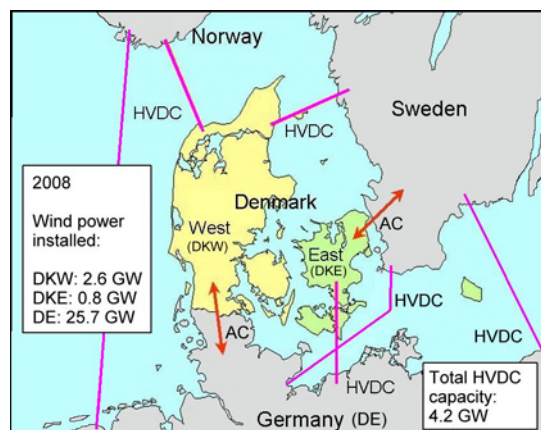


1. Summary

1. The use of wind power has been developed in Denmark since the 1990s. Now wind energy accounts for nearly 20% of the electricity demand at transmission level (including grid losses, but excluding local consumption in power stations), though it should be noted that there is a complex pattern of exports behind this figure (see point 9. Below). Nevertheless, due to this high share, recent Danish experience of system operation and market performance is relevant to other countries embarking on renewable energy programs.
2. The original purpose of the current study was to analyze the impact of wind power on market prices in Denmark, and to discuss its possible influence on power system economy. **The objective was to evaluate the hypothesis that there is a statistical coherence between energy flows from wind power, spot prices, balancing prices, transfer capabilities and price volatilities in the Danish system. These variables proved to have only weak mutual correlations.**

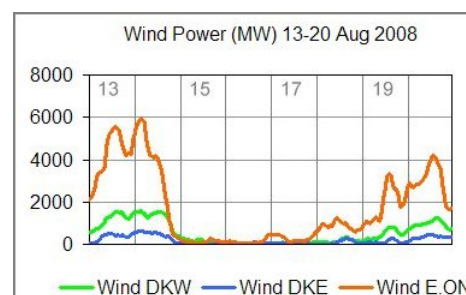
3. However, *analysis revealed surprisingly strong relationships between German and Danish data in several of these areas.* In response the study was adjusted to render it more international in scope.
4. The installed wind power capacity at the end of 2008 was 3.3 GW in Denmark and 25.7 GW in Germany. The penetration of wind power in Germany was 6.5 % (by MWhs) in 2008.



5. Denmark has strong interconnections with Norway, Sweden, and Germany, but the two parts of Denmark, East and West, are not yet interconnected. Denmark has joined the *Nord Pool* spot market, while the German spot market is operated by *European Energy Exchange* (EEX) in Frankfurt.
6. The essential difference between traditional power sources and wind power is intermittency, or, as some would prefer, uncontrollable variability. This characteristic places special demands on the rest of the system. Fortunately for Denmark and Germany, Norway and Sweden have significant hydropower installations, a technology that is suitable in many respects to balance fluctuations in wind power output. Indeed, the sale of balancing services for wind power systems is an important market for the hydro operators in both these countries. However, the total transfer capability between the Nordic and the continental AC systems was 4.2 GW at the end of 2008, considerably less than the combined wind power total. Therefore only a fraction of the necessary balancing services could be supplied from the Nordic hydro systems, and the bulk of this support must be provided locally from continental thermal systems.

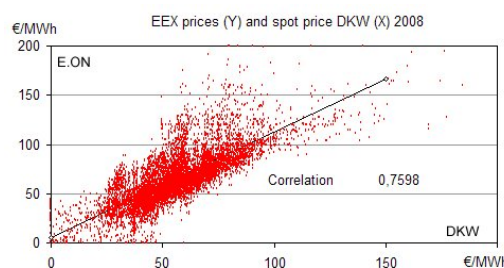
7. Two major findings of the study are:

- 7.1. **There is a high positive correlation between energy flows from wind power in Denmark and Germany**
- 7.2. **There is also a high correlation between spot prices in Denmark and Germany.**



8. The observations in Germany refer to the E.ON control area, which contains about a third of German wind power. *Consecutive days of high wind or calm in both countries have been observed, the longest calm period observed being two weeks in December 2007.*
9. The Nord Pool Spot is a day-ahead-market defining prices for each hour. Due to long distances and limited transmission capacity six *bidding areas* (or price areas) have been defined. In the absence of congestion the area prices are identical with the system price. There is normally a transit through Denmark, either from the north or the south. When there is congestion on the northern interconnectors the spot price in Denmark approaches the German price. Therefore Danish area prices seem to switch between Nordic area and German area spot prices depending on the location of bottlenecks.

10. Spot prices in Denmark and Germany have been plotted and analyzed for the study period. **By separately comparing the two parts of Denmark with the E.ON control area, high spot price correlations have been found in all cases, a result that suggests Denmark and Germany can be considered as one spot market.** In fact, Nord Pool and EEX are developing a market coupling as a replacement of the current auctions of transmission capacity between the two market systems, and this improvement is expected to tie the market areas even closer together.



11. Due to the close relations between the electricity markets in Denmark and Germany **it is reasonable to question whether Denmark has in fact successfully integrated nearly 20% wind energy** (by MWhs), as is sometimes supposed. **A different interpretation is that Germany and Denmark together have solved the integration problems for 7% of wind energy.** This is an important distinction with technical and economic implications.
12. The **attempts to demonstrate a relation between wind power and area prices gave less convincing results.** The reason is that several other factors have a significant influence on spot prices. The study demonstrates some of the most important influences, such as load variations, transmission outages, congestion policies, and bidding policies.

13. Nord Pool determines the spot price by taking the intersection of the demand curve and the supply curve, both curves resulting from a bidding process. Sometimes the two curves have no intersection, and Nord Pool must curtail either supply or demand bids in order to find a price. **In case of curtailments some market players experience an unsatisfactory market service.** The number of such cases are shown in the table with 0 €/MWh and 100 €/MWh as the critical limits. The numbers indicate the quality of market service and should be observed for a longer period than 3 years.

Market service	2006		2007		2008	
	Spot price = 0	Spot price >100	Spot price = 0	Spot price >100	Spot price = 0	Spot price >100
No of hours						
West Denmark (DKW)	28	11	85	105	28	193
East Denmark (DKE)	5	131	30	89	9	225
Nord Pool system price	0	1	0	0	0	2
EEX, Germany	10	266	28	307	35	888

14. **In spite of the weak statistical correlations between wind power and spot prices a certain coincidence of extreme winds, low or high, and extreme price can be observed.** In 2008 the average wind power output at zero prices was high, namely 1,698 MW in

West Denmark and 444 MW in East Denmark. By contrast significantly lower average outputs, 307 MW and 148 MW, were found during price peaks. It is reasonable to conclude that **a significant increase in the wind power capacity may increase the number of hours with extreme prices and reduce the quality of market service.**

15. Power shortfalls and surpluses arising from wind power forecast errors can be balanced through the Nord Pool intra-day market, *Elbas*. Due to low liquidity and high transaction costs the wind power traders prefer to pay the system operator for providing regulating power in the Nordic real time market. Considerable development efforts are being made in order to improve the accuracy of the wind power forecasts, but, unfortunately, there are no indications that a breakthrough is approaching.
16. A part of the Danish wind energy has been exported. This is a commercial choice and not necessarily a problem. The wind energy export has been defined for each system and for each hour as the smaller value of generated wind energy and net export.

	MWh	2006	2007	2008
West Denmark	Wind energy generated	4.614.315	5.561.711	5.191.701
	Wind energy exported	3.257.083	2.611.979	2.203.872
	Share	70.6%	47.0%	42.4%
East Denmark	Wind energy generated	1.489.519	1.610.371	1.785.197
	Wind energy exported	1.144.857	628.719	374.736
	Share	76.9%	39.0%	21.0%

17. An average spot market value of the wind energy generation can be calculated and compared with the corresponding average value of the electricity consumption and of the wind energy export. The calculation was made, hour by hour, by multiplying the quantity by the relevant spot price. The average value of the wind energy profile is 5 to 7 €/MWh (or 9 to 18 %) lower than the demand profile. The value of wind energy export was in most cases found to be somewhere between the two other values.

Average values	West Denmark (DKW)			East Denmark (DKE)		
€/MWh	2006	2007	2008	2006	2007	2008
Consumption	45.81	34.82	58.34	50.26	35.15	58.32
Wind energy	40.55	28.65	51.20	44.86	30.46	53.13
Wind energy exported	42.50	30.06	48.98	44.36	32.22	53.19

18. There is a strong relationship between the quality of market service and the capacity of transmission systems and interconnections. Consequently, there is a pressing need for the transfer of power and energy between Norway and the continent. Indeed, the existing interconnectors are highly utilized and transfer directions are often reversed daily. However, the Danish markets are small, and there are several links and potential bottlenecks between Norway and Germany. For example, the interconnector capacity released for commercial use is frequently adjusted by the system operators for security reasons or due to technical faults. It is obvious therefore that there is a growing demand for increased international transfer capabilities.
19. The tentative Danish target for wind energy is 50% penetration (by MWhs) by 2025, and even Germany, which already has very large wind fleets, has ambitious targets for further expansion. Such ambitions will entail further and considerable challenges of integration. **Since it is a political decision to install new wind power there must be a corresponding political attention to the infrastructure necessitated by this decision.** Most importantly **it must be recognised that the implementation of new infrastructure in due time is not straightforward, and requires planning, and that the costs of this new infrastructure will increase consumer prices, perhaps significantly.** A combination of improved international trading opportunities and the provision of additional balancing capa-

bilities will probably form the best development strategy, if the targets for wind power are to be realised. Namely:

- 19.1. The reinforcement of transmission systems and interconnectors should be advanced. **Real competition in the network should guarantee an optimum allocation of resources at a European level**, and therefore trade systems should be improved and trade barriers removed as far as possible.
- 19.2. **Politicians must recognise that the installation of new wind power does not necessarily incentivise the installation of the necessary balancing resources.** Indeed, **given the effects on extreme spot prices it may act as a disincentive to investors in despatchable plant.** Therefore each country aiming at an increased share of wind power should in advance provide for access to the necessary system services, either from national or foreign resources.