EFFECTS OF LARGE-SCALE DISTRIBUTION OF WIND ENERGY IN AND AROUND EUROPE

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Abstract: Europe is the continent with the highest installed capacity of wind energy in the world. At the same time, the installation rates grow at about 30-40 %/year. This paper is to shed some light on the limits of integration.
Using wind power data for one year from 50+ sites in Europe, the apparent smoothing effects within the dataset are shown. The resulting spatially averaged time series is then fed into a scheduling model for the whole European power system. The results are that, under certain assumptions, 20% of the European demand can be covered by wind energy even without changes to the power system.
Additionally, Reanalysis data has been used to identify areas around Europe with good wind resource. Here, two areas will be shown where local measurements corrobate the quality of the resource: one on the north western shore of Africa, and another one in Egypt, at the south western Gulf of Suez.
It is shown that under the assumptions given, wind energy from southern Morocco can be produced locally for below 3 €c/kWh, and transported to central Europe (Kassel) via HVDC for another 1.5 €c/kWh. At the same time, the large-scale build-up of wind energy in Morocco would constitute a substantial transfer of money and other resources to a less-developed country. Were Morocco to provide 10% of Europe's energy needs, it would see investment worth about two times its current GDP.

Keywords: Large-scale integration, dispersed turbine systems, complementary power plant, fossil fuel power generation

INTRODUCTION

The wind industry had phenomenal success in the last few years, with growth rates of 25% per year and more. The aim of this paper is to open the eyes to a few future trends and the implications of continued growth.

Usually, the next large step for wind energy is considered to happen offshore. This has different reasons from country to country, but generally in Europe, the best sites in the countries with the best wind power support schemes are already taken. Since wind power installations are strongly correlated with the national climates (more with the political than the wind climate), the huge growth of wind power in Europe in the last few years has happened mainly in three markets: Denmark, Spain, and above all Germany. While there still are windy sites available in Spain, and a new support scheme has brought attention to France, many of the windy counties in Germany and Denmark declared a stop for further increase in installation. In the UK, wind power has been hampered by the planning process, which also favours offshore wind power.

Thyge Weller[1] claims that offshore wind power is "*an escape solution aimed at finding new windy sites in countries with financial support systems*". He believes "*that in the long term, very large terrestrial wind farms are the way to go.*" Wheeling power over long distances is just a question of price for the consumer – it is not important whether it comes from the local waters or from abroad, as long as it is clean wind power. This paper will look at two places a bit more in detail: north western Africa and a site in Egypt.

Another problem of wind energy is that it is not always available. However, since there is always some wind somewhere, the spreading out of wind turbines over an area as large as Europe (and especially taking into account areas around Europe) smoothes the wind power generation sufficiently to reach higher penetrations in the European grid than without this effect. Our paper will also address this point.

WIND POWER IN EUROPE

One year (1990) of wind power data from 50+ sites all over Europe[2] has been used to assess the variability of the resource and the limits of penetration in the grid. Since typical weather patterns over Europe are only ca. 1500 km wide, there will be in most cases some wind in Europe. Using this data, and using data from the Reanalysis project[3], it can be shown that at all times some power is produced from wind in Europe.

For a comparison of the generation, three data sets have been produced: Average, Selection and Malin Head. The latter is one site in Ireland, which had the highest production amongst all of the sites investigated (over 3800 equivalent Full Load Hours FLH). The Average data set is the resulting wind power production time series from 50+ stations all over Europe, spatially averaged at each hour. Selection is the same, just for stations with good wind conditions (>2000 full load hours). The noteworthy feature here is that the Average series exhibits much less variation and extremes than the single site data set. Actually, the minimum production in the Average data set is 1.5% of the installed power, meaning that the assumption of always having some wind power in the grid is true. The reason for this is of course that the wind power time series are uncorrelated over large distances. The correlation actually drops more or less exponentially with a characteristic distance of ca. 700 km. From about 2500 km distance, the correlation seems random (meaning that there are as many anticorrelated station pairs as there are correlated ones). The highest production was in winter. The unusual shape of the production probability of Malin Head comes from the fact that often, the wind is either low or full force, with touching the area in between only during the changes. The Average time series is also much less variable: all changes from one hour to the next are smaller than ±15 % of the installed capacity, with a probability of over 95% that the changes are not larger than ±5 %. In contrast, the maximum change of the best single site within one hour was 85% of the installed capacity, with a probability of 5 % that the change is larger than ±18 %.

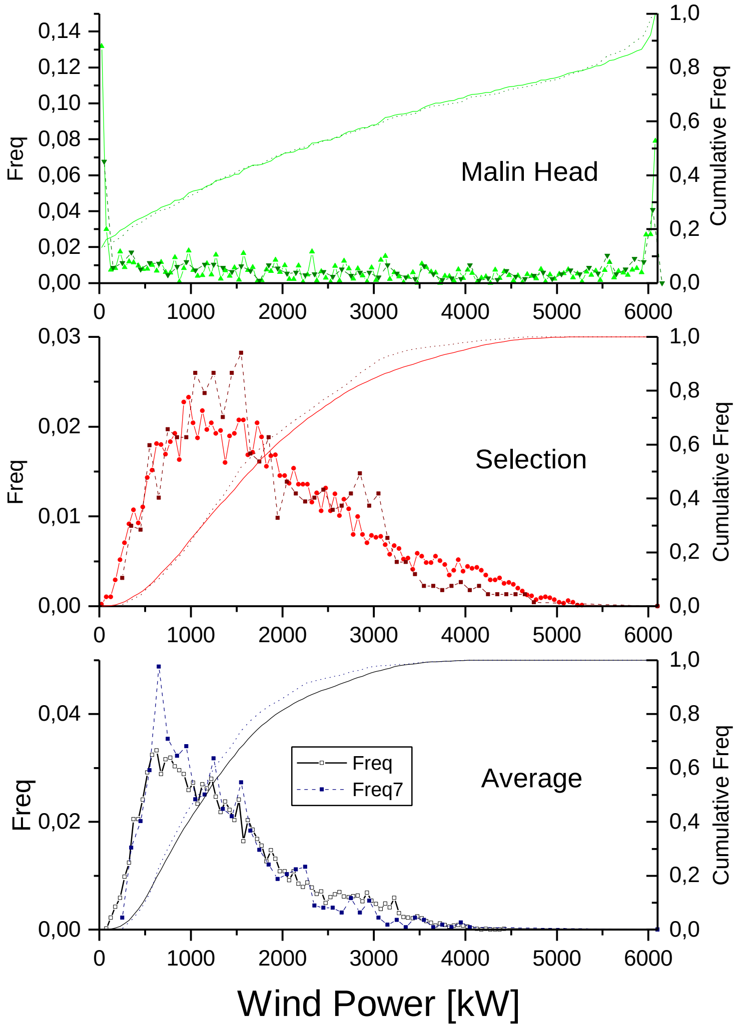

Figure 1: The frequency distributions of wind power generated from all over Europe. The frequency distribution is shown on the left x-axis, the cumulative frequency on the right. The results were calculated from a collection of turbines with 6100 kW installed effect, to simulate a distribution of sizes. The full lines are for the whole year 1991; the dashed lines refer to the 7-week winter period with the highest load. Average, Selection and Malin Head are explained in the text.

To assess the influence of the variability on the limits of penetration in the European grid, these time series are fed into a model for the electrical grid of Europe (the National Grid Model of CLRC Rutherford Appleton Laboratories/Reading University was used). It simulates the one-hourly scheduling and dispatch of power plants to meet the demand on a large area network. It can accommodate the effects of wind or photovoltaic power generation. The demand was highest during a 7-week period in winter. The network is herein treated as one node, ie transmission is not an issue. The output of the model is the total cost of fossil fuel to run the electricity system for one year using a number of assumptions. The amount of spinning reserve was optimised for minimal fossil fuel usage, under the constraint that no loss-of-load-event could occur. It was fed with data from 3500 power stations of 12 European countries, plus fossil fuel prices and ramping possibilities of these stations. Wind power forecasting was used, either with perfect or with persistence forecasting.

The results of this optimisation show that forecasting is more important for higher penetrations. This is not very surprising, since for small penetrations, the wind power variations get washed out in the overall variations the utility has to prepare for, like load variations or drop-outs of major power stations. The result also shows that wind power can be better integrated into the existing power system without many changes to the power plant composition if the generation profile is less variable. While perfect forecasting allows Malin Head to be integrated up to 10 % of the demand covered (with much higher penetrations possible, but impractical), the Average generation profile can easily contribute more than 20% of the European electricity demand. Under the assumptions of the scheduling model, this leads to savings of 60% of the fossil fuel cost, worth about 7 G€. This would mean a value of the wind power of 2.2€c/kWh just for the fossil fuel saved. Keep in mind that this is dependent on the power plant mix that is assumed. The installed wind power capacity replaces at this stage somewhat more than 10% of the installed capacity.

WIND POWER FROM AROUND EUROPE

The smoothing effects can be even higher when wind power from even further away is taken into account. Not only is the distance higher, and thereby the normal smoothing due to the size of the weather patterns, another effect comes in when looking at the northern African countries: they are actually in different climatic zones, and therefore the smoothing effect is even more increased. While most of Europe is having the maximum wind speeds in winter, the trade wind areas south of the Mediterranean have maxima in summer.

Two areas are there in the Maghreb that this paper is shows in detail: the north western African tip near the Atlantic Ocean (southern Morocco, West-Sahara, Mauretania), and the south-western end of the Gulf of Suez, near the Gulf of El-Zayt. These sites are showing much potential: high mean wind speeds, plenty of available land, in part even a good grid connection, cheap labour for the maintenance and building works, and large markets short of electricity locally, with not too much distance to the much larger European market.

Western Africa

One of the main advocates for very large-scale implementation of wind energy on the Atlantic coast of Africa is Saharawind[4]. The resource is very good, since the wind comes from the Atlantic Ocean onto the shore in the area of the trade winds.

The potential size of the installation is tremendous: "*With a wind turbine spacing of 2.4 MW/km² over the 2000 kilometres of coastline from Morocco to Mauritania, a production of more than 1000 TWh per year could be achieved. This would be sufficient to cover almost half of the entire yearly production of the EU (2300 TWh). This very large potential represents several dozen times the electrical requirements of the North African countries, and cannot be utilized locally.*" The wind resource in southern Morocco or northern Mauretania yields local production cost of below 3 €c/kWh [5]. The transport to Kassel via High-Voltage DC would make a large-scale installation possible, and would drive the cost up to ca 4.5 €c/kWh. This includes the price for the HVDC line, but does not look at the (mostly political) problems involved in planning and constructing that line.

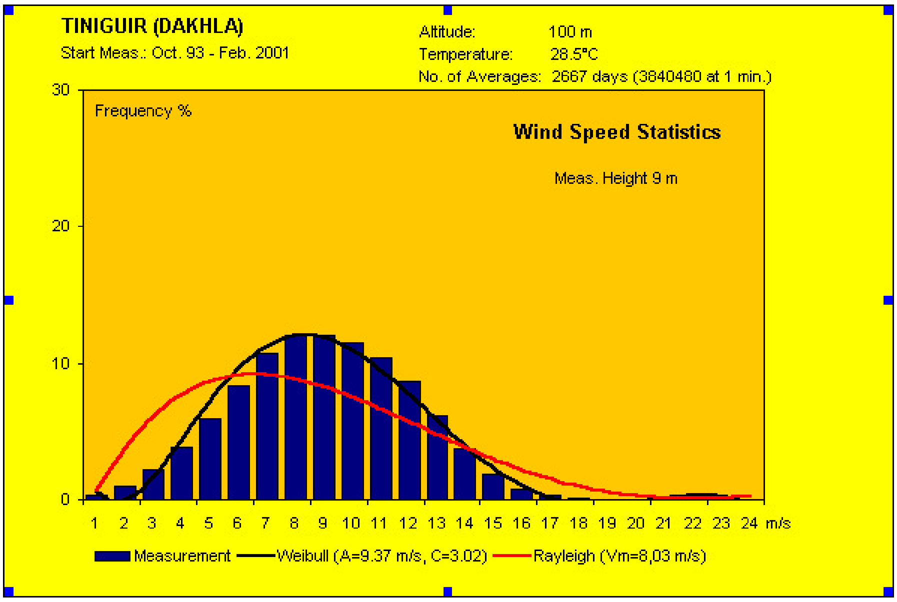

Figure 2: The wind speed distribution for Tiniguir/West Sahara/Morocco. Graphics from saharawind.com.

In Figure 2, wind data from a little test station near Dakhla (West Sahara) is shown. One can see that instead of the typical Weibull distributions we are used to from the higher latitudes, the data is nearly Gaussian in shape, neither showing significant portion of low winds or of very high wind speeds (where the turbine would shut down, *ie* >25 m/s). The distribution is even more remarkable since it is from only 9 m above ground level (a.g.l.) results from Reanalysis data for 50 years confirm this picture. The wind data fits in well with the results of the MED2010 project[6], where measurements were presented for a site further up the coast, on

Cap Sim near Essaouira, Morocco. There, the mean wind speed in 40 m a.g.l. was 9.25 m/s, with an overall maximum at only 24.5 m/s. A WAsP analysis with 60, 1 MW turbines yielded a total production of 316 GWh/y, or an average 5250 full load hours. Another set of data confirming the resource has been measured under the TERNA project of the GTZ (Gesellschaft für Technische Zusammenarbeit, the German development aid agency)[7]. The measurements ran for nearly a year, and yielded mean wind speeds in 40 m a.g.l. of 7.7 m/s (Tarafaya), 8.9 m/s (Essaouira) and 9.2 m/s (Laâyoune).

Monthly Mean Electric Production of Wind Power within Selected Favourable Regions at Land Sites and *Electric Demand*

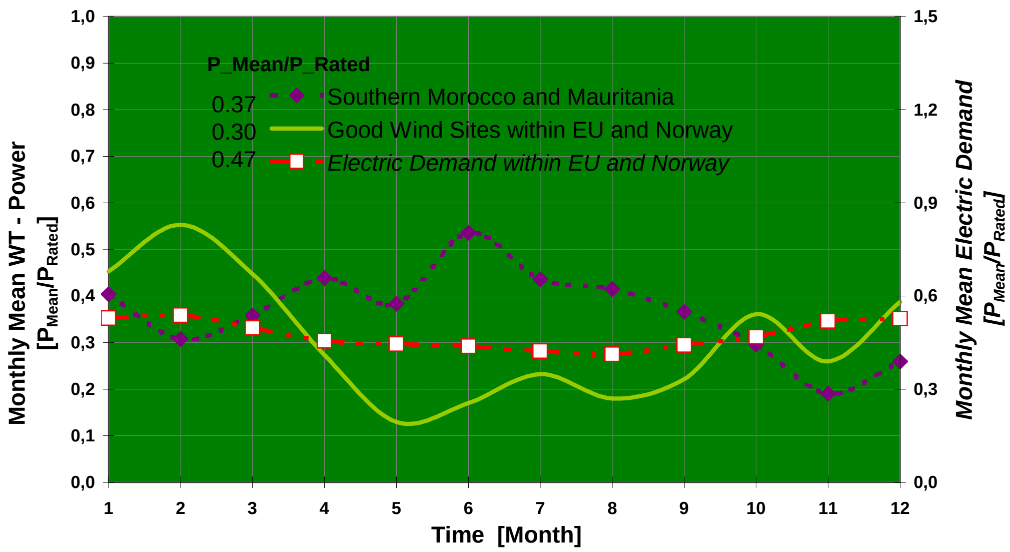

Figure 3: The production profiles of wind power north and south of the Mediterranean. Additionally shown is the electricity demand in Europe, as a percentage of the installed capacity. Also take note that the relative production swings more than the demand. Meteorological data for one year from the ECMWF Reanalysis project[8].

Along with the low price of the resource, another helpful feature comes in: the production profile over the year is anti-correlated with the production in Europe. From Figure 3, it can be seen that the production in Europe has a clear maximum in winter, while the production in north western Africa has a maximum in the summer months. This equalization effect helps to smooth out the variation in the wind power production, and allows wind power to be integrated into the grid with higher penetrations.

A possible strategy for implementation could be to bilaterally extend the German Energy Feed Law or similar other support mechanisms of Spain, France or also Denmark to Morocco. Alternatively, these national regulations could be replaced by a European solution with a clause for Northern African new renewable power. The magnitude should be given by the difference between the local price of electricity and the production price. Since the latter is very low, this incentive would be in the order of 1-2 €c/kWh, and thereby much lower than the corresponding add-on within Europe. The current electricity consumption in Morocco is rather low, therefore already with a total installation below 1 GW one would have to export wind power to Spain. This phase of the build-up would also be over soon, since at the moment, the transport capacity between Spain and Morocco is 350 MW, with a doubling to 700 MW being envisaged. However, the bottleneck then could already be within Morocco, where not enough transmission capacity is available from the South to the North. While these stages would be natural, and probably will happen in any case, the large-scale implementation of wind energy for the European market needs dedicated transmission capacity. The Spanish transmission node closest to Morocco has a capacity of ca. 5 GW. A HVDC link of ca. 4 GW would increase the price in Spain of the Moroccan wind power by less than 1 €c/kWh. This means that up to ca. 5 GW wind power exports, the technology and investment involved is rather straightforward.

To exploit even larger parts of the potential, dedicated transport systems would have to be built, potentially bypassing the Spanish grid totally and feeding directly to the French, Italian or even German grid. Even including an HVDC line of that length, the resulting price per kWh would still be about 30% lower than producing the same amount of wind power in Germany. However, to invite European investors to this kind of involvement, state guaranteed loans would seem necessary. Obviously, this concept is not limited to either wind energy or Morocco. Solar chimneys or solar thermal generation could also be used, partly to smooth out the generation. Alternatively, this kind of support scheme could bring large-scale wind power to Egypt or Kazakhstan, where similarly large potential exists.

Egypt

Some of the lowest price for wind power is currently being paid for the new (2002) wind farm at Zafarana: 2.89 USc/kWh is paid by the National Renewable Energy Authority[9]. Due to the high winds (4570 Full Load Hours) and the low-interest loans from both the German and Danish aid banks (3% over 15 years), the 60 MW wind farm can turn a profit. In that calculation, a moderate contribution from CO_2 trade ($10/ton) is made.

The recently finished Wind Atlas for the Gulf of Suez[10] shows that the site in Zafarana is not even the best site in Egypt: the wind resource is significantly higher in the Gulf of El Zayt, a few hundred kilometres down the coast. Here, the measured mean wind speeds at 25 m a.g.l. are over 10 m/s, with highs in the summer months. The Gulf of El Zayt has a winter mean of 8.2 m/s, and a summer mean of 12.6 m/s. The daily variations are typically smaller than the seasonal variation, which means that the wind blows much more steady here than in most places in Europe. Wind speeds are highest directly near the shore, with a strong gradient towards the land (can be more than 1 m/s over a distance of only 20 km). The data at the Gulf of El Zayt translates into ca. 6000 Full Load Hours. The size of the area is enough for ca 20 GW of installed wind power plants. For the initial phase, the transport of the produced electricity is not a problem either, since the main ring transmission line of Egypt runs past this area. In short, using a factor given by the ratio between the Zafarana FLH and the Gulf of El Zayt FLH, a cost price of electricity of just above 2.2 USc/kWh can be estimated.

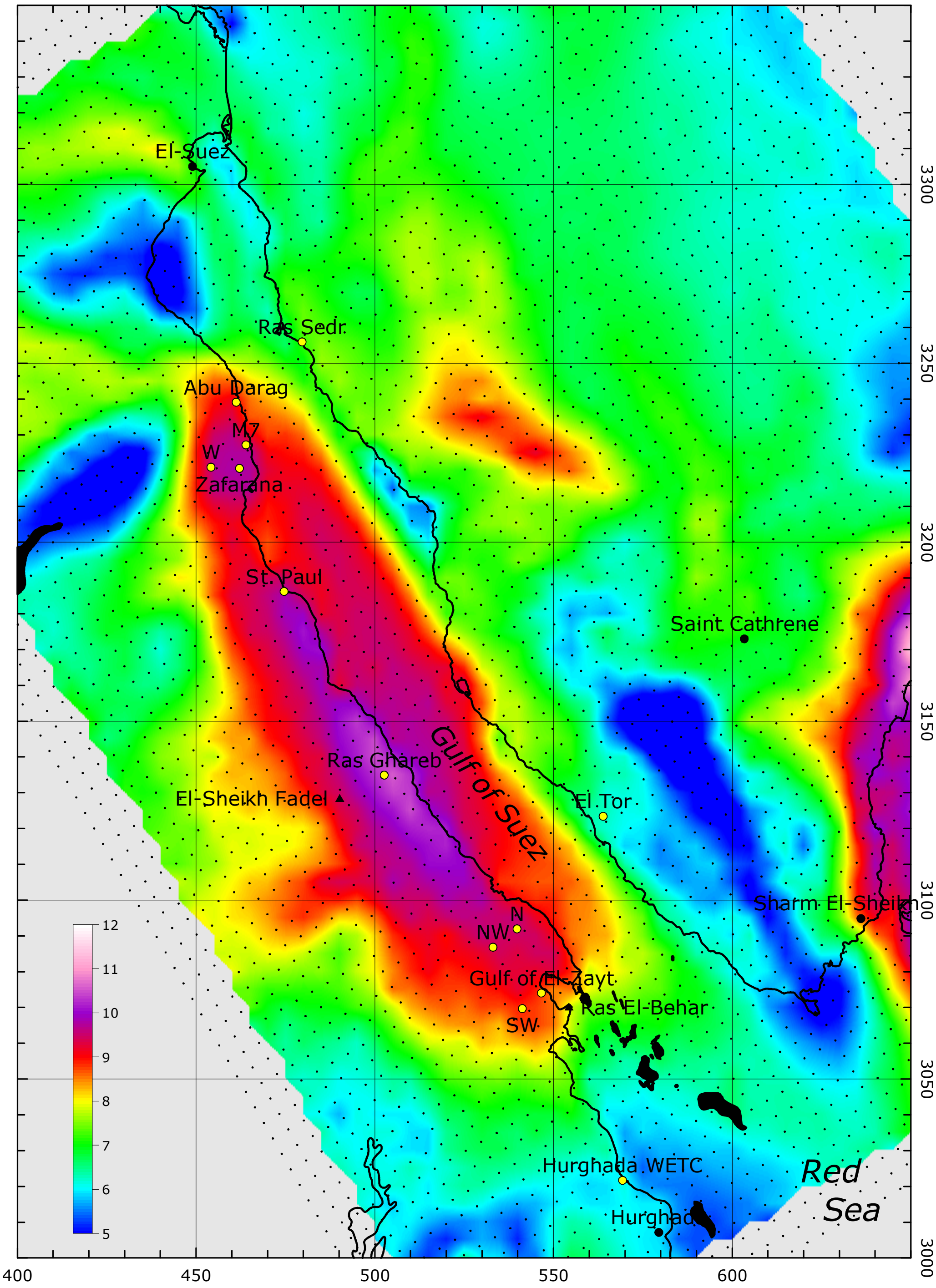

Figure 4: The mean wind speeds in m/s at 25 m a.g.l. over a roughness of z_0=0.2 cm. in the Gulf of Suez. The co-ordinates are UTM in km. The dots are the grid points of the calculation grid. The Suez Canal is on the upper left.

Implications of the investments

The implications for the development of the region are especially noteworthy. Consider the example of Germany and Morocco: Germany yearly spends 40 billion euro for its electricity supply which is about 2% of its GDP, whereas the total GDP of Morocco lies somewhat above 30 G€. Today's Moroccan electricity consumption is 2.5% of Germany's 490 TWh. Let us assume Morocco would produce 10% of the European demand. This would involve a total investment of more than 50 G€ for the wind power plants erected in Morocco, which is close to twice its GDP. On the other hand, for the European industry this size of development would mean a large opportunity in a time when the stock prices are low and the earnings depend very much on a few politically supported markets. The financial and know-how transfer would probably stretch out over the next decades. To follow such a concept would among other implications mean developing the infrastructure and thus could become a worthy form of development aid based on the needs of both sides.

DISCUSSION

Wind energy is an electricity generation option that is relatively benign to the environment. The economics of wind energy depend mostly on the wind resource at the site of interest; therefore it makes sense to build wind farms at high-wind sites. The huge success of wind power in Europe (especially Denmark and Germany) is more due to a favourable support scheme than to the wind speeds. Thanks to the Kyoto mechanisms, wind power in third world countries can help developed nations reduce their greenhouse gas emissions, while lowering pollution from fossil fuels in these countries. In the regions with very high wind speeds, the population density is usually rather low, ie large-scale installations are possible. The investment in these regions could be rather large, creating local employment for erection and maintenance, and probably even production of turbines (since it often is cheaper to build a wind turbine production line for a very large farm locally than to transport the large items over many thousand kilometres). Building the farms with a high content of local labour reduces the price for the turbines, which leads to even lower cost per kWh.

These lower cost also translates to lower cost per ton CO_2 avoided for the European countries benefiting from the Clean Development Mechanism. In the end, it is all a question of price: whether wind power is cheaper than the local electricity, whether wind power transported from these high-wind regions to Europe is cheaper than locally produced offshore wind, and what the technology development on both technologies will come up with.

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