Wind Power and Spot Prices in Denmark and Germany

Statistical Survey 2010

Preface

This text supplements *Wind Power and Spot Prices: German and Danish Experience 2006-2008*[1] and *Statistical Survey 2009* by adding data for the calendar year 2010 and extending the study by Irish wind power data.

The evaluations are based on market data published by Energinet.dk, by the four German transmission system operators and by Eirgrid, and on market reports from Energinet.dk. Furthermore data from Norwegian Water Resources and Energy Directorate[2], Statnett[3] and Nord Pool Spot[4] has been used. Evaluations are offered, though with reservations regarding the accuracy of the data.

Abbreviations:

EEX	European Energy Exchange	DKE	Denmark East	DE	Germany
NP	Nord Pool	N	Norway	ENDK	Energinet.dk
DKW	Denmark West	S	Sweden	IE	Ireland

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[1] http://www.ref.org.uk/PublicationDetails/53
[2] http://nve.no/
[3] http://www.statnett.no/
[4] http://www.nordpoolspot.com/

1. Overview

Wind power performance

2010		Denmark	Germany	Ireland
Wind	GWh	7.808	36.055	2.598
Max	MW	3.333	21.204	1.214
	Load factor	0,27	0,19	0,24
Share	%	22,0	6.0	9,8

- The average capacity factors in Denmark were 0.20 onshore and 0.40 offshore[5]. The corresponding duration hours were 1,787 hours onshore and 3,495 hours offshore.
- For Denmark and Germany together the share of wind energy has been estimated as equivalent to 7% of the aggregated demand.
- There is a high positive correlation between German and Danish wind power energy flows.
- Calm periods with low wind power output occur simultaneously in Denmark and Germany. The minimum average wind power output during 24 consecutive hours in 2010 was 0.33% of the maximum hourly production for Denmark, and 1.31% for Denmark and Germany together (1.75% for Denmark, Germany and Ireland together).

Poor interconnector performance

Max capacity MW	To DKW	From DKW	To DKE	From DKE
Norway	1.000	1.000		
Sweden	680	740	1.300	1.700
Germany	950	1.500	600	585
DKW			590	600

Availability	To DKW	From DKW	To DKE	From DKE
Norway	92.4%	91.7%		
Sweden	40.0%	39.9%	87.8%	84.9%
Germany	90.7%	76.3%	82.0%	83.4%
DKW			95.8%	95.8%

- The Danish interconnections had low availability for trade in 2010 due to outages of interconnector equipment, and the limited capacity of adjoining transmission grids.
- The Konti-Skan interconnector between West Denmark and Sweden was running at less than half capacity most of the year due to a transformer outage. Normal capacity was reported from 17 December 2010.
- The Great Belt interconnector between West and East Denmark was commissioned in August 2010.
- The average availability has been poor for the years 2006-2010 for all interconnectors between Denmark and the neighbouring countries.

Increasing shortage of transmission capacity

- The EWIS study (European Wind Integration Study) has predicted increasing congestion levels for interconnectors by 2015.

[5] Based on installed capacity for wind turbines operating throughout the year

- Ambitious wind power plans combined with poor interconnector availability stresses the need for careful consideration of the future need for transmission capacity in order to maintain reasonable function of the international electricity markets

Spot market performance

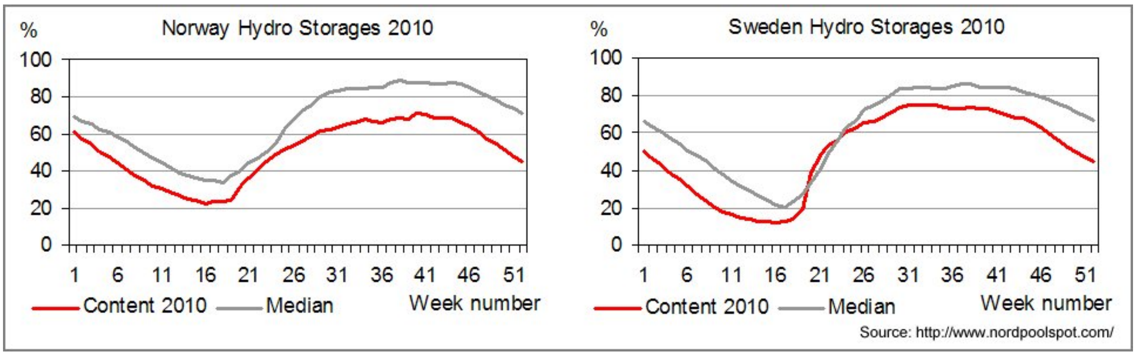
2010	Average area prices	Spot prices <= 0	Standard deviation
	€/MWh	No of hours	€/MWh
West Denmark (DKW)	46,34	12	11,89
East Denmark (DKE)	56,77	6	54,53
Nord Pool system price	52,83	0	16,05
EEX, Germany	44,36	12	13,97

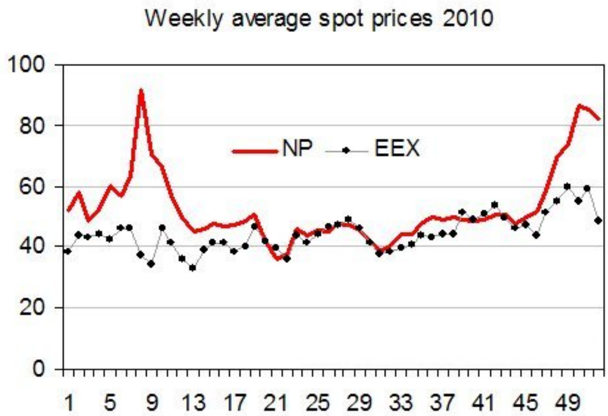
- The market seems to have been divided in 2010 with the lowest prices in Germany and West Denmark and higher prices to the north.
- Low standard deviations indicate good spot price stability, but do not exclude the occurrence of extreme prices.
- High prices and standard deviation in East Denmark reflect insufficient interconnection capacity. The commissioning of the Great Belt interconnection in September 20010 may rectify the problem.
- The number of hours with negative spot prices in Germany is the lowest since 2006.
- Nord Pool allowed negative spot prices in Denmark from October 2009: in 2010 12 hours with negative spot prices occurred in West Denmark and 6 hours in East Denmark.

Energy perspectives

- The estimated inflow of water to the Norwegian hydro system was 107 TWh in 2010. The electricity demand was 131 TWh. The content of the water storages in Norway at the end of 2010 was 37 TWh (21 TWh below the normal level).
- The Swedish nuclear power stations produced 50 TWh in 2009. It is 15 TWh below average for the years 1999-2009 and 25 TWh below the output in 2004. Swedish data for 2010 are not yet available.
- The Swedish hydro system produced 65 TWh in 2009. It is 2 TWh below average for the years 1999-2009. The combined nuclear and hydro production in Sweden in 1999 was the lowest for the years 1999-2009.
- Uncertainty about the future use of nuclear energy in Germany after the nuclear events in Japan will influence expectations for future European energy balances.

2. Neighbouring countries in 2010





The water storage levels in Norwegian and Swedish hydro have been below normal most of the year.

Low nuclear output in Sweden in 2009, low inflow of water in Norway in 2010 and increased demand for electricity in Norway in 2010 are among the contributing factors.

The result was periods in 2010 with high Nord Pool spot prices. The German prices (EEX) were more stable, but slightly increasing throughout the year.

Time series with hourly wind power output in 2010 were downloaded for Denmark, Germany and Ireland.

We know from previous analyses that wind power in Denmark and Germany has a significant co variation.

The Irish data has been added in order to be able to analyse the smoothing effect of combining wind power over a considerable distance from east to west.

The German electricity consumption in 2010 is estimated at 600 TWh.

The German system operators are: TenneT (former Transpower and E.on Netz), Amprion (RWE), EnBW and 50Hertz (former Vattenfall Transmission).

3. Main characteristics of Danish power systems in 2010

3.1. Annual key figures

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

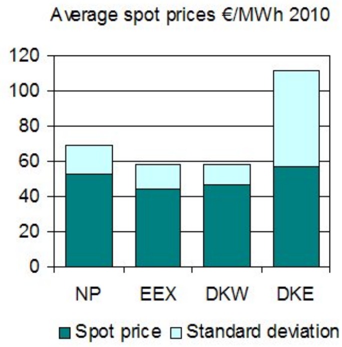
2010	Demand			Thermal	Wind		Hourly net exchange	
	MWh	Max MW	Duration Hours	Generation MWh	Generation MWh	% of demand	Export MWh	Import MWh
DK West	21.120.804	3,677	5,588	18.850.724	5.874.562	27,8	4.517.260	912.895
DK East	14.364.460	2,614	5,374	9.962.158	1.933.138	13,5	754.694	3.223.978
DK (total)	35.485.263	6,287	5,503	28.812.882	7.807.700	22,0	4.228.791	3.093.710

The net export has been calculated hour by hour as the total of all exchange from each of the two Danish systems and from the entire country.

The duration hours have been calculated as annual energy demand divided by maximum load. They tell the same story as the load factor (duration hours divided by the number of hours in the year). The year 2010 had 8,760 hours.

The average market conditions are summarized in this table:

	Area price	St.Dev.		Spot price	St.Dev.
	€/MWh	€/MWh		€/MWh	€/MWh
DK West	46.34	11.89	NP	52.83	16.05
DK East	56.77	54.53	EEX	44.36	13.97

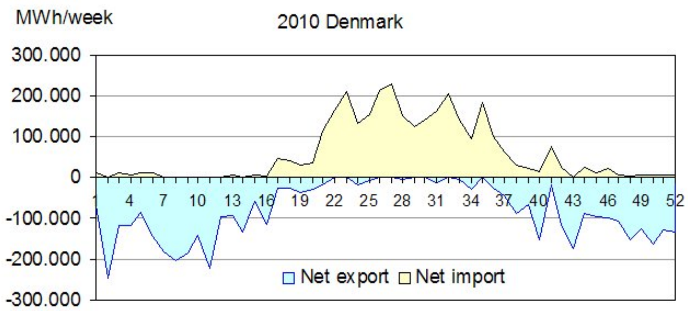


The standard deviation is an indicator of the price volatility. The possible reasons for the differences will be discussed subsequently.

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 to zero and downwards balancing prices 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 introduced negative spot prices in October 2009.

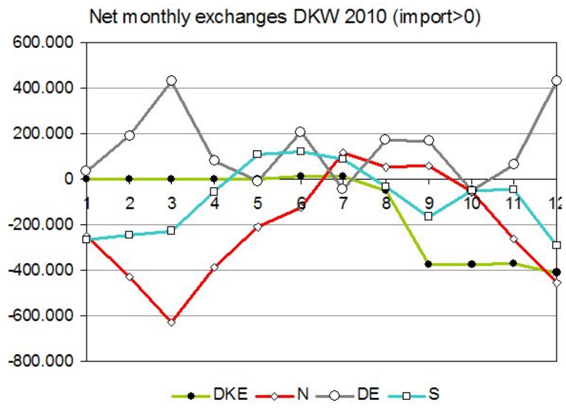
No of hours	Spot price <= 0	Spot price >100	Bal. price <= 0	Bal. price >100
DK West	12	8	301	163
DK East	6	412	4	478
Nord Pool	0	139		
EEX	12	7		

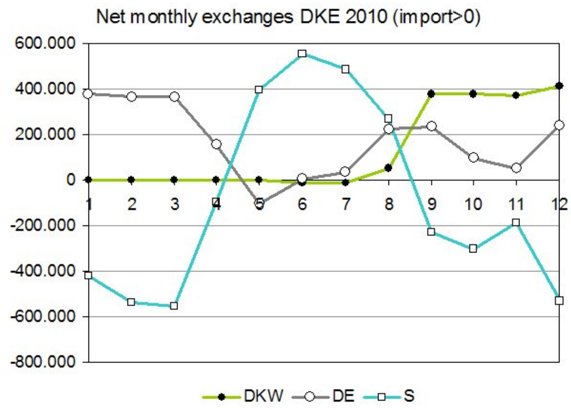
3.2. Weekly and monthly averages



Due to the commissioning of the Great Belt link in August 2010 weekly exchange of power is shown only for the entire country.

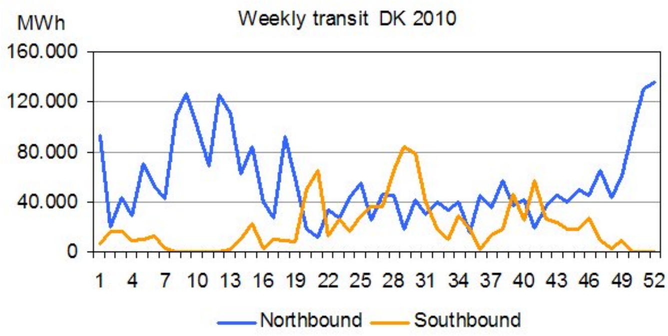
Net exchanges have been accumulated weekly per hour for Denmark (left) and monthly for each border (below). The pattern reflects both international market conditions in 2010 and Danish energy balances during the year.



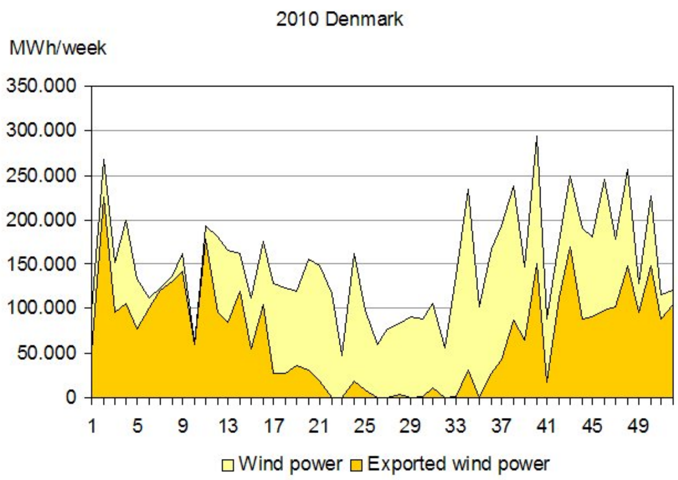


In 2010 there has been a net import from Germany at 3.7 TWh and a net export to Norway at 2.6 TWh. The net export to Sweden was 2.2 TWh, but with distinct seasonal variations.

Transit has been calculated hour by hour. In accordance with the spot price profile (chapter 2) there is a mainly northbound transit during the cold seasons, but no predominant direction during the summer. This pattern is unusual. The total transit was 2.8 TWh northbound and 1.0 TWh southbound.



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

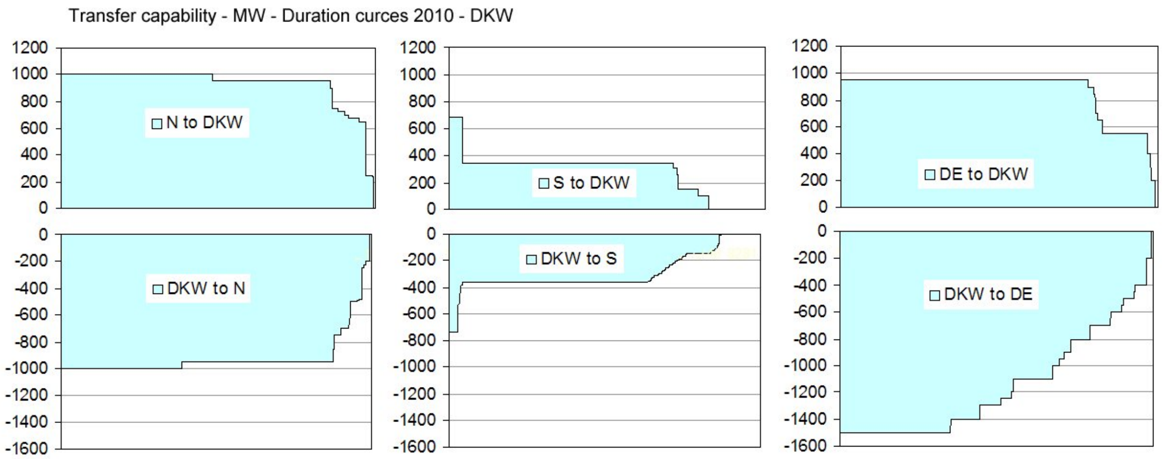


The wind energy is divided into an export share (the light brown area) and a share used locally (the light yellow area). The estimate of exported wind energy is a sensitive matter because it raises doubts about the beneficiary of subsidised Danish renewable energy. In this context the *wind energy export* has been defined for each hour as the smaller value of generated wind energy and net export. The chart indicates that the share of exported wind energy is high during the cold seasons when increased demand for heat entails high electricity production from the CHP plants.

3.3. Interconnector Performance

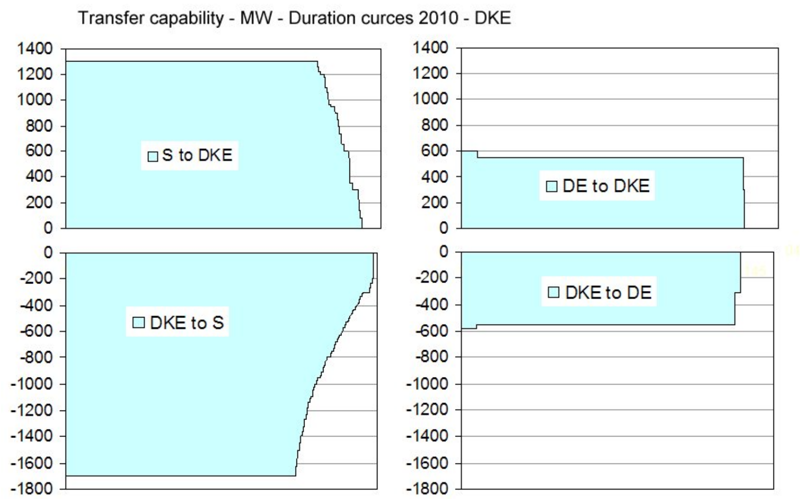
The electricity market is the modern tool for optimizing power system operation across national borders. Sufficient transport capacity is a decisive factor for both reasonable system security and an efficient market service.

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



The Konti-Skan interconnector between West Denmark and Sweden was running at less than half capacity most of the year due to a transformer outage. Normal capacity was reported from 17 December 2010. Even the HVDC links to Norway continued to suffer from hardware faults during 2010, the transfer capability from West Denmark to Germany being more or less reduced for nearly half of 2010.

The AC interconnection between Denmark East and Sweden is a main life line for East Denmark, but the transfer capability can be very low during critical periods. The Nordic system operators use different methods for the handling of internal bottlenecks. So far it has been the Swedish policy to maintain the same spot price for all parts of the country. Therefore internal bottlenecks are



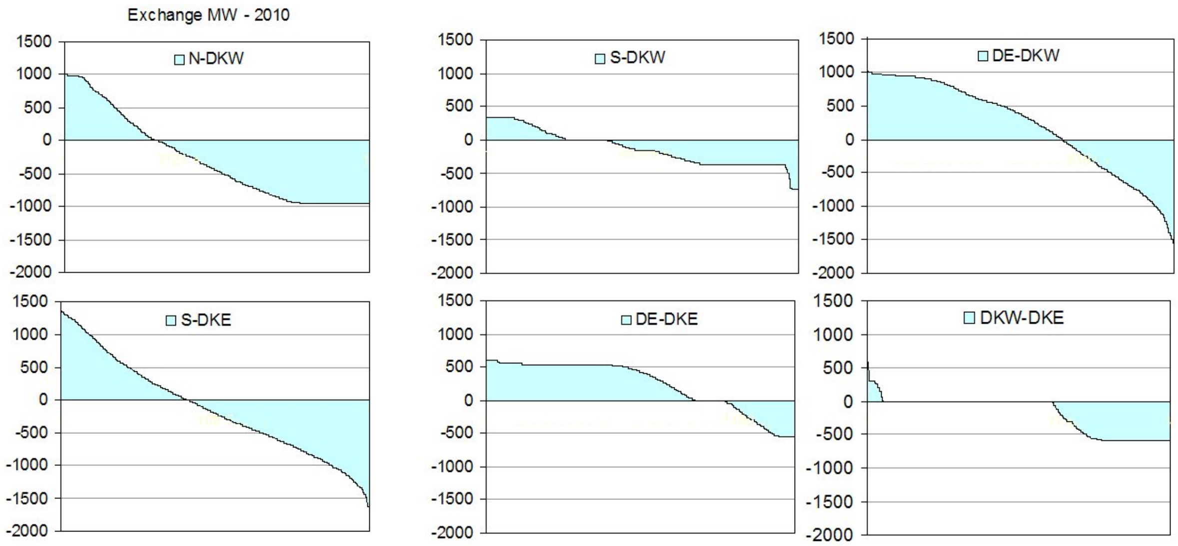
transferred into reduced trading capacity on interconnectors.

Interconnections are often supposed to have nearly 100% availability. The Danish observations from the period 2006 to 2010 demonstrate that the practical availabilities are much lower.

2010	Average availabilities of interconnections			
%	To DKW	From DKW	To DKE	From DKE
Norway	92,4	91,7		
Sweden	40,0	39,9	87,8	84,9
Germany	90,7	76,3	82,0	83,4
DKW			95,8	95,8

Interconnections can help smooth spot price oscillations due to intermittent generation (particularly wind power), but, obviously, this is only true if there is capacity available for this purpose.

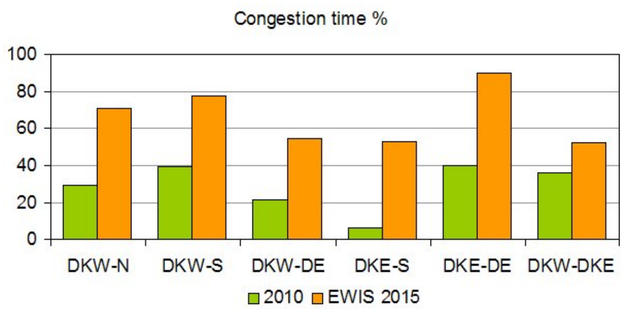
The following charts give an impression of the amounts exchanged on each interconnection in 2010:



In the following table the number of hours with import, export and congestion in 2010 is shown for each of the five interconnectors.

Hours	Export	Congest.	Import	Congest.	Total	% congest.
DKW-N	6070	1851	2652	713	8760	29,3
DKW-S	5619	2776	2312	648	8760	39,1
DKW-DE	3199	854	5560	1029	8760	21,5
DKE-S	5158	304	3601	244	8760	6,3
DKE-DE	2009	373	5959	3145	8760	40,2

The chart compares congestion time in 2010 with estimated values for 2015 from the EWIS study[6]. The comparison suggests careful consideration of the future need for interconnector capacity in order to maintain reasonable function of the international electricity markets.



[6] European Wind Integration Study: EWIS Final Report, 31 March 2010

3.4. Wind Power Performance

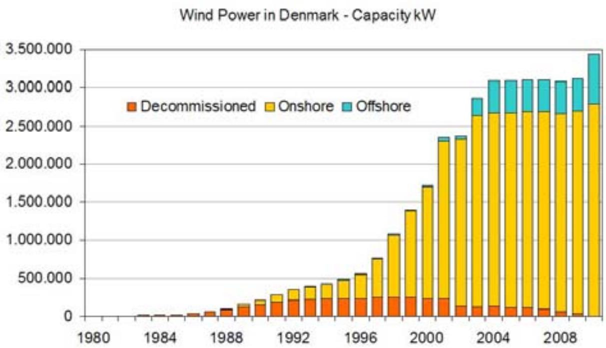
Downloading hourly wind power output for Germany and Ireland allows us to study the wind power profile for a larger geographical area than Denmark. It is particularly interesting as a means of evaluating whether the smoothing effect can eliminate the occurrence of sharp peaks and times of zero production.

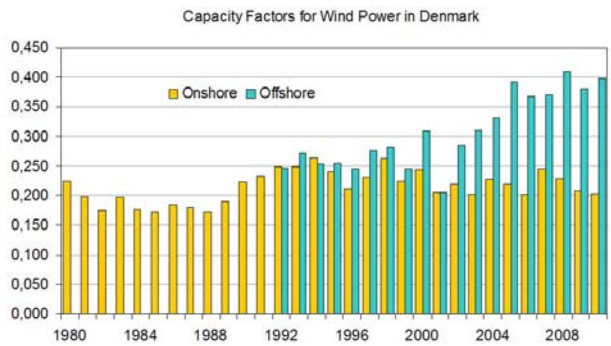
2010		TenneT DE	50 Hertz	Amprion	EnBW	DE total	EirGrid
Wind	GWh	14.463	15.133	5.983	476	36.055	2.598
Max	MW	8.822	9.721	3.827	371	21.204	1.214
Min	MW	0	15	0	0	104	0
	Load factor	0.19	0.18	0.18	0.15	0.19	0.24
Share	%	-	-	-	-	6.9	9.8

The German share of wind energy has been based on an estimated total electricity gross consumption of 600 TWh.

2010		DKW	DKE	DK total	DE+DK	DK+IE
Wind	GWh	5.875	1.933	7.808	43.863	10.405
Max	MW	2.483	864	3.333	24.315	4.182
Min	MW	0	0	2	124	17
	Load factor	0.27	0.26	0.27	0.21	0.28
Share	%	27.8	13.5	22.0	7.3	16.8

At the end of 2009 the installed wind power capacity in Denmark was 3,482 MW of which 661 MW was offshore capacity.[7] The installed capacity in Germany at the end of 2009 was 25,777 MW.[8] The first German offshore wind farm, Alpha Ventus (60 MW), was completed in 2009.[9] On the island of Ireland 1746.7 MW of wind power was installed on 19 July 2010.[10]





Note that these charts include only those wind turbines which have been in operation during the entire year.

3.5. Smoothing effect of international aggregation of wind power

Time series of wind power have different profiles in the three countries reflecting both geography and different shares of offshore wind.

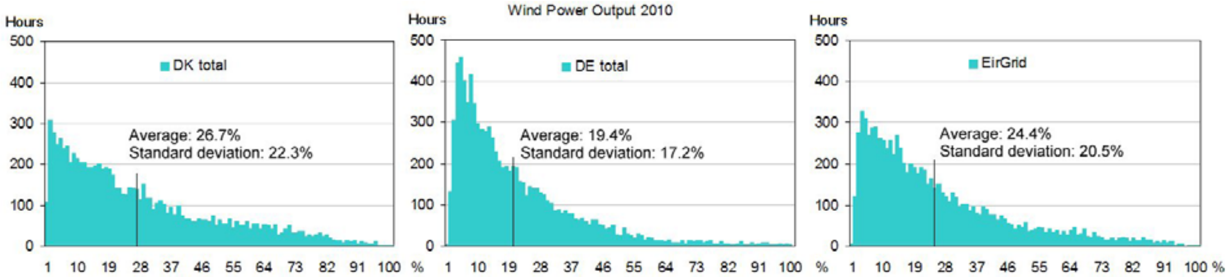
The maximum simultaneous wind power production for Denmark and Germany was 24,315 MW in 2010 or 92.3% of the sum of the six local hourly *peak* productions (26,088 MW). The

[7] http://www.ens.dk
[8] http://www.wind-energie.de/de/statistiken/datenblatt-2009/
[9] http://www.offshore-wind.de
[10] http://www.iwea.com/index.cfm/page/windenergyfaqs?#q21

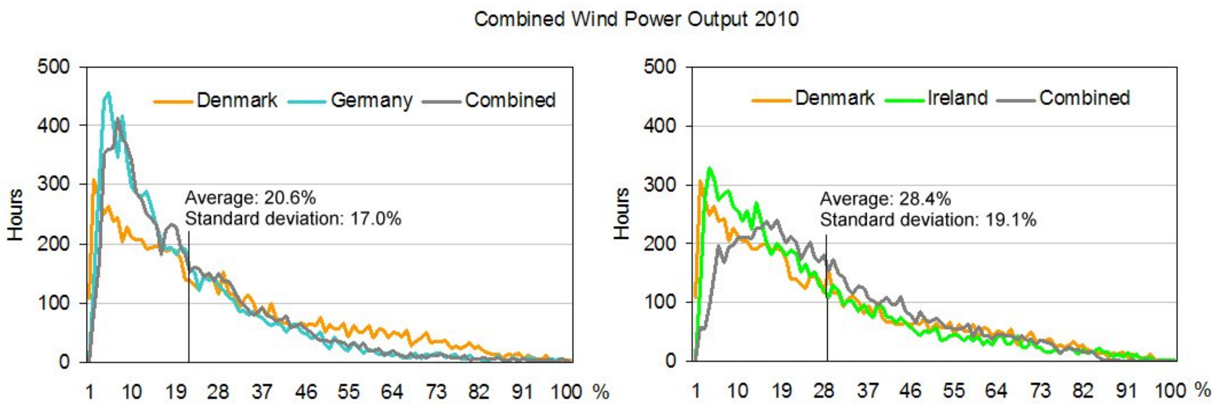
maximum simultaneous wind power production for Denmark and Ireland was 4,182 or 91.7% of the sum of the three local hourly *peak* productions (4,561 MW).

It seems that the maximum wind power peaks can be reduced by about 10% by extending the geographical zone considered.

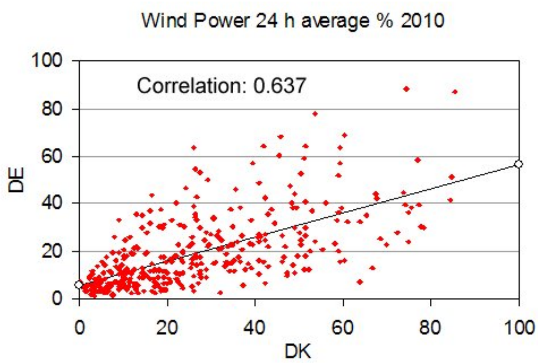
The following charts show the number of hours recorded for 1% steps of maximum production. The average values of the three distributions are identical with the load factors.

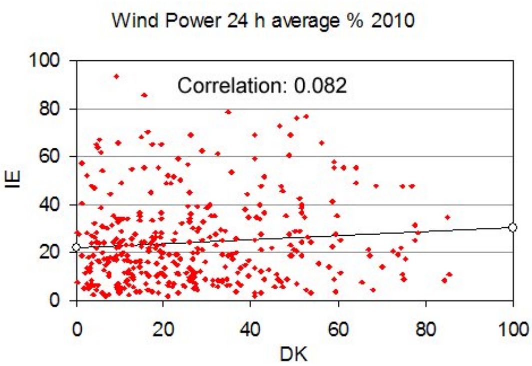


It is difficult to quantify the smoothing effect of aggregating wind power across a larger geographical area, but it can be demonstrated that combining Denmark and Ireland has more effect than combining Denmark and Germany:

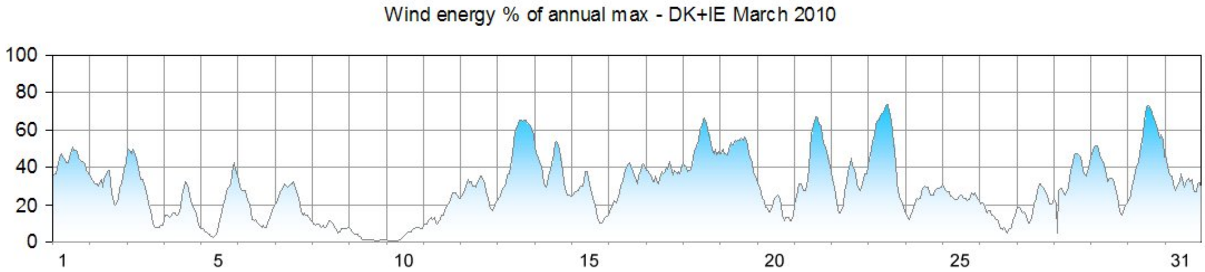


It is obvious that the combined distribution for Denmark and Ireland has another profile with a higher average value (28.4%) than the separate distributions for the two countries (26.7% and 24.4%). A scatter plot of 24 hours average values is a different presentation:



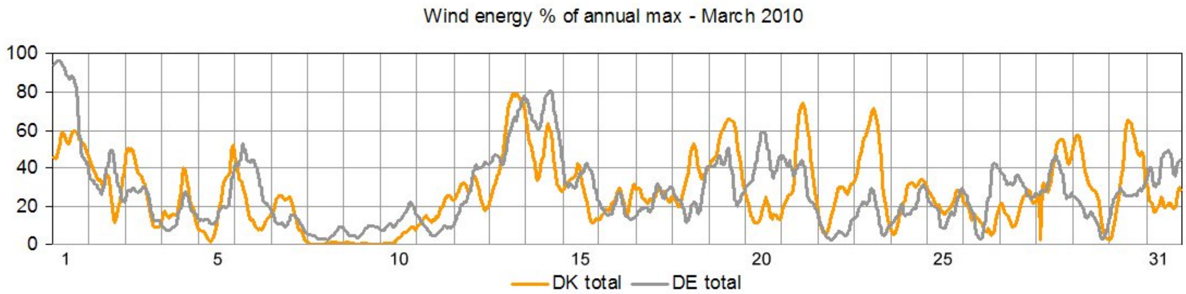


The low correlation between Danish and Irish wind power could suggest a smooth aggregated wind power output. However, even the combination of Danish and Irish wind power has a high variability:



The chart shows a typical combination of Danish and Irish wind power (March 2010). The aggregated wind power would have a slightly better theoretical capacity credit than local wind power, but it would still not make a steady source of energy. From 8th March more than 3 consecutive days have less than 20% output.

Danish and German wind power have a high degree of simultaneousness. March is a fair example with cases of obvious co-variation and cases of less related variations:



The minimum aggregated wind power output can be presented in a more systematic way:

2009	Wind power minimum average sustained output in % of annual hourly maximum									
	DKW	DKE	TenneT	50 Hz	Amprion	EnBW	EirGrid	DK total	DK+DE	DK+IE	DK+DE+IE
Hours	%	%	%	%	%	%	%	%	%	%	%
1	0.02	0.00	0.00	0.15	0.00	0.00	0.00	0.05	0.51	0.39	0.61
12	0.09	0.02	0.64	0.26	0.17	0.00	1.05	0.19	1.10	1.12	1.48
24	0.17	0.08	1.10	0.32	0.64	0.66	1.81	0.33	1.31	1.30	1.75
48	0.55	0.17	1.37	0.62	1.45	1.65	2.25	0.54	2,11	3,24	2,79
96	5.24	0.82	2.43	2.30	2.11	1.86	5.29	4.13	3,74	6,97	4,21

The table shows for example that the aggregated Danish, German and Irish wind power output for 48 consecutive hours has been 2.79% of the aggregated maximum value.

A capacity credit can be calculated for a fleet of wind turbines by use of statistical methods, and capacity credits between 6 and 10% of the installed wind power capacity have been proposed.

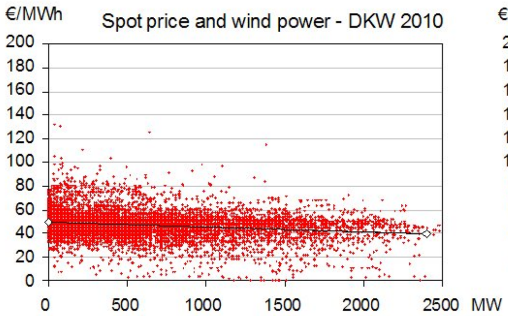
However, it should be noted that the capacity credits for adjacent areas cannot be added. Wind power plants do not operate in a stochastically independent manner, because they all depend on a common and related source, the wind.

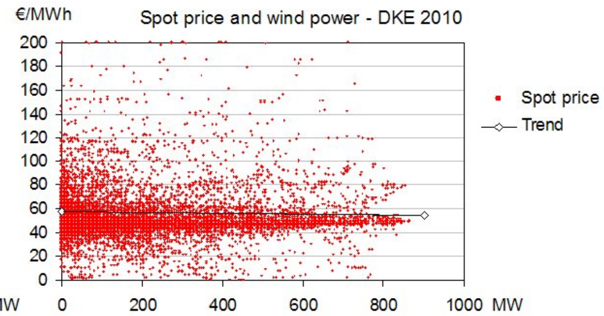
4. Wind Power and Spot Markets

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

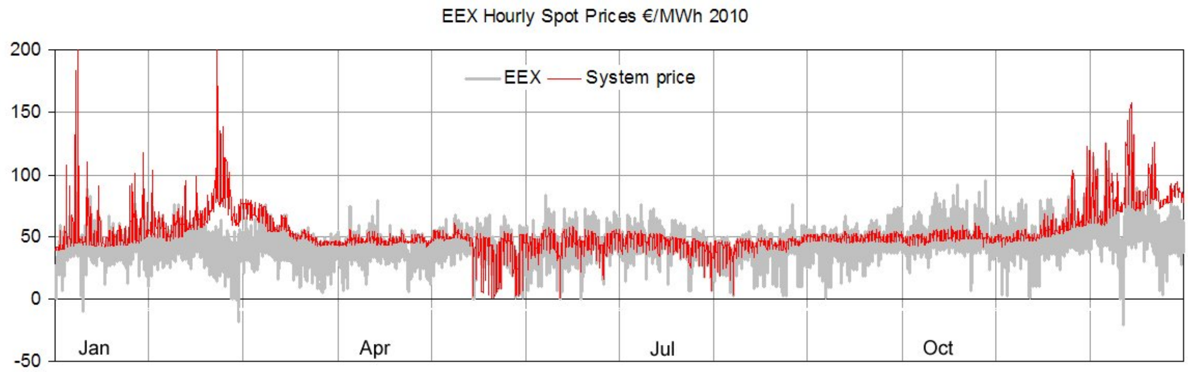
- increasing wind generation may cause reduced prices
- the volatility of wind power may cause price volatility

The following diagrams show local hourly spot prices and wind power for the entire year 2010. The correlations are surprisingly low. The reason is that several other factors than wind power have an impact on market prices.



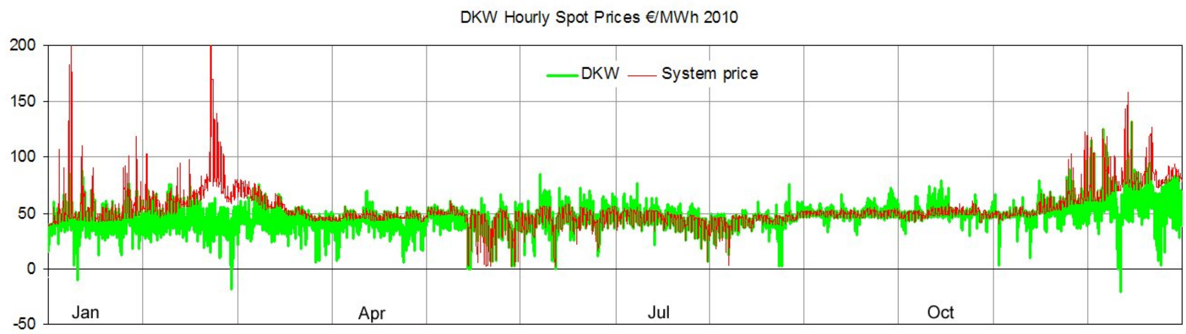


A time series with hourly spot prices can be used for the identification of some characteristic periods.

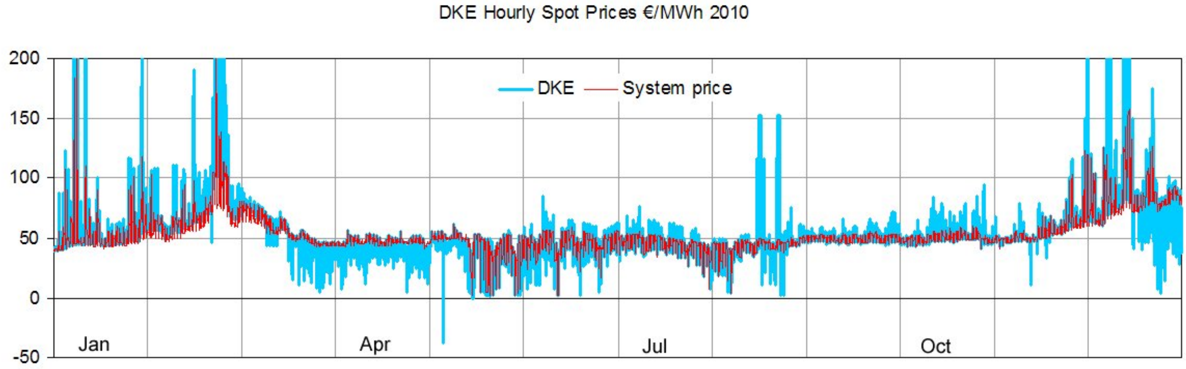


The chart above compares the EEX spot price with the Nord Pool system price. 2010 is different from previous years in the way that the EEX price seems to be more stable than the Nord Pool price.

The following chart indicates spot that prices in Western Denmark are closer related to EEX prices than to Nord Pool prices.



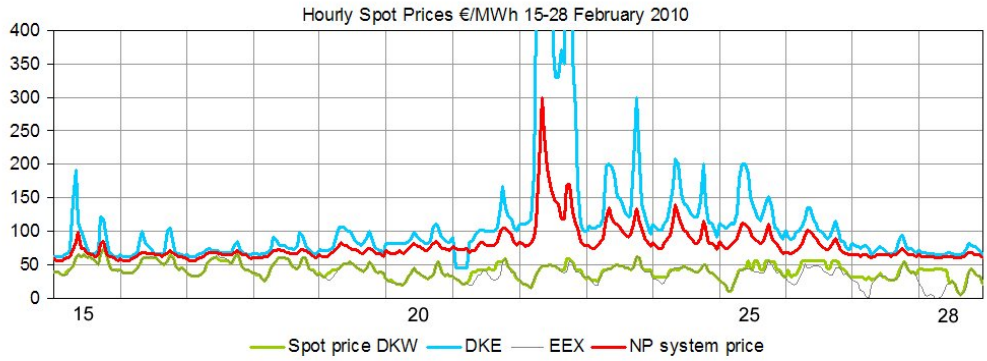
Only a few cases of zero prices have been observed in Eastern Denmark.



The following observations from these charts have been selected for examination:

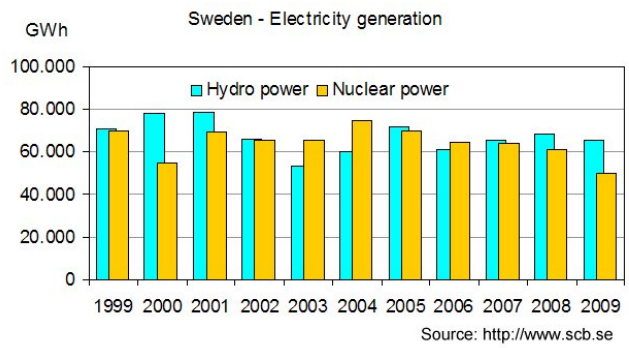
- 4.1: February: Nordic energy shortage
- 4.2: February: Zero Prices in Germany and West Denmark
- 4.3: May: Strange falls of Nordpool's system price
- 4.4: August: Capacity shortage in East Denmark
- 4.5: December: Price instability in Denmark and Germany

4.1. 22 February 2010: Nordic energy shortage



The spot prices in the last half of February indicate a separation between Germany and West Denmark on one side and the rest of Scandinavia on the other side. Germany has stable spot prices with daily fluctuations and very low night prices at the end of the period. The Nordic system seems to be subject to an energy shortage culminating on the 22nd.

In 2009 the nuclear production in Sweden was 50.0 TWh. The Swedish hydro production was 65.3 TWh. Together nuclear and hydro power plants produced less electricity than in any other year since 1999.[11]

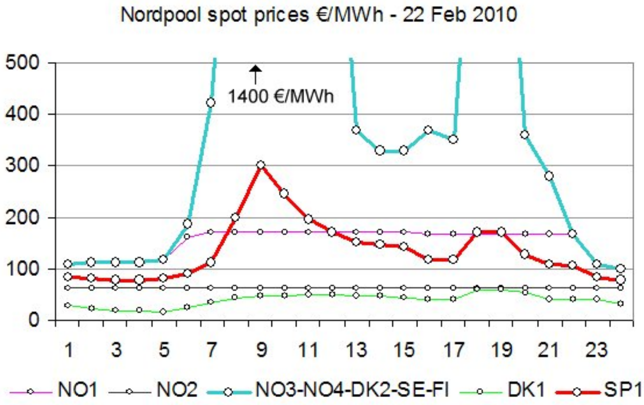


In order to understand the differences in spot prices on 22 February, the transport

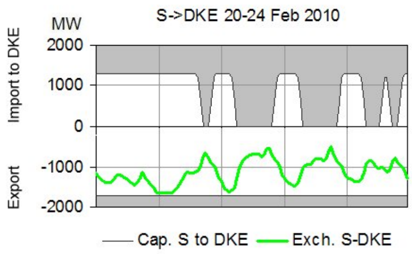
[11] http://www.scb.se

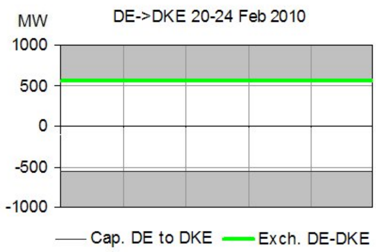
pattern and the bottlenecks in the Nordic grids must be identified.

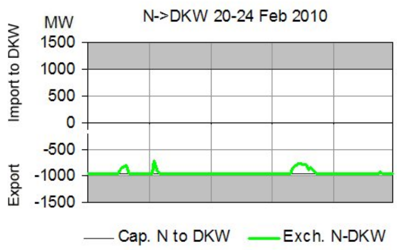
According to the Nordpool spot prices none of the eight Nordic price areas followed the Nordpool system price on that particular day. The four Norwegian price areas formed three price zones with different prices. East Denmark (DK2) formed together with Sweden, Finland and the two northernmost areas in Norway a price zone with particular high prices. The overall picture is a northbound transport with bottle necks on the HVDC links and in the Norwegian grid.

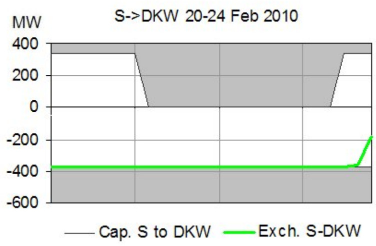


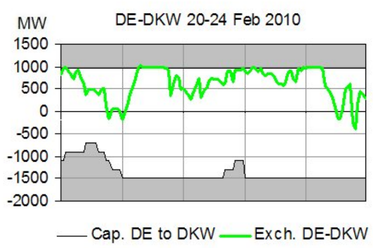
For East Denmark the northbound transit from Germany causes congestion on the HVDC link between Germany and Denmark and different spot prices in Germany and East Denmark.











The HVDC links from West Denmark to Norway and Sweden are congested most of the time. Therefore West Denmark as a mail rule follows the German spot prices.

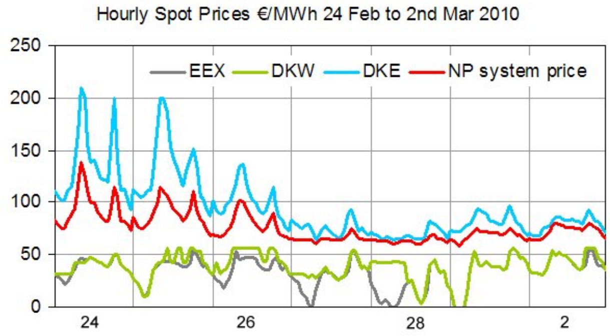
Three HVDC links are congested in this case. It is reasonable that the most expensive links form the bottlenecks. Cold weather, low availability of nuclear power plants and low water level in the hydro storages have been reported as the reasons for the energy shortage. The energy shortage combined with insufficient transfer capability of the main transit channels are the main reasons for the very high spot prices.

Wind power and temporary reductions of transfer capability are less important in this case.

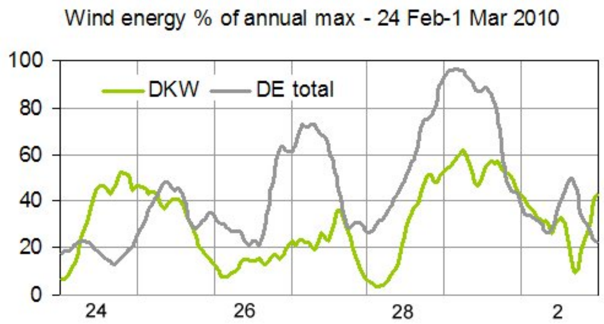
4.2. At the end of February 2010: Zero Prices in Germany and West Denmark

In the days after 22 February the Nordic spot prices are move towards a stable and reasonable level. At the same time very low nightly spot prices in Germany and West Denmark are indicating wind power peaks.

Wind power is one reason for the low prices in Germany.

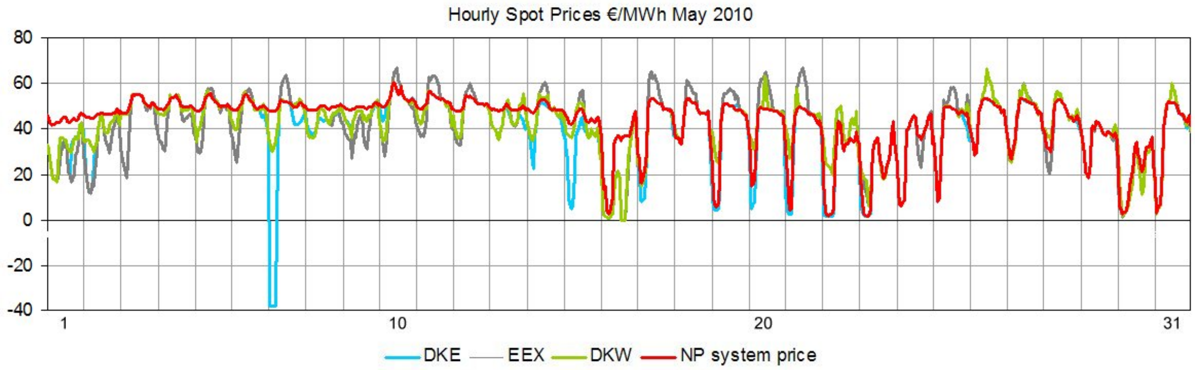


Very low prices occur in Germany on 27 and 28 February and on 1 March. West Denmark has the same low prices on 28 February and 1 March. The wind power output explains some of the variations, but not all:



This is an opportunity to repeat that wind power is one factor among several others with influence on the spot prices.

4.3. May 2010: Strange falls of Nordpool's system price



On 7 May 2010 East Denmark saw the first negative spot prices since this solution was implemented in Denmark in October 2009.

From 16 May several cases with very low Nordpool system prices at night attract attention. For some of the nights even the German EEX price was low. A reasonable explanation of these price valleys has not been identified.

The Energinet.dk market report for May 2010 does not explain the volatility, but emphasizes that the hydro storage levels are close to normal (see chapter 2):

Rising hydro-reservoir levels caused minor price falls in the Nordic countries

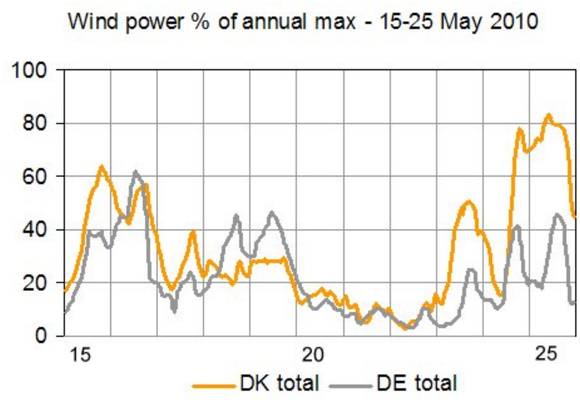
- - -

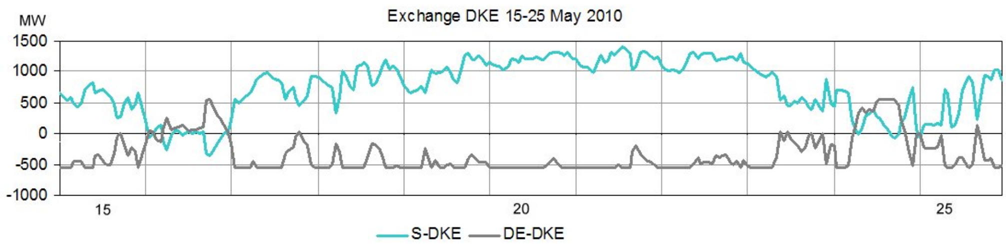
The water level in the Nordic hydro reservoirs increased considerably in the middle of the month because rising temperatures caused the snow in the Nordic mountains to melt. At the end of the month, the water level was close to normal for the time of the year. So the very low water level that characterised the spring months never managed to push the spot price in the Nordic market up in any dramatic way.

- - -

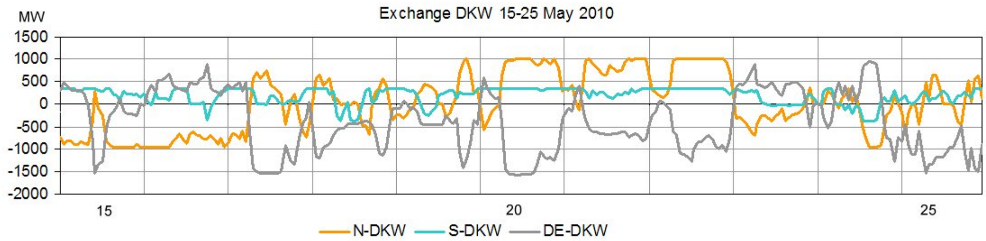
Surplus of wind power could be a reason for very low spot prices, but in this case wind power output has been rather low in both Germany and Denmark.

From the beginning of the year and until the middle of May a northbound transit was predominant. From 17 March the transit was southbound. The 7 days southbound transit is clearly visible on the chart for East Denmark:





West Denmark also had a southbound transit, most clearly on 20 to 22 May, but the nights were different.

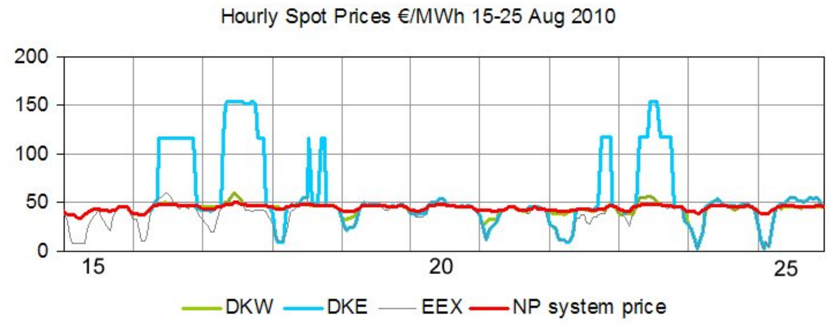


A possible explanation could be expectations among energy traders of an upcoming energy surplus due to an intensive spring flood in Sweden.

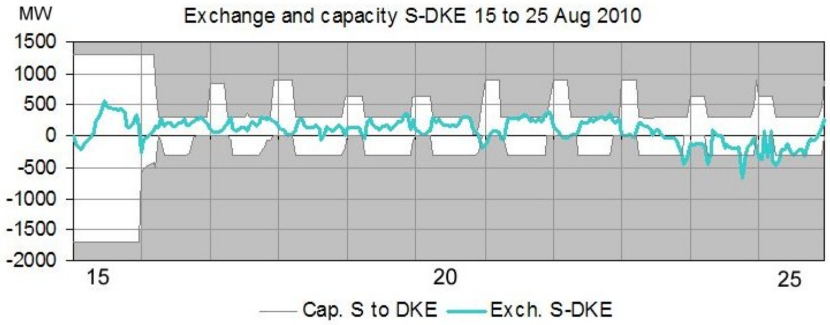
4.4. August 2010: Capacity shortage in East Denmark

In August a few cases of spot prices at 150 €/MWh were observed in East Denmark. The observation suggests unfavourable combinations of wind power and transfer capabilities.

The Great Belt interconnection between West and East Denmark was about to begin commercial operation. Test operation was recorded between 11 June and 9 August. The link was ready for commercial operation from 26 August.

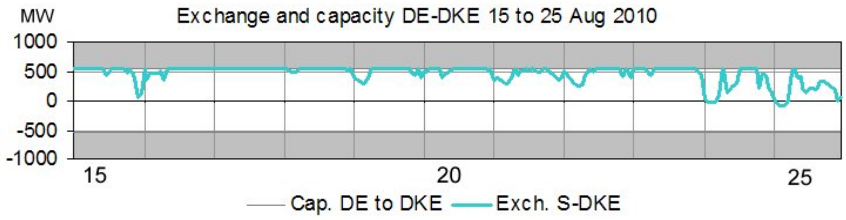


The increased level of spot prices occurred between Monday 16 August and Wednesday 18 August and on Sunday 22 August to Monday 23 August.

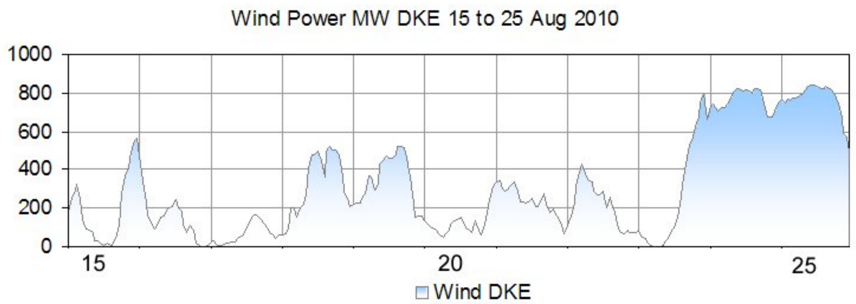


From 16 August the capacity of the East Denmark's main interconnector to Sweden was reduced to 300 MW import in the daytime and 0 MW export at night. According to the Energinet.dk market report the reason was inspection and maintenance. These constraints leave a very narrow band for the operation.

The KonTek interconnection with Germany was used for maximum import most of the time:



Wind power could have contributed to the supply, but the output was rather low on 16 and 17 August.



The case is classical. Wind power requires full backup capacity, either from local generation or from interconnection with strong grids.

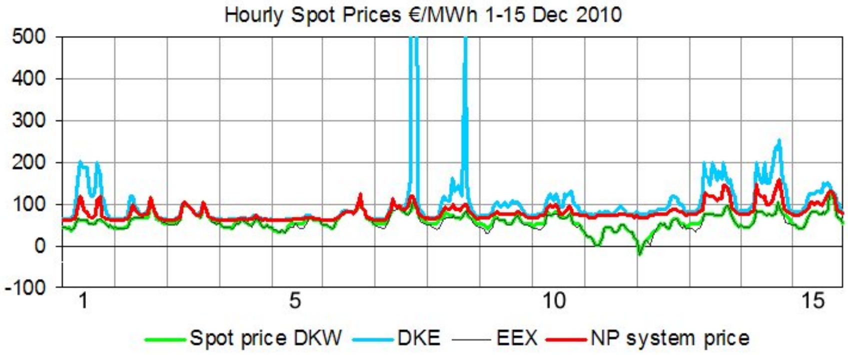
The Nordic power system covers a large area and bottlenecks in the grid cannot be avoided. A system of price areas makes the optimal use of congested lines between price areas possible. However, so far it has been Swedish policy to have the same spot price all over the country. Internal bottlenecks are handled by constraints on international interconnections.

This policy has destabilized the electricity market in East Denmark for several years and Danish Energy Association has filed a complaint against Svenska Kraftnät (Swedish system operator) with the EU Commission over limitations in the capacity of the interconnectors between Sweden and Denmark.

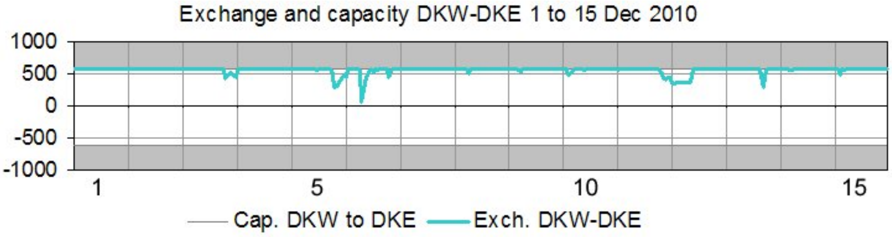
The European Commission has adopted a decision rendering legally binding commitments offered by Svenska Kraftnät that will increase trade in electricity within Sweden and between Sweden and neighbouring countries. The improvements must be effective by 1 November 2011 at the latest. According to Nord Pool Sweden will be divided into 4 price areas.

4.5. December 2010: Price instability in Denmark and Germany

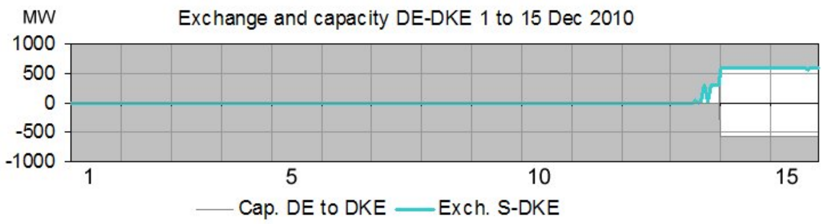
Cold weather and wind power variations caused volatility in the spot market in December 2010. The spot prices in the first half of December have some similarities with the observations in August with a few very high prices in East Denmark and a few very low prices in West Denmark and Germany.



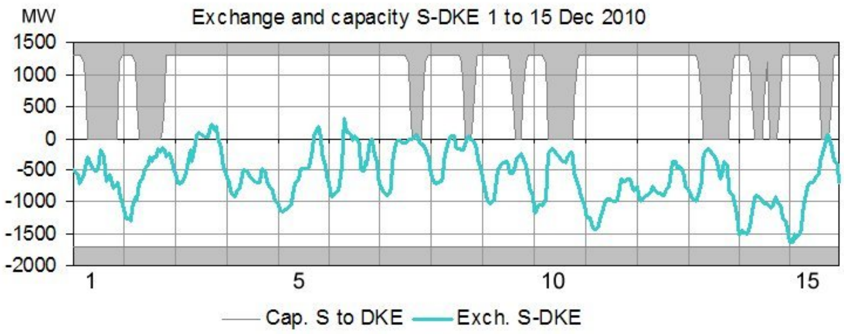
The Great Belt link was in full operation in December with nearly maximum transfer from west to east.



The KonTek link between East Denmark and Germany was out of service from 20 November to 13 December.



The AC link between East Denmark and Sweden still has a highly variable capacity, but with more room for variations than in August:



The reductions of import capacity from Sweden make the power balance in East Denmark vulnerable. The wind power does not exactly improve stability.

	Production	Share of capacity
Denmark	45 MW	1%
Germany	577 MW	2%
Great Britain	133 MW	6%
Ireland	313 MW	18%

The weather was cold in December. On the 7th December wind power output was very low during the evening peak, not only in Denmark, but also in some neighbouring countries. The consequence was a moderate increase in German and Nordic spot prices. For East Denmark only 590 MW import was available on the top of no wind power. Therefore the spot price was limited by the price ceiling at 2,000 €/MWh.

On 11 December a combination of increasing wind and low load during the night causes low spot prices in West Denmark and Germany. The following night the wind is decreasing, but still at a high level at the beginning of the night.

The cases support the view that interconnectors may have lower availability than generally assumed.

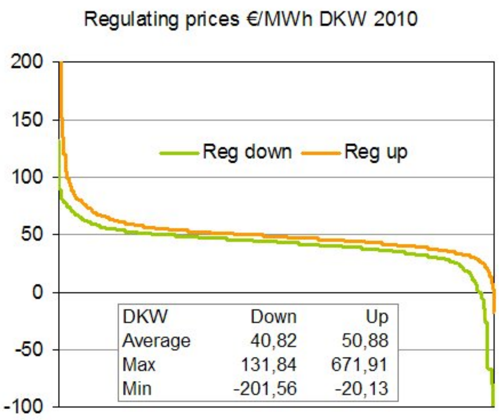
5. Regulating Power

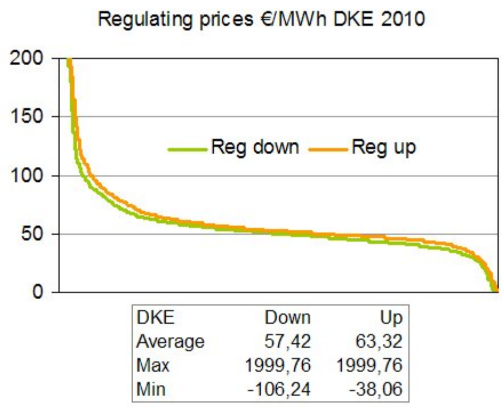
Nord Pool Spot is a wholesale market for buyers and sellers, the gate closure being for the following day at noon. Therefore its spot prices are based on expectations 24 to 36 hours before real time, and day-ahead wind power forecasts are very inaccurate.

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.

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





Negative prices for regulating power occurred in 22 hours in West Denmark and 0 hours in East Denmark.

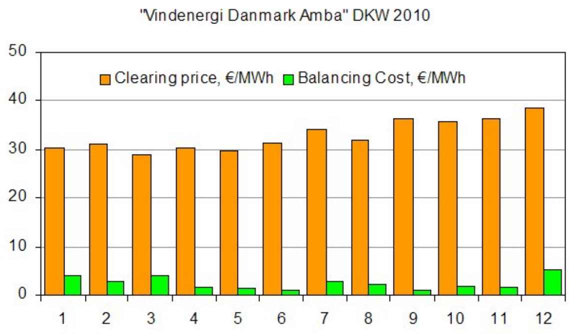
No of hours	Downwards		Upwards	
€/MWh	<-100	<=0	>100	>200
DK West	22	301	163	32
DK East	0	4	478	179

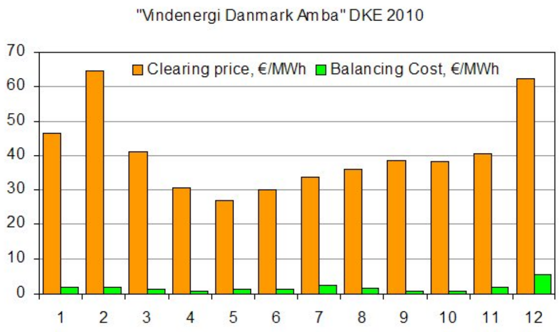
In 2010 there is still a difference between west and east in Denmark. West Denmark has significant need for downwards regulations while high prices for upwards regulation are most frequent in East Denmark. It remains to be seen how the Great Belt interconnection will change this picture.

6. Wind energy trading

One of the important traders of wind energy in Denmark is “Vindenergi Danmark Amba”, which is a co-operative of owners of wind power plants, who must sell wind energy commercially. The web site, www.vindenergi.dk, presents the following trading statistics for 2009 (with my translations):

	Jan	Feb	Mar	April	May	June
West Denmark						
Installed capacity, MW	1075	1102	1110	1125	1157	1186
Production, GWh	204	133	184	188	180	131
Clearing price, øre/kWh	30.2	31.1	28.9	30.2	29.6	31.3
Balancing cost., øre/kWh	4.0	2.7	4.1	1.6	1.5	1.1
East Denmark						
Installed capacity, MW	212	219	226	231	234	238
Production, GWh	39	31	34	33	33	19
Clearing price, øre/kWh	46.3	64.6	41.0	30.4	27.0	30.2
Balancing cost., øre/kWh	1.9	1.9	1.1	0.7	1.0	1.2
Total						
Installed capacity, MW	1287	1321	1336	1356	1392	1425
Production, GWh ,	242	164	218	221	213	151
	July	Aug	Sep	Oct	Nov	Dec
West Denmark						
Installed capacity, MW	1222	1244	1267	1285	1310	1381
Production, GWh	124	161	220	243	273	201
Clearing price, øre/kWh	34.0	31.9	36.2	35.7	36.2	38.5
Balancing cost., øre/kWh	2.7	2.3	1.1	2.0	1.6	5.1
East Denmark						
Installed capacity, MW	242	251	254	261	266	273
Production, GWh	17	26	40	47	48	47
Clearing price, øre/kWh	33.5	35.9	38.6	38.2	40.6	62.2
Balancing cost., øre/kWh	2.3	1.5	0.6	0.9	1.8	5.5
Total						
Installed capacity, MW	1465	1495	1520	1546	1575	1654
Production, GWh	142	186	260	290	322	248



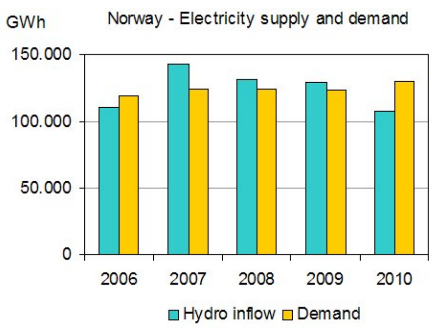


7. Trends 2006-2010

7.1. Hydrology and nuclear availability

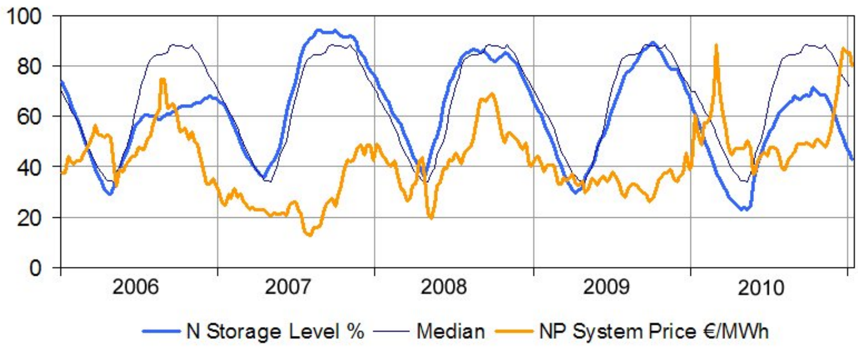
The Nordic energy balance depends on the hydro power systems in Norway and Sweden and on the availability of nuclear power in Sweden and Finland. This is demonstrated by a few charts with data form Norway and Sweden.

The inflow of hydro energy in Norway is irregular and has considerable variations from year to year. The inflow was 143 TWh in 2007 and 107 TWh in 2010. Inflow was preferred for this chart instead of production.



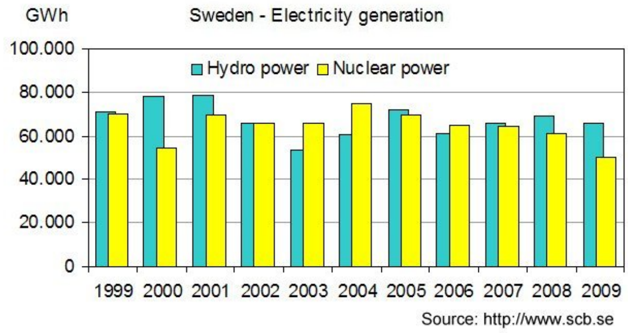
The variations are offset by international exchanges, by using the hydro storages (84.3 TWh) and from 2009 by thermal generation on the gas-fired Kårstø power station (440 MW).

The content of the hydro storages follows an annual pattern. In dry years the content can be considerably lower than in normal years.

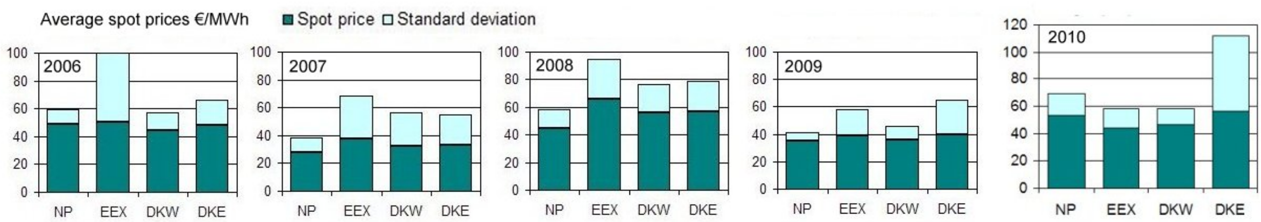


Similar variations can be observed in Sweden. The Swedish hydro production was 78 TWh in 2001 and 53 TWh in 2003. The nuclear production was 75 TWh in 2004 and 50 TWh in 2009.

The Swedish aggregated hydro and nuclear production was lower in 2009 than in any other year since 1999.



7.2. Spot prices



Average spot prices change from year to year and between price areas depending on local balances between supply and demand. The lowest average price, 27.80 €/MWh, was observed for the Nord Pool system price in 2007. The following year the German EEX price had an average value over 60 €/MWh.

The standard deviations reflect the price volatility. A high standard deviation indicates a less stable spot market. The reasons may be different, but in most cases bottlenecks in the grid play a decisive role.

Number of hours	2006	2007	2008	2009	2010
	Spot price <= 0				
West Denmark (DKW)	28	85	28	55	12
East Denmark (DKE)	5	30	9	4	6
Nord Pool system price	0	0	0	3	0
EEX, Germany	10	28	35	73	12
Balancing power	Downwards price <=0				
West Denmark (DKW)	229	194	80	159	301
East Denmark (DKE)	45	53	25	30	4

The magnitude of the overflow problem due to Danish wind power can be indicated by the number of hours with spot prices and downwards balancing prices 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 introduced negative spot prices in October 2009.

7.3. Wind energy

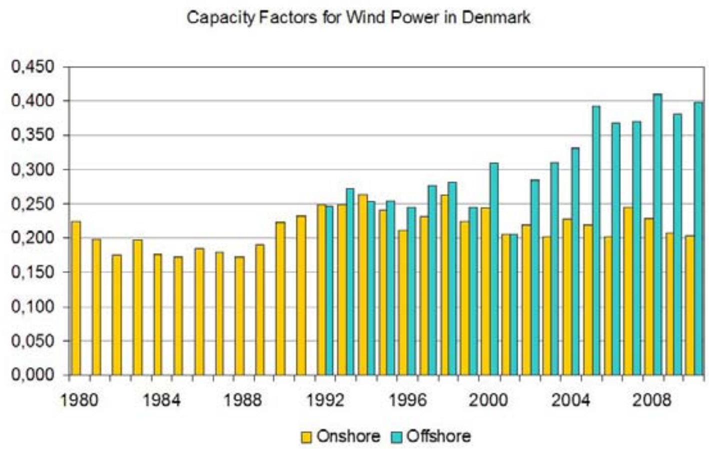
Wind energy	Denmark		Germany		Ireland	
	TWh	Share	TWh	Share	TWh	Share
2006	6.1	17%	39.5[12]	-	1.6[13]	-
2007	7.2	20%	40.0	-	2.0	-
2008	7.0	19%	43.0	-	2.4	-
2009	6.7	19%	37.7	7%	2.9	-
2010	7.8	22%	36.1	7%	2.6	10%

German and Irish data were collected only from 2009.

Capacity factors have been calculated for Danish wind turbines.

Like hydro power wind energy has variations from year to year. For the years 1983 to 2008 the wind energy index varies between 85% and 120%.[14]

The calculation includes only those wind turbines which have been in service during the entire year.

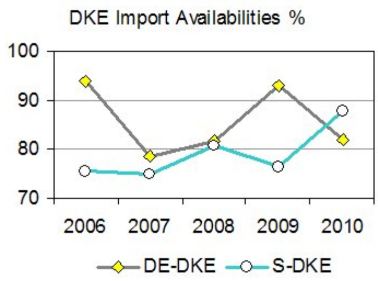


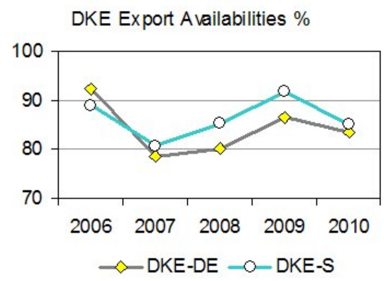
The increasing capacity factors, particularly for offshore wind farms, are probably the result of a maturation process for the new technology.

[12] http://www.wind-energie.de/de/statistiken/
[13] http://www.seai.ie/
[14] http://www.dkvind.dk/fakta/pdf/M3.pdf (in Danish)

7.4. Interconnector availability

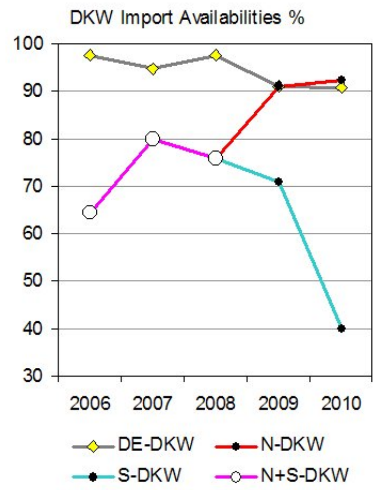
It is an essential result of the collection of data since 2006 that the average availability of the interconnectors is much lower than usually assumed.

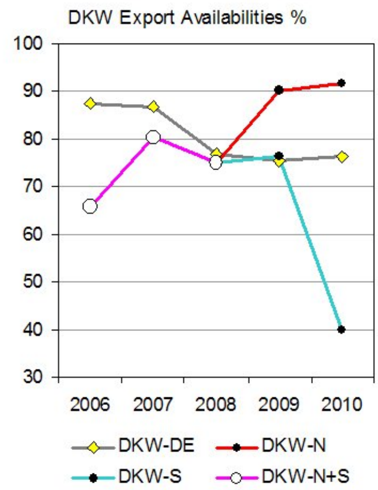




The reasons can be outages due to technical breakdowns or capacity reductions due to problems elsewhere in the grid. It could be interesting to know the unavailability for each of the two possible causes, but the available data do not support such quantification.

For the years 2006-2008 data for the HVDC interconnections between West Denmark and Norway and Sweden were aggregated as for one interconnector. Therefore the chart shows a common value for the first three years for the Skagerrak and the Konti-Skan interconnections.





An interconnection is supposed to have at least 90% availability every year. Long outages may occur, but should be rare.

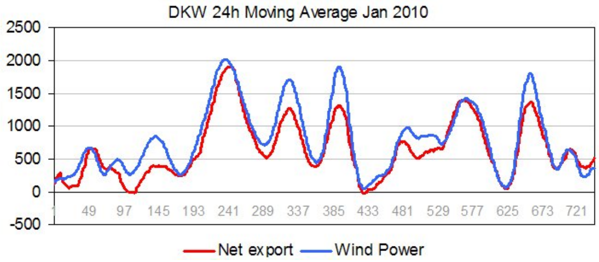
The fact that **all** interconnectors have a worse availability **every** year, in one direction or the other, indicates a need for a careful rethinking of the capacity planning for the international grid. According to the EWIS report the congestion problems will be more serious within the next few years. Insufficient transmission capacity may cause market instability and at worst collapse of the electricity markets.

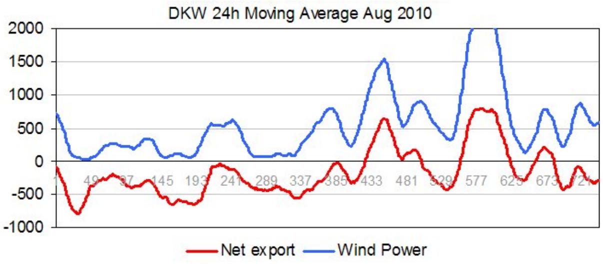
8. Danish wind power and export of electricity

The previous statistical surveys presented an estimate of the export share of the Danish wind energy. The *wind energy export* was defined for each of the two Danish price areas and for each hour as the smaller value of generated wind energy and net export.

The same algorithm was used in the CEPOS study, "Wind Energy – The Case of Denmark" (September 2009). The claim that a considerable share of the Danish wind energy was exported caused persistent scientific criticism. The main argument was that the export was due to competitive Danish thermal power plants and that the exported electricity was dispatchable thermal energy rather than wind energy.

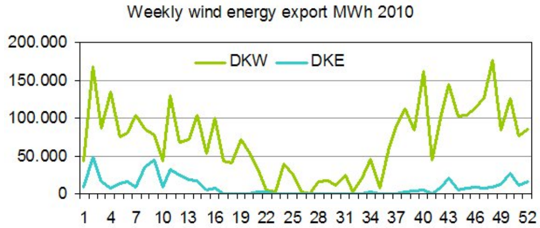
The discussion of the *origin* of the exported electricity may be an interesting academic matter. But the *variations* of wind power and electricity export can easily be compared. The following charts show 24 hours moving average for West Denmark in January and August 2010:





This seems to be convincing evidence that waves of wind energy causes waves of electricity export. The use of CHP (combined heat and power) in Denmark explains the difference between winter and summer. Therefore a correlation analysis for the entire year will give misleading results.

The estimated export share of wind energy in 2010 was 62.7% for West Denmark and 23.6% for East Denmark. Most of the export can be observed for the cold seasons. The reason is simple. There is not sufficient electricity demand in Denmark for both CHP and wind power.



It is irrelevant if wind energy or CHP electricity has been exported, but adding new wind power to the power system without adding new electricity demand will cause growing electricity export. An increasing dependency on foreign balancing services would be in conflict with the intentions behind the new wind power. Therefore the development of domestic measures should be encouraged and supported in order to facilitate parallel commissioning of new wind turbines and new flexible electricity demand.