Enlarged Wind Power Statistics 2010

including

Denmark, Germany, Ireland and Great Britain

Background

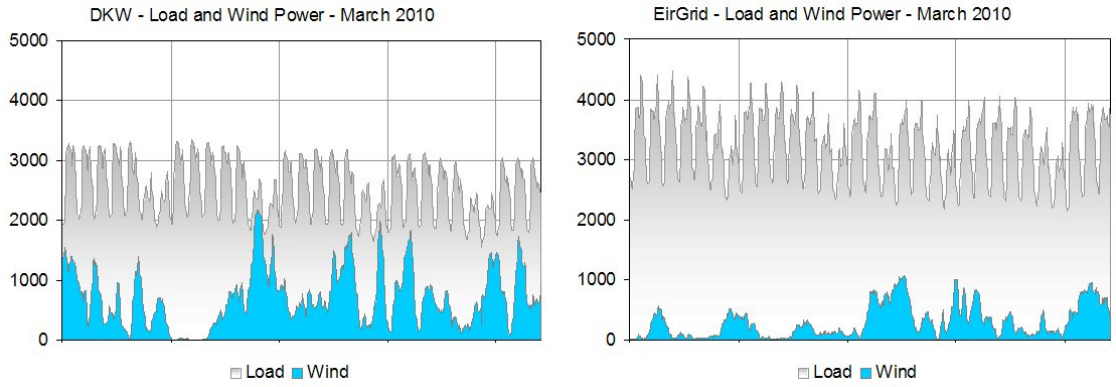
This work is based on hourly time series for wind power output in Denmark, Germany, Ireland and Great Britain. The purpose is to observe wind power profiles for countries with different wind power penetrations and different shares of offshore wind power and to demonstrate the smoothing effect of combining wind power for larger geographic areas.

It has been a main problem to extract data from relevant bodies in each country and to convert data from different formats into a common format which can be used for presentations and analyses. If would be extremely helpful if the data administrators could agree on a common data format for energy data for international comparisons.

The British wind power output data (including England, Wales and Scotland) has been added to my collection of data since the presentation of my Statistical Survey 2010. Therefore this paper should be seen as a supplement to the Statistical Survey 2010.

Wind Power Profiles

The wind power variability can be demonstrated in a comparison with the demand profile:



The charts show wind power output and electricity demand for March 2010 for West Denmark and for Ireland (including the Republic of Ireland and Northern Ireland).

The four countries have different wind power penetrations, different operating conditions and different market conditions. The wind energy share is supposed to increase in all four countries during the next few years. It remains to be seen how efficient each of the four countries will be able to utilize the increasing amount of wind energy in the future.

Strong interconnections have been decisive for the absorption of wind energy corresponding to 28% of the electricity demand in West Denmark.

Similar illustrations have not been made for Germany and Great Britain because the German time series for demand are incomplete and relevant British time series have not yet been found.

Paul-Frederik Bach

26 June 2011

National Wind Power Output

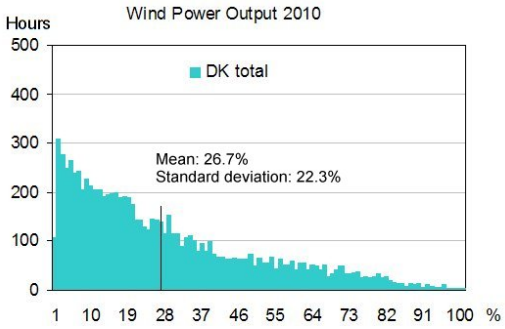
Time series have been collected for the Irish island, for Great Britain, for the two parts of Denmark (west and east) and for the four German transmission system operators (Amprion, TenneT, 50hertz and EnBW Transportnetze).

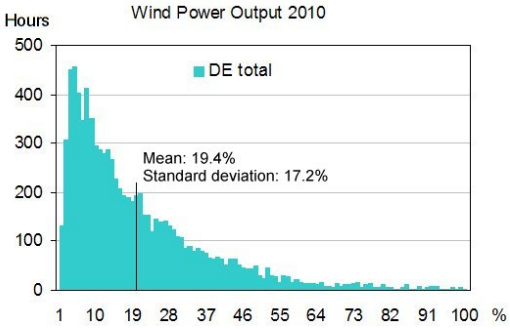
National time series for Denmark and Germany have been created by adding the two Danish time series and by adding the four German time series.

The wind power main characteristics of the four countries are:

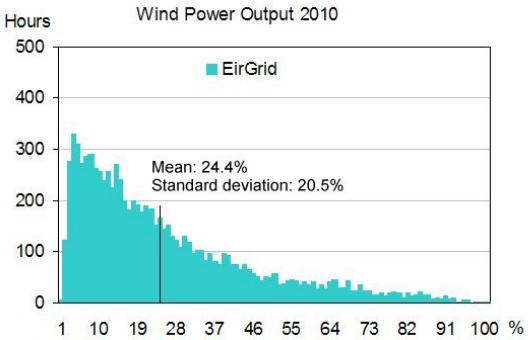
2010		Denmark	Germany	Ireland	Great Britain
Wind	GWh	7,808	36,055	2,598	3,680
Max	MW	3,333	21,204	1,214	2,058
	Load factor	0.27	0.19	0.24	0.20
Share	%	22.0	6.0[1]	9.8	0.9

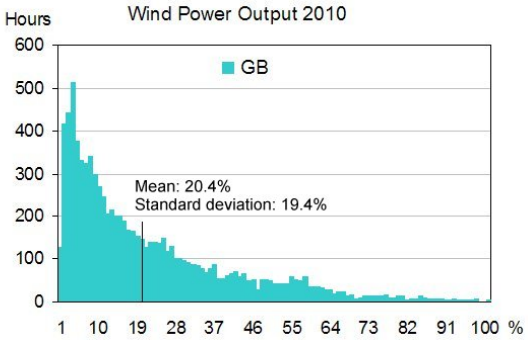
Statistical distributions can be used for characterizing the time series. The following charts show the number of hours recorded for 1% steps of maximum production. The mean values of the distributions are identical with the load factors.





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. This difference may be set off when new German offshore wind parks have been commissioned.

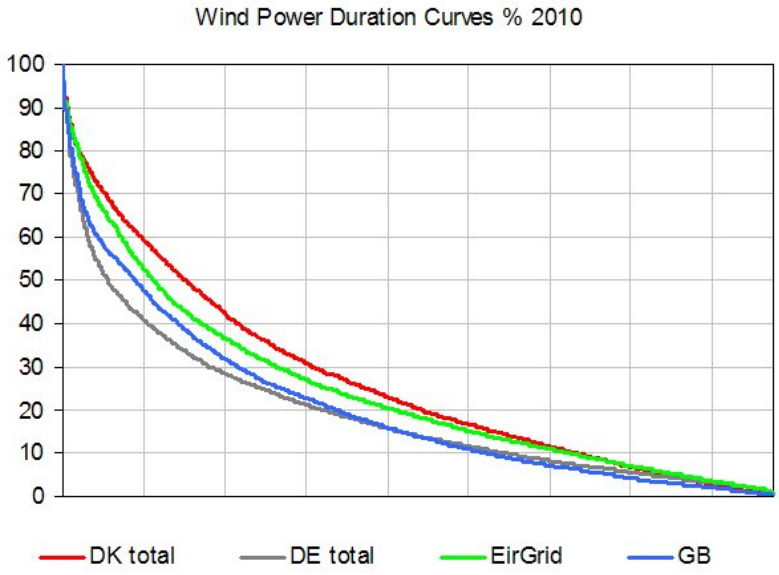




Irish and British wind power distributions show a similar difference. Ireland is known to have excellent wind conditions. The exploitation of Irish offshore wind power resources might contribute to one of the best achievable wind power distributions in Europe.

[1] Based on estimated electricity consumption

Duration curves can also be used for a 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 suggests a rank in terms of energy production compared with maximum production.

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.

The variability of wind power may create surplus of power and shortage of power. The **national minimum and maximum wind production** in 2010 has been identified:

	One hour	Denmark	Germany	Ireland	Great Britain
Minimum	MW	2	103	0	0
	Share of max	0.1%	0.5%	0.0%	0.0%
	Date and hour	9 Mar 20-21	29 Jun 09-10	13 Oct 11-12	4 May 02-03
Maximum	MW	3,333	21,204	1,214	2,058
	Date and hour	11 Dec 11-12	12 Nov 14-15	26 Dec 16-17	12 Nov 11-12

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:

		Denmark		Germany		Ireland		Great Britain	
	Consecutive hours	MW	%	MW	%	MW	%	MW	%
Minimum	12	6	0,2	186	0,9	13	1,1	5	0,2
	24	11	0,3	216	1,0	22	1,8	9	0,4
	48	18	0,5	383	1,8	27	2,3	19	0,5
	96	138	4,1	663	3,1	64	5,3	24	1,1
Maximum	12	3,198	96.0	20,303	95.8	1,188	97.9	1,967	95.6
	24	2,889	86.7	19,392	91.5	1,138	93.7	1,914	93.0
	48	2,851	85.6	16,283	76.8	954	78.5	1,770	86.0
	96	2,359	70.8	12,053	56.8	796	65.5	1,280	62.2

This table seems to suggest that sustained low wind power output is more common that sustained high wind power output.

The **residual load** is the difference between gross electricity demand and wind power output. The following characteristics have been extracted for Denmark and Ireland:

	Denmark			Ireland		
	GWh	Max MW	Min MW	GWh	Max MW	Min MW
Load	35,485	6,347	2,216	26,544	5,087	1,628
Residual load	27,678	6,237	33	23,947	5,042	882
Difference	7,807	110	2,183	2,597	45	746

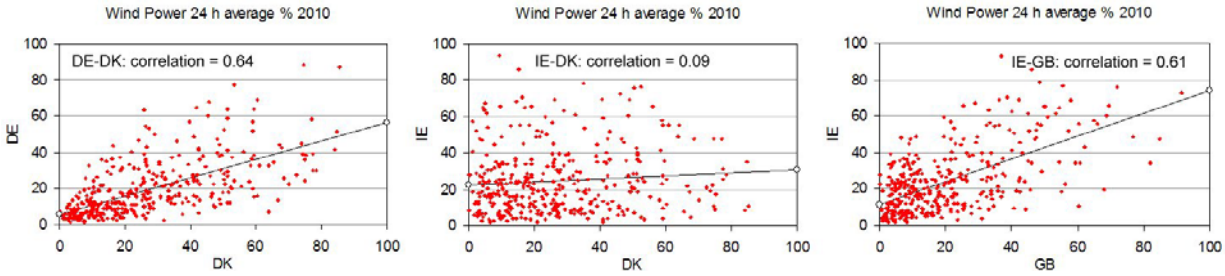
The differences are caused by wind power. Wind power has improved the energy balance while the contribution to peak capacity is insignificant. In Denmark the very low minimum residual load causes export of electricity because the CHP systems need electricity demand and a certain production on large thermal units is required in order to maintain the operational security.

International aggregation

It was a main result of my work for Renewable Energy Foundation in 2009 (ref. 1) that there is a strong correlation between Danish and German wind power. This is reflected in the spot prices in the two countries and leads to the conclusion that the two countries must be considered as one system in the future balancing of an increasing share of wind power.

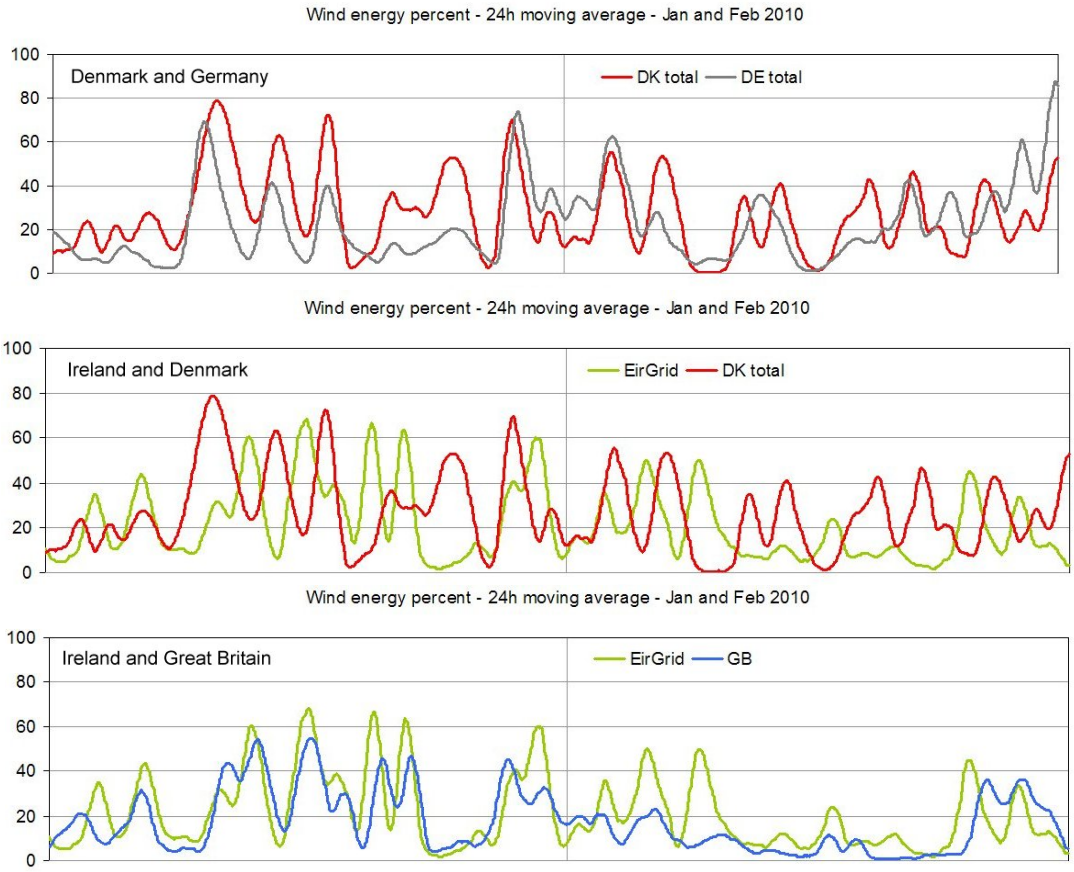
This work demonstrates that wind power in Great Britain and Ireland have similar relations as wind power in Denmark and Germany.

The relations can be demonstrated by a correlation analysis. The average daily wind power output (365 observations) has been normalized to percent of maximum output.



The correlation is quite high for combinations of Denmark and Germany (0.64) and Ireland and Great Britain (0.61). The combination of Denmark and Ireland has a much lower correlation coefficient (0.09). This is strong evidence that Denmark and Germany should be considered as one wind power system and Great Britain and Ireland as another.

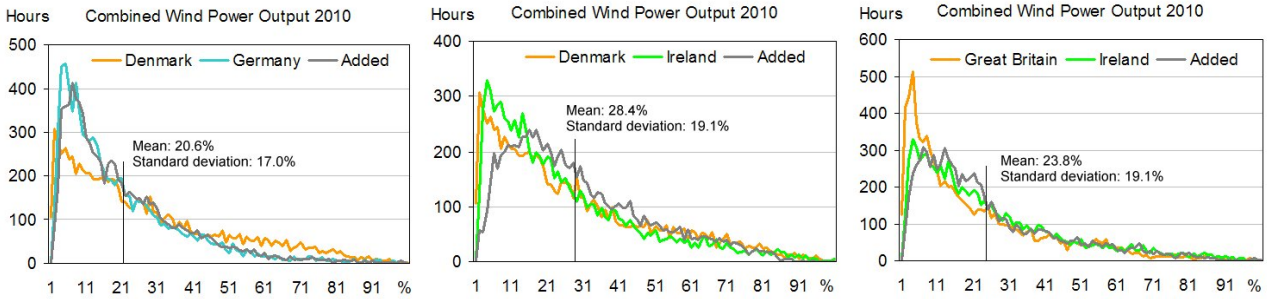
Extracts from the time series can support the observation. In order to eliminate noise from the time series 24 hour moving averages are used for the following charts.



The charts confirm the weak relationship between wind power output in Denmark and Ireland. 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	0.60	0.08	0.55
24 h moving average	0.65	0.11	0.64

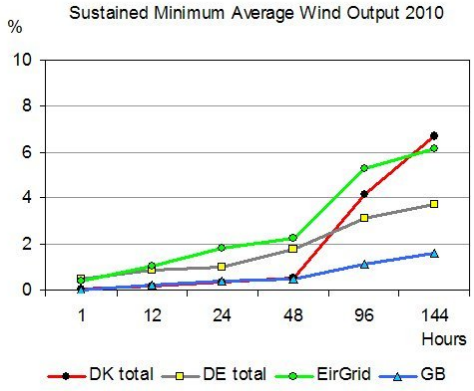
The four areas concerned are different in geographic extension and wind power penetrations. The simplest method for studying wind power properties for larger areas is by **adding the time series**. The results will reflect the present conditions but cannot necessarily be used for estimates of the future.

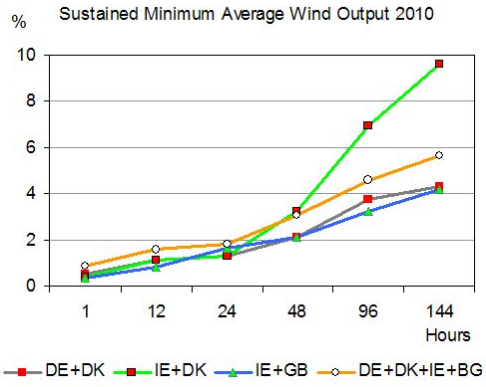


Mean values of wind power distributions 2010			
Germany	Denmark	Ireland	Great Britain
19.4%	26.7%	24.4%	20.4%
20.6%	28.4%		23.8%

The result of adding Danish wind power to German wind power is very close to the German data because wind power production is much larger in Germany than in Denmark. It is remarkable that the mean value of the sum of Danish and Irish wind power is larger than the mean for any of the two countries separately.

The need for backup capacity could be reduced by adding production together for larger areas. The average minimum production for a number of hours should reveal an improvement.

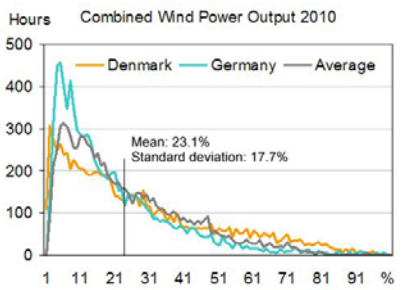


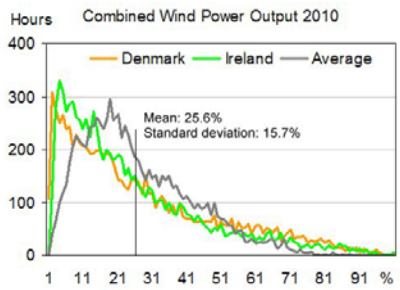


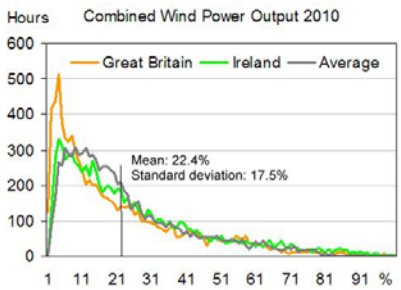
It is not surprising that the result of adding Danish wind power to German wind power cannot move the German average output significantly, but adding Danish and Irish productions shows significant improvement for 48 hours and more. 24 hours with less than 2% output must be anticipated for the combinations considered.

Theoretical studies have indicated wind power capacity credits of 6% or more. However, even for the aggregated wind power of all four countries backup capacity seems to be needed for 98% of the maximum wind power output for at least 24 hours.

Most of the future development of German wind power is supposed to be located in Northern Germany, particularly offshore. It might be more realistic to eliminate the difference in installed capacity by considering an **average** of relative Danish and German wind power distributions instead of added values. This method would give two locations the same weight in comparisons.







Regardless of the aggregation method wind power has many hours with very low output, even for very large geographical areas.

This work is intended to be continued as observations of the development of wind power properties in future data surveys.

References

1. Paul-Frederik Bach: Wind Power and Spot Prices: German and Danish Experience 2006-2008, Renewable Energy Foundation, London, 2009
2. Paul-Frederik Bach: Statistical Surveys 2006-2010, http://pfbach.dk/
3. Data sources:
    - Denmark: http://energinet.dk/
    - Germany:
        - http://www.tennettso.de/
        - http://www.50hertz-transmission.net/
        - http://www.amprion.de/
        - http://www.enbw.com/
    - Ireland (Republic of Ireland and Northern Ireland): http://www.eirgrid.com/
    - Great Britain (England, Wales and Scotland): http://www.elexon.co.uk/