

Statistical Survey 2007

1. General

The purpose of the study is to analyze the impact of wind power on market prices and to discuss its possible influence on power system economy in Denmark.

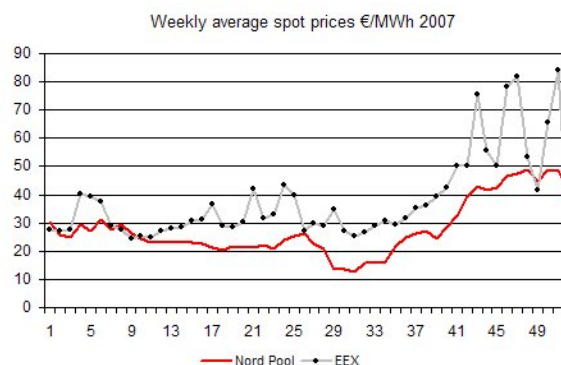
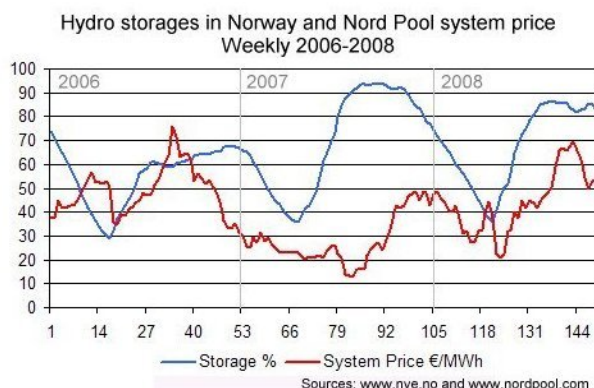
The study is made by Paul-Frederik Bach for Renewable Energy Foundation in London.

The purpose of the survey is to screen a set of data on hourly market and operational conditions in order to identify characteristics for further analysis. The data are extracted from the Energinet.dk web site unless other sources are specified.

Abbreviations:

| | | | | | |
|-----|--------------------------|-----|--------------|----|---------|
| EEX | European Energy Exchange | DKE | Denmark East | DE | Germany |
| NP | Nord Pool | N | Norway | | |
| DKW | Denmark West | S | Sweden | | |

2. Neighbouring countries in 2007



The water level in the hydro reservoirs in Norway was high in 2007 compared with the dry 2006. Therefore the Nord Pool spot prices were lower than in 2006. The following comment from the Energinet.dk Market Report November 2007 mentions a strike in the French nuclear power sector as a possible reason for increasing German spot prices at the end of the year:

The high Danish spot price on 15 November came about as a consequence of the strike in the French nuclear-power sector, which pulled the German spot price up. As the high German spot price lead to greater demand in Western Denmark, Danish spot prices increased.

The weekly spot prices seem to have encouraged a southbound transit from the Nordic area most of the year. The situation on 15 November will be analysed in a separate section.

3. Main characteristics of Danish power systems in 2007

3.1. Annual key figures

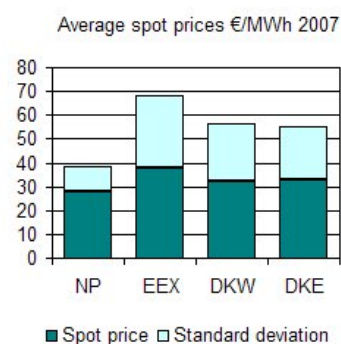
The following table is based on market data from Energinet.dk:

| | Demand MWh | Net exchange | | Wind generation MWh | % of demand | Wind energy export | | |
|---------|---------------|---------------|---------------|------------------------|----------------|--------------------|-------|-------------------------|
| | | Export MWh | Import MWh | | | MWh | Hours | % of wind generation |
| West | 21.595.508 | 3.130.797 | 1.355.178 | 5.561.711 | 25,8 | 2.611.979 | 5.048 | 47,0 |
| East | 14.515.894 | 1.185.385 | 2.011.749 | 1.610.371 | 11,1 | 628.719 | 3.453 | 39,0 |
| Denmark | 36.111.401 | | | 7.172.083 | 19,9 | | | |

The net export has been calculated hour by hour as a total of all exchange from each of the two Danish systems. In this context the *wind energy export* has been defined for each system and for each hour as the smaller value of generated wind energy and net export.

The average market conditions are summarized in this table:

| | Area price | St.Dev. | | Spot price | St.Dev. |
|---------|------------|---------|-----|------------|---------|
| | €/MWh | €/MWh | | €/MWh | €/MWh |
| DK West | 32,28 | 24,01 | NP | 27,80 | 10,67 |
| DK East | 32,89 | 22,03 | EEX | 37,91 | 30,35 |

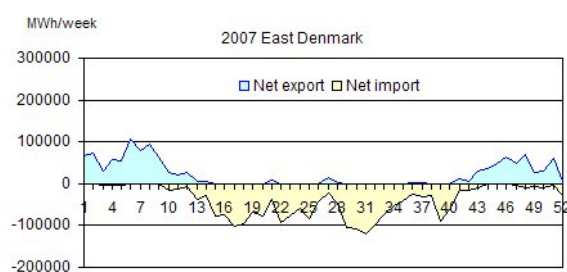
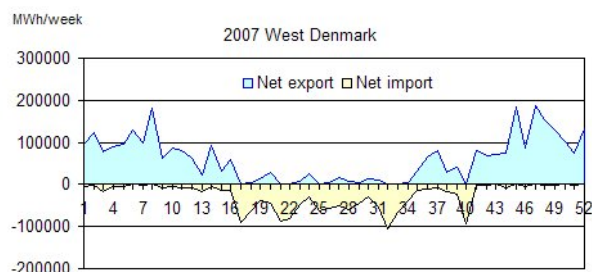


The standard deviation is an indicator of the price volatility. The possible reasons for the differences will be discussed subsequently.

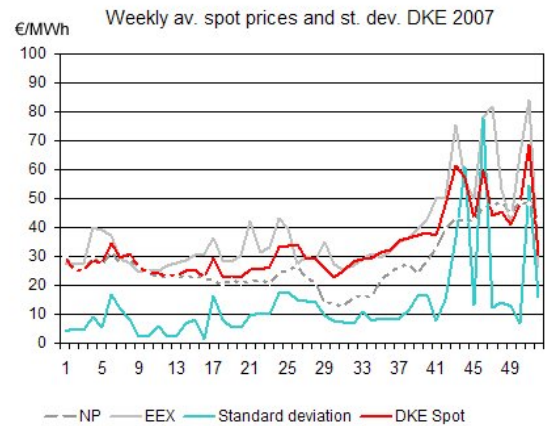
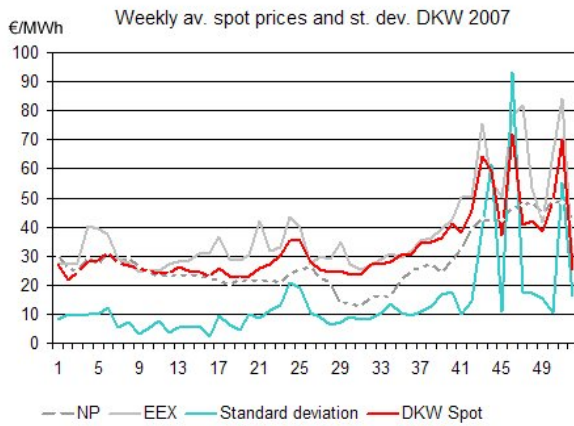
The magnitude of the overflow problem due to Danish wind power can be indicated in a table with number of hours with spot prices equal zero and balancing prices downwards equal to or below zero. When the price of balancing (or regulating) power is below 0 the system operator must pay for export of energy. Nord Pool is currently preparing the handling of negative spot prices.

| No of hours | Spot price = 0 | Spot price >100 | Bal. price <= 0 | Bal. price >100 |
|-------------|----------------|-----------------|-----------------|-----------------|
| DK West | 85 | 105 | 194 | 204 |
| DK East | 30 | 89 | 53 | 244 |
| Nord Pool | 0 | 0 | | |
| EEX | 28 | 307 | | |

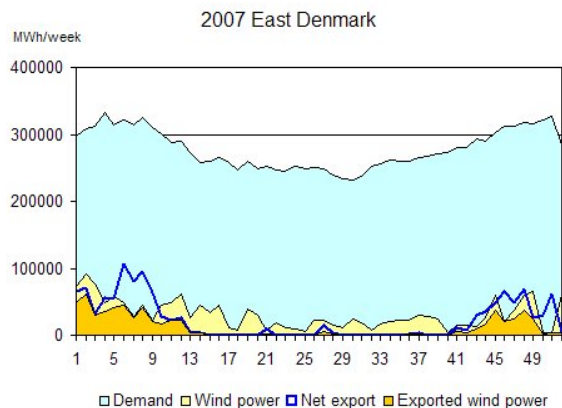
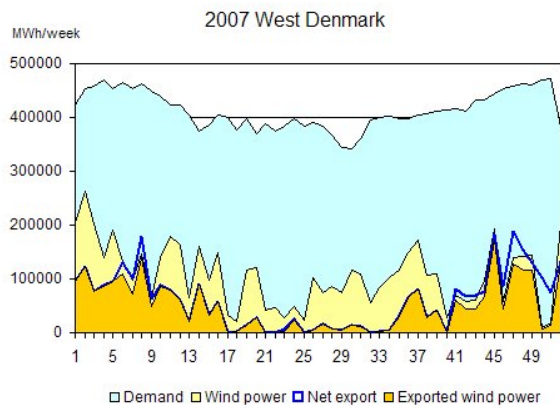
3.2. Weekly averages



During transit periods congestion on one of the interconnectors is common. The spot prices of the two Danish systems follow either Nord Pool or EEX depending on which interconnector is congested.

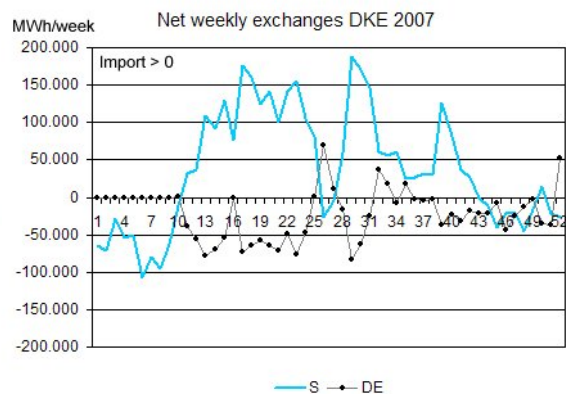
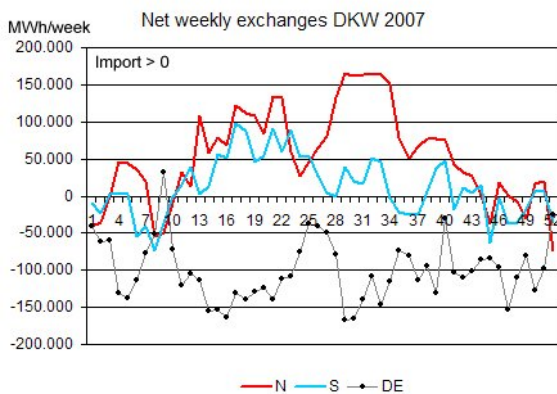


In chapter 4 we shall take a closer look at the weeks with volatile prices in both Danish systems. The generation of wind energy varies considerably from week to week.



Following the definition in 3.1 the wind energy is divided into an export share (the light brown area) and a share used locally (the light yellow area). The dark blue curve is the net electricity export. There seems to be some correlation between wind energy and net export.

Net weekly exchanges have been calculated for each border in order to verify the transit directions suggested above from the spot prices.



3.3. Operational Incidents

The Energinet.dk Annual Report 2007 mentions some of the operating incidents, which had an impact on the power market:

| Operating incidents | | |
|--|---|--|
| <p>During the storm over the New Year 2006/07, the Kontek Link between Eastern Denmark and Germany broke down when damaged by a ship's anchor. The interconnection was operational again in mid-March 2007.</p> <p>On 24 February 2007, most of Denmark was lashed by a severe ice storm combined with high winds. As a result, many overhead lines were glazed with ice, which in turn made the lines oscillate. This caused galloping lines and thus short-circuiting, which made the light blink.</p> | <p>In May 2007, a serious fault in the German electricity grid came within inches of spreading to the West Danish electricity system. Automatic disconnection of electricity generation and intervention on the DC interconnections to the Nordic countries ensured that the West Danish electricity consumers remained unaware of this incident.</p> <p>In August 2007, the Danish transformer in the Skagerrak 3 interconnection, which is one of the three DC interconnections between Jutland and Norway, broke down,</p> | <p>putting the 500 MW interconnection out of operation. The interconnection is expected to be operational again in summer 2008.</p> <p>As Skagerrak 3, a key interconnection in the Nordic electricity market, has been out of operation several times in recent years, the Norwegian TSO, Statnett, which co-owns the interconnection, and Energinet.dk are presently examining whether spare transformers are required.</p> <p style="text-align: right;">From Energinet.dk Annual Report 2007</p> |

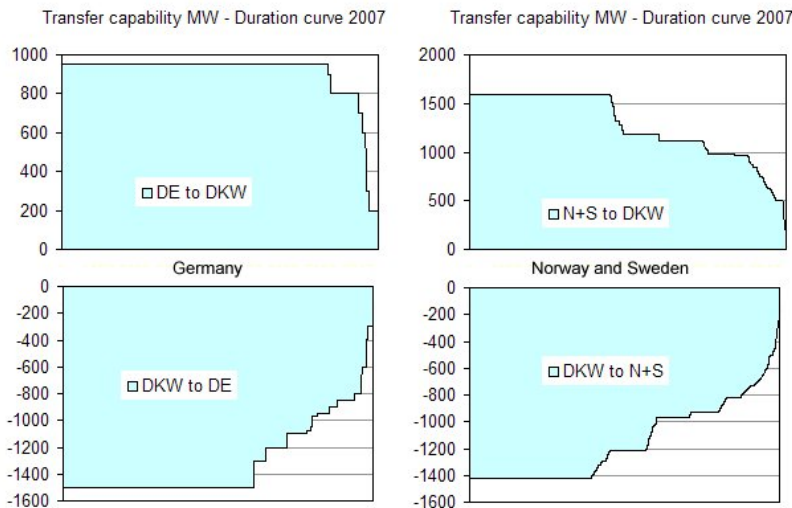
3.4. Interconnector Capacity

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

The trading capacity on the 400 kV AC interconnection between West Denmark and Germany depends on stability limits of the interconnected AC networks.

The duration curve shows how the transfer capability from Denmark to Germany has been more or less reduced nearly half of the time in 2007.

The HVDC links to Norway and Sweden still suffered from severe hardware faults during 2007. There were capacity reductions most of the time. At the worst less than a third of the nominal capacity was available.

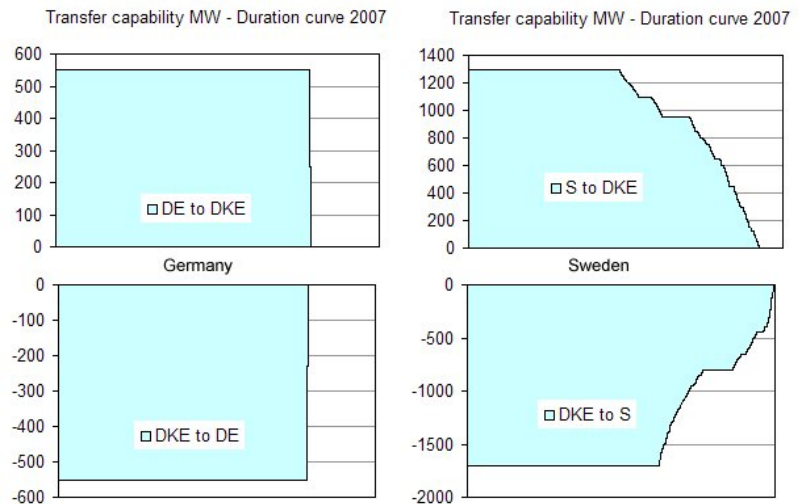


The Kontek HVDC link between Denmark East and Germany was unavailable for 10 weeks from the beginning of the year due to the cable damage mentioned among the operating incidents.

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.

The interconnections can help smoothing spot price oscillations due to intermittent generation (particularly wind power), if there is capacity available for this purpose.

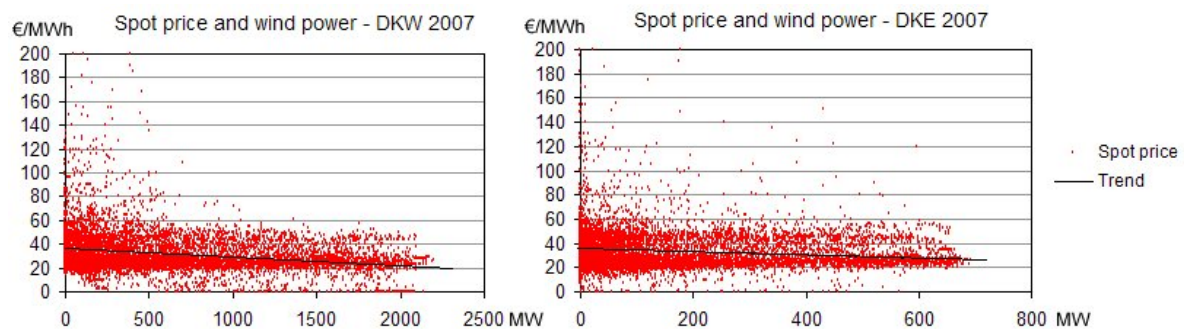


4. Wind Power and Spot Markets

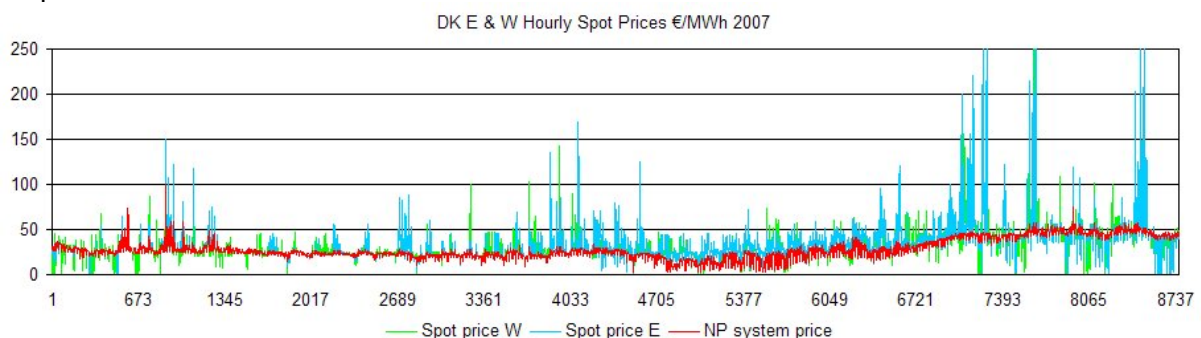
Wind power has an impact on market prices in two ways:

- increasing wind generation may cause reduced prices
- the volatility of wind power may cause price volatility

The following diagram shows local spot prices and wind power for the entire year 2006.



The average trend is obvious, but the dispersion is considerable and several other factors have an impact on market prices. A view on the hourly spot prices reveals some characteristic periods.



Price patterns are similar in DKW and DKE in 2007 and cannot be distinguished in the diagram. Periods with zero prices and with high spikes (maximum 943 €/MWh) occur in both areas. Causes and relations will be demonstrated in examples.

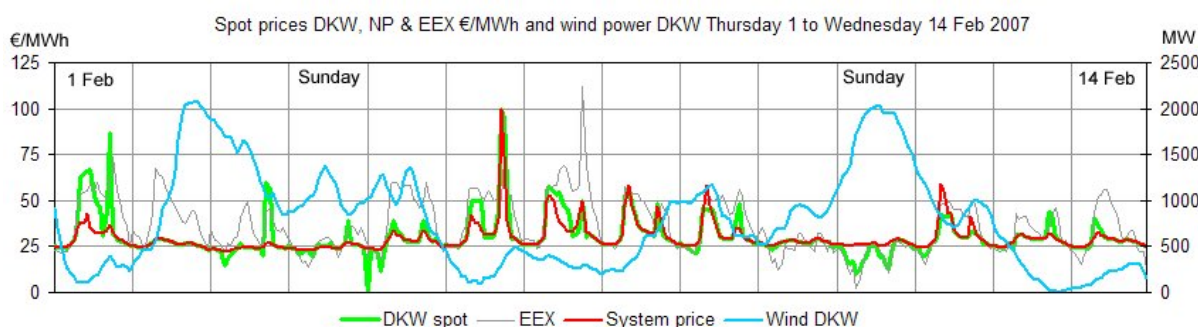
4.1. 1st to 14th February 2007: Nord Pool Capacity Shortage

The Energinet.dk Market Report February 2007 refers to cold weather in Finland and repair works on Swedish nuclear power plants as reasons for capacity shortage in the Nordic area:

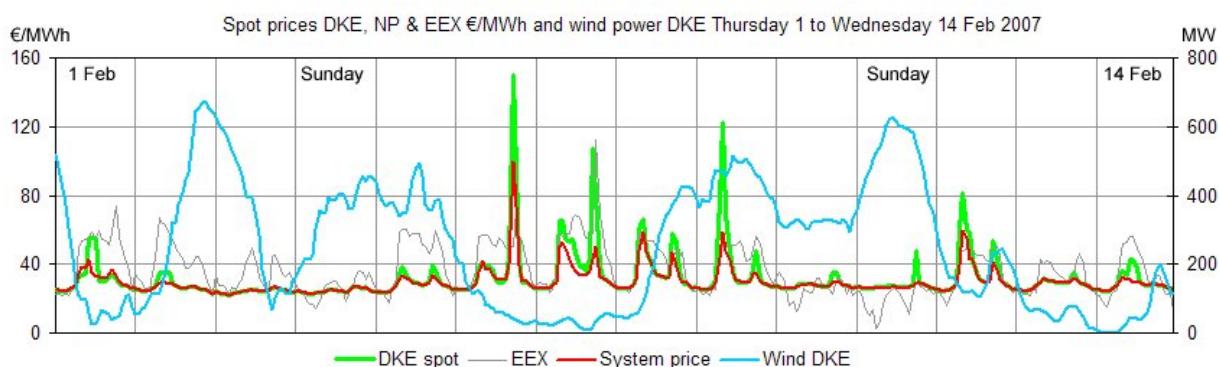
In most of February, the electricity price remained close to DKK 200/MWh everywhere in the Nordic market, ie there was no change in relation to January's price level. However, a few hours saw considerably higher prices. These spectacular price spikes occurred in Eastern Denmark, Sweden and Finland, where the price on a particular day early in the month soared as high as DKK 1,120/MWh.

The price spikes developed mainly in hours marked by severe shortage of capacity in Finland caused by the very cold weather. The cold made import from Sweden to Finland necessary, but the Swedish nuclear power production was limited because of ongoing repair work. Electricity was therefore exported from Eastern Denmark to Sweden, and in those particular hours prices were high in Sweden as well as Finland and Denmark.

The following diagram shows the situation in West Denmark the first two weeks of February:



The DKW spot price follows either Nord Pool or EEX most of the time. It is interesting that the Nordic problems seem to get worse when the wind generation is low. Similar observations can be made for East Denmark:

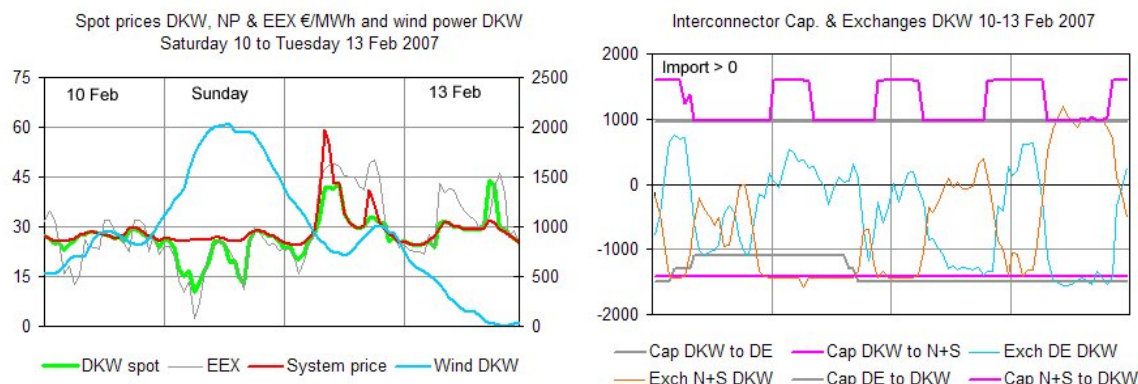


The Energinet.dk Market Report February 2007 has this explanation on wind power:

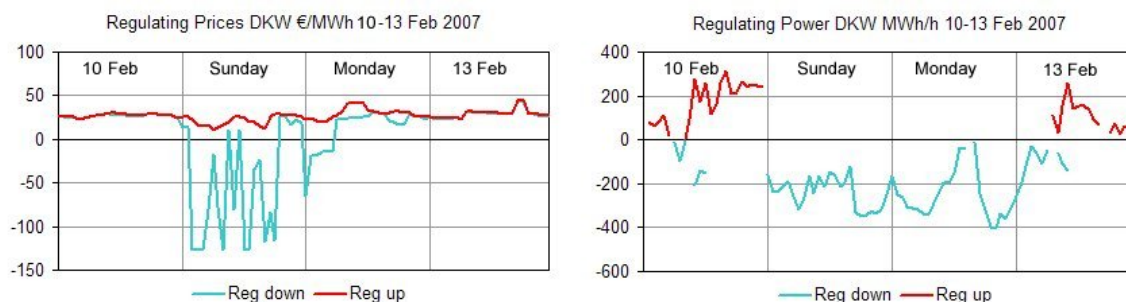
The general price-pressing effect of wind power in Eastern Denmark became evident in February, wind power being decisive for the price formation on several days of the month. The prices rose significantly when wind power generation was low. However, wind power is not a price-setting factor in the market, but high wind power generation can result in some of the usual and more expensive price setters such as coal and gas-fired power stations being priced out of the market.

4.2. DKW 10th to 13th February 2007: Negative Balancing Prices

Negative balancing prices mainly occur during periods with low electricity demand and high wind generation. A typical case was observed in West Denmark on 11th February 2007:



A surge of wind seems to have been expected for Sunday, because the EEX and DKW spot prices were lower than the Nord Pool system price. The interconnectors to Norway and Sweden were fully loaded nearly every hour. A look at the market for regulating power shows that corrections were necessary for DKW throughout both Sunday and Monday:

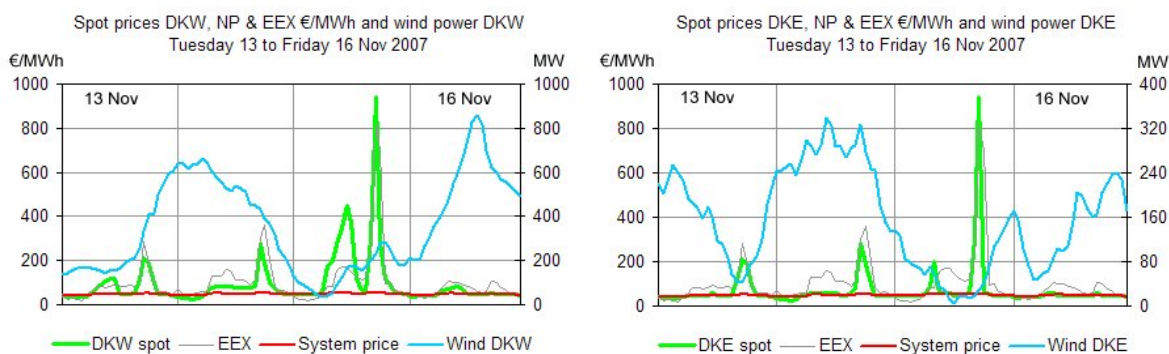


There was a certain demand for regulating power Monday. 5830 MWh were sold for € 64,880 or at an average price of 11.13 €/MWh.

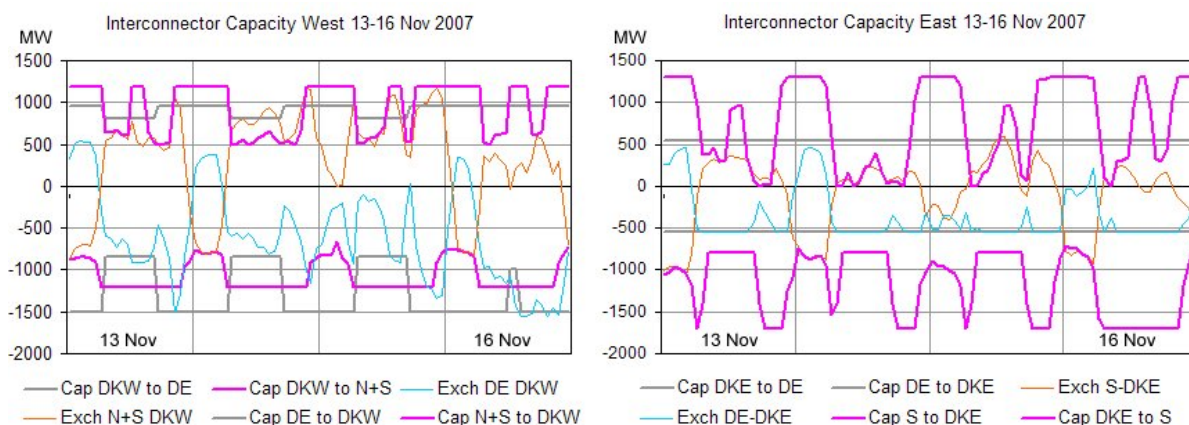
Sunday was more difficult. Energinet.dk had to pay € 250,059 or 43.70 €/MWh for the removal of 5722 MWh.

4.3. 13th to 16th November 2007: Capacity shortage and price spikes

If the sale bids in the Nord Pool spot market are insufficient Nord Pool performs a *curtailment of purchase offers*. In such cases the buyers must purchase lacking capacity in the intraday market (Elbas) or in the balancing market, because demand is supposed to be inelastic. One of the cases in 2007 occurred on 15th November:



The Energinet.dk Market Report November 2007 mentions a nuclear strike in France as the reason for the EEX price spikes. Low wind generation on Thursday 15th November in both Germany and Denmark has probably boosted the shortage.



There have been considerable changes in the trade capacities of the interconnectors during the 4 days. German buyers have competed with Danish demand for power. This is reflected in the net exchanges (import > 0):

| MWh | DKW | | DKE | |
|--------|--------|---------|--------|---------|
| | N+S | DE | S | DE |
| 13 Nov | 5.117 | -11.199 | -3.174 | -6.774 |
| 14 Nov | 9.463 | -10.067 | -3.782 | -7.160 |
| 15 Nov | 15.832 | -14.454 | 2.690 | -11.851 |
| 16 Nov | 561 | -22.389 | -5.137 | -8.904 |

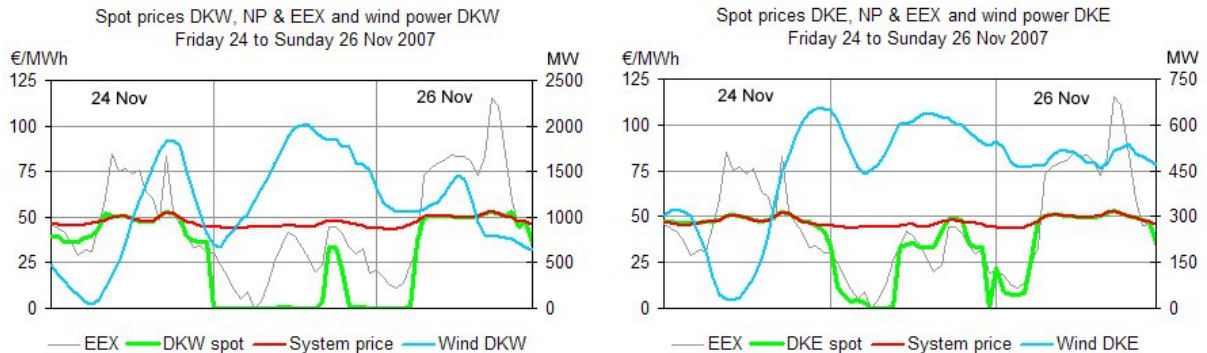
The result was a high net export to Germany. DKE had an export in both directions while there was a considerable transit through DKW. The differences between day and night should also be observed. The range of the transfer capabilities has been fully utilized. A stronger transmission system would allow a better allocation of available generation resources.

4.4. 24th to 26th November 2007: Zero Spot Prices

The Nord Pool spot market defines a day-ahead market price for each hour. The price depends on balance between supply and demand in the bids. Wind energy at zero prices is part of the bidding. If there are insufficient demand bids Nord Pool performs a *curtailment of sale*

offers. The resulting spot price will be zero. A curtailment means that some market users cannot be properly served.

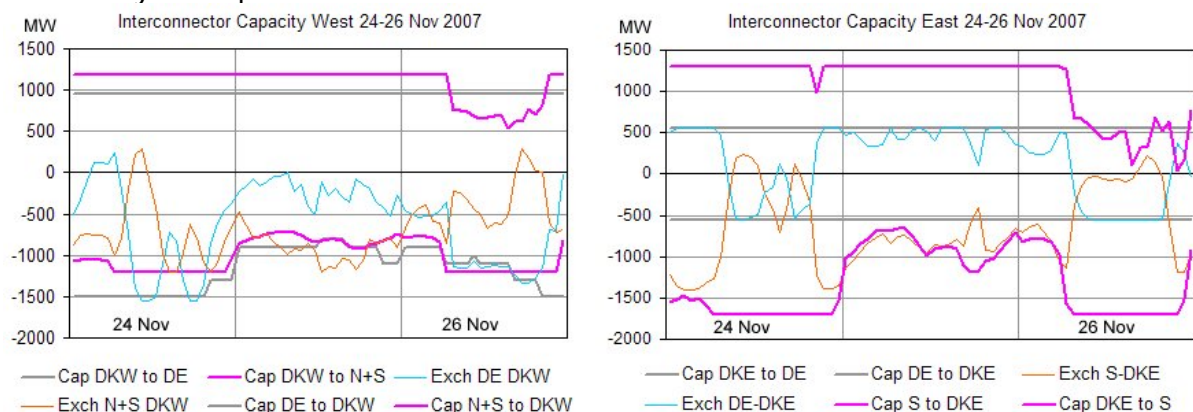
In 2007 zero prices occurred 85 hour in West Denmark and 30 hours in East Denmark, mainly during weekends when the electricity demand is reduced. Here is Saturday 25th November used as a case.



The spot prices in the two Danish areas follow the Nord Pool system price most of the time Friday and Sunday. During Saturday the prices in East Denmark follow the German EEX prices most of the day, while the prices in West Denmark collapse apart from a few hours.

There is no direct relation between spot prices and recorded wind power. The reason is that the spot prices are based on day-ahead expectations, which can be very much different from the recorded values.

The exchanges form a quite complicated pattern, because the power moves towards the best price. The movements are most obvious on the right side diagram for East Denmark. Exchanges with Germany change from maximum export Friday to maximum import Saturday, when the export to Sweden approximately follows the capacity limit defined by the Swedish System operator.



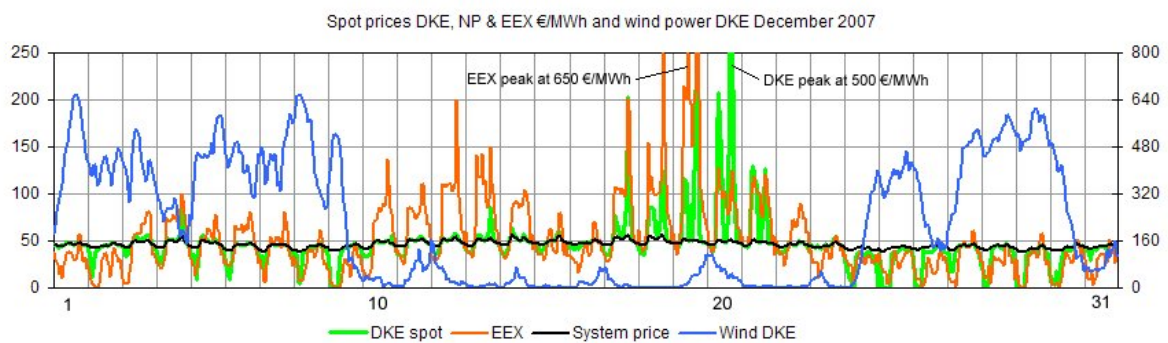
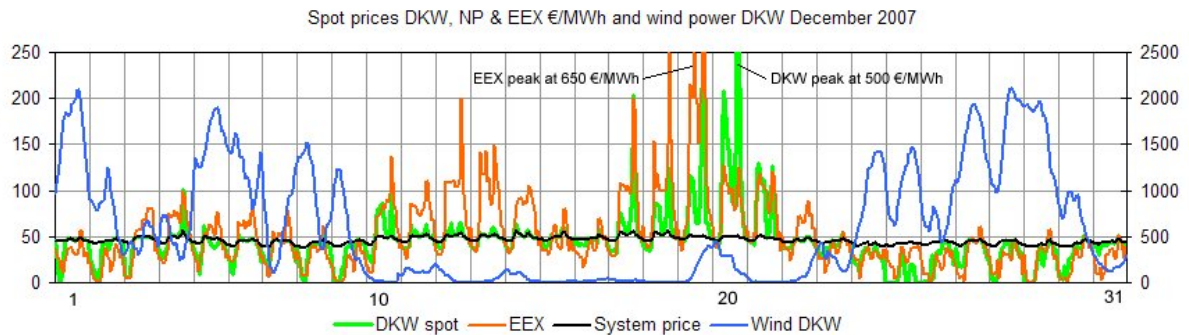
The results indicate an insufficient interconnector capacity for a reasonable market service.

4.5. December 2007: Two weeks with low wind power generation

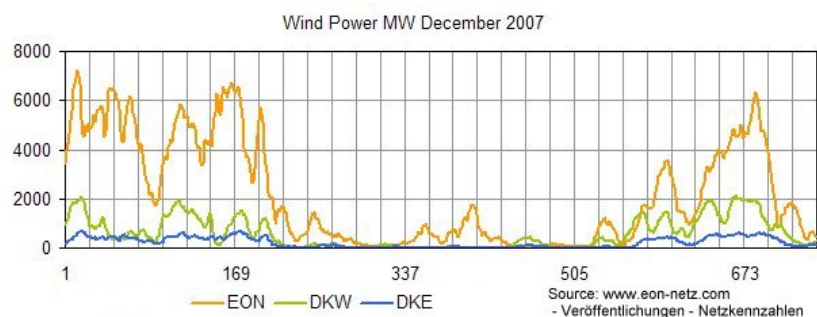
Energinet.dk Market Report, December 2007:

Mid-month, there was a period characterised by very low wind-power generation, and its effect could be noted in the spot prices as this period saw a number of very significant price spikes as a result of Danish peak-load spot prices being considerably higher than those of the other Nordic countries.

The effect of the low wind generation is evident on the diagrams for both Danish areas:



It is remarkable that the EEX spot prices seem to have a corresponding sensitivity to low wind generation. It reflects that the wind generation has been very low during two weeks in both Denmark and in the German control area of E.ON Netz.



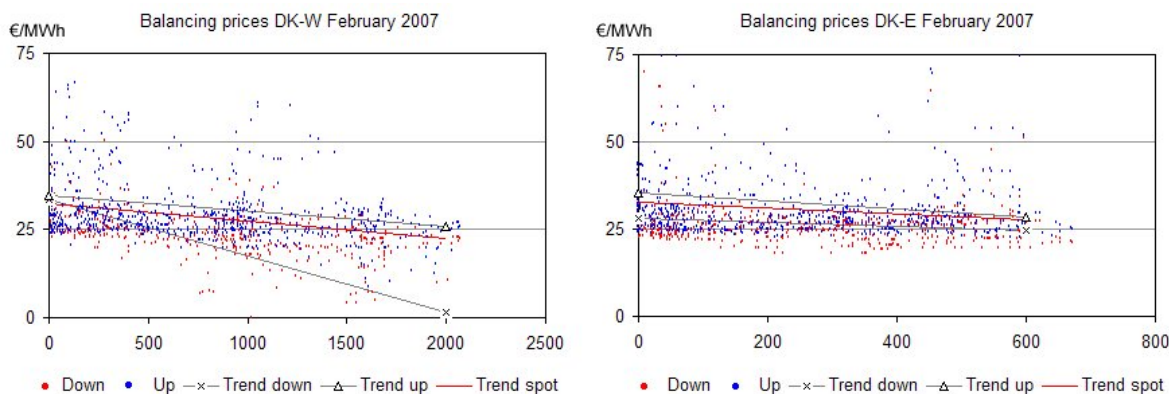
5. Regulating Power

Nord Pool Spot is a wholesale market for both buyers and sellers. Nord Pool Spot has gate closure for the following day at noon. Therefore the spot prices are based on expectations 24 to 36 hours before real time, and day-ahead wind power forecasts are very inaccurate.

The Nord Pool ELBAS market offers market players access to intra-day trade until 1 hour before delivery.

The Nordic system operators use the Nordic regulating power market for real time balancing. Market players are bidding in advance, and the system operators can activate the bids when needed. In Denmark there are different prices for regulating upwards and downwards.

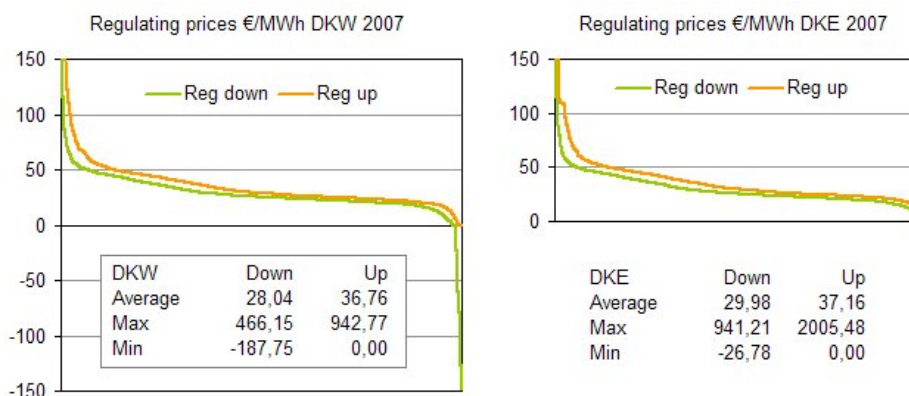
Prices and quantities depend very much on the situation. Plots with regulating prices and wind power for the two parts of Denmark show very different patterns in the sample below.



The correlation is weak for both upwards regulation (blue dots) and downwards regulation (red dots). Dots below 0 and above 75 €/MWh are not shown.

For DKW the wind generation seems to press the price for regulation downwards, while the price for regulation upwards is similar to the spot price. For DKE there is only little difference between the 3 trends. The trends are not typical but different from month to month.

Dispersed regulating prices are a first warning of unsatisfactory market stability.



Different rules apply for balancing within Nordel and UCTE. This is probably the reason why the need for purchasing regulating power is higher in West Denmark than in East Denmark. Negative prices for regulating power occurred 194 hours in West Denmark and 53 hours in East Denmark.

6. Economic Key Figures

Nord Pool's key figures according to the Annual Report 2007:

| | | |
|---------------------------------|---------|----------|
| Turnover financial market | 2007 | 2006 |
| Volum (TWh) | 1059.9 | 765,9 |
| Value (mEUR) | 43 202 | 36 294 |
| Number of transactions | 108 631 | 89 147 |
| Turnover trading and cleared | 2007 | 2006 |
| Volum (TWh) | 2 369.2 | 2 220 |
| Value (mEUR) | 81 645 | 81 932 |
| Number of transactions | 159 337 | 141 218 |
| <i>Nord Pool Spot AS</i> | | |
| Turnover, Elspot | 2007 | 2006 |
| Volum (TWh) | 290,6 | 249,8 |
| Value (mEUR) | 9 608,4 | 12 139,4 |
| Market share in the Nordic area | 0,689 | 0,614 |
| Turnover, Elbas (TWh) | 1,6 | 1,1 |

The Nord Pool Annual Report compares traded and cleared volumes with PWX, Paris, and EEX, Frankfurt. The following shares are shown:

- Nord Pool: 66 %
- EEX: 31 %
- PWX: 2 %

The value of the regulating power in 2007 was for DKW 25.5 million € and for DKE 0.8 million € (source: Energinet.dk annual report 2007).

Power plants for renewable energy (mainly wind power) were supported with 260 million € (DKW) and 132 million € (source: Energinet.dk annual report 2007).

The support for local CHP plants was 157 million € (DKW) and 55 million € (source: Energinet.dk annual report 2007).

7. Wind energy trading

One of the important traders of wind energy in Denmark is "Vindenergi Danmark Amba", which is a cooperative of owners of wind power plants, who must sell wind energy commercially. The web site, www.vindenergi.dk, presents the following trading statistics for 2007 (with my translations):

| | Jan | Feb | Mar | April | May | June |
|--------------------------|-------|------|-------|-------|-------|-------|
| West Denmark | | | | | | |
| Installed capacity, MW | 310 | 357 | 376 | 394 | 414 | 430 |
| Production, GWh | 112,8 | 73,0 | 82,1 | 71,0 | 54,9 | 34,0 |
| Clearing price, øre/kWh | 17,8 | 19,8 | 17,4 | 17,6 | 17,6 | 23,9 |
| Balancing cost., øre/kWh | 1,3 | 2,8 | 0,8 | 0,8 | 1,0 | 1,6 |
| East Denmark | | | | | | |
| Installed capacity, MW | 64 | 70 | 87 | 88 | 90 | 92 |
| Production, GWh | 24,4 | 12,5 | 18,0 | 14,0 | 9,4 | 7,5 |
| Clearing price, øre/kWh | 19,7 | 21,9 | 17,2 | 17,3 | 17,4 | 25,1 |
| Balancing cost., øre/kWh | 0,9 | 0,7 | 1,8 | 0,5 | 1,7 | 2,7 |
| Total | | | | | | |
| Installed capacity, MW | 375 | 427 | 463 | 482 | 504 | 522 |
| Production, GWh , | 137,3 | 85,4 | 100,1 | 85,0 | 64,3 | 41,5 |
| | July | Aug | Sep | Oct | Nov | Dec |
| West Denmark | | | | | | |
| Installed capacity, MW | 440 | 457 | 469 | 482 | 504 | 521 |
| Production, GWh | 75,8 | 66,0 | 108,8 | 47,1 | 107,6 | 90,3 |
| Clearing price, øre/kWh | 16,8 | 21,3 | 24,1 | 32,0 | 29,1 | 25,3 |
| Balancing cost., øre/kWh | 0,6 | 2,4 | 1,3 | 4,7 | 2,0 | 3,7 |
| East Denmark | | | | | | |
| Installed capacity, MW | 99 | 100 | 105 | 106 | 111 | 115 |
| Production, GWh | 14,7 | 11,1 | 19,9 | 9,5 | 22,3 | 20,4 |
| Clearing price, øre/kWh | 19,4 | 22,6 | 25,5 | 35,6 | 32,0 | 28,2 |
| Balancing cost., øre/kWh | 1,8 | 1,7 | 1,8 | 1,7 | 0,8 | 0,7 |
| Total | | | | | | |
| Installed capacity, MW | 538 | 557 | 574 | 587 | 615 | 636 |
| Production, GWh | 90,5 | 77,1 | 128,7 | 56,6 | 129,9 | 110,7 |

