power bids at zero price

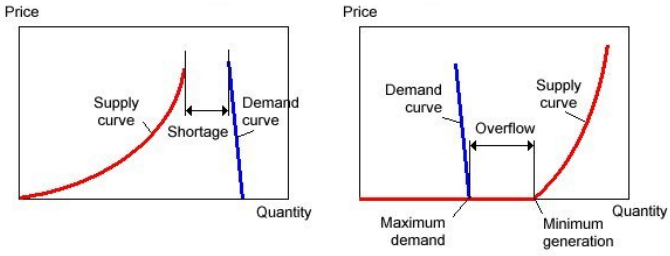

Figure 2 Bidding curves causing extreme spot prices

In such cases Nord Pool must curtail either supply or demand bids in order to find a price, and some participants are consequently poorly served by the market.

Under the present rules the result of curtailments will be either high spot prices or zero spot prices. Therefore the number of hours with extreme spot prices is suggested as a yardstick for the quality of market service.

Table 1 shows the number of hours with 0 €/MWh and 100 €/MWh as the critical limits.

TABLE 1 NUMBER OF HOURS WITH EXTREME SPOT PRICES

	2006		2007		2008	
Spot Price €/MWh	= 0	>100	= 0	>100	= 0	>100
West Denmark (DKW)	28	11	85	105	28	193
East Denmark (DKE)	5	131	30	89	9	225
Nord Pool system price	0	1	0	0	0	2
EEX, Germany	10	266	28	307	35	888

The number of high spot prices seems to be increasing during the observation period. However, the average spot prices also increased over the period 2007 to 2008. Perhaps the upper limit should have been set in relation to the annual average spot price.

Several zero spot prices have been recorded in Denmark and Germany, but not for the Nord Pool system price. Nevertheless the level of market service in Denmark and Germany is considered to be reasonable during the observation period.

There is no doubt that an increasing share of wind power will create more hours with extreme spot prices and less satisfactory market service, unless new appropriate measures are implemented.

In order to improve market service in bidding areas with a high share of wind power Nord Pool will introduce negative minimum spot prices from October 2009. Bids will be accepted with € -200 as the price floor.

These negative prices will change the incentives in the market and reduce the number of hours without crossing bidding curves, but it will not reduce the waste of energy. Alternative utilisations of the energy surplus will be needed.

IV. OBSERVED SPOT PRICE VOLATILITIES

The spot price in the Danish price areas depends on several factors, such as demand level, available interconnector capacities, congestion policies, bidding policies and uncontrollable generation.

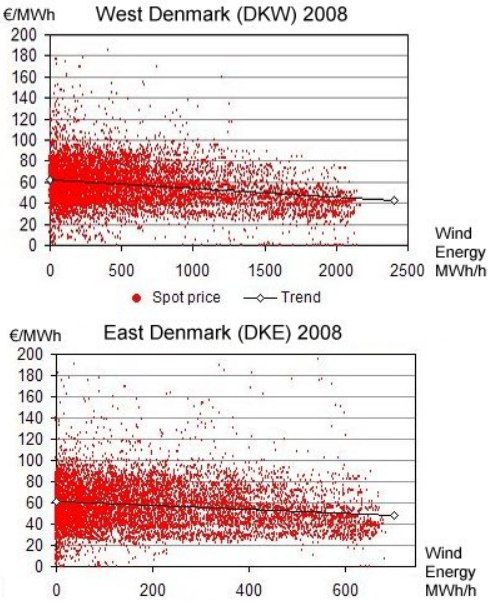

Figure 3 Wind power and spot prices in Denmark 2008

Due to this multiple dependency the correlation between wind power and spot prices is weak. The linear trend has a slight negative slope. The dispersion of the spot prices is high, particularly when the output of wind energy is low.

The negative slope has been taken as an indication that increasing wind power causes decreasing spot prices. The basic condition of this understanding is that traditional producers would make the same bidding in a reference case without wind power.

This assumption is not necessarily true. A producer will probably not have the same capacity ready for operation when an inflow of wind energy must be anticipated. Even if sufficient thermal capacity exists it may take days to bring a unit from a long term reserve state into operational reserve.

Therefore it could also be argued that absence of wind power causes an increase in spot prices.

Taking both possibilities into account we cannot give a definitive opinion on whether wind power contributes to higher or lower average spot prices.

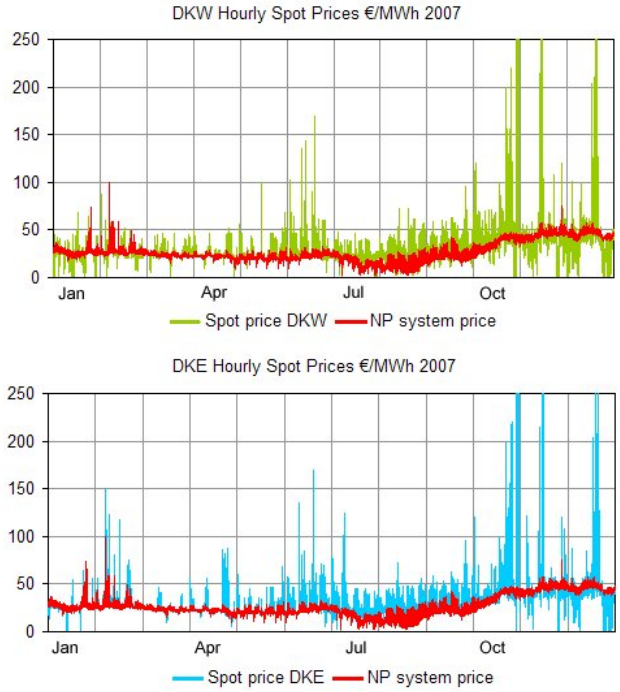

Figure 4 Spot prices, time series 2007

Time series can help in identifying periods with extreme spot prices. 2007 has been selected as an illustration. 2006 and 2008 are different in specifics, but would give rise to similar observations:

1. The dispersion of spot prices is higher for the two Danish price areas than for the Nord Pool system price.
2. Both West and East Denmark have price peaks in June when the wind energy output is low.
3. In the last quarter of 2007 both zero prices and very high price peaks occur in both parts of Denmark (maximum price 8,490 €/MWh).

It is natural to assume that the higher dispersions of spot prices in Denmark are caused by the wind power, but this is not the whole truth. An examination of extreme cases can demonstrate the influence of wind power under different operational conditions.

December 2007 has been selected as an instructive example.

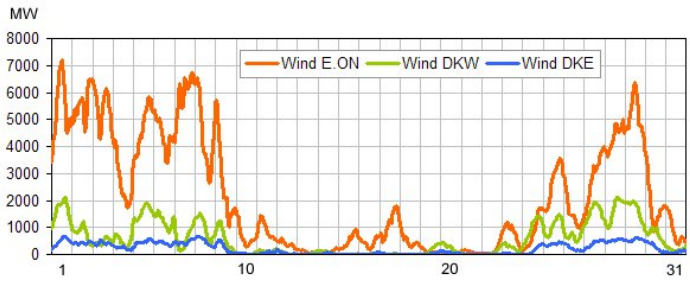

Figure 5 Wind power in Denmark and Germany - December 2007

Fig. 5 shows the wind power time series for the two Danish control areas and for the E.ON Netz control area in Germany. The first 9 days can be used for the study of system response to high wind power generation. The following two weeks are characterized by low wind power output in both Denmark and Germany.

V. Bottlenecks and Congestion Policy

The electricity market is the modern tool for optimization of power system operation across national borders. Sufficient transport capacity is a decisive factor for both reasonable system security and an efficient market service.

In the Nordic day-ahead electricity market, Nord Pool Spot controls the allocation of available transfer capabilities between countries and price areas. The real transfer capabilities are far from the nominal capacities of the interconnectors, which may be reduced for technical reasons (such as cable or transformer faults) or due to internal bottlenecks within a price area. A protection of national commercial interests would be less acceptable.

Capacity reductions have been observed for all Danish interconnectors for each of the three years. Duration curves can give a visual impression of the magnitude of the capacity reductions.

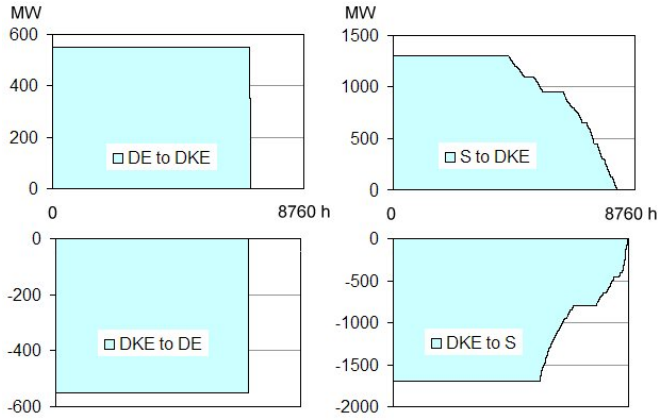

Figure 6 Duration curves for transfer capabilities DKE 2007

The Kontek HVDC link between Denmark East and Germany was unavailable for 10 weeks from the beginning of 2007 due to cable damage.

The capacity reductions on the AC interconnection between Denmark East and Sweden reflect the Swedish congestion policy. The Nordic system operators are using different methods for the handling of internal bottlenecks. Norway is divided into areas with different area prices in case of congestion. It is a Swedish policy to maintain the same spot price for all parts of Sweden. Therefore internal bottlenecks are transferred into reduced trading capacity on interconnectors.

During the month of December the combined heat and power plants (CHP) produce a considerable quantity of electricity, as a result of demand for heat which gives these plants the opportunity to generate. The electricity from CHP and wind exceeded the local demand during night time

periods in East Denmark 1-9 December 2007, and significantly low spot prices have been observed (fig. 7).

The nominal export capacities are 550 MW to Germany and 1,700 MW to Sweden. There are two reasons why the actual export was much below these figures:

1. Very cheap energy was offered from Germany as a result of the German wind power generation.
2. The export capacity to Sweden was kept low during nights as a result of the Swedish congestion policy.

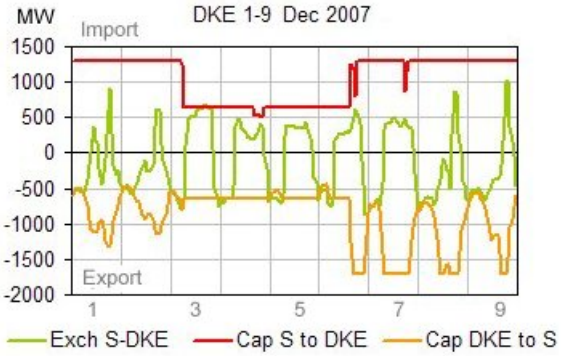

Figure 7 Exchange limitations DKE 1-9 Dec 2007

Fig. 7 shows the limits set by the Swedish system operator, Svenska Kraftnät, and the actual exchange between DKE and Sweden. During this period the range of exchange was reduced to less than half of the nominal range. The reduction of export capacity during the night is remarkable.

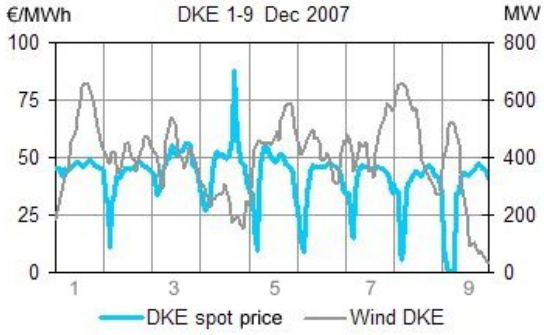

Figure 8 Wind power and spot price DKE 1-9 Dec 2007

Fig. 8 demonstrates how wind power can influence local spot prices.

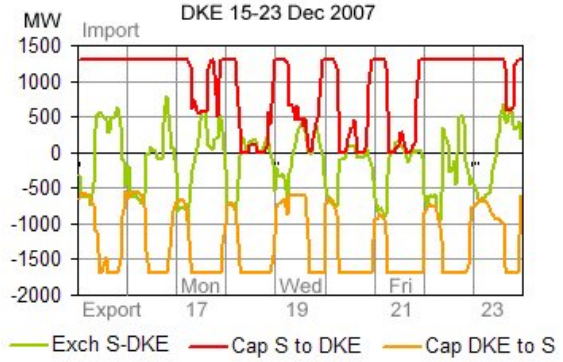

Figure 9 Exchange limitations DKE 15-23 Dec 2007

The diagram for 15th to 23rd December 2007, when wind power output was very low, seems to reflect the Swedish limitation policy even more clearly. The lack of wind power in Germany and Denmark caused a demand for imports from Sweden during the daytime, but there was still a surplus of energy from CHP plants during the night. The response to this situation was a reduction of the capacity for import to Denmark on weekdays during peak hours while the capacity for export was reduced every night.

Such "targeted" reductions are much more severe than average figures would suggest.

High wind and low demand is one critical market combination. Low wind and high demand is another one. When such conditions meet capacity reductions at the borders the market function may be disturbed.

The market reports from Energinet.dk have referred to the Swedish congestion policy as a reason for unstable prices in East Denmark. In July 2006 Dansk Energi (Danish Energy Association) asked the European Commission to open a case against Svenska Kraftnät [2]. The Commission opened the proceedings in April 2009.

All system operators use temporary capacity reductions when it is necessary to maintain operational security. These reductions are too little studied in most international considerations on the ease and cost of future large scale integration of wind power.

VI. Wind Power in Denmark and Germany

Figure 10 The four German control areas

The market data, downloaded from Energinet.dk, included spot market prices for the European Energy Exchange, EEX, in Germany. The German data extends the analysis to a geographical area which is about 1,150 km from north to south, but only about 400 km from west to east.

The analyses revealed a better correlation between Danish and German spot prices than between The Danish spot prices and the Nord Pool system price.

TABLE 2 CORRELATIONS BETWEEN SPOT PRICES 2008

	EEX	NP System Price
DK west	0.7598	0.6539
DK east	0.7389	0.6744

The reason for this coherence could be a synchronism between wind power in Denmark and in Germany. In order to test this hypothesis wind power data were downloaded for one of the four German control areas, E.ON Netz.

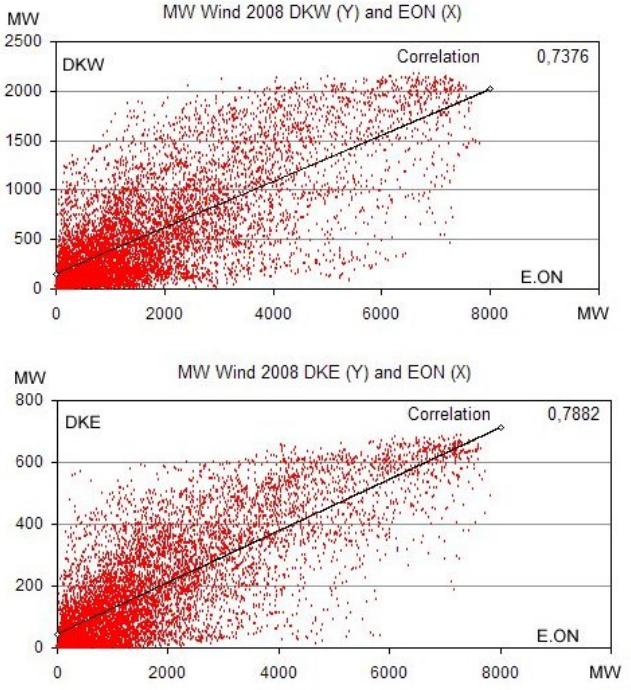

Figure 11 Danish vs. German wind power 2008

Statistical data can be interpreted in various ways. This comparison between Danish and German wind power can be read as a high correlation or as a good smoothing effect, depending on the preferred perspective.

The time series show numerous examples of simultaneous wind power peaks and simultaneous calm periods. Again December 2007 will be used to demonstrate the relationship between the Danish and the German electricity markets.

The calm period, shown on fig. 5, is the longest calm period during the three years. It is interesting to see how the Danish and German power systems react to the lack of wind power.

There is a remarkable difference between the two calm weeks. During the first week the German market reacts more strongly to the missing wind energy than the Danish market areas. There was still some import from Sweden (see fig. 9) and export to Germany rose to the capacity limits.

Two events contributed to more strained Danish markets during the second week.

- The available support from Sweden to East Denmark during daytime was reduced to zero (see fig. 9)
- A 600 MW power plant had to be disconnected in West Denmark.

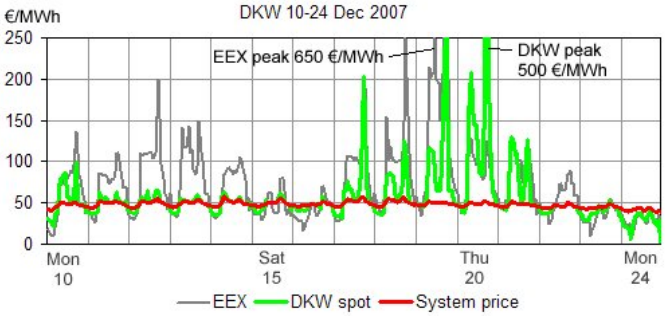

Figure 12 Spot prices 10-24 Dec 2007 DKW

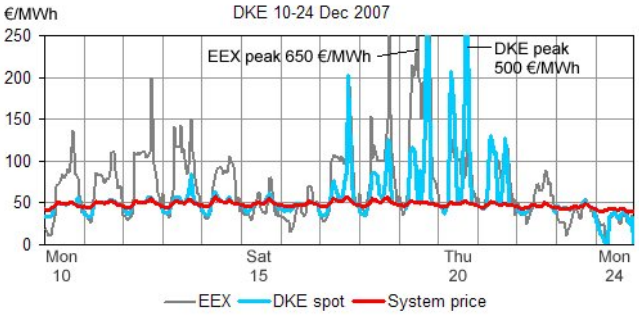

Figure 13 Spot prices 10-24 Dec 2007 DKE

These observations support the view that lack of wind power can create market problems when combined with high load, disabled power plants and reduced exchange opportunities. Each of these circumstances alone could not disturb the market.

According to this study there is only a little smoothing effect in connecting wind farms in an area 1,150 km from north to south. In Europe it is more likely that coordination within an area ranged on the east west axis, could result in better smoothing. The magnitude of this is not easy to determine at present, and therefore new statistical studies covering more European countries are desirable.

Due to the close relations between the electricity markets in Denmark and Germany it is reasonable to question whether Denmark has in fact successfully integrated nearly 20% wind energy (by MWhs), as is sometimes supposed. A different interpretation is that Germany and Denmark together have solved the integration problems for 7% of wind energy. This is an important distinction with technical and economic implications.

CONCLUSIONS AND RECOMMENDATIONS

This study has examined both market behaviour and power system operation in order to understand the impact of wind power, and we have seen that wind power has added new stochastic elements to the power system.

However, there is so far only a limited understanding of how security criteria in system planning and operation should be changed in order to maintain the normal security of supply in a power system with a high share of wind power.

Hourly spot prices seem to reflect the system condition, with extreme spot prices indicating a strained market and a

reduced level of service to market participants, and ultimately to the consumer. The study suggests that the number of hours with extreme spot prices can be used as a quality indicator for each price area of the electricity market.

The situations placing the market under strain depend on unfavourable combinations of wind power output, demand, power plant availability and transfer capability.

In spite of the strained situations observed the level of market service during the observation period in Denmark and Germany can be considered to be reasonable, though there must be concerns for the future.

The study has revealed that the practical capacity of the interconnectors is far below the nominal capacity. Bearing this in mind it seems that most current studies of future wind power integration are overestimating the capacity of the transmission systems. It is not known if an adjustment of the national congestion policies and better international coordination will be sufficient to improve the overall power system performance. If it is not, considerable grid reinforcements will be necessary, with significant cost implications.

Even with such measures it must be remembered that interconnection is not in itself a solution to a balancing problem, but rather it is a channel through which such a solution can be reached. The presence of interconnection does not guarantee the existence of the balancing resources themselves, and this must be borne in mind by planners and policy makers.

Many references have been made to the successful Danish integration of about 20% wind energy. This study has shown that the relation between the electricity markets in Germany and Denmark is so close that it is more realistic to say that Germany and Denmark together have integrated about 7% of wind energy.

The European TSOs are recommended to develop and publish harmonized market and power system data in order to encourage larger and better international statistical studies.

STATISTICAL OVERVIEW [1]

2006	Demand	Net exchanges		Wind generation	
		Export	Import		% of
DK	MWh	MWh	MWh	MWh	demand
West	21,397,717	4,771,496	269,971	4,614,315	21.6
East	14,576,135	2,791,770	353,869	1,489,519	10.2
Total	35,973,852			6,103,833	17.0

2006	Average area price	St. Dev.		Average spot price	St. Dev.
DK	€/MWh	€/MWh		€/MWh	€/MWh
West	44.12	13.30	Nord Pool	48.51	11.13
East	48.46	17.55	EEX	50.75	49.42

2007	Demand	Net exchange		Wind generation	
		Export	Import		% of
DK	MWh	MWh	Mwh	MWh	demand
West	21,595,508	3,130,797	1,355,178	5,561,711	25.8
East	14,515,894	1,185,385	2,011,749	1,610,371	11.1
Total	36,111,401			7,172,083	19.9

2007	Average area price	St. Dev.		Average spot price	St. Dev.
DK	€/MWh	€/MWh		€/MWh	€/MWh
West	32.28	24.01	Nord Pool	27.80	10.67
East	32.89	22.03	EEX	37.91	30.35

2008	Demand	Net exchange		Wind generation	
		Export	Import		% of
	MWh	MWh	Mwh	MWh	demand
West	21,619,685	2,682,452	1,655,208	5,191,701	24.0
East	14,482,611	585,248	3,066,726	1,785,197	12.3
Total	36,102,296			6,976,898	19.3

2008	Average area price	St. Dev.		Average spot price	St. Dev.
DK	€/MWh	€/MWh		€/MWh	€/MWh
West	56.33	20.22	Nord Pool	44.61	13.71
East	56.52	21.91	EEX	65.68	28.66

Wind power installed in Germany and Denmark 2005 and 2008			
MW	Germany	Denmark West	Denmark East
31 Dec 2005	18,428	2,393	735
31 Dec 2008	25,745	2,560	766

Transit	Northward		Southward	
GWh	DKW	DKE	DKW	DKE
2006	1,794	1,745	1,391	791
2007	499	456	3,975	1,644
2008	321	284	5,029	1,665

ACKNOWLEDGMENT

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[1] Paul-Frederik Bach, *The Effects of Wind Power on Spot Prices*, Renewable Energy Foundation, London, March 2009.

[2] *The economic consequences of capacity limitations on the Oeresund link*, Copenhagen Economics, April 2006.

[3] http://www.energinet.dk/en/menu/Market/Download+of+Market+Data/Download+of+Market+Data.htm

[4] http://www.transpower.de/pages/tso_en/Transparency/Publications/Network_figures/Overview/index.htm

[1] Paul-Frederik Bach has worked at ELSAM, the coordinating office for west Danish power stations, until 1997 and at Eltra, transmission system operator in west Denmark, until retirement in 2005. He is now active as a consultant. See www.pfbach.dk.

[2] Renewable Energy Foundation is a UK registered charity publishing data and analysis on the renewable and broader energy sector. It is supported by private donations, and has no corporate membership or political affiliation. For further information see www.ref.org.uk