Statistical Survey 2006

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.

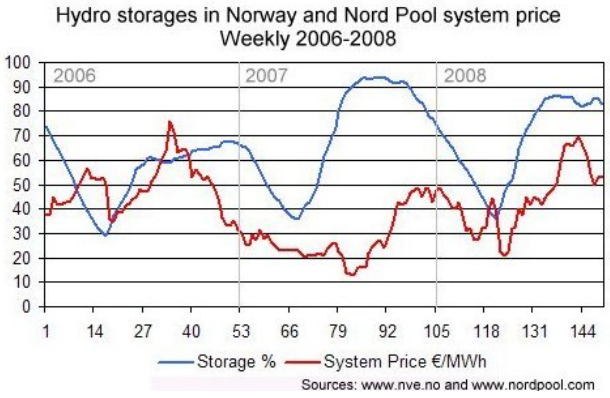
The study is made by Paul-Frederik Bach for Renewable Energy Foundation in London.

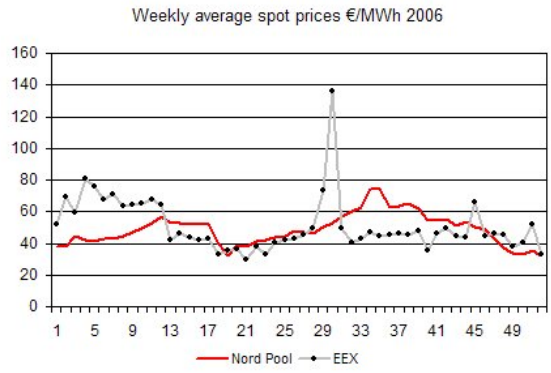
The purpose of the survey is to screen a set of data on hourly market and operational conditions in order to identify characteristics for further analysis. The data are extracted from the Energinet.dk web site unless other sources are specified.

Abbreviations:

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

2. Neighbouring countries in 2006





The inflow of water in Norway was pretty low in 2006. The water level in the hydro reservoirs was correspondingly low. Therefore the Nord Pool spot prices were significantly above the normal level in 2006 and at the same level as the German EEX spot prices.

The high spot prices created a demand for electricity from Danish thermal power plants and a net export of electricity from Denmark. Based on the market prices the export should be mainly southbound during the weeks 1 to 12 and 29 to 30 and mainly northbound during the weeks 31 to 44. The diagram shows a remarkable peak for EEX spot price in week 30. The Energinet.dk Market report July 2006 offers the following explanation:

> The summer heat on the Continent had driven continental peak spot prices to very high levels of over DKK/MWh 2000. The Nordic price level had also increased to around DKK/MWh 400, up from DKK/MWh 300 in June. This is due to the continued lower level of hydro reserves compared to the July median level.

3. Main characteristics of Danish power systems in 2006

3.1. Annual key figures

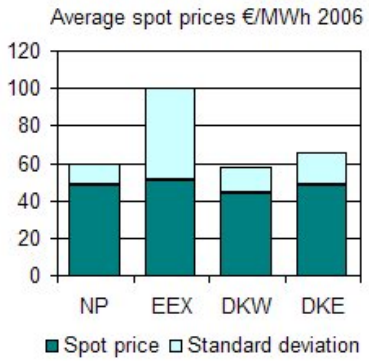
The following table is based on market data from Energinet.dk:

	Demand	Net exchanges		Wind generation		Wind energy export		
		Export	Import		% of			% of wind
	MWh	MWh	MWh	MWh	demand	MWh	Hours	generation
West	21.397.717	4.771.496	269.971	4.614.315	21,6	3.257.083	7.435	70,6
East	14.576.135	2.791.770	353.869	1.489.519	10,2	1.144.857	6.929	76,9
Denmark	35.973.852			6.103.833	17,0			

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	44,12	13,30	NP	48,51	11,13
DK East	48,46	17,55	EEX	50,75	49,42

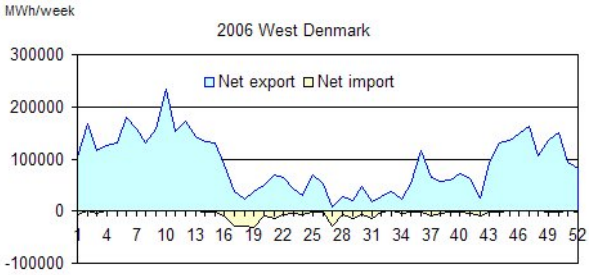


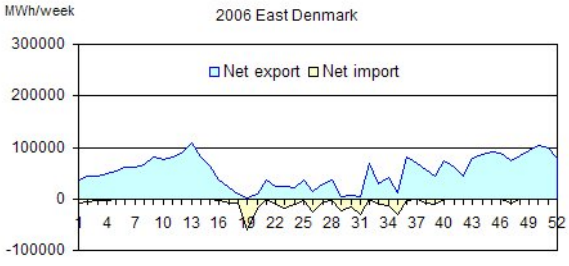
The standard deviation is an indicator of the price volatility. The very high EEX standard deviation is probably due to the exceptional conditions in July.

Due to the high demand from abroad the overflow problem has not been significant in 2006. The magnitude of the problem can be indicated by a table with number of hours with very low and very high spot prices and balancing prices. 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.

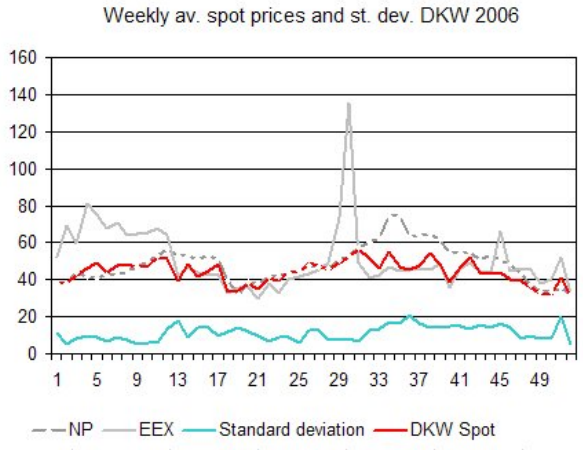
No of hours	Spot price = 0	Spot price >100	Bal. price <= 0	Bal. price >100
DK West	28	11	229	67
DK East	5	131	45	226
Nord Pool	0	1		
EEX	10	266		

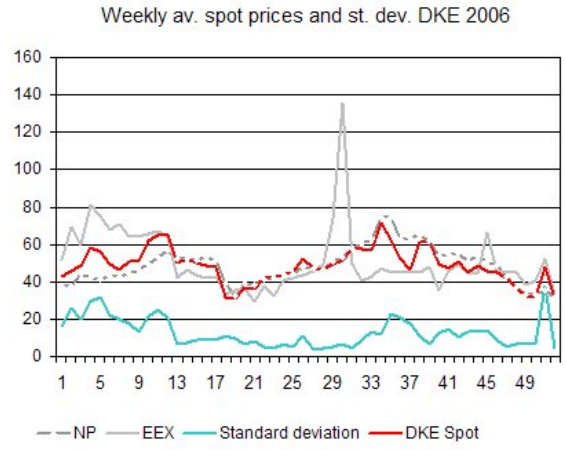
3.2. Weekly averages



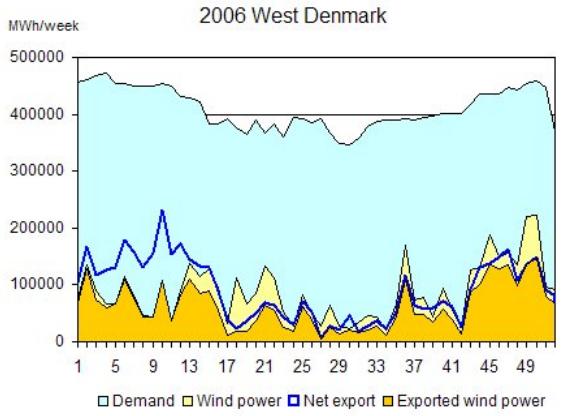


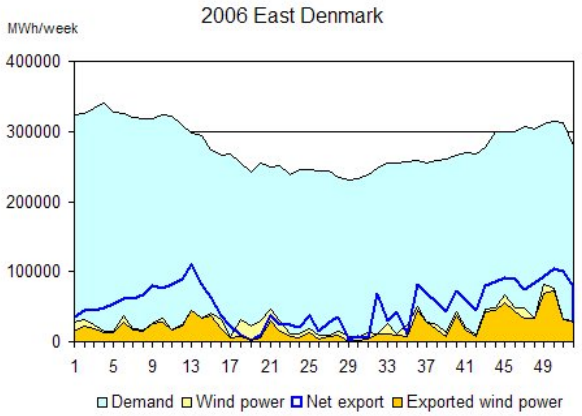
During transit periods congestion on one of the interconnectors is common. The spot prices of the two Danish systems follow either Nord Pool or EEX depending on which interconnector is congested.





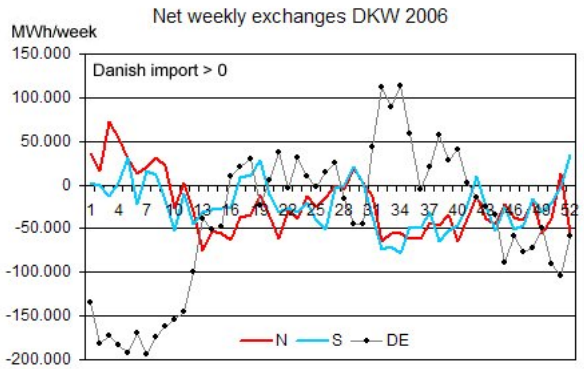
The generation of wind energy varies considerably from week to week.

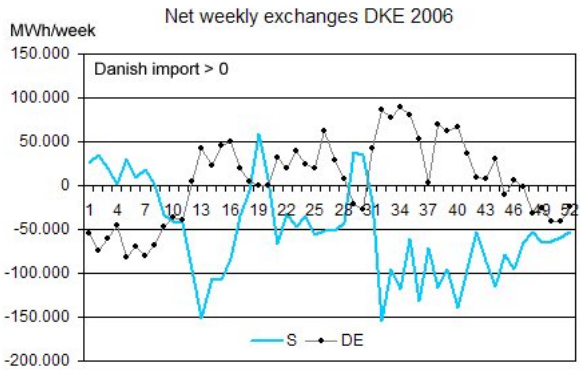




Following the definition in 3.1 the wind energy is divided into an export share (the light brown area) and a share used locally (the light yellow area). The dark blue curve is the net electricity export. There seems to be some correlation between wind energy and net export.

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





3.3. Operational Incidents

From Energinet.dk "Annual Report 2006":

System disturbances

On 19 and 20 January 2006, Denmark was lashed by a severe ice storm, and many overhead lines in the transmission and distribution grids began oscillating because of the glaze. In several places, the oscillations resulted in short-circuiting and momentary power cuts affecting about 140,000 consumers.

A major system disturbance occurred in Europe on 4 November 2006, affecting the power system in Western Denmark as well. The frequency increased markedly in connection with a split-up of the European transmission system caused by the tripping of a transmission connection in Germany. In Western Denmark, the system disturbance was dealt with without consumers being affected, but about 15 million electricity consumers in other European countries were affected by power cuts lasting less than an hour. A subsequent analysis of the sequence of events demonstrated the need of improving procedures, rules and communication in the Union for the Coordination of Transmission of Electricity (UCTE).

Technical problems

In January 2006, a Norwegian transformer for the Skagerrak 3 interconnection broke down – the newest of the three cables between Jutland and Norway. The 500 MW connection was out of operation until the Norwegian TSO, Stattnet, completed the installation of a temporary transformer on 30 November 2006.

During the storm on New Year's Eve 2006, the Kontek Link between Eastern Denmark and Germany broke down when a ship's anchor damaged the submarine cable. The interconnection was operational again in mid-March 2007.

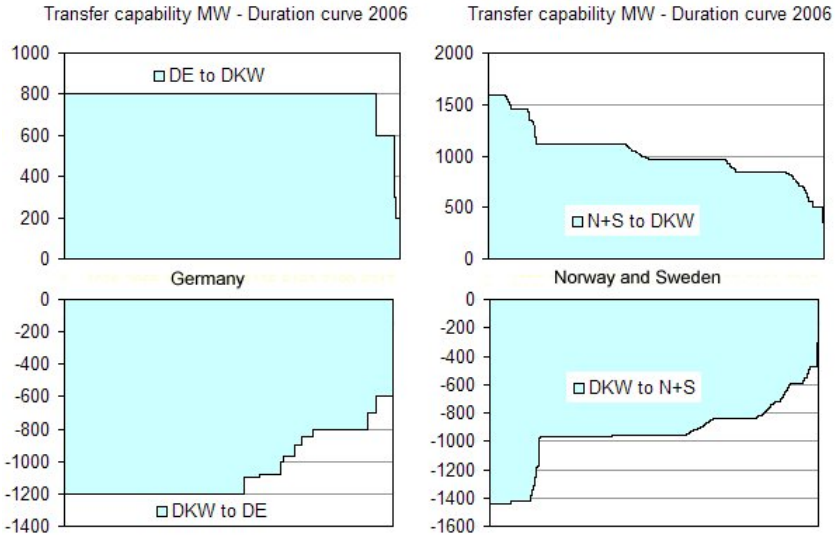
3.4. Interconnector Capacity

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.

Bottlenecks in the grids are often reflected in the available trading capacity on the interconnectors.

The transfer capability on the 400 kV AC interconnection between West Denmark and Germany depends on the stability limits of both the Danish and the German AC grids.

The duration curve shows how the transfer capability from Denmark to Germany has been more or less reduced nearly half of the time in 2006.

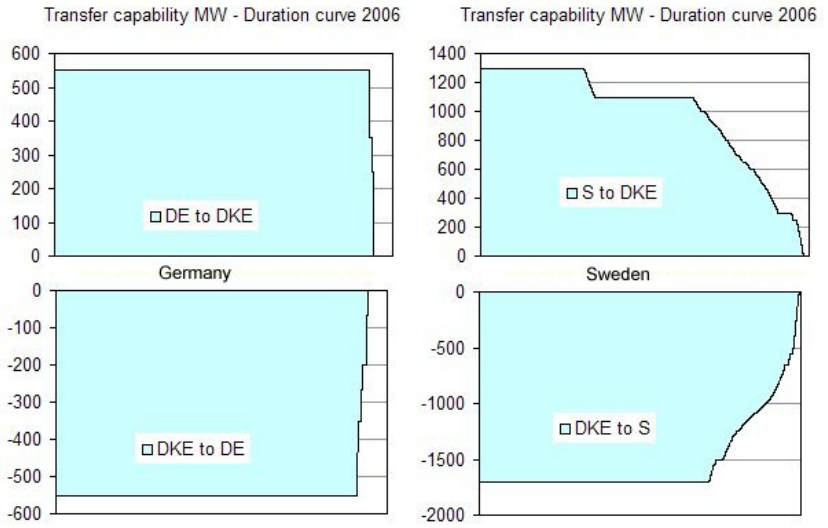


The HVDC links to Norway and Sweden suffered from severe hardware faults during 2006. There were capacity reductions most of the time. At the worst only about $\frac{1}{3}$ of the nominal capacity was available.

The Kontek HVDC link between Denmark East and Germany had a good performance in 2006. The link had to be unavailable for maintenance because it has only one pole.

The frequent and comprehensive 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.



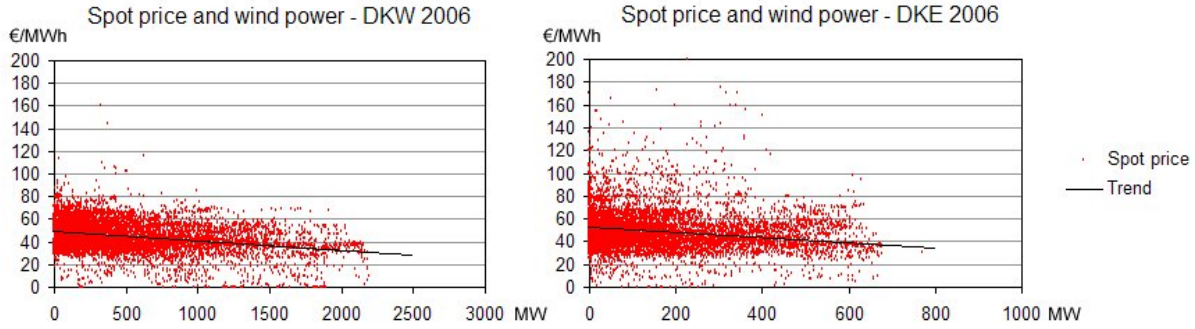
The interconnections can help smoothing spot price oscillations due to intermittent generation (particularly wind power), if there is capacity available for this purpose.

4. Wind Power and Spot Markets

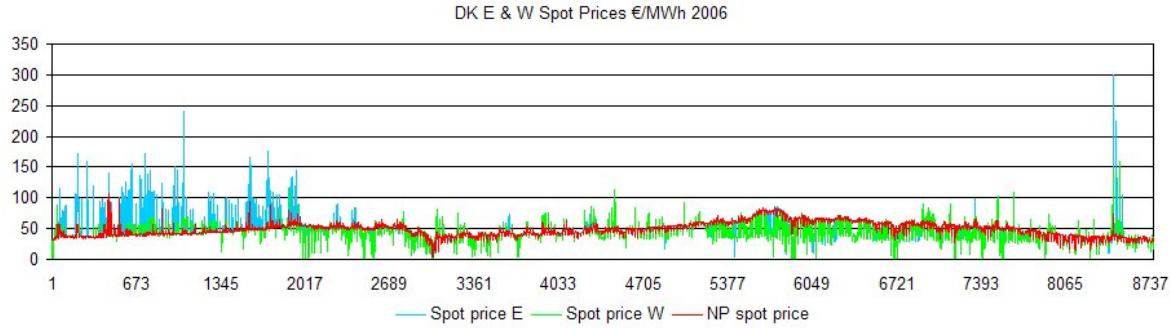
Wind power has an impact on market prices in two ways:

- 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.

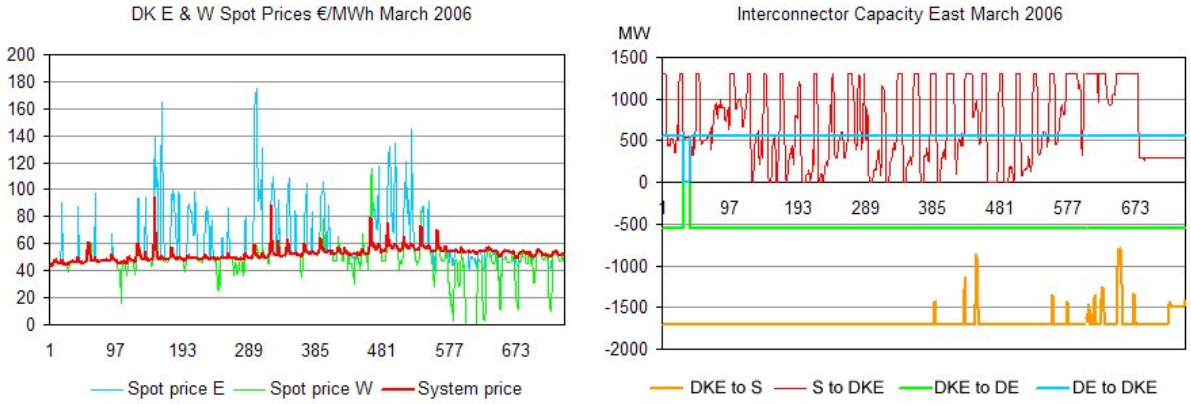


The average trend is obvious, but the dispersion is considerable and several other factors have an impact on market prices. A view on the hourly spot prices reveals some characteristic periods.



The first 12 weeks have high and volatile prices in DKE. Several other periods have low and volatile prices in DKW. Causes and relations will be demonstrated in examples.

4.1. DKE March 2006: spot prices with spikes

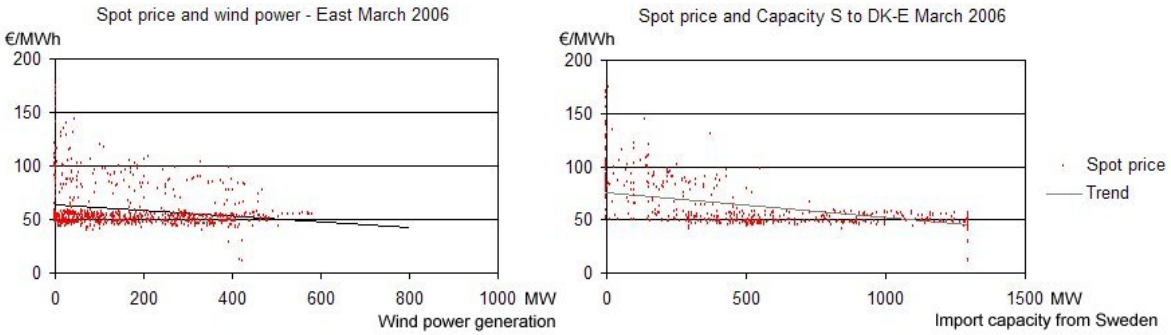


Price spikes in DKE occurred between the hours 100 and 500 when the import capacity from Sweden was reduced to 0. The Energinet.dk market report February 2006 explains:

> Svenska Kraftnät continues to manage internal congestion by reducing the trading capacity on the Øresund interconnector, and this is still the main reason for the many East Danish price spikes, which combined result in a higher average price than in Western Denmark.

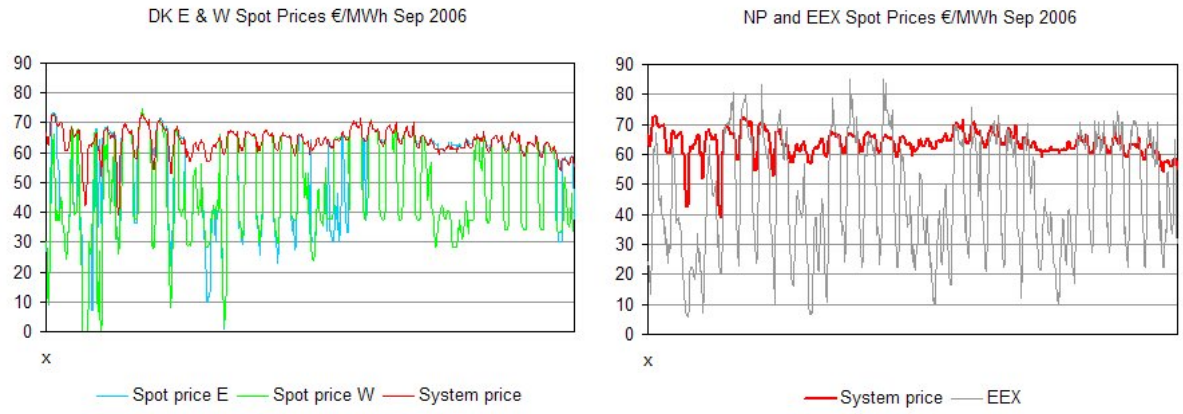
The Nordic system operators are using different methods for the handling of internal bottlenecks. Norway is divided into areas with different area prices in case of congestion. It is a Swedish policy to maintain the same spot price for all parts of Sweden. Therefore internal bottlenecks are transferred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

The DKE spot price variation as a function of wind power is quite dispersed, particularly at low wind power values. A similar image appears on a diagram showing the spot price as function of the import capacity of the interconnector to Sweden.



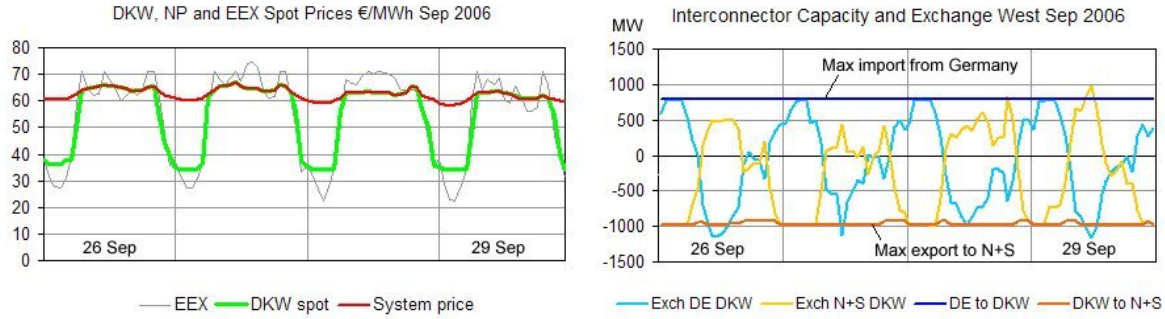
A combination of low wind generation and poor access to support from abroad (< 400 MW) may cause higher market prices than in the neighbouring countries. The reason can be either lack of competitive generating capacity or lack of local competition. Due to the Swedish congestion policy the new Danish interconnector, which is under construction across the Great Belt, is expected to curb the DKE spot price volatility.

4.2. DKW September 2006: spot prices during northbound transit



The Nord Pool system prices were high in September 2006, while the EEX prices showed a daily pattern with large variations. The two Danish areas followed very much a common pattern and they cannot always be distinguished on the left diagram.

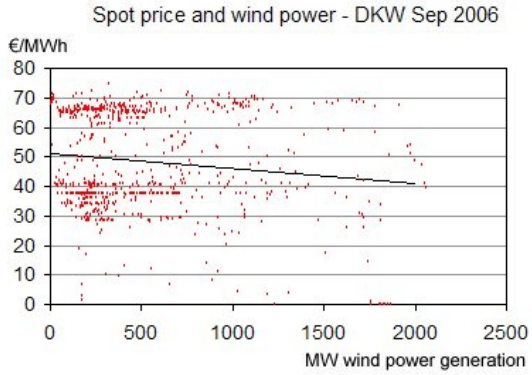
4 days have been selected to demonstrate the relation between transit and spot prices:

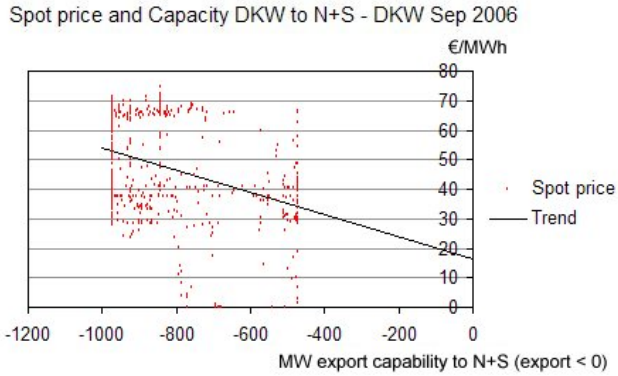


DKW has a spot price of its own during a few night hours when all interconnectors run fully loaded. Only interconnectors to Norway and Sweden are fully loaded on the ramps and the DKW spot price follow EEX. During the days when there is no congestion DKW follows the Nord Pool system price as intended due to the Nord Pool market coupling.

There was no market coupling between Nord Pool and EEX in 2006. However the differences between the Nord Pool and the EEX prices during the days in the sample are small and no significant opportunities are lost.

The local wind power only plays a minor role in this game. Therefore there is no convincing correlation between wind power and spot price or between export capability and spot price in September 2006.





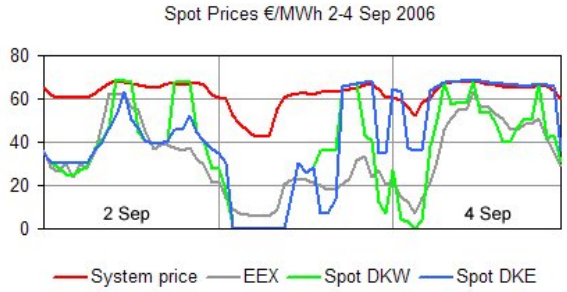
The Energinet.dk Market Report September 2006 has the following comment on the market conditions in September:

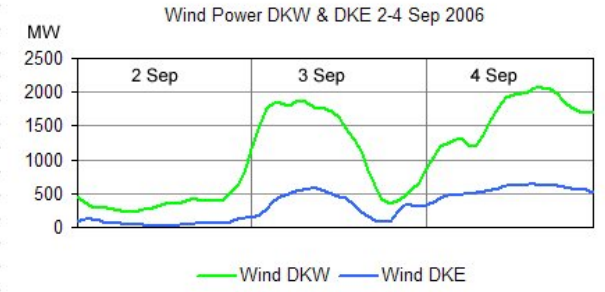
> High wind power production, low weekend consumption and bottleneck in export direction led to zero prices on the 3rd of September in both West and East Denmark. In a completely different scenario, the weekend of 23rd and 24th of September saw high prices of DKK 450/MWh, which is unusual for a weekend. There was full import from the KONTEK price area and the export to Sweden was not unusually high. There was production outage on a single generator with total capacity of 250 MW.

In 2005 Nord Pool started a bidding area in the Vattenfall Europe Transmission control area in Germany called the *KONTEK price area* in order to give German market players direct access to the Nordic electricity market. The KONTEK price area was planned to serve German users until the start of a regular market coupling between Nord Pool and Germany in 2008 (EMCC).

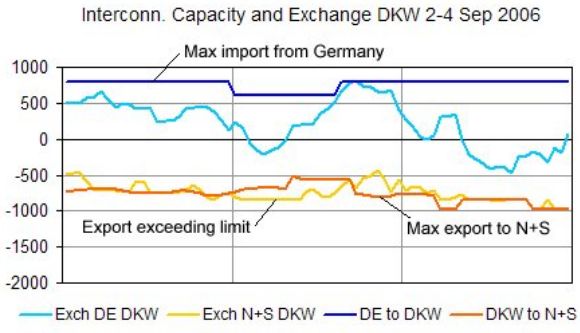
4.3. 2nd to 4th September 2006: Zero spot prices in both parts of Denmark

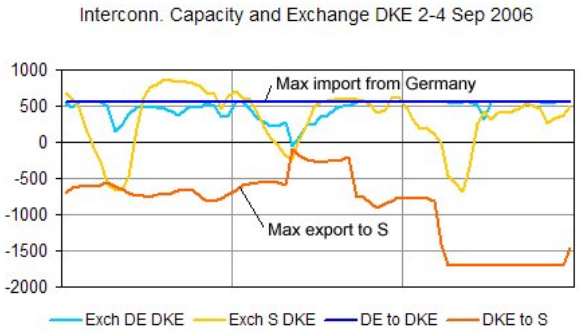
On 3 September a combination of low demand and high wind power generation caused zero spot prices in both DKW and DKE:



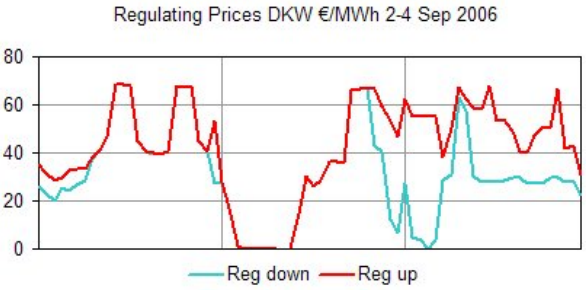


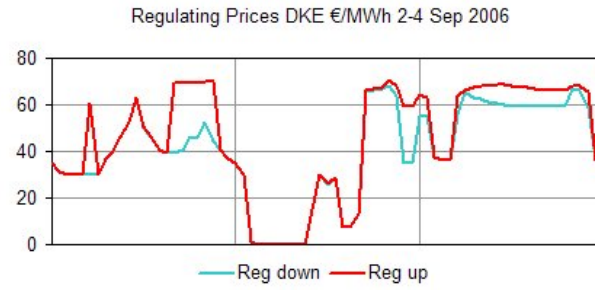
The very low EEX price on that particular Sunday probably reflects a similar situation in Germany and a pressure for a northbound transit. Therefore Danish surplus power can only be exported to Norway and Sweden. Unfortunately the northbound transfer capability was reduced on 3rd September.





For DKE there seems to have been idle export capacity while the spot price was zero. One reason can be that spot prices are based on expectations the day before and that the real operating conditions can be very different. This is reflected in the prices of regulating power:



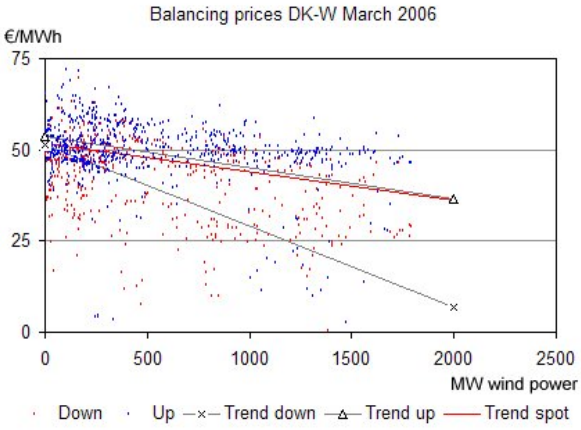


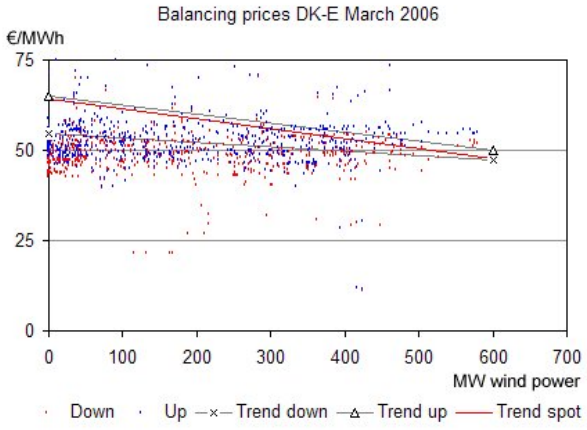
5. Regulating Power

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.

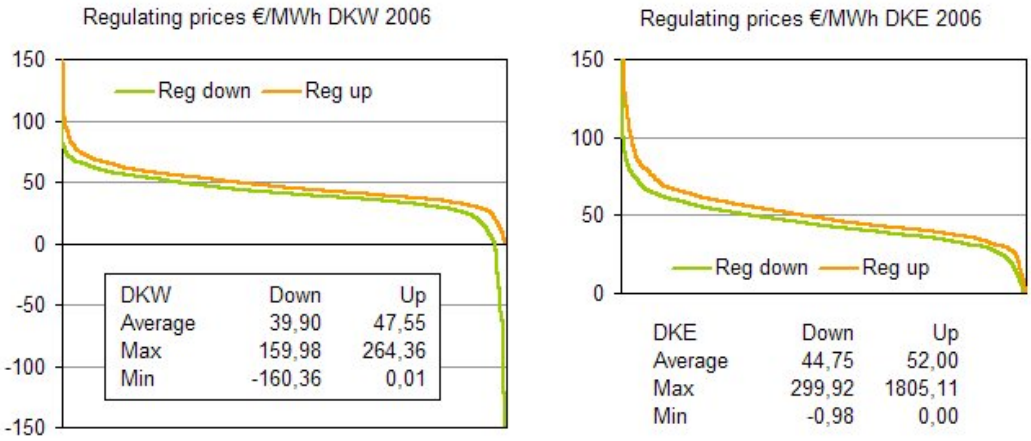




Prices and quantities depend very much on the situation. Plots with regulating prices and wind power for the two parts of Denmark show very different patterns in the sample.

Upwards regulation (blue dots) is not much different from the spot price while prices for downwards regulation (red dots) can be considerably lower than spot prices, particularly for high wind power values. Dots below 0 and above 75 €/MWh are not shown.

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 then in East Denmark. Negative prices for regulating power occurred 229 hours in West Denmark, but practically not yet in East Denmark.

6. Economic Key Figures

According to Nord Pool's annual report 2006 the Danish trade in the spot market was about 13 % of the total spot market volume or about 33 TWh. This is 92 % of the Danish electricity demand in 2006 and 72 % of the Danish gross electricity generation in 2006. Based on these figures the magnitude of the Danish spot market trade in 2006 can be estimated at 1,500 million €.

The value of the regulating power in 2006 was for DKW 26 million € and for DKE 4 million € (source: Energinet.dk annual report 2006).

Power plants for renewable energy (mainly wind power) were supported with 98 million € (DKW) and 69 million € (source: Energinet.dk annual report 2006).

The support for local CHP plants was 44 million € (DKW) and 10 million € (source: Energinet.dk annual report 2006).

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 2006 (with my translations):

Vindenergi DK 2006	Jan	Feb	Mar	April	Maj	Juni
West Denmark						
Installed capacity, MW	207	216	220	228	228	238
Production, GWh	30,3	24,4	32,9	35,8	40,8	26,4
Clearing price, øre/kWh	30,2	34,2	32,9	31,8	26,2	32,4
Balancing cost., øre/kWh	2,5	1,9	2,8	3,1	1,8	1,3
East Denmark						
Installed capacity, MW	45	47	45	46	46	51
Production, GWh	5,0	4,0	6,3	6,0	7,7	3,5
Clearing price, øre/kWh	34,2	36,5	41,9	36,3	26,1	33,9
Balancing cost., øre/kWh	33,1	2,7	1,6	0,9	0,8	2,3
Total						
Installed capacity, MW	252	263	265	273	274	288
Production, GWh ,	35,3	28,4	39,1	41,8	48,5	29,9
	Jul	Aug	Sep	Oct	Nov	Dec
West Denmark						
Installed capacity, MW	245	256	266	270	284	294
Production, GWh	15,2	19,1	40,5	35,8	75,5	83,9
Clearing price, øre/kWh	35,7	38,5	34,9	28,9	28,7	24,2
Balancing cost., øre/kWh	1,4	3,2	1,6	2,1	3,3	1,2
East Denmark						
Installed capacity, MW	53	54	57	62	63	64
Production, GWh	2,3	4,6	7,3	9,3	14,1	17,9
Clearing price, øre/kWh	37,0	43,7	39,7	33,3	32,2	24,6
Balancing cost., øre/kWh	2,0	3,8	0,5	1,0	1,7	0,4
Total						
Installed capacity, MW	298	310	323	332	347	358
Production, GWh	17,5	23,7	47,7	45,1	89,6	101,8