Wind Power in Denmark, Germany, Ireland, Great Britain and France

Statistical Survey 2011

Preface

This text supplements *Wind Power and Spot Prices: German and Danish Experience 2006-2008*[1] and Statistical Surveys 2009 and 2010 by adding data for the calendar year 2011.

The evaluations are based on data published by Energinet.dk, by the four German transmission system operators, by Eirgrid and by Elexon Portal. French data has been extracted form the eCO2mix/RTE web site by Hubert Flocard. 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.

A selection of the hourly time series used for the statistical analyses in this text is available at http://pfbach.dk/.

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
GB	Great Britain	F	France		

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[1] http://www.ref.org.uk/publications/148-spot-price-study-in-germany-and-denmark-
[2] http://nve.no/
[3] http://www.statnett.no/
[4] http://www.nordpoolspot.com/

1. Overview

Energy perspectives

– The estimated inflow of water in Norway increased from 107 TWh in 2010 to 156 TWh in 2011. The total content of the hydro storages in Norway, Sweden and Finland was **41 TWh** higher at the end of 2011 than one year before.
– After the nuclear events in Japan 8 German nuclear units (8 GW) have been taken permanently out of service.
– These changes resulted in a tilting energy balance in 2011 between Norway and Sweden on one side and Germany on the other side.
– The remaining German nuclear units will be phased out until 2022. In 2010 the capacity of nuclear power in Germany was 22 GW and the production 141 TWh.

Spot market performance

2011	Average area prices	Spot prices <= 0	Standard deviation
	€/MWh	No of hours	€/MWh
West Denmark (DKW)	47,87	18	13,61
East Denmark (DKE)	49,32	17	14,94
Nord Pool system price	46,96	0	15,72
EEX, Germany	51,02	16	13,59

– The market areas seem to have been well connected in 2011. The new Great Belt link has contributed to more uniform conditions for the two Danish bidding areas.
– The low standard deviations indicate good spot price stability in all market areas, but do not exclude the occurrence of extreme prices.
– The observations for 2011 confirm previous year's conclusions: spot prices in Germany and Denmark are closely related. Congestions occur mainly on the interconnections between Denmark and the other Scandinavian countries.
– The spot market reflects the tilting energy balance in 2011 between Norway and Sweden on one side and Germany on the other side. Electricity transit towards north at the beginning of the year was replaced by southbound transit after April 2011.
– Nord Pool allowed negative spot prices in Denmark from October 2009. In 2011 most of the negative spot prices occurred simultaneously in Denmark and Germany.

Wind power performance

2011		Denmark	Germany	Ireland	Great Britain	France
Wind	GWh	9,751	43,009	4,256	9,715	11,249
Max	MW	3,520	22,654	1,459	3,327	4,434
Load factor		0.32	0.22	0.33	0.33	0.29
Share	%	28.2	7.8	16.5	3.1	2.4

Correlation coefficients Hourly wind power	2011	France	Great Britain	Ireland	Germany
	Denmark	0.21	0.39	0.27	0.70
	Germany	0.45	0.38	0.26	
	Ireland	0.23	0.73		
	Great Britain	0.28			

- The average capacity factors in Denmark were 0.25 onshore and 0.45 offshore[5]. The corresponding duration hours were 2,163 hours onshore and 3,919 hours offshore.
- For Denmark and Germany together the share of wind energy has been estimated as equivalent to 9% of the aggregated demand.
- Wind power has a high positive correlation between Denmark and Germany and between Ireland and Great Britain.
- The recorded minimum wind power output in 2011 was 4% of maximum for France and 0.2% or lower for each of the other countries.
- International aggregation of wind power cannot create a smooth total output, not even for all 5 countries together. The minimum average wind power output for 5 countries during 24 consecutive hours in 2011 was 3.4% of the hourly maximum.

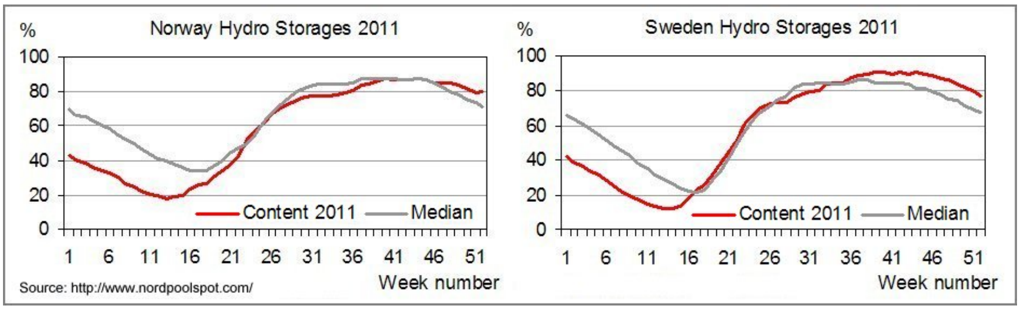
Interconnector performance

	Max capacity MW				Trading availability 2011			
	To DKW	From DKW	To DKE	From DKE	To DKW	From DKW	To DKE	From DKE
Norway	1.000	1.000			89.7	91.0		
Sweden	680	740	1,300	1,700	80.2	67.7	80.1	68.3
Germany	950	1.500	600	585	75.9	50.7	91.9	89.7
DKW			590	600			91.3	92.5

- The trading capacity across a border can be reduced due to technical faults at the interconnector or due to operational limits in the interconnected AC networks.
- The average trading availability for all Danish interconnectors for the years 2006-2011 is 82% which is well below typical planning assumptions for interconnectors.
- Operational limitations and wind power variations seem to be equal important as reasons for congestions and market problems.
- Operational limitations on the Øresund link have caused spot price volatility for East Denmark in previous years. The Great Belt interconnector seems to have relieved the problems.

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

2. Scandinavian and German energy perspectives 2011

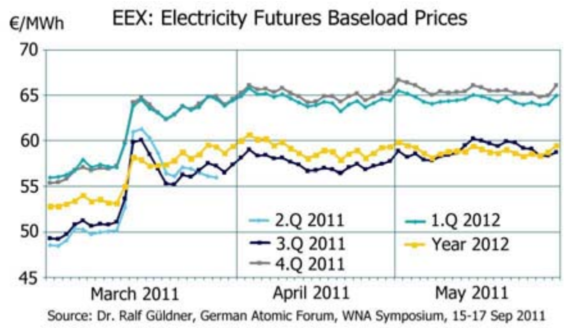


The Norwegian and Swedish hydro storages have recovered to the normal level during 2011. The inflow of water in Norway increased from 107 TWh in 2010 to 156 TWh in 2011. While the total production in the four Nordic countries went down by 4.1 TWh in 2011 (1.1%) the total content of the hydro storages was **41 TWh** higher at the end of 2011 than one year before.

GWh	Production		Hydro storages	
	2010	2011	Ult. 2010	Ult. 2011
Norway	123.972	126.516	37.135	65.722
Sweden	144.146	146.734	14.964	25.955
Finland	74.871	68.314	2.386	3.459
Denmark	36.458	33.749		
Total	381.456	377.324	54.485	95.136
Source:	Nordpool Spot			

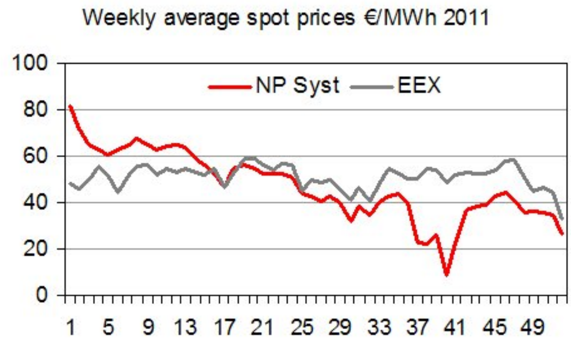
Against the background of the destruction of the Japanese nuclear power station Fukushima the German government decided on the 14th March 2011 to take 8 nuclear units with 8,422 MW out of service for 3 months for comprehensive security tests. These plants have been commissioned between 1975 and 1984.

The German futures market responded by increasing prices by 10% or more from March to May 2011.



On the 6th June 2011 the German minister of Economics and Technology, Philipp Rösler, announced that the 8 units will be out of service permanently and that the remaining nuclear units will be phased out until 2022. In 2010 the capacity of nuclear power in Germany was 22 GW and the production 141 TWh. The magnitude of the immediate energy loss can be as much as **50 TWh** per year.

The Nordpool system prices clearly reflect the improved Nordic energy balance. The German EEX spot price was quite stable during 2011 in spite of the nuclear moratorium. The Nordic surplus may have contributed to the stability.



The changes in 2011 have tilted the energy balance between Scandinavia and Germany. The interconnections and the international electricity markets clearly demonstrate their significance.

3. Main characteristics of Danish power systems in 2011

3.1. Annual key figures

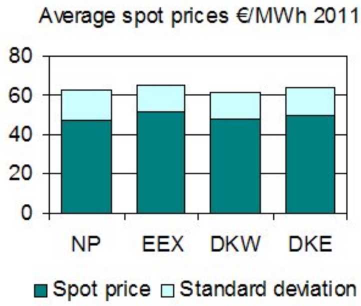
The following table is based on market data from Energinet.dk:

2011	Gross demand			Thermal	Wind		Hourly net exchange	
	MWh	Max MW	Duration Hours	Generation MWh	Generation MWh	% of demand	Export MWh	Import MWh
DK West	20,699,290	3,664	5,650	14,908,285	7,129,314	34.4	3,299,621	1,961,392
DK East	13,861,296	2,568	5,398	8,582,848	2,622,015	18.9	500,364	3,156,890
DK (total)	34,560,586	6,231	5,546	23,491,134	9,751,329	28.2	3,224,230	4,542,527
Source: Energinet.dk								

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 2011 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	47,87	13,61	NP	46,96	15,72
DK East	49,32	14,94	EEX	51,02	13,59



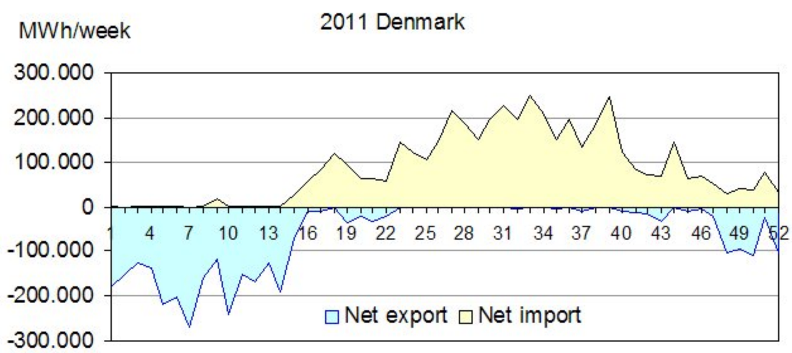
The standard deviation is an indicator of the price volatility.

The Great Belt link between East and West Denmark has been in service throughout the year. This may have contributed to the equalization between the two parts of Denmark.

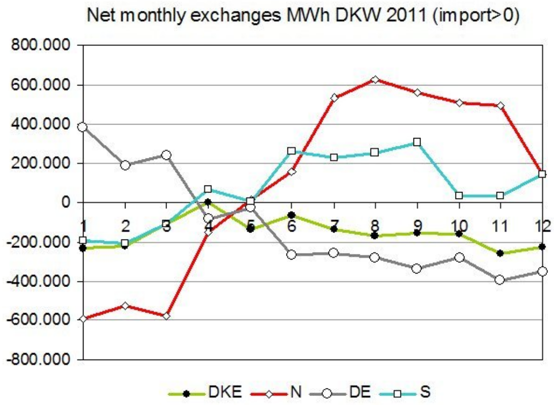
The magnitude of the overflow problem due to Danish wind power can be indicated in a table with number of hours with spot prices less than or equal to zero and downwards balancing prices equal to or below zero. When the price of balancing (or regulating) power is below 0 the system operator must pay for export of energy. Nord Pool introduced negative spot prices in October 2009.

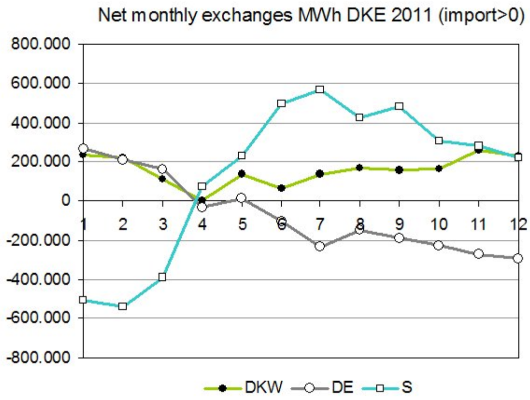
No of hours	Spot price <= 0	Spot price >100	Bal. price <= 0	Bal. price >100
DK West	18	2	166	108
DK East	17	25	144	209
Nord Pool	0	0		
EEX	16	11		

3.2. Weekly and monthly averages

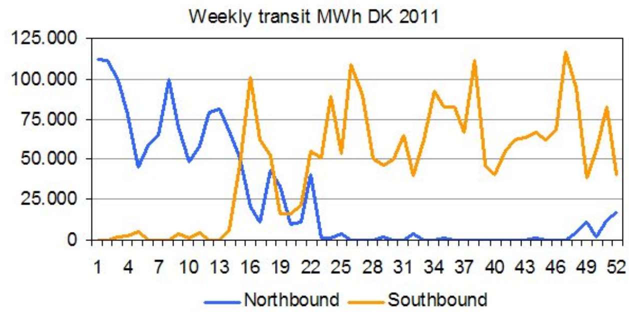


Net exchanges have been accumulated weekly per hour for Denmark (left) and monthly for each border (below). The pattern reflects the variation of the Danish balance of electric energy during the year.

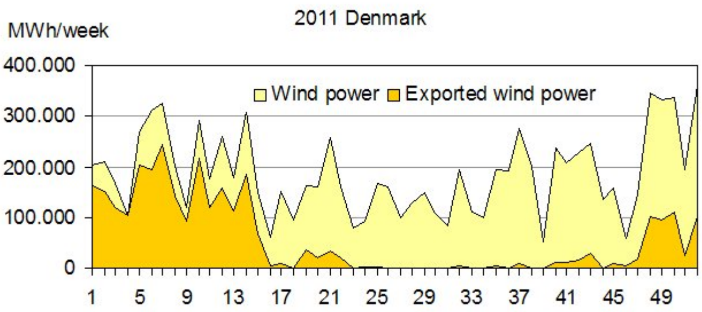




These charts clearly demonstrate how the balance between Scandinavia and Germany changed during the spring of 2011. The transit has been calculated hour by hour. In accordance with the spot price profile (chapter 2) there is a northbound transit during the first months of the year and a southbound transit during the second half-year. The total transit through Denmark was 1.4 TWh northbound and 2.4 TWh southbound. The transfer from West to East Denmark was 1.9 TWh.



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

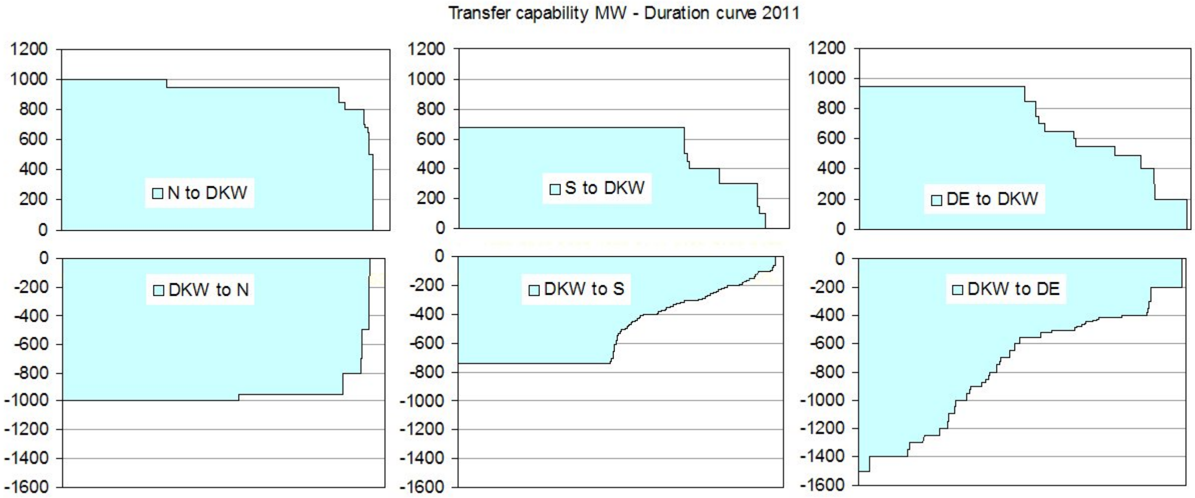


The wind energy is divided into an export share (the light brown area) and a share used locally (the light yellow area). The estimate of exported wind energy is a sensitive matter because it raises doubts about the beneficiary of subsidised Danish renewable energy. In this context the *wind energy export* 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. It cannot be denied that there is not sufficient demand in Denmark for electricity from both CHP and wind power during the winter season. According to this estimate the export of wind energy was 3.0 TWh in 2011 or 31% of the wind energy production.

4. Interconnector Performance

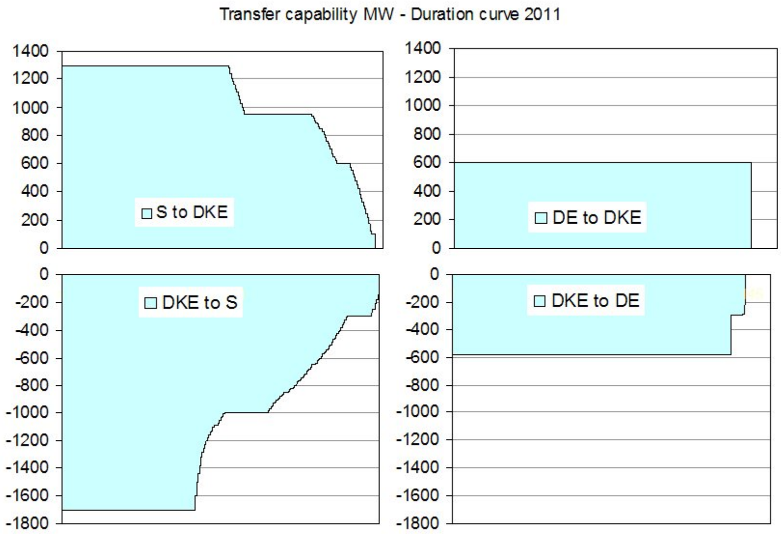
The electricity market is the modern tool for optimizing power system operation across national borders. Sufficient transport capacity is a decisive factor for both reasonable system security and an efficient market service.

Availabilities of Danish interconnectors can be shown because Energinet.dk publishes hourly trading capacities. The trading capacity across a border can be reduced due to technical faults at the interconnector or due to operational limits in the interconnected AC networks. Unfortunately the statistics cannot separate the two reasons.



The AC interconnections between between West Denmark and Germany and between East Denmark and Sweden are main life lines for the Danish power systems, but the transfer capability can be very low during critical periods.

The most remarkable observation in 2011 is the reductions in export capacity from West Denmark to Germany.



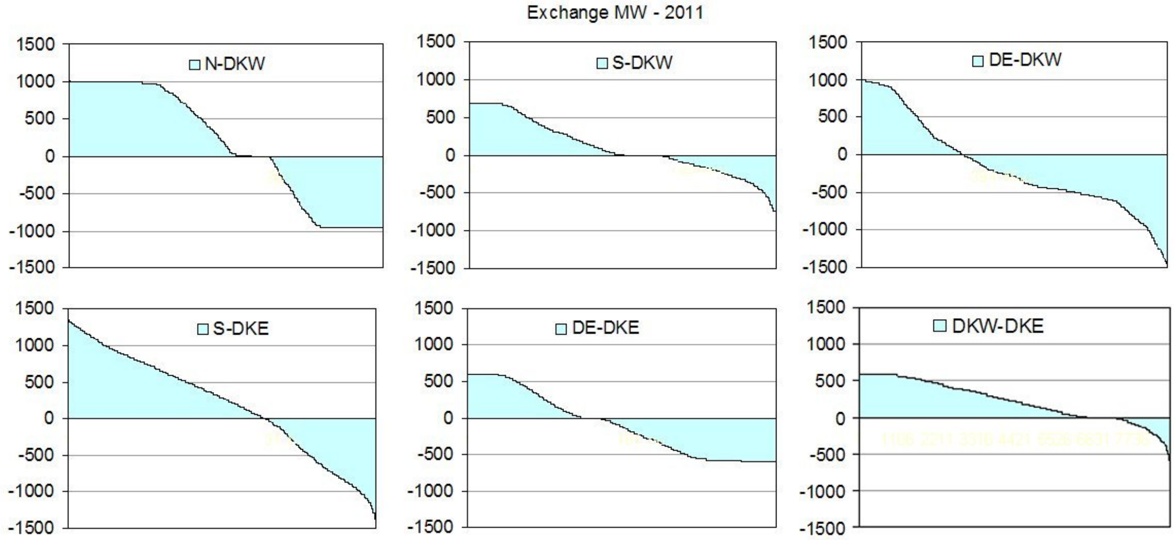
It is important to use realistic availabilities in the long term planning.

However, interconnections are often supposed to have nearly 100% availability. The Danish observations from the period 2006 to 2011 demonstrate that the practical availabilities are much lower.

2011	Average availabilities of interconnections			
%	To DKW	From DKW	To DKE	From DKE
Norway	89,7	91,0		
Sweden	80,2	67,7	80,1	68,3
Germany	75,9	50,7	91,9	89,7
DKW			91,3	92,5

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

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



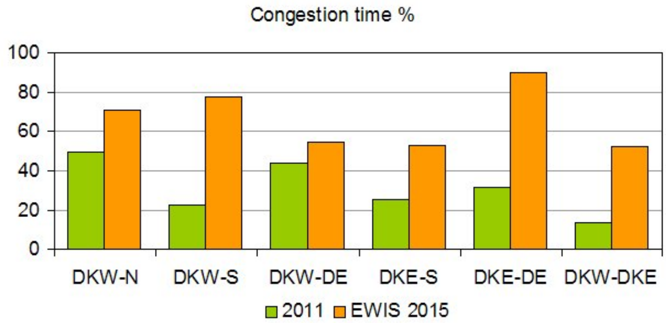
The table shows transferred volumes of energy. The transfer of energy in 2011 between Norway and Sweden via West Denmark was 1499 GWh eastbound and 156 GWh westbound.

	→ GWh	← GWh	Total GWh
DKW-N	2,411	3,598	6,009
DKW-S	834	1,654	2,487
DKW-DE	3,064	1,599	4,663
DKE-S	1,908	3,533	5,441
DKE-DE	2,083	1,234	3,317
DKW-DKE	2,157	277	2,434

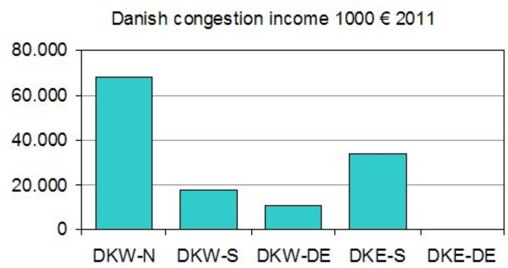
The charts indicate low levels of congestion, but the impression is misleading. Due to the operational limitations there is more congestion than suggested by the charts. In the following table the number of hours with import, export and congestion in 2011 is shown for each of the six interconnectors.

Hours	Export	Congest.	Import	Congest.	Total	% congest.
DKW-N	3263	1565	5072	2722	8760	48,9
DKW-S	4188	1108	4388	844	8760	22,3
DKW-DE	5839	3361	2921	509	8760	44,2
DKE-S	3182	1263	5577	948	8760	25,2
DKE-DE	5035	1982	3366	778	8760	31,5
DKW-DKE	6409	1075	2154	123	8760	13,7

The congestion time in 2011 exceeds 40% for the links between Norway and West Denmark and between Germany and West Denmark.

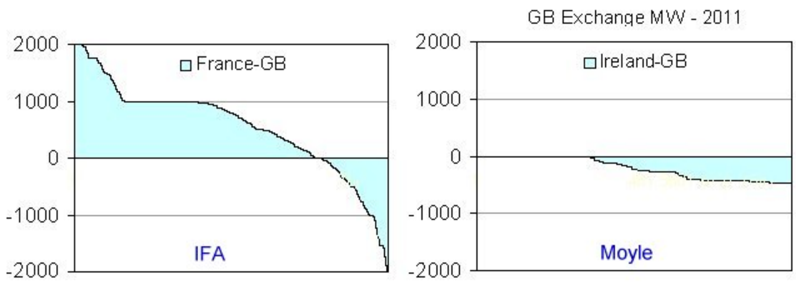


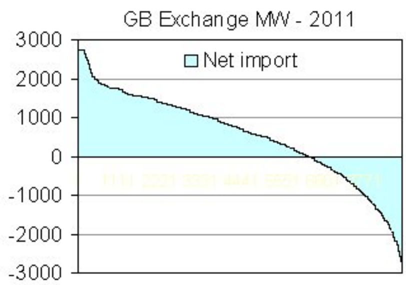
This chart compares the observed congestion times in 2011 with estimated values for 2015 from the EWIS study[6]. The comparison suggests careful consideration of the future need for interconnector capacity in order to maintain reasonable function of the international electricity markets.



The congestion income is another indicator for the demand for more transfer capacity. According to Energinet.dk the total Danish congestion income in 2011 was 130 million €.

The British data include exchanges for each of the three interconnectors. Duration curves for 2011 are shown below.





Trading capacities have not been available for this survey. The interconnection with France, IFA, has been operated at half capacity from 13 March to 2 November 2011 due to major refurbishment of assets at the converter stations on both the UK and the French sides.

The link with Ireland, Moyle, was out of service from 24 August to 18 January 2012 due to a cable fault. The Moyle interconnector is a 500 MW dual pole HVDC link, but in normal operation the trading capacity will be limited to between 287 MW and 450 MW due to security constraints in the two interconnected AC grids[7].

Test operation has been recorded for the BritNed interconnection during the first quarter of 2011. Commercial operation started on 1 April 2011.

GWh	Import	Export	Net import
IFA	6,077	1,324	4,753
Moyle	0	1,781	-1,781
Britned	2,510	718	1,792
Total	8,587	3,823	4,763

The table shows the exchanged volumes. The net import to Great Britain was 4.8 TWh in 2011.

The observations on British data for 2011 seem to confirm that the average trading capacity of interconnectors can be considerably lower than the nominal capacity.

[6] European Wind Integration Study: EWIS Final Report, 31 March 2010
[7] http://www.uregni.gov.uk/uploads/publications/110930_MIL_SONI_NG_Capacity_Calc_combined_Sept_2011.pdf

5. Wind Power Performance

5.1. National Wind Power Output

Time series have been collected for Ireland, for Great Britain, for France for the two parts of Denmark (west and east) and for the four German transmission system operators (Amprion, TenneT, 50hertz and EnBW Transportnetze).

National time series for Denmark and Germany have been created by adding the two Danish time series and by adding the four German time series.

The wind power main characteristics of the five countries are:

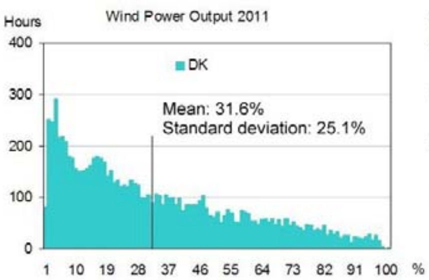
2011		Denmark	Germany	Ireland	Great Britain	France
Wind	GWh	9,751	43,009	4,256	9.715	11.249
Max	MW	3,520	22,654	1,459	3.327	4.434
Min	MW	1	91	5	0	180
	Load factor	0.32	0.22	0.33	0.33	0.29
Share	%	28.2	7.8	16.5	3.1	2.4

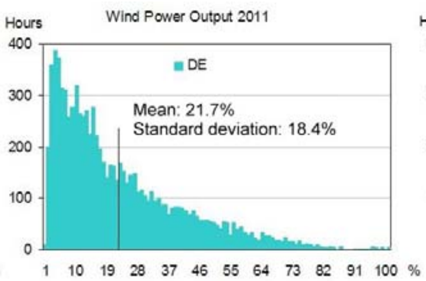
The German share of wind energy has been based on an estimated total electricity gross consumption of 550 TWh.

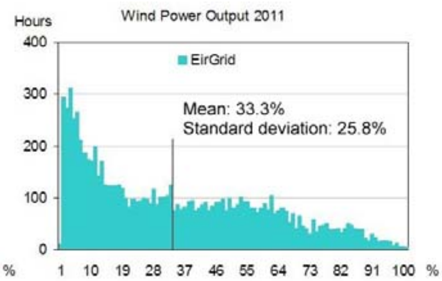
The installed wind power capacity in Denmark in service throughout 2010 was 3,749 MW of which 868 MW was offshore capacity.[8] The installed capacity in Germany was 27,299 MW at the end of 2010 and 29,075 MW at the end of 2011.[9] The first German offshore wind farm, Alpha Ventus (60 MW), was completed in 2009.[10] On the island of Ireland 1746.7 MW of wind power was installed on 19 July 2010.[11]

Statistical distributions can be used for characterizing the time series. The charts below show the number of hours recorded for 1% steps of maximum production. The mean values of the distributions are identical with the load factors.

In this paper **load factors** are related to the highest observed hourly production. A **capacity factor** would refer to the installed capacity which for wind power usually changes during the year. Therefore wind power capacity factors are less well defined unless calculated for a group of wind turbines with a full year's service.







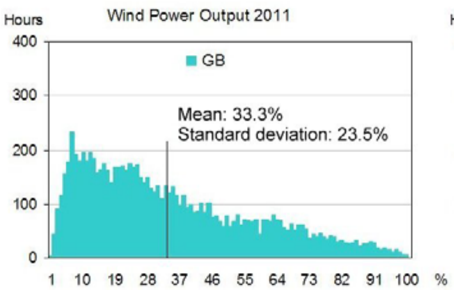
[8] http://www.ens.dk

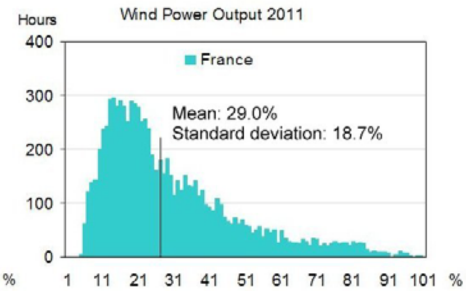
[9] http://www.wind-energie.de/sites/default/files/attachments/press-release/2012/jahresbilanz-windenergie-2011-deutscher-markt-waechst-wieder/statistik-jahresbilanz-2011.pdf

[10] http://www.offshore-wind.de

[11] http://www.iwea.com/index.cfm/page/windenergyfaqs?#q21

Wind power has a lower output per installed MW than most other power sources. Therefore the observed distributions are left-skewed. The difference between Denmark and Germany indicate better wind conditions in Denmark and a higher share of offshore wind. Ireland is known to have excellent wind conditions.

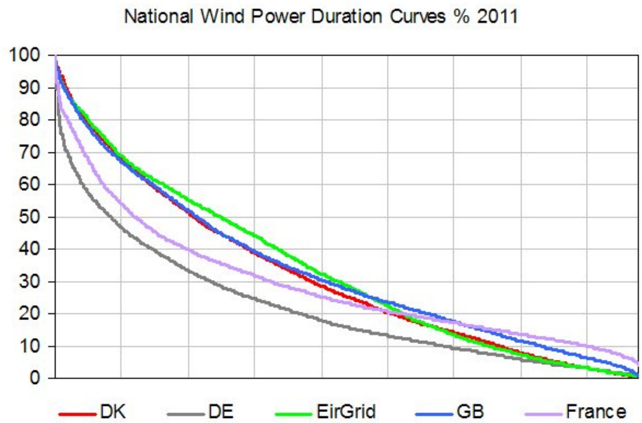




2011 was a better wind year than 2010. The observed mean values are correspondingly higher.

Duration curves can be used for a direct comparison of the national wind power output profiles. For the comparison the wind power output has been normalized to percent of the highest observed hourly production.

The chart reflects the different national wind conditions. It is remarkable that no hour in 2011 had less than 180 MW wind power production (4%) in France.



The irregular **variability of wind power** may cause two types of problems. When there is a low output of wind power there is a risk of shortage of power which must be prevented by mobilization of suitable amounts of reserve power. A high output of wind power may cause overflow of power. Overflow is mainly an economic problem. Curtailment of wind power implies loss of energy and should therefore be minimized.

In order to quantify the two types of problems periods with very low and very high wind power production will be identified.

The **national minimum and maximum wind production** in 2011 has been identified:

2011	One hour	Denmark	Germany	Ireland	Great Britain	France
Minimum	MW	1	91	5	10	180
	Share of max	0.0%	0.4%	0.3%	0.3%	4.1%
	Date	1 Oct	5 Jul	27 Jul	28 Mar	10 Jul
	Hour	15-16	10-11	00-01	02-03	10-11
Maximum	MW	3,520	22,654	1,459	3,327	4,434
	Date	25 Dec	4 Feb	26 Nov	24 Nov	7 Dec
	Hour	20-21	19-20	19-20	20-21	08-09

The average wind power output has been calculated for 12, 24, 48 and 96 consecutive hours. The following **minimum and maximum average production levels** have been found:

2011	Consecutive hours	Denmark		Germany		Ireland		Great Britain		France	
		MW	%	MW	%	MW	%	MW	%	MW	%
Mini-mum	12	12	0.34	159	0.70	9	0.63	35	1.04	225	5.07
	24	21	0.61	270	1.19	14	0.95	60	1.80	271	6.11
	48	37	1.04	437	1.93	25	1.70	61	1.83	347	7.83
	96	141	4.02	779	3.44	40	2.71	158	4.75	407	9.17
Maxi-mum	1	3,520	100.0	22,654	100.0	1,459	100.0	3,327	100.0	4,434	100.00
	12	3,378	95.96	21,986	97.05	1,394	95.51	3,232	97.15	4,261	96.09
	24	3,278	93.14	21,867	96.52	1,284	88.02	3,135	94.26	3,945	88.98
	48	3,078	87.46	20,264	89.45	1,221	83.69	2,985	89.73	3,714	83.76
	96	2,686	76.32	17,383	76.73	1,095	75.08	2,799	84.14	3,670	82.76

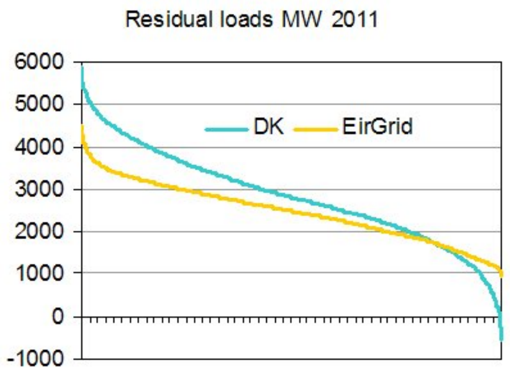
This table indicates that sustained low wind power output is more common that sustained high wind power output. France has more wind power output during low winds than the other countries.

The **residual load** is the difference between gross electricity demand and wind power output. The profile of the residual load is interesting because it must be supplied by more traditional sources. The following characteristics have been extracted for Denmark and Ireland:

	Denmark			Ireland		
	GWh	Max MW	Min MW	GWh	Max MW	Min MW
Load	34,561	6.231	2.177	25.808	4.608	1.586
Residual load >0	24.818	5.891	-564	21.552	4.480	955
Residual load <0	9			0		
Difference	9,752	340	2,741	4,256	128	631

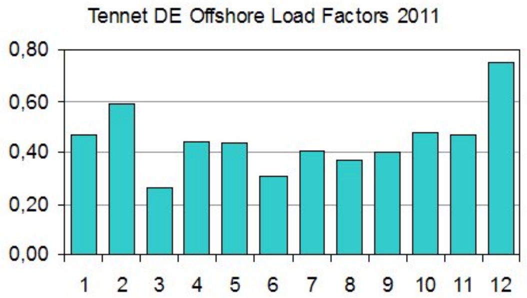
The differences are caused by wind power. Wind power has improved the energy balance while the contribution to peak capacity is insignificant.

In Denmark the very low minimum residual load causes export of electricity because the CHP systems need electricity demand and a certain production on large thermal units is required in order to maintain the operational security.



5.2. Offshore wind

The German transmission system operator, TenneT, is responsible for connecting German North Sea wind parks to the grid. TenneT has published a time series for offshore wind in 2011. The production was 435 GWh in 2011 with a maximum output at 128 MW. The annual load factor was 0.39. The offshore data for 2011 is insufficient for real comparisons with the national time series, but with a suitable production volume the separate offshore data can be a very interesting source in the future.



5.3. International aggregation of wind power

It is difficult to quantify the smoothing effect of aggregating wind power across a larger geographical area. The following combinations will be considered: Denmark/Germany, Ireland/Great Britain and Denmark/Ireland. The latter combination has the purpose to evaluate the effect of a long distance from west to east.

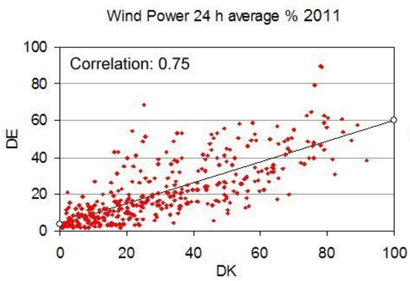
The first approach will be based on statistical methods.

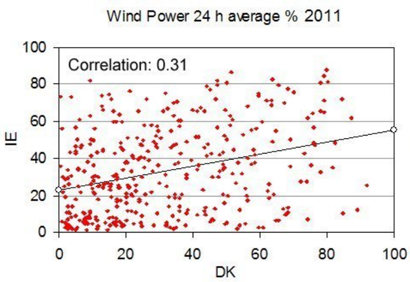
Correlation coefficients have been calculated for all combinations based on hourly wind power data.

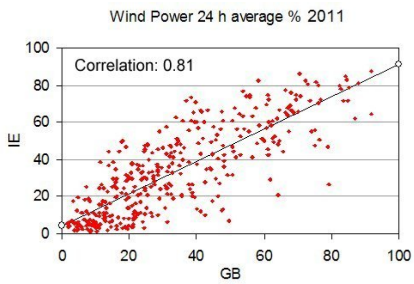
Correlation coefficients Hourly wind power	2011	France	Great Britain	Ireland	Germany
	Denmark	0.21	0.39	0.27	0.70
	Germany	0.45	0.38	0.26	
	Ireland	0.23	0.73		
	Great Britain	0.28			

The strongest correlations are found between Denmark and Germany and between Ireland and Great Britain. The weakest correlations are found between France and Denmark and between France and Ireland.

The correlations between daily average wind power productions for three pairs of countries have been analysed.





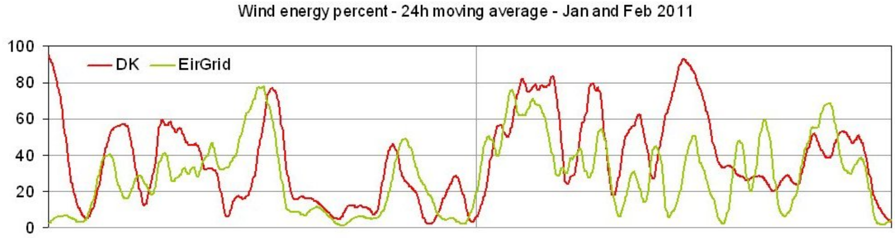


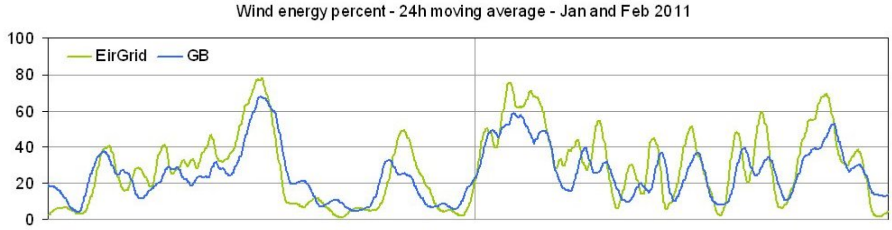
It is obvious from the results that there is a high degree of co-variation of wind power in Ireland and Great Britain. Wind power in Denmark and Germany shows similar properties. The correlation between wind power in Ireland and Denmark is positive, but at a much lower level. This is evidence that Denmark and Germany should be considered as one wind power system and Great Britain and Ireland as another.

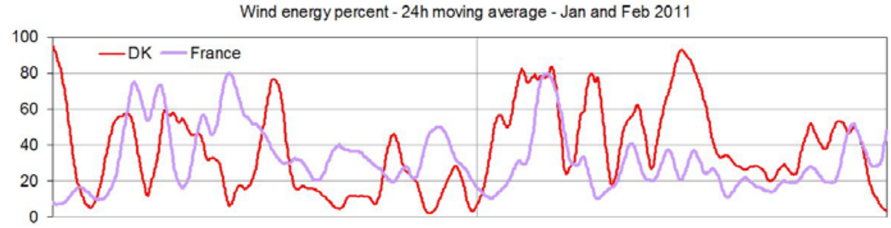
Extracts from the time series can visually confirm the positive correlation coefficients, though less obvious for Denmark and France.

In order to eliminate noise from the time series 24 hour moving averages are used for the following charts. The correlation coefficients (based on hourly data) are slightly higher for the moving average:

8760 observations	Denmark-Germany	Denmark-Ireland	Ireland-Great Britain
Raw data	0.70	0.27	0.73
24 h moving average	0.75	0.32	0.81

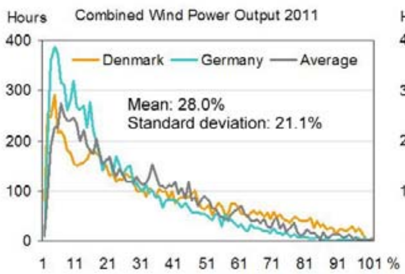


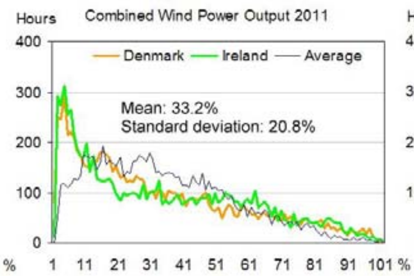


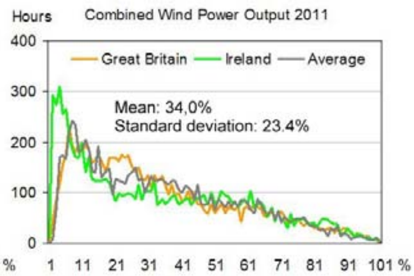


All countries had quite low wind power output during the last half of January 2011.

The **combined wind power output** for two countries can be analysed either by just adding them together or by calculating an average. The following results are based on the latter method because it eliminates the effect of different magnitudes of the national wind power fleets.



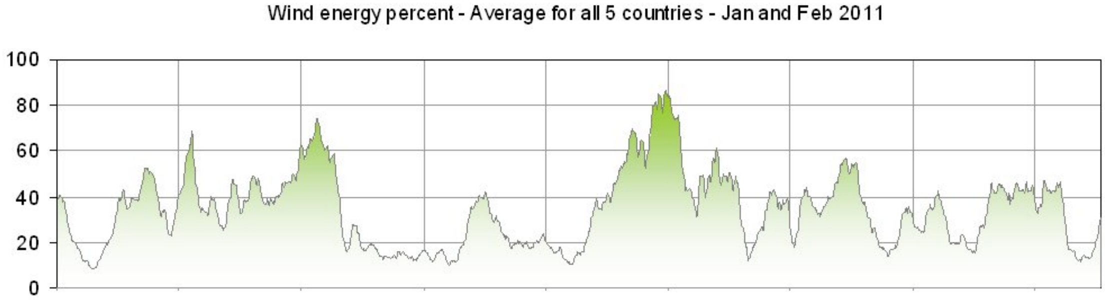




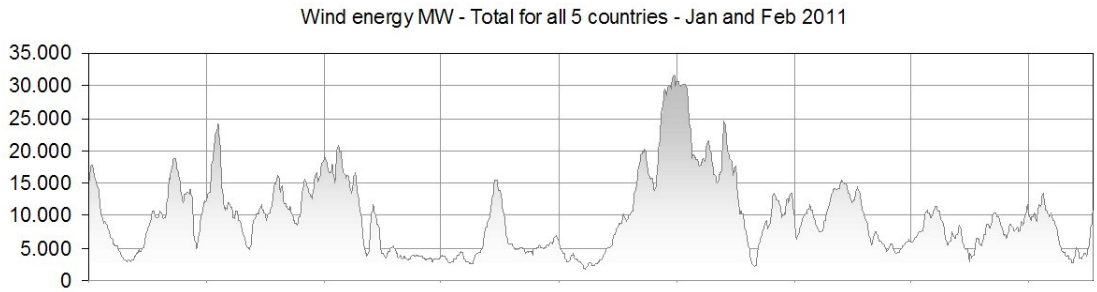
The average distribution for all five countries has a mean value of 33.9% and a standard deviation of 18.3%.

While the Danish-Irish average wind power distribution has a different shape, creating average distributions for Denmark and Germany and for Ireland and Great Britain does not change the shape of the distribution significantly. However, the distribution is still very left-skewed. The result will not be a smooth output of power.

The average time series are used for evaluation of the sustainability of wind power in system operation.



The average hourly wind power output for the five countries eliminates some peaks and valleys at each country's production profile. However, with a standard deviation of 18.3% the variability is still high, and the aggregated wind power production cannot be considered as a reliable source of power.



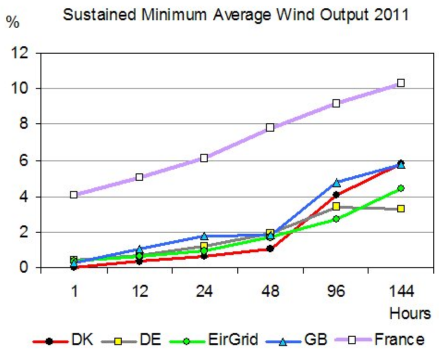
Adding national wind power in MW outputs instead of calculating average in % gives a slightly different profile. The mean value is 28.1% instead of 33.9% while the standard deviation is practically unchanged (18.3% instead of 18.2%). Thus the variability of the two distributions is the same. The lower mean value reflects a higher influence of the German data.

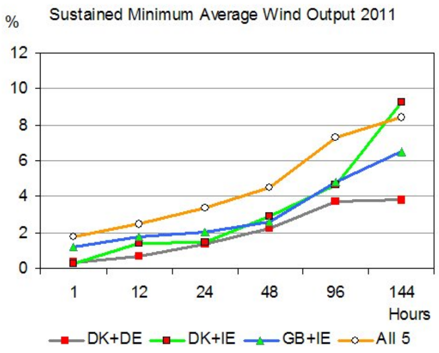
The minimum aggregated wind power output can be presented in a more systematic way. Periods with minimum and maximum production have been analysed for the following combinations of average wind power output:

2011	Consecutive hours	DK+DE		DK+IE		GB+IE		All 5	
		MW	%	MW	%	MW	%	MW	%
Minimum	12	176	0.69	67	1.38	84	1.79	790	2.49
	24	339	1.33	70	1.45	96	2.05	1,069	3.37
	48	566	2.22	142	2.93	124	2.64	1,430	4.51
	96	950	3.73	224	4.63	226	4.82	2,307	7.27
Maximum	1	25,444	100.0	4,839	100.0	4,690	100.0	31,709	100.00
	12	24,953	98.07	4,628	95.64	4,536	96.73	30,819	97.19
	24	24,681	97.00	4,553	94.09	4,334	92.42	30,421	95.94
	48	23,007	90.42	3,944	81.52	4,125	87.96	28,391	89.53
	96	19,475	76.54	3,665	75.74	3,807	81.18	23,579	74.36

The table shows for example that the minimum average aggregated wind power output of the five countries in 2011 for 24 consecutive hours has been 3.37% of the aggregated maximum value. The maximum average aggregated output for 24 consecutive hours has been 95.94%.

The following charts summarize the minimum results by comparing national results with aggregated results:





The left-hand chart demonstrates the exceptional characteristics of French wind power. Production values lower than 4% do not occur for 2011. The reason could be that the installed wind power in France has two gravity centres, one in the North West depending on Atlantic winds and one in the southern part of France depending on Mediterranean winds. The four other countries in this study are supposed to be dominated by Atlantic winds. For future studies a set of Spanish data might be able to open new interesting perspectives, if available.

Combining Danish and Irish wind power seems to promise a slightly higher resulting minimum sustained output than any other combination, including combined wind power from all 5 nations.

International combinations of wind power during high wind periods have also been analysed but the results seem to be unchanged compared with the national data.

5.4. Wind power capacity credit

The minimum observed sustained average wind power outputs in 24 hours in 2011 were (in % of maximum hourly output):

Denmark	Germany	Ireland	Great Britain	France
0.61%	1.19%	0.95%	1.80%	6.11%

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.

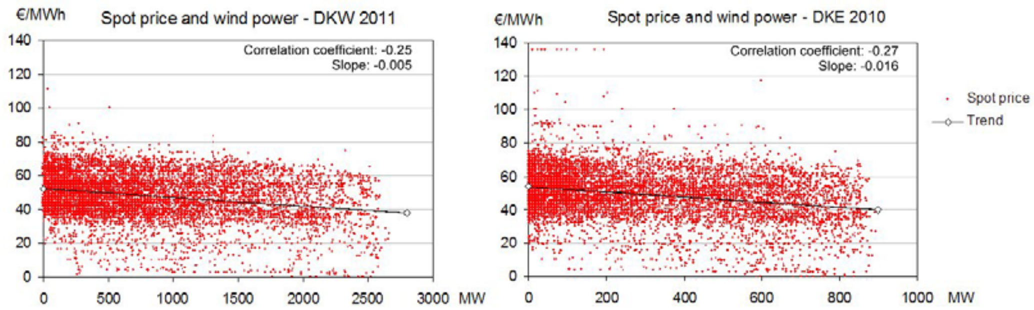
6. Wind Power and Spot Markets

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

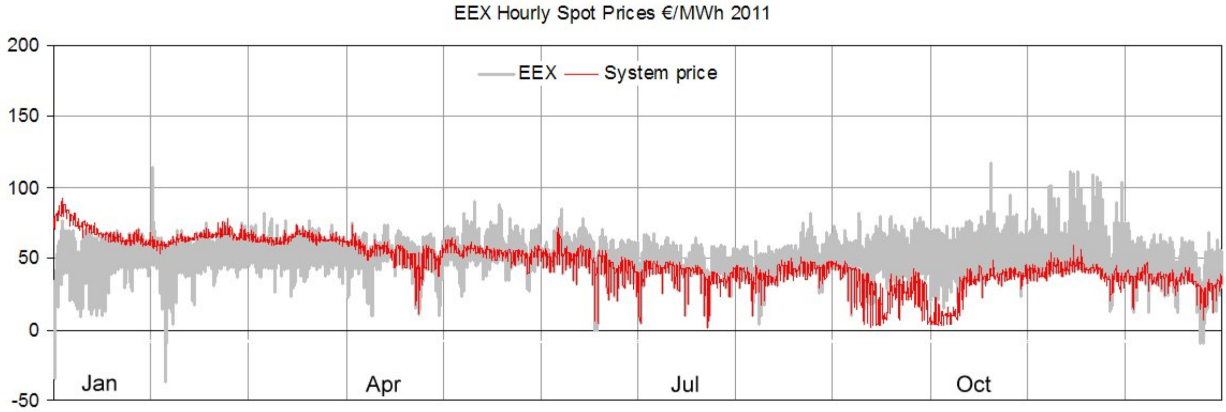
On 1 November 2011 Sweden was divided into four bidding areas. The decision was made by Svenska Kraftnät after legally binding commitments from Svenska Kraftnät to the European Commission.

The following diagrams show local hourly spot prices and wind power for the entire year 2011. The correlations are surprisingly low. The reason is that several other factors than wind power have an impact on market prices.



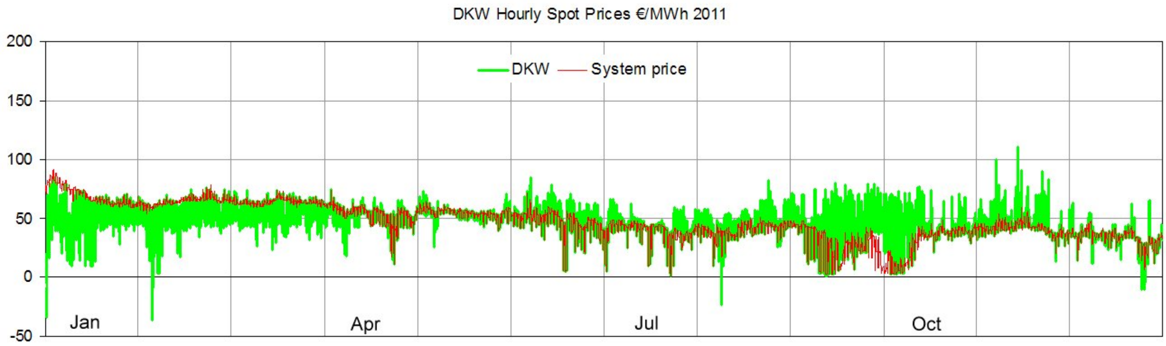
The two distributions are rather much alike. The volatility for East Denmark is much lower than in the previous years. The new Great Belt is probably a main reason for this national equalisation.

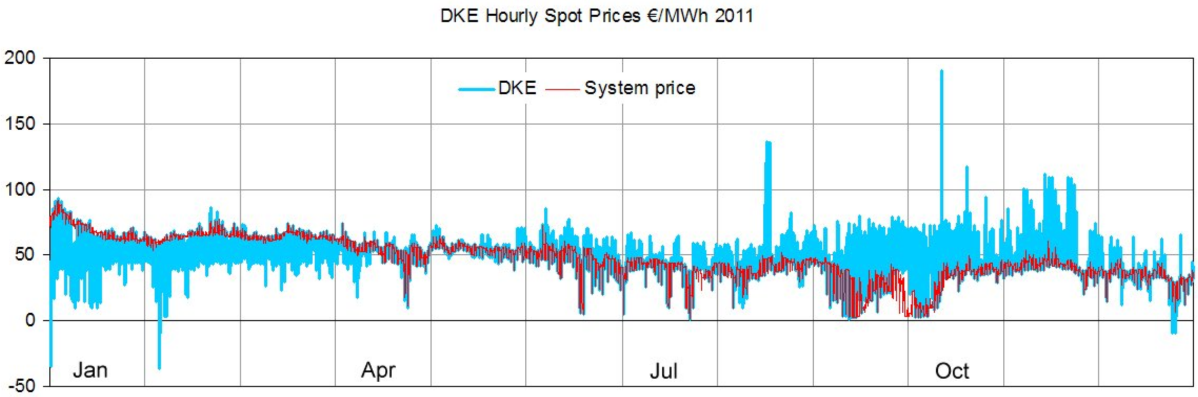
A time series with hourly spot prices can be used for the identification of some characteristic periods.



The chart above compares the EEX spot price with the Nord Pool system price. The tilting energy balance between the Nordic countries and Germany in April is clearly reflected. The two time series have formally the same volatility for the whole year but according to the chart nevertheless different properties.

The following charts for the two Danish price areas confirm that the Danish spot prices are closer related to EEX prices than to Nord Pool prices. Several cases of zero prices and negative prices occur simultaneously in Denmark and Germany.

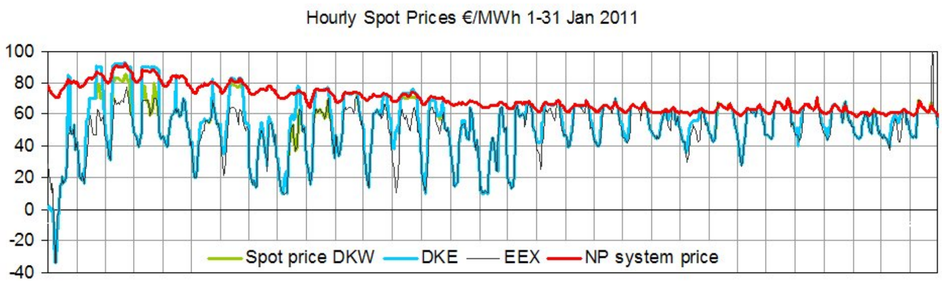


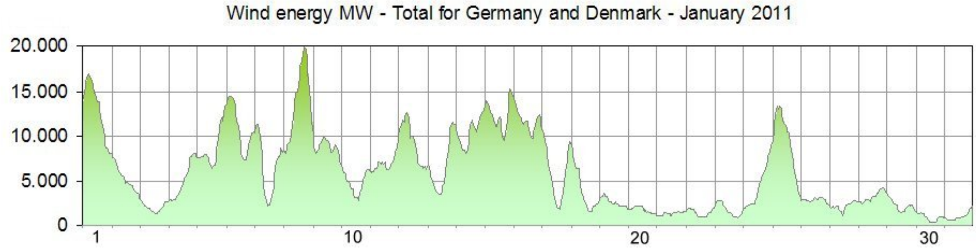


The following observations from these charts have been selected for examination:

- 6.1: January: Different wind power levels
- 6.2: February: Negative spot prices
- 6.3: August: Power shortage in East Denmark
- 6.4: September: Very low NordPool spot prices

6.1. January 2011: Different wind power levels





During the first half of January 2011 a surplus of wind energy has affected the spot prices at night in Denmark and Germany. There has been a large northbound transit through Denmark. Due to congestions at the borders to Norway and Sweden the NordPool system prices have not been affected.

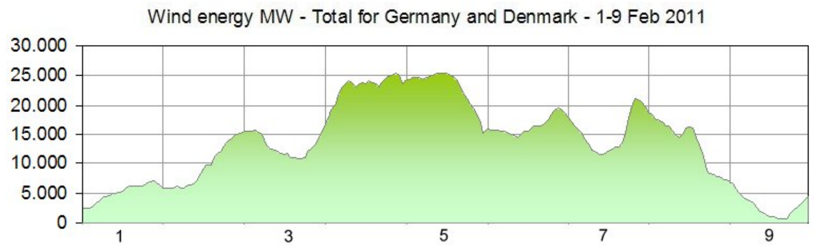
The case demonstrates what could be a typical spot price profile in the future unless national sources of balancing power are developed in line with the growing wind power capacity. Statnett in Norway has recognized the trend as a promising future business opportunity[12].

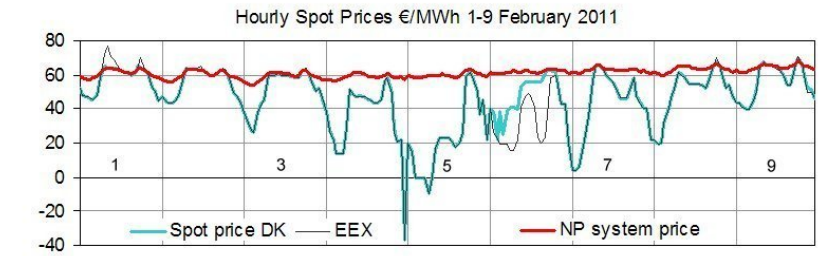
6.2. 5 February 2011: Negative spot prices

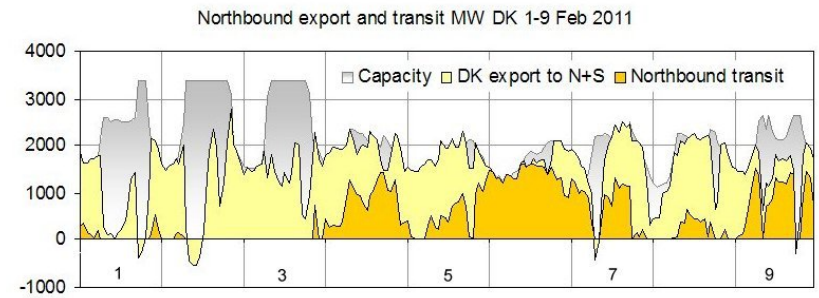
There was an even bigger mountain of wind power in the beginning of February.

The market response was negative spot prices in the night between the 4th and the 5th February. The two Danish price areas had identical spot prices throughout the period. The German spot prices were the same except on the 6th February.

The transfer capacity to Norway and Sweden was utilised to the limits most of the time, but the German market seems not to have anticipated the mountain.





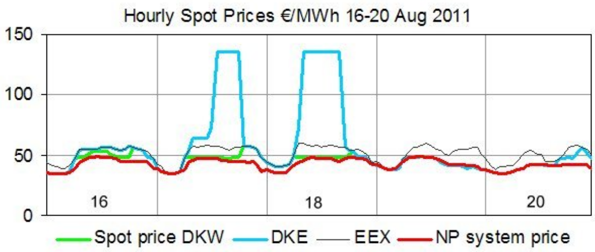


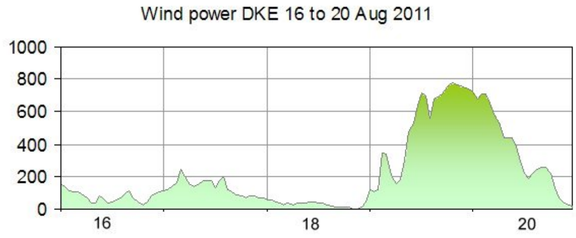
This case also demonstrates the competition between Denmark and Germany for access to the Nordic market. On the 6th February nearly all the capacity has been taken over by German exporters.

The capacity reductions occurred at the interconnections to Sweden. Such limitations are often declared when the capacity is most needed.

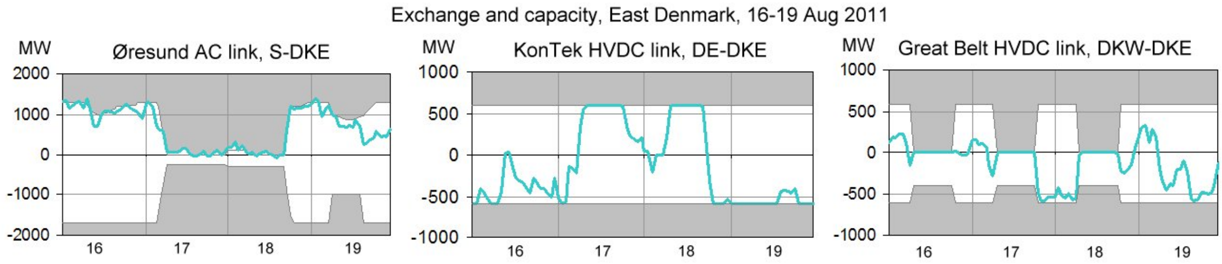
[12] Statnett: Nettutviklingsplan 2010, p. 70

6.3. 17 and 18 August: Power shortage in East Denmark





On the 17th and 18th August 2011 rather high spot prices were observed for East Denmark. Both the Øresund AC link to Sweden and the Great Belt HVDC link to West Denmark were closed for import while 600 MW could be imported from Germany. Unfortunately the wind power output was rather low on these two days.

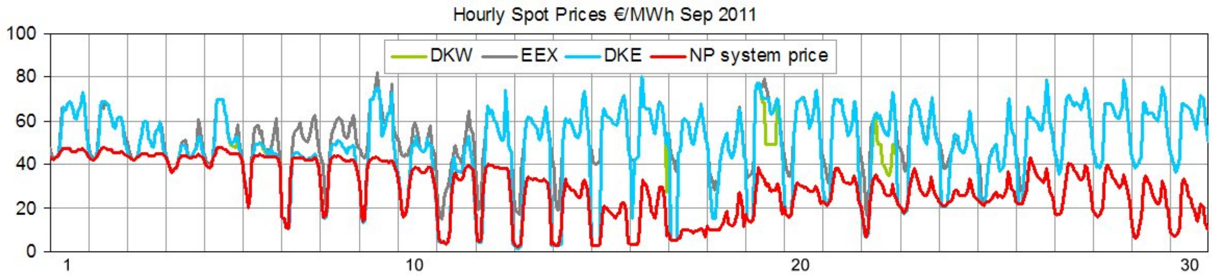


The market report from Energinet.dk says:

> The month of August also saw repeated inspection and maintenance of the transmission grids in Denmark and the neighbouring countries, which influenced the capacity available on, for instance, the Øresund Link, the connection between Western Denmark and Germany and the Great Belt Power Link. The exchange via the transmission grid was primarily southbound, and both Western and Eastern Denmark imported from the Nordic countries and exported to Germany.

The case demonstrates that availability of interconnections and wind power variations are two equal important factors with impact on the wholesale electricity markets.

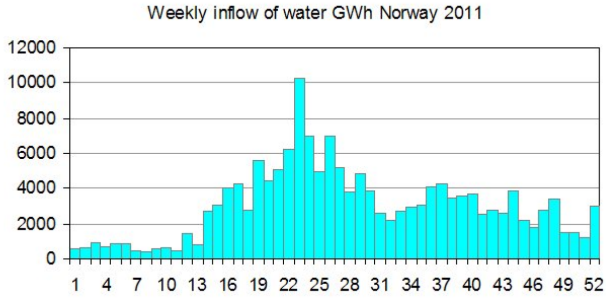
6.4. September: Very low NordPool spot prices

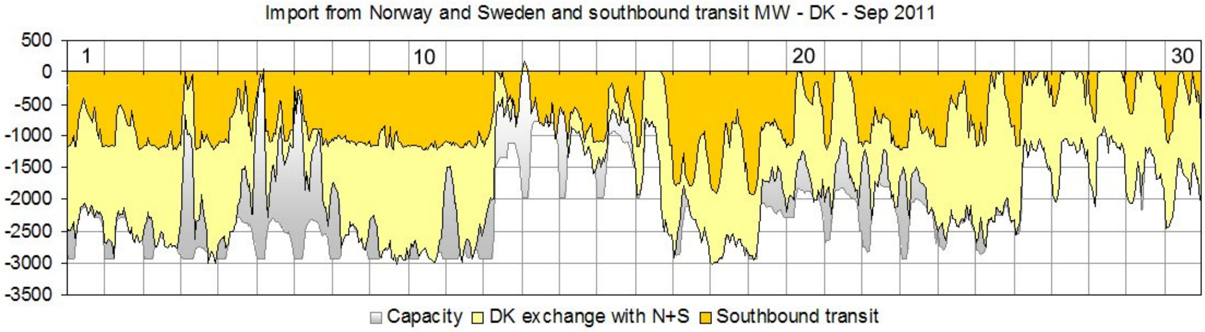


The Danish and German spot prices were identical for nearly all hours in September. The NordPool system price was lower and during several nights extremely low.

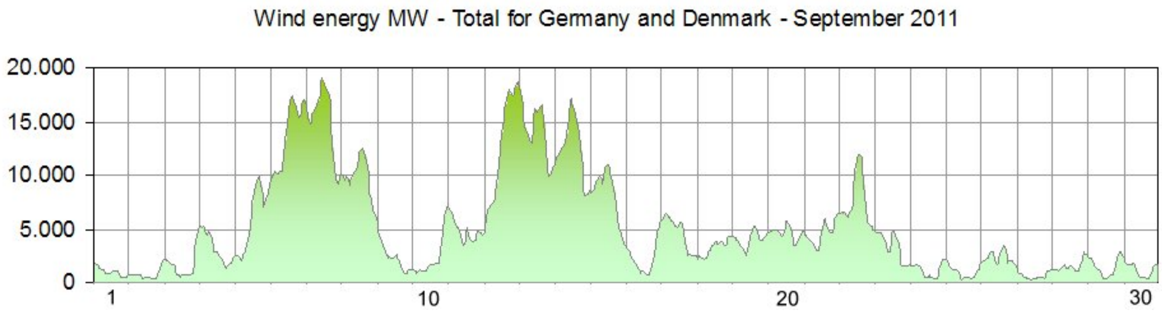
The reason for the very low prices may have been an unusual high inflow of water in 2011 and local overflow of water in some parts of Norway and Sweden.

The result was export of power up to the capacity limits of the interconnectors most of the time.





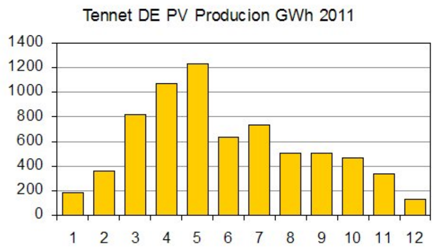
A combination of temporary capacity limitations on the interconnections and the mountains of wind power have been decisive for the outcome.

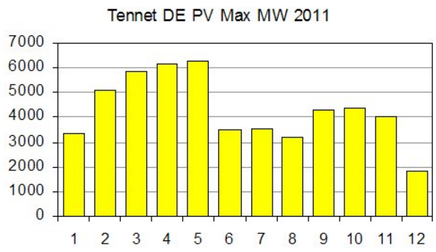


This example identifies three factors of importance for the future European electricity markets: the Scandinavian water balance, the variability of the continental wind power and the availability of the interconnections.

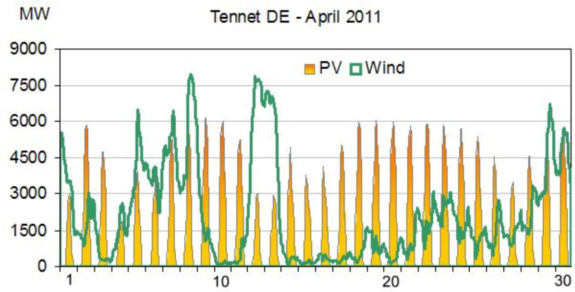
7. Photovoltaic

Photovoltaic (PV) has gained considerable importance in Germany. In 2011 TenneT (one of four German transmission system operators) has published estimated hourly production data. The total production in 2011 was 6,966 GWh with a maximum output of 6,282 MW. The corresponding load factor is 0.13.





The monthly energy output reflects the weather conditions in 2011.



The variability of PV is different from the variability of wind power. It can be argued that the daily variations could make PV more useful than wind power. The question is if PV can make the shape of the residual load smoother.

The vertical grid load is the load recorded by TenneT. Apparently it does not include all electrical loads in TenneT's geographical area. In April 2011 the maximum value was 14,298 MW and the minimum value 1,809 MW. The standard deviation was 2,730 MW.

The residual load after subtracting the wind power still has 14,298 MW as the maximum value, but the minimum is -4,966 MW and the standard deviation 3,626 MW.

The maximum residual load when also PV has been subtracted is still 14,298 MW. The minimum is -10,219 MW and the standard deviation 4,176 MW.

The result of this limited evaluation is that adding PV does not relieve the balancing problem in the TenneT area. Hopefully better data in the future can pave the way for more comprehensive analyses.

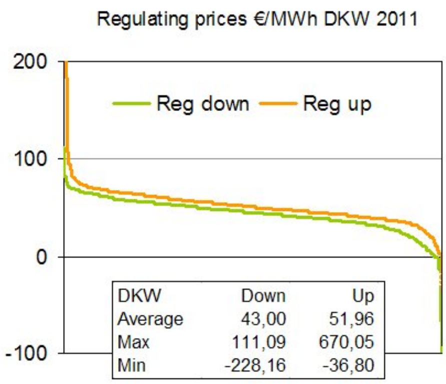
8. Regulating Power

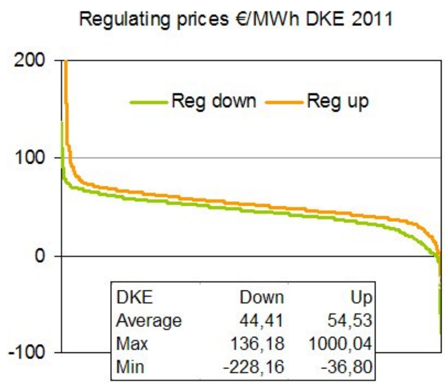
Nord Pool Spot is a wholesale market for buyers and sellers, the gate closure being for the following day at noon. Therefore its spot prices are based on expectations 24 to 36 hours before real time, and day-ahead wind power forecasts are very inaccurate.

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 166 hours in West Denmark and 144 hours in East Denmark.

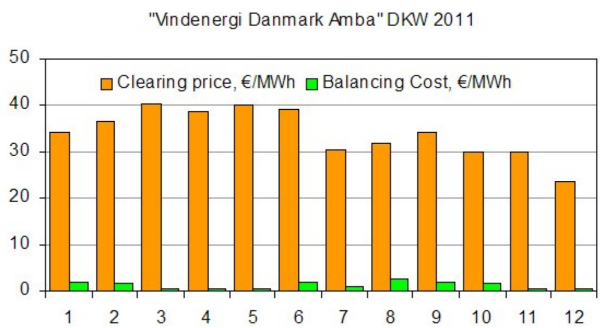
No of hours	Downwards		Upwards	
€/MWh	<-100	<=0	>100	>200
DK West	4	166	108	50
DK East	2	144	209	111

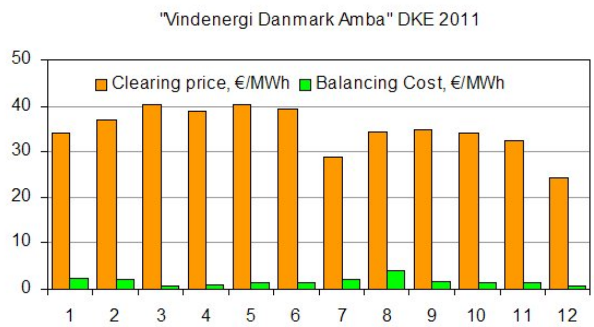
In 2011 the difference between west and east in Denmark was practically eliminated. This is probably another consequence of the installation of the Great Belt link.

9. 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 2011 (with my translations):

	Jan	Feb	Mar	April	May	June
West Denmark						
Installed capacity, MW	1.404	1.437	1.449	1.466	1.480	1.485
Production, GWh	233	376	305	239	272	171
Clearing price, øre/kWh	34,1	36,4	40,3	38,8	39,9	39,0
Balancing cost., øre/kWh	1,9	1,5	0,8	0,8	0,7	1,9
East Denmark						
Installed capacity, MW	275	305	305	300	304	305
Production, GWh	33	82	59	49	45	29
Clearing price, øre/kWh	34,0	37,0	40,1	38,9	40,3	39,1
Balancing cost., øre/kWh	2,4	2,0	0,6	0,9	1,4	1,4
Total						
Installed capacity, MW	1.679	1.742	1.754	1.766	1.784	1.790
Production, GWh ,	266	458	364	288	317	200
	Juli	Aug	Sep	Okt	Nov	Dec
West Denmark						
Installed capacity, MW	1.487	1.505	1.508	1.518	1.521	1.610
Production, GWh	161	207	248	327	250	435
Clearing price, øre/kWh	30,4	31,9	34,2	29,9	30,1	23,4
Balancing cost., øre/kWh	0,9	2,6	2,0	1,5	0,7	0,6
East Denmark						
Installed capacity, MW	305	306	306	306	306	328
Production, GWh	38	44	46	59	43	97
Clearing price, øre/kWh	28,8	34,3	34,6	34,1	32,3	24,3
Balancing cost., øre/kWh	2,1	3,9	1,6	1,4	1,3	0,7
Total						
Installed capacity, MW	1.793	1.811	1.814	1.825	1.827	1.939
Production, GWh	198	250	294	386	292	531



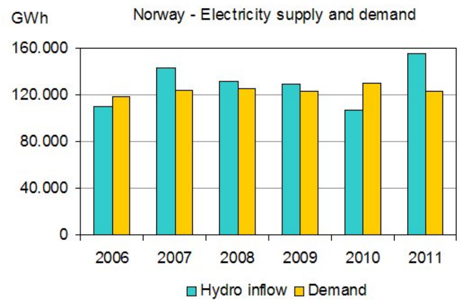


10. Trends 2006-2011

10.1. Hydrology and nuclear availability

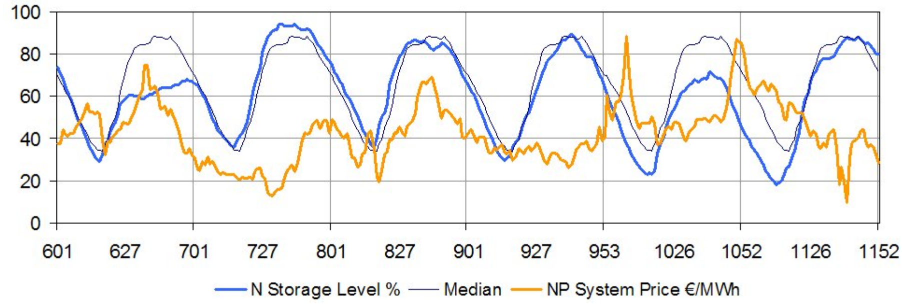
The Nordic energy balance depends on the hydro power systems in Norway and Sweden and on the availability of nuclear power in Sweden and Finland. This is demonstrated by a few charts with data form Norway and Sweden.

The inflow of hydro energy in Norway is irregular and has considerable variations from year to year. The inflow was 107 TWh in 2010 and 156 TWh in 2011. Inflow was preferred for this chart instead of production.

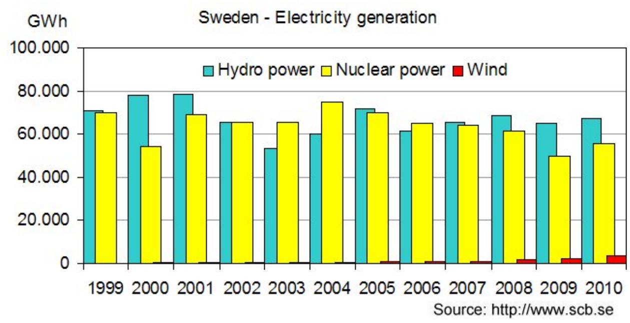


The variations are offset by international exchanges, by using the hydro storages (84.3 TWh) and from 2009 by thermal generation on the gas-fired Kårstø power station (440 MW).

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

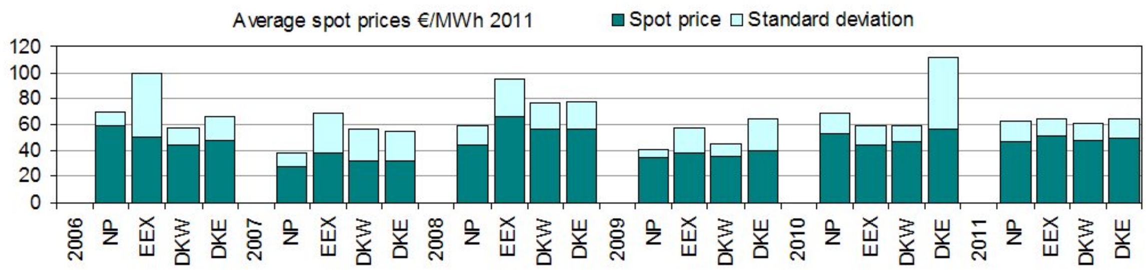


Similar variations can be observed in Sweden. The Swedish hydro production was 78 TWh in 2001 and 53 TWh in 2003. The nuclear production was 75 TWh in 2004 and 50 TWh in 2009.



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

10.2. 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	2011
	Spot price <= 0					
West Denmark (DKW)	28	85	28	55	12	18
East Denmark (DKE)	5	30	9	4	6	17
Nord Pool system price	0	0	0	3	0	0
EEX, Germany	10	28	35	73	12	16
Balancing power	Downwards price <=0					
West Denmark (DKW)	229	194	80	159	301	166
East Denmark (DKE)	45	53	25	30	4	144

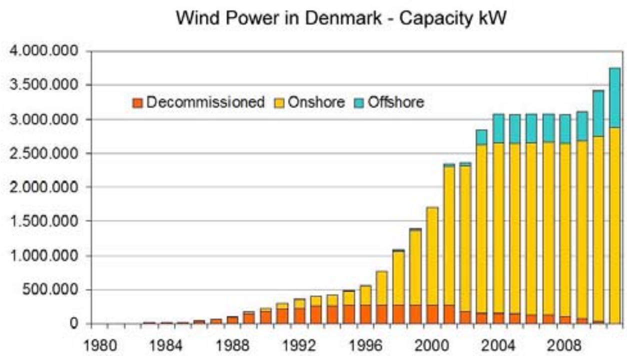
The magnitude of the overflow problem due to Danish wind power can be indicated by the number of hours with spot prices and downwards balancing prices equal to or below zero. When the price of balancing (or regulating) power is below 0 the system operator must pay for export of energy. Nord Pool introduced negative spot prices in October 2009.

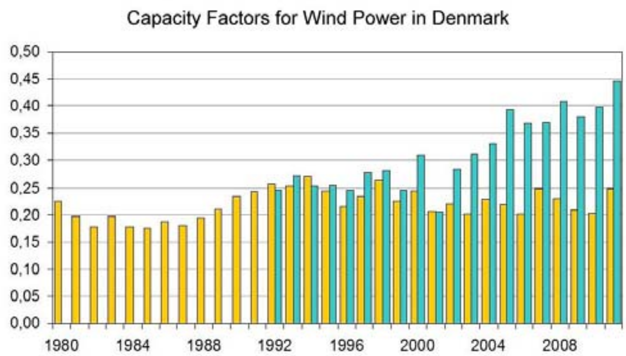
The spot market in 2011 seems to have been the best harmonised and the least volatile in the observation period.

10.3. Wind energy

Wind energy	Denmark		Germany		Ireland		Great Britain		France	
	TWh	Share	TWh	Share	TWh	Share	TWh	Share	TWh	Share
2006	6.1	17%	39.5[13]	-	1.6[14]	-	-	-	-	-
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%	-	-	-	-
2011	9.8	28%	43.0	8%	4.3	17%	9.7	3%	11.2	2%

Capacity factors have been calculated for Danish wind turbines. Only wind turbines which have been in service during the whole year are included.



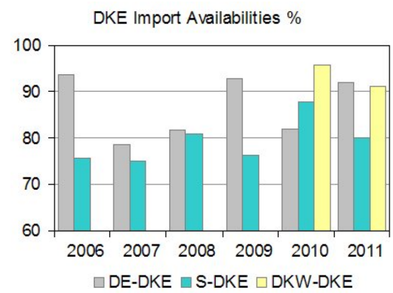


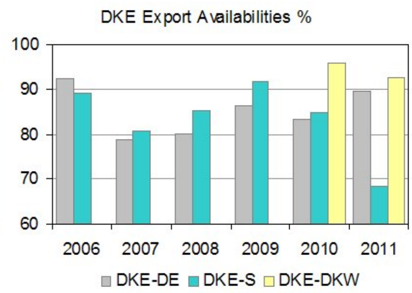
[13] http://www.wind-energie.de/de/statistiken/
[14] http://www.seai.ie/

Like hydro power wind energy has variations from year to year. For the years 1983 to 2010 the wind energy index varies between 85% and 120%.[15]

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

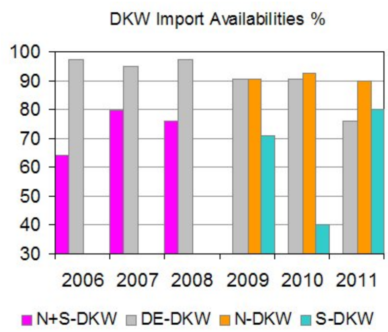
10.4. Interconnector availability

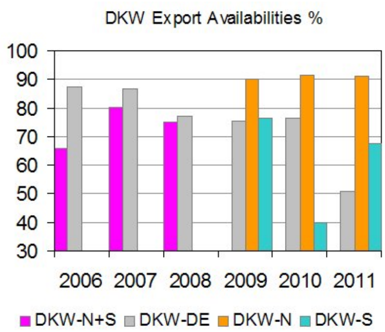




It is an essential result of the collection of data since 2006 that the average availability of the interconnectors is much lower than usually assumed.

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 most interconnectors have a worse availability in most years 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. Consequences of insufficient transmission capacity have been demonstrated in the previous chapters.

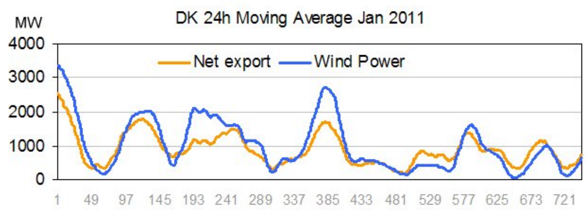
[15] http://www.dkvind.dk/fakta/pdf/M3.pdf (in Danish)

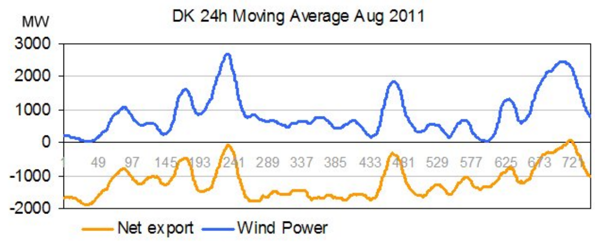
11. Danish wind power and export of electricity

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.

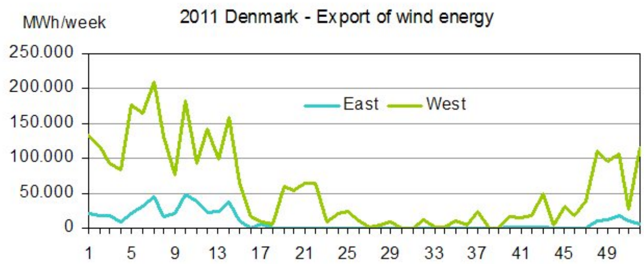
The discussion of the *origin* of the exported electricity may be an interesting academic matter. But the *variations* of wind power and electricity export can easily be compared. The following charts show 24 hours moving average for Denmark in January and August 2011:





This seems to be convincing evidence that waves of wind energy cause corresponding waves of electricity exchange. 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 2011 was 3 TWh or 31% of the Danish wind energy production. 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.