Is least cost wind power always local in Europe?

A balancing act between more transmission and lower load factor

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On- and offshore wind power development has taken on the forms of big business. Wind power in the age of well over 30$/barrel oil is at the best sites in Europe already fully competitive with new conventional generation. However, the available resources are exploited differently in different countries - some countries have a favourable political climate for wind power, but not necessarily the best wind climate, and still attract the largest investments in wind power. This paper analyses the options to provide wind power to selected load centres in Europe, looking at the production cost of the kWh at the production site, and includes realistic transmission cost to provide kWhs at the demand site. The resource is estimated from global wind power data based on NCEP Reanalysis and from previous wind resource studies, the financial data is from experience. Installation cost are calculated differently for on- and offshore installations. The result of this study is open yet, but we expect to shed some light on the question whether it might be more cost-effective to build more transmission for wind power than to try to exploit it yourself at mediocre sites - a trend which is even continuing with larger penetration, since the best sites are already gone.

1 Introduction

This paper is heavily modelled after the paper presented by us in the EWEC 2004 in London [1]. Let me summarise here some of the key messages from this paper:

The wind resource available in Europe on land and offshore is easily enough to provide the current target of Greenpeace and EWEA [2] of providing 12% of wind energy in Europe. Actually, the resource would allow to cover the total European electricity demand by wind energy alone, using the wide areas in the North Sea. The wide distribution of wind power would also firm up the resource (transport issues notwithstanding) due to the fact that wind power is correlated on a scale of about 700 km, which means that wind power from a large area is fairly smooth. Also, wind power offshore has less diurnal and yearly variation than wind power onshore. The smoothing effect has been shown in the previous paper using the reanalysis derived generation profiles from 6 offshore sites (Thames Estuary, Baltic Sea, Orkney, Celtic Sea, Trafalgar, Mediterranean (Marseilles)). "*With all wind capacity installed at one location, the frequency of no wind production is around 13%. Periods of full load are also quite frequent, occurring approximately 30% of the time. The distribution of load* *factors has two peaks; one at full load and the other at zero load. This is to be expected, considering the shape of a turbine power curve. This pattern is reflected at all [single] locations […]. As capacity is added [distributed] successively to each location, the probability of no wind production falls to zero. The distribution of load factors takes on a more Gaussian shape; with just one peak around 55% load factor. The majority of production is clustered around the median value with 2/3 of all load factors between 30-70% of total capacity.*" Also the observed changes in power output over 6 hours were mostly below 10% of the installed generation for the well-distributed case.

In this paper, we want to have a closer look at the financial impact of putting wind farms where the wind is good, and compare this to the higher transmission cost this incurs. Is there a "rule of thumb" for when a wind farm should be built close to the consumer or closer to high wind speeds? And how can the political support system be tailored to achieve the goals? Which are those, anyway?

2 The Balancing Act

In the last years, the installation of wind power in Europe has advanced by leaps and bounds. However, while the wind resource is greatest in the north-west of Europe (the British Isles and any part of Europe with a westerly shore), most of the installation was in Denmark (fairly windy), Germany (windy in parts) and Spain (with a few really windy locations). This is due to the fact that the political climate for wind energy was traditionally better in these countries than for instance in the UK. In the end of 2004, the Republic of Ireland had 339 MW installed, the UK a disappointing 888 MW, but Germany had 16 629 MW, Denmark 3 117 MW and Spain 8 263 MW installed [3]. The current plans for offshore use seems to straighten out this imbalance somewhat, but Germany remains the clear leader with announcements of about 50 GW of capacity installed offshore (though next to nothing has been installed yet), while the UK has over 1700 MW in various stages of planning, being built or already operating.

The system or state has some goals: the security of supply is one, both in the short term (no power outages) and long term (using fuels available for a longer period in the future). Also, a good environment with a corresponding low output of climate and noxious gases is a goal, as well as the least cost of electricity for industry and consumers alike. The state (be it the nation state or the intergovernmental European Union) has the market rules at its disposal to influence the best combination of fulfilling these goals.

There are two sides to the installation success: the support scheme in place and the ease of the planning process. In the three onshore leaders, both were in place. In the UK, the planning process onshore delayed many wind farms for years, leading at some stage to more than 2 GW of projects being stuck in the planning pipeline. Offshore, the permitting process is easier, which explains the quick expansion of offshore wind in the UK. In Denmark, the change of government in 2002 reversed the support scheme, which led to a sharp drop in new installations. In Germany, the situation onshore is characterised by a lack of areas in good wind conditions, as the windiest sites near the coast are already taken. The problem illustrated here is that wind power, due to the purely national nature of the support schemes, gets built at technically sub-optimal sites. In the following, we want to show therefore what the solution could look like with a fully European access and support scheme in place.

Under the assumption of a supra-national extension of support schemes, the question can be posed whether it is better to build wind power at mediocre sites, or to go further away to high-wind places and bear the additional transmission cost. To investigate this optimisation problem, we will introduce in the following a financial model and populate it with real-life data.

2.1 Capital Cost of Wind farms

For onshore wind farms, the range of costs are taken from fig.2.3 p. 99 in the EWEA publication [4]. These range from 900 euro to 1,150 euro per kW installed, including grid connection. For the purposes of this analysis, the figure of 1000 euro is used. For offshore a cost of 1500 euro per kW installed is used.

2.2 Cost Estimates for New Grid Elements

The cost of transmission has been estimated assuming the use of DC technology. For power levels of 500MW+ and distances of 100km+ this is the only viable technology. Due to the absence of a synchronous source, is has been assumed that it would be necessary to use voltage source converters at the wind farm end. Although to date this technology has not been used at these power levels, there are no obvious technical reasons why this could not be done [5,6]. At the load end, conventional converter technology would be employed with transmission voltages in the region of +/- 450kV.

Costs have been estimated using averages of several internal and external sources including the above reference. Capital costs and losses split between fixed costs (/MW) and variable costs (/MWkm) have been assumed as follows:

	Capital costs	
	DC	DC
	Fixed cost	**Variable cost**
Cost (€m/MW)	0.378	▨
Offshore cost (€/MWkm)	▨	630
Onshore cost (€/MWkm)	▨	200
	Losses	
	DC	DC
	Fixed cost	**Variable cost**
%	2%	▨
%/100km	▨	0.33%

Table 1 Capital Costs

It has been assumed that annualised costs are equivalent to 10% of capital costs. This results in transmission costs excluding losses ranging from under €0.02/kWhr to around €0.06/kWhr, as distances range from 500km to 3000km and depending on the offshore/onshore balance. This compares with average costs paid for grid capacity of €0.006/kWhr from England to France and €0.019/kWhr from Germany to the Netherlands in 2003.

Whilst there is likely to be a charge for connecting to the AC grid at the load end, this may be a negative charge if the wind farm output has, as is assumed above, been transported to a major load centre. Therefore a zero charge has been assumed here as a conservative assumption.

3 Results

A number of production cases with widely varying wind resource has been used here. While the amount of equivalent Full Load Hours (FLH) depends on the type of turbine and the shape of the wind speed distribution, the most important factor is the mean wind speed. The number of FLH ranges from just below 1600 hours for the low wind area onshore, to over 2600 FLH for the onshore high-wind area. Offshore, the wind resource is often even better, like in the case of the assumed 10 m/s case in North Sea South with over 3600 FLH, or the planned Greater Gabbard wind farm in the Thames Estuary with 3200 FLH. For comparison, two very high wind onshore cases south of Europe have been taken into account (already presented in a previous paper at the predecessor to this conference [7]). In southern Morocco or the Western Sahara, where the wind gains momentum over 4000 km of Atlantic Ocean, and where the coastline is not everywhere densely populated, high and steady wind speeds allow for 4000 FLH. Local effects of channelling and thermally driven winds make the Gulf of El Zayt, along the Egyptian Red Sea coast, probably the best wind power site in the world, with up to 6000 FLH. Since the financial model divides the installation cost by the number of FLHs, the very high capacity factor site in Egypt is doing well despite the very long line to Athens (the closest major point of consumption in Europe).

TRANMISSION CASES				
	Distance Onshore Km	Offshore Km	Total	**Total capital costs (€m)**
Scotland to Dublin	175	55	230	448
Dublin to French Alps	1355	45	1400	678
NW Africa to Spain	1500	30	1530	697
N Norway to Mid Germany	500	1500	2000	1424
NW Russia to Mid Germany	2000	0	2000	778
Greater Gabbard to Köln	290	160	450	537
Baltic to Mid Germany	200	200	400	544
Greater Gabbard to Netherlands	50	200	250	514
South Irish Sea to Köln	800	240	1040	689
North Sea North to Mid Germany	300	500	800	753
North Sea South to Mid Germany	350	250	600	606
Irish Sea to France	1	500	501	693
Celtic Sea to Mid Spain	300	1000	1300	1068
Gulf of El Zayt to Athens	500	2000	2500	1738

Table 2 Transmission cases

To calculate the cost of transmission of a MWh from a wind farm to a load centre, the utilisation factor of the wind farm was set equal to the capacity factor of the wind farm. This is a worse case assumption, as the likely utilisation factor of parts if not all of the transmission line could be much higher as other power could also be transmitted. The capital cost of production per MWh at the wind farm site is calculated using a capacity factor derived from the estimated wind speed at the site.

Case	Wind speed m/s	Capital cost generation per MWh	Capital cost transmission per MWh	Total Capital cost at load centres per MWh
High Wind Area (Onshore)	7.07m/s at 60m*	379	0	379
Medium wind area (Onshore)	6.45m/s at 60m*	450	0	450
Low wind area (Onshore)	5.5 m/s at 60m*	633	0	633
Egypt to Athens	11.5 m/s at 40m	167	289	456
NW Africa to Spain	9.25 m/s at 40m	250	170	420
South Irish Sea to French coast	8.5m/s at 100m	512	237	749
South Irish Sea to French coast	10m/s at 100m	414	192	606
North Sea South to Germany	8.5m/s at 100m	510	206	716
North Sea South to Germany	10m/s at 100m	413	167	580
North Sea North to Mid Germany	>10m/s at 100m	<413	<167	<580
Baltic Sea to Mid Germany	8.5m/s at 100m	510	185	695
Baltic Sea to Mid Germany	10m/s at 100m	419	210	629
Thames Estuary to Netherlands	~9m/s at 100m	467	160	627

**. Adjusted from 50m with Log Law r=0.3*

Table 3 Total capital costs at load centres per MWh

The results show that good onshore sites in Europe are hard to beat. Have in mind that this table only includes the investment needed to exploit the resource - the operations and maintenance cost of the transmission line and the wind farm are not explicitly modeled. Often though this can be modeled as a percentage of the total investment, and while the percentage for the wind farm will be different from the one of the transmission line, both will be relatively small, only a few percent per year.

While the best sites are clearly high-wind onshore sites, both cases in northern Africa can provide power at an investment cost including transmission similar to a medium site onshore. However, there are two further considerations: near these sites, electricity use is increasing rapidly, therefore most of the produced wind power can be used locally. Also, getting a pan-European market agreement in place is difficult, and integrating outsiders probably even more so.

4 Conclusions for Europe

What emerges from examination of the table above through ranking the cases on the basis of the delivered capital cost of the electricity per MWh, is that after medium to high wind speed areas of Europe are no longer available, it is more economic to facilitate development in high wind areas on land such as in the UK, Ireland and offshore in the North Sea and Irish Sea. Some specific high-wind areas in Africa could also be used, but exploitation of these in the near term for European electricity consumption seems unrealistic. To facilitate this development, it would be necessary to plan for extensive new transmission in the North Sea, and also between Ireland and the UK to avail of this secure source of electricity.

5 A Project for Europe: The European Super Grid

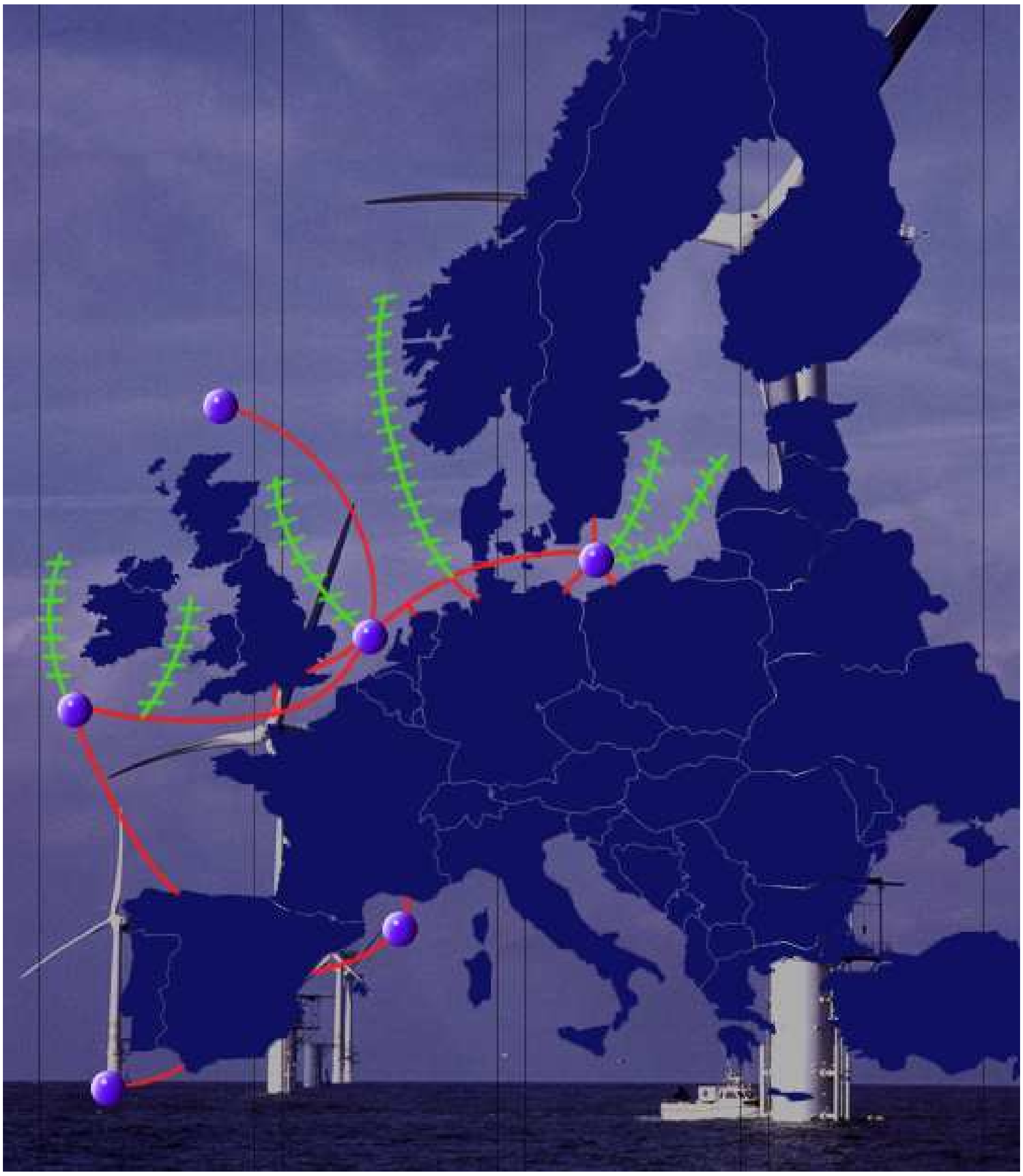

Figure 1: The European Super Grid for Wind Power. Idea Paul Dowling, Airtricity.

6 References

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