Economic viability of transmission capacity expansion at high wind penetrations

Østergaard, Poul Alberg

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Poul Alberg Østergaard
Energy Planning Group
Department of Development and Planning
Aalborg University
Fibigerstræde 13
9220 Aalborg Ø
Denmark
e-mail: poul@plan.aau.dk – website: www.energyplanning.aau.dk

Abstract
With growing wind power penetrations in many countries, grid and system integration becomes more and more important issues. This is particularly the case in countries or regions with good wind resources as well as substantial installed wind power capacity as found in e.g. Northern Europe.
At 20% penetration in Western Denmark, the issue is pertinent here in relation to future plans of further expansion which is planned in accordance with the Danish Government's climate change mitigation initiatives.

This paper analyses the potential economic benefit of selling excess electricity production on the Nordic power pool *Nord Pool* in relation to the added expenses of expanding national and international transmission capacity from Denmark in order to accommodate the added export. This is done through energy systems analyses, transmission grid modelling, analyses or the required transmission grid investments and analyses of the Nord Pool price variations. The analyses are done for varying degrees of wind power penetrations ranging from 20% of the West Danish electricity demand up to 100% of the demand.

The analyses demonstrate, that while there is an economic potential for some expansion in some years, in most cases the added investment proves unfeasible and either reduction of the wind turbines production under excess generation situations or other uses is more profitable unless the wind penetration very high.

Introduction
Since the oil crises of the 1970s, Denmark has pursued an active energy policy of reducing dependency on imported fossil fuels. With added focus later from national carbon dioxide emission reduction target as well as the Kyoto protocol requirement adapted by Denmark, exploitation of renewable energy sources has played an important role in the pursuit of this policy. Over-all energy efficiency improvements have also come from an extensive exploitation of cogeneration of heat and power for the purpose of district heating generation. With 20% wind penetration and a share of small-scale CHP at 26% in Western Denmark in 2004 [Eltra (2004)], much emphasis has thus been given these fuel saving technologies.

While a shift to a more market-based pricing system for wind power supplied to the grid has more or less halted Danish expansion of land-based wind turbines, political agreement was reached in 2004 regarding the establishment of two new 200 MW off-shore farms. This is an expansion of approximately 16% compared to the present level in terms of capacity but in terms of production it is closer to a 30% expansion due to more annual full-load operating hours off-shore.

In 2004, peak relative hourly wind production came to 118% of the demand and small-scale non-dispatchable CHP came to 64%. The two combined had a maximum share of 148% of the demand. Adding to that generally high shares indicated in Figure 1 and the fact that the large power plants also have to operate for reasons of grid stability and in order to generate district heating for large urban areas, the result is that there are times, where there are large excess productions. In normal thermal or hydro-based systems, there is not such a high non-dispatchable production however the opposite is the case here. At many points in time throughout the year, there is thus a necessity to export electricity.

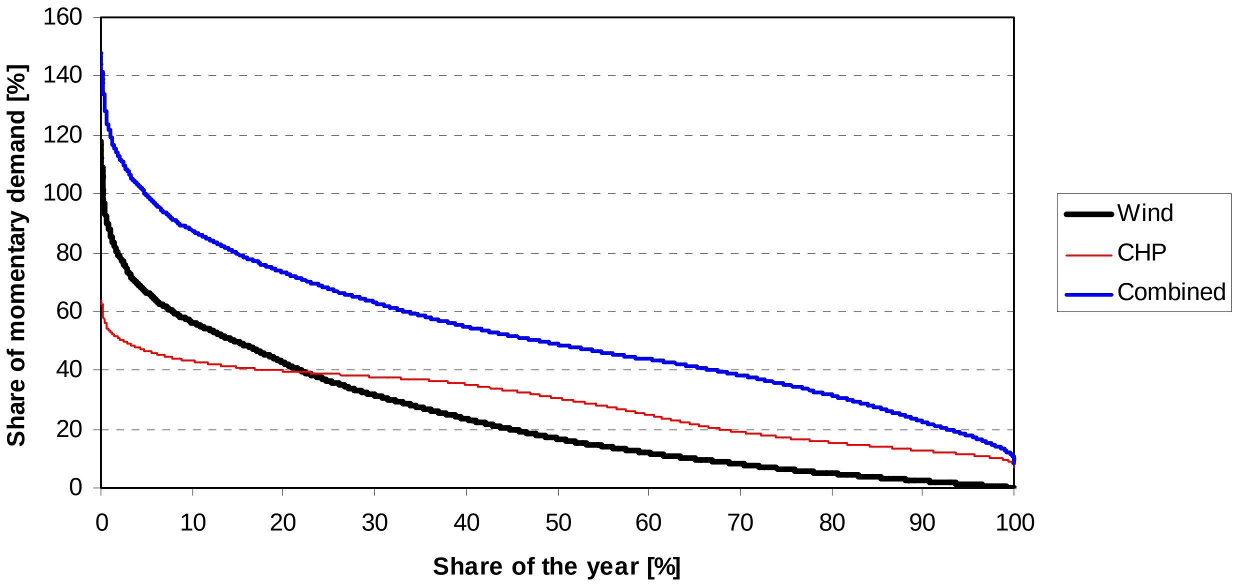


Figure 1: Duration curves for wind power and small-scale (local) CHP in Western Denmark in 2004. Based on data from Eltra (2005a).

Western Denmark does have a relatively strong grid (Figure 2) with strong electric connection abroad totalling approx 2900 MW, however 1200 MW of this is to Germany with its high degree of wind power and thus limited possibilities of picking up excess power generation from Denmark during periods of high wind velocities.

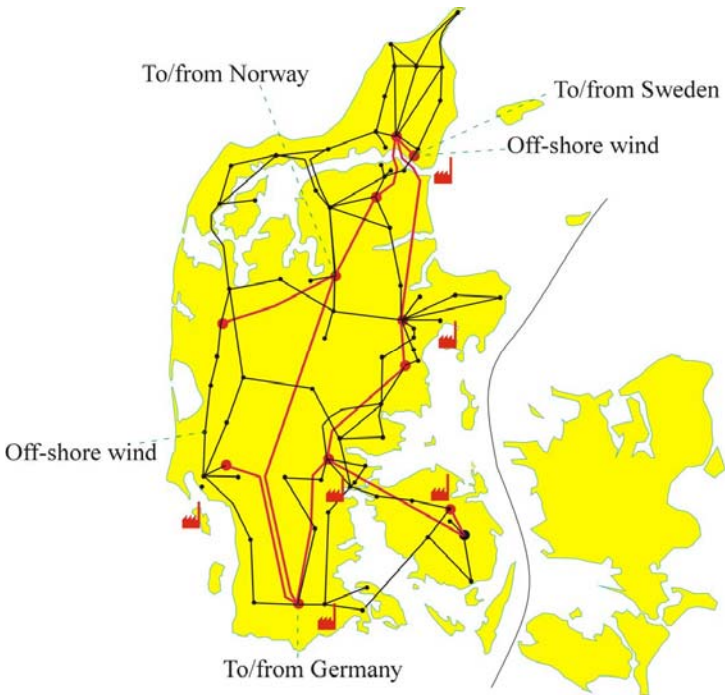


Figure 2: The transmission grid in Western Denmark.

Scope of article

With much of the production system beyond the control of the central dispatch, export is utilised for integration of wind power today however this option is limited by the existing lines. A number of alternatives thus exist including better control of the small-scale CHP plants, moveable loads (including heat pumps, electrolytic converters or battery storages in vehicles) and improved connections abroad. All three general categories change the timing of either load or production however potentials and not the least costs differ greatly between the options.

This article analyses whether it is economically feasible to expand the domestic transmission system as well as export capacity from Western Denmark to Norway and Sweden based on added income from selling additional export on the Nord Pool power exchange at higher wind penetrations.

The energy systems' analyses are based on extrapolations and calculations based on empirical data whereas the transmission grid analyses are more analytically-based being founded on a transmission grid description and a load-flow model.

Energy system scenario

The analyses take their point of departure in actual hourly values of demand, wind power generation, import, export and available export capacity for five years in Western Denmark. The five years are all with annual wind energy contents (wind index) at or below average (see figure 3). Largest exports would naturally occur at the above average wind conditions, however, data were not available for above-average years.

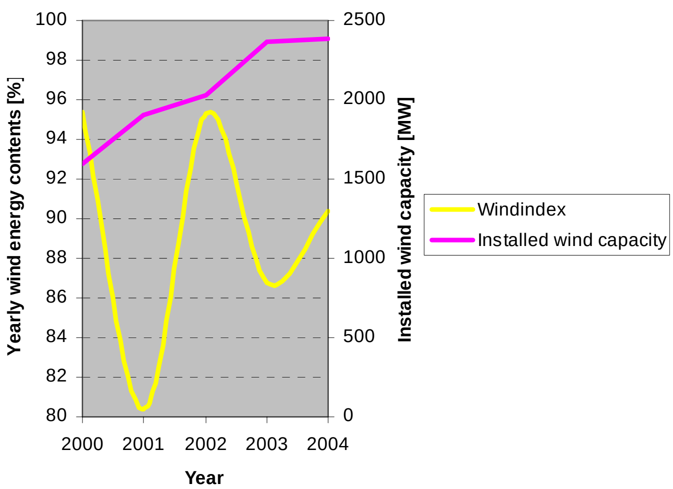


Figure 3. Installed wind capacity and relative wind energy contents in the five years modelled. Sources Eltra (20056) and EMD (2005).

In these analyse, wind power is modelled at levels from the current level of approximately 20% and up to 100% wind penetrations. These percentages are in shares of the demand in Western Denmark however without taking into consideration the timing of production and demand. Some thermal production is hence required even at 100% wind penetration but this is not addressed in detail in these analyses.

For each hour of the five years, installed wind power capacity is modelled expanded up to 100% wind penetration by simple extrapolation. Over the period of years indicated in Figure 3, installed wind capacity has grown. This is compensated in the modelling so all are referred to year 2004 levels.

Available export capacity is the physical export capacity minus momentary export plus imports where the physical capacity is the approximately 1700 MW minus temporary reductions due to e.g. maintenance. Import and export of course does not take place at the same time at least not in a physical sense. Import is therefore included in the calculations as import in an hour may be perceived as an additional available export capacity. Additional capacity may subsequently be added and the additional momentary export be determined by comparing with the available momentary wind power. Figure 4 and 5 show available export capacity for two weeks in 2004. It should be noted that the week numbers are not coinciding with the European week numbering system but rather, the first seven days of the year is defined as week number one.

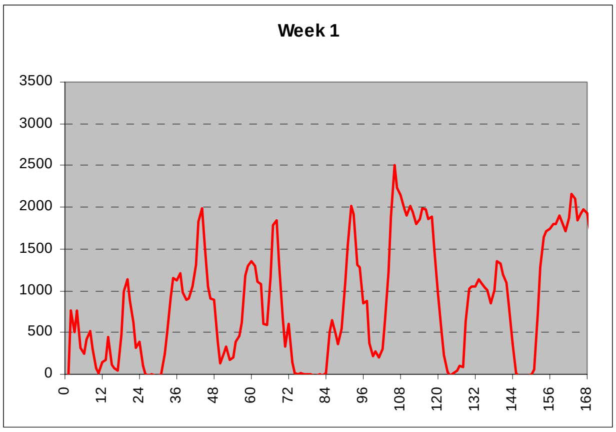


Figure 4: Available export capacity to Sweden and Norway without additional capacity added – a winter week.

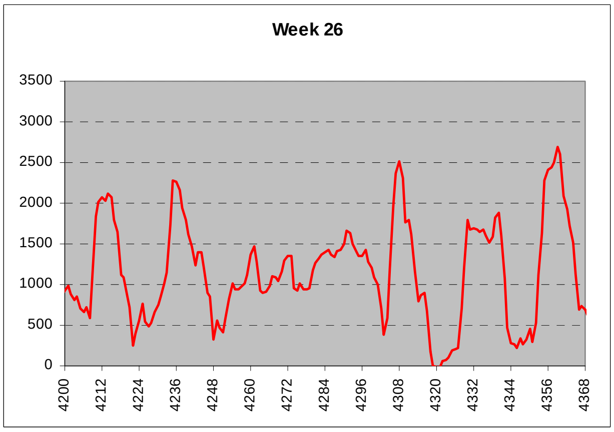
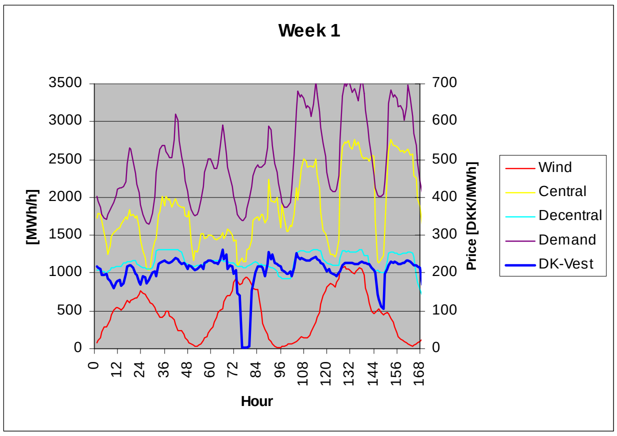


Figure 5: Available export capacity to Sweden and Norway without additional capacity added – a summer week.

It is clear from the two figures that available export capacity changes considerably over the day and the week as an indication of the use of these connections.

Pool prices on the Nord Pool power exchange vary considerably over time, but there is no immediate correlation with momentary wind power as indicated in Figures 6 and 7 showing pool prices for Western Denmark along with momentary wind input. These prices are used to determine the value of additional export caused by expansion of wind power. At high wind expansions there could come some correlation between momentary wind power and pool-prices however Danish electricity consumption and generation is very modest compared to the Norwegian and Swedish consumptions, though a correlation is still perceivable.



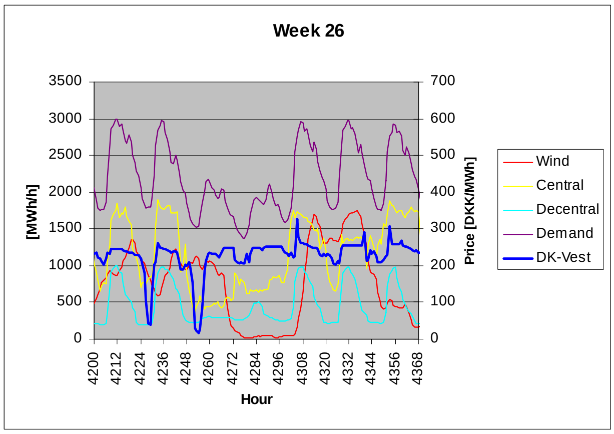


Figure 6: Production, demand and spot market price in a winter week of 2004

Figure 7: Production, demand and spot market price in a summer week of 2004.

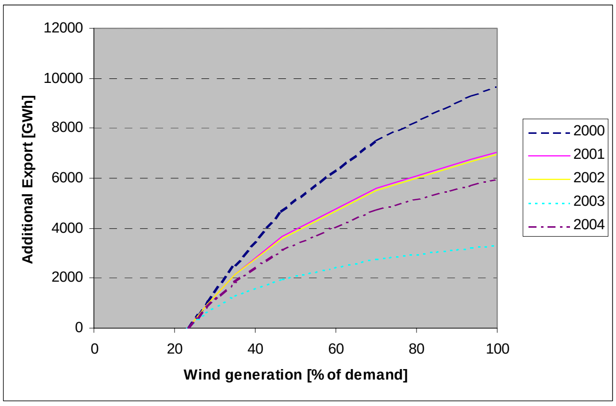
Expansion of export capacity is in the form of a 600 MW HCDC line at a total cost of 1350 million Danish Kroner (DKK) [Eltra (2002)]. Calculated as an annuity over 30 years and adding 2% O&M costs annually, this comes to approximately 70 MDKK per year.

Domestic grid expansions are determined by load-flow analyses of the Western Danish grid using the energyPRO GRID model [Andersen & Mæng, (2004)] and databases established for the Mosaic project (Østergaard et al (2004)] for all hours in the year. In the modelling, the over-loads in the transmission system are identified assuming an otherwise intact grid and reinforcements are priced. These costs are subsequently annuitised using the same factors as for the HVDC lines and are then added these.

The total grid costs may lastly be deducted from the added income of selling electricity on the Nord Pool thereby revealing the potential income from expansion of export capacity. It should be noted that it is not an analysis of the potential income of expanding wind power; turbine costs are not considered.

Results of the analyses

Additional export varies from year to year in the models as shown in Figure 8 with a tendency that high-wind years also have higher additional exports. It is however interesting comparing years 2001 and 2002. In spite of a significant difference in annual wind energy contents, additional exports are more or less identical demonstrating that the timing is very important. The average diurnal variation does not change much from year to year however seasonal variations in wind energy contents do manifest themselves as indicated by Figure 8.



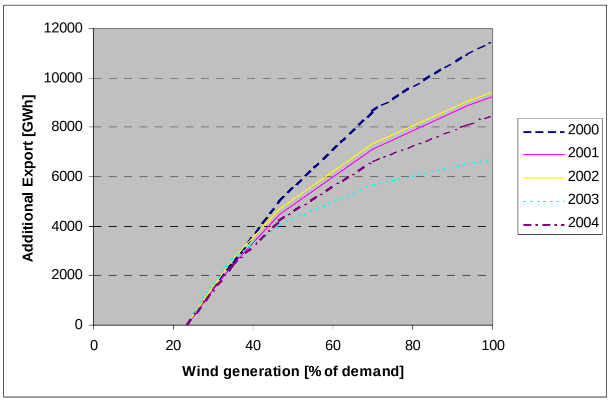
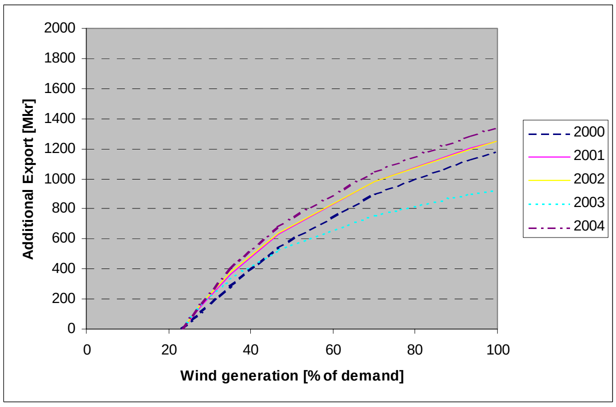


Figure 8: Additional export using available export capacity, based on 2004 data.

Figure 9: Additional export using available export capacity plus an additional 600 MW, based on 2004 data.

Adding an extra 600 MW export facility gives an additional export as indicated in Figure 9. Again, in spite of 2001 having by far the lowest annual wind energy contents, additional exports this year are among the highest due to the annual distribution of wind.



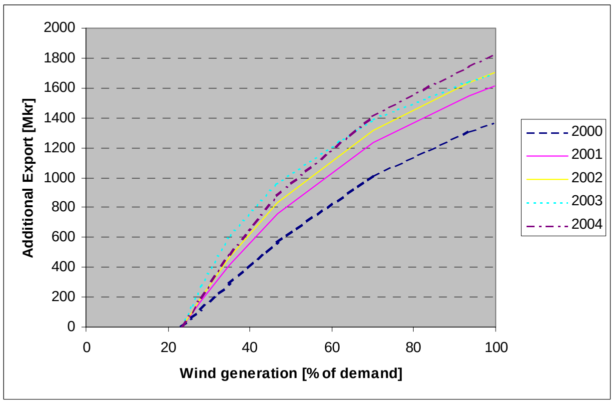


Figure 10: Additional income without added export capacity

Figure 11: Additional income with 600 MW added export capacity

Applying the momentary Nord Pool prices for the momentary additional exports at higher installed wind capacities gives the incomes in Figures 10 and 11 where the difference shown in Figure 12 thus reveals the economic benefit of the added export capacity without taking the grid expansion costs into account though.

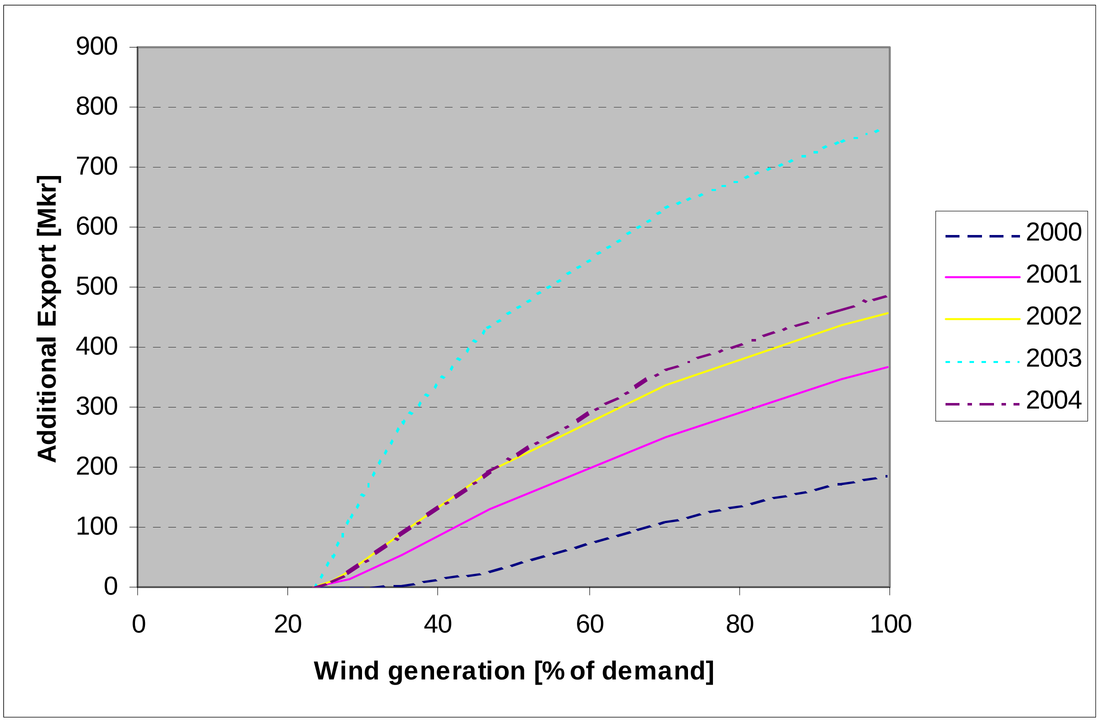


Figure 12: Marginal income from investing in 600 MW export capacity – grid costs not included.

Calculating the grid expansion needs give the results listed in figure 13. It is quite clear that the most important investment is in the international HVDC cables whereas domestic expansions at low wind penetrations is more of less negligible. At higher penetrations this becomes more important though never at a level comparable to the HVDC line.

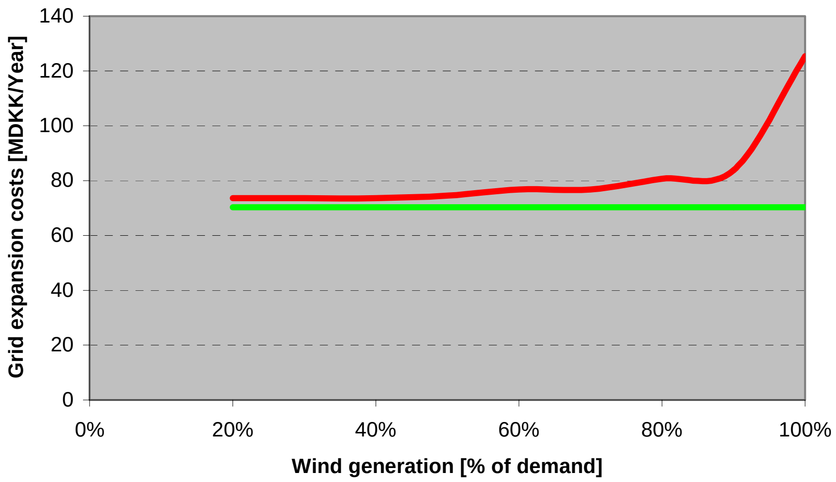


Figure 13: Grid expansion costs. The lower line is for HVDC connection alone; the upper line is including domestic transmission capacity expansion.

Adding these costs as previously outlined gives the over-all income of expanding the transmission system and HVCD export capacity to Norway/Sweden. These results are given in Figure 14

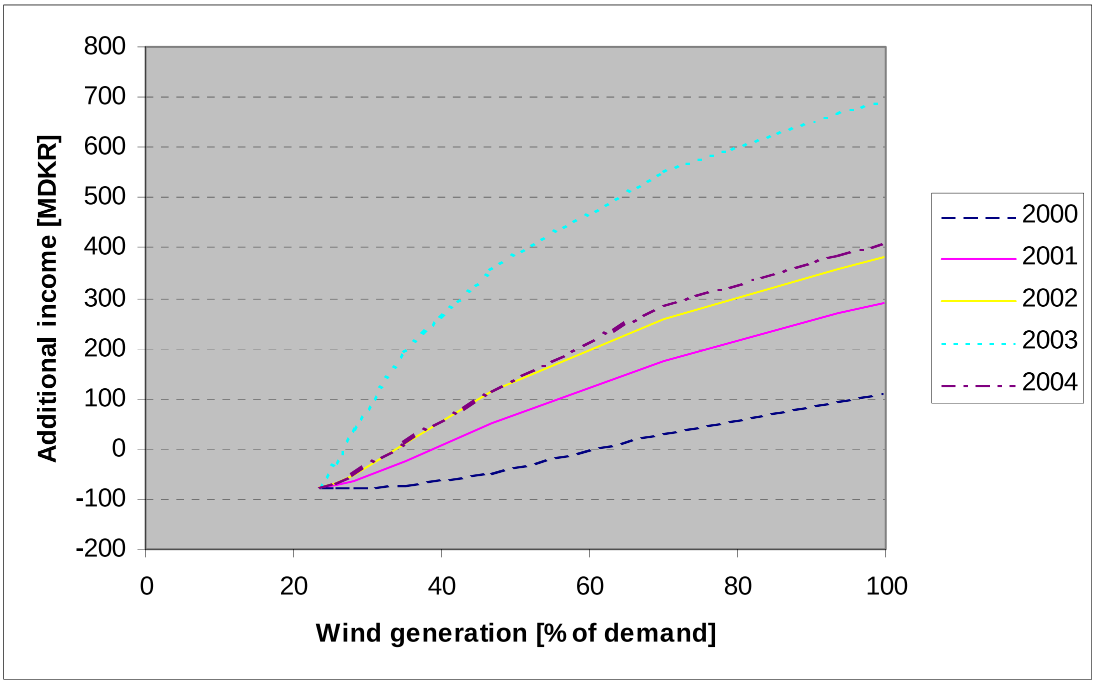


Figure 14: Added income from investing in transmission and export capacity expansion and selling excess wind power generation on the Nord Pool power exchange.

It is clear from the figure that the economic viability of expanding the transmission system and export connections vary considerably from year to year. If the timing of the excesses is wrong compared to the pool price (as in the year 2000) a strong expansion of wind power is required in order to make the investment feasible. In most of the other years, expansion is only feasible at a wind power penetration around 35-40% though in one year (2003), only a modest expansion compared to the present approx. 20% penetration is required.

Expansion with an additional 600 MW HVDC capacity to a total of 1200 MW is feasible in some of the years but generally only at very high wind penetrations above 50-60%. These analyses are not detailed further here as other issues become more pertinent at such high levels.

Conclusions

Expansion of grid connections from Western Denmark to neighbouring countries is feasible if Denmark pursues a path of wind power expansion. While not relevant under present circumstances, added export capacity becomes economically favourable when wind penetration reaches and surpasses 35-40%

Capacity expansion to even higher levels – 1200 MW in these analyses – are only feasible at very high wind penetrations

The analyses are done using statistical data for five years however these five years were in fact comparably low-wind years. Higher wind velocities would naturally increase the utility of added transmission capacity domestically and internationally. Potential required transmission grid expansions in the receiving end is not included

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