Wind Power and District Heating

New business opportunity for CHP systems: sale of balancing services

Executive summary

- Both wind power and Combined Heat and Power (CHP) can reduce the consumption of fossil fuel. However, the electricity demand in Denmark during the winter season is insufficient to accommodate the outputs of both CHP and wind power, and the economic viability of one or both may be put in jeopardy.
- Due to low variable cost an increasing wind power capacity is able to displace thermal power in the market, and thus the likelihood is that CHP plants would have reduced access to the market.
- Nevertheless, wind power output variations are not synchronised with demand for electricity, and Denmark's consequent need for balancing services has so far been supplied mainly through export and import relations with its neighbours, such as Norway.
- However, by the appropriate use of hot water tanks, electric heaters and heat pumps, Danish CHP plants could provide these balancing services by purchasing cheap surplus electricity, and at other times, when profitable, produce electricity through co-generation.
- The paper presents results from a computer simulation for Denmark in 2025. The results demonstrate that the district heating systems are able to absorb a considerable part of the anticipated wind power variations.
- The Danish case may have significant implications for other countries contemplating a major increase in wind power, especially those with proportionally lower levels of interconnection, such as the United Kingdom.

District heating systems as forerunners of smart grids

The installed capacities of wind power are expected to continue to increase in most European systems. This introduces management problems in some power systems. Most of these issues are flowing from insufficient electricity demand and the fact that, unlike conventional generation, wind power cannot follow demand for electricity.

So far, the predominant solution adopted in those systems has been the trading of electricity with neighbouring networks in which balancing solutions can be found. For example Denmark and Germany have relied heavily on the existence of flexible Norwegian hydro. This has worked reasonably well, but it will not necessarily be a viable solution in the future when additional countries, including the United Kingdom, are competing for access to Norway's balancing services.

Consequently, it has been generally acknowledged that there is a need for remedies located within the various systems themselves, the usual emphasis being on "smart grids", which are understood by system engineers as sophisticated demand management. That is to say, an intelligent network providing consumer incentives to adjust consumption in accordance with supply. Concepts of this kind, and particularly electric vehicles, have attracted a great deal of attention, and while it is important to investigate these options, it is clear that there is still a long way to go before they can contribute perceptibly to system balancing.

Fortunately, other options are available immediately, for example the flexible operation of combined heat and power (CHP) systems. Surprisingly, this potential has not received much attention hitherto, a lack that the present paper attempts to address.

CHP plants under pressure from wind power

Electricity demand in Denmark is insufficient to allow CHP and wind power unfettered market access. Since wind power has a degree of variability in its output, high levels of wind power are normally followed by a corresponding increase in electricity export. However, for the reasons discussed above, it is likely that future export of electricity during windy periods will be constrained.

Since the variable cost of wind energy is very low it is able to displace most types of thermal production, with the result is that wind turbines and CHP plants will compete for an electricity demand which in Denmark cannot accommodate both types of supply. As a result there will be pressure on CHP plants to reduce combined generation. In other words, wind power may gradually force CHP plants out of the market.

However, CHP plant owners can defend themselves against this threat by aiming to serve the increased demand for balancing services caused by wind power. Indeed, this paper argues that CHP plants have considerable potential for such services if steps are taken to facilitate utilization of the flexibility already present in District Heating systems. Specifically, district heating systems can absorb large quantities of electricity by using heat pumps and electric heaters for heating of water.

To understand why, we need only recognise that CHP systems can overcome the common observation that while surplus electricity can be converted into hot water it is impossible to convert that hot water back into electricity. They can do this because most CHP systems include a large hot water tank, which they employ to supply without CHP production. During periods of suitable demand for electricity and hence profitable market prices, CHP plants can supply heat while recharging the hot water store.

Consequently, district heating systems can buy electricity when the supply situation is favourable and sell electricity when demand is high. The precondition for this argument is that the CHP concept is efficient and clean, and thus a core element of Danish energy policy.

Wind power and export of electricity

The possibility of using CHP systems as an electricity storage system can be demonstrated by computer simulations. For example, in January, if the hot water tanks are appropriately operated, Danish electricity consumption is sufficient for the electricity production from the CHP systems. However, if wind power output is combined with that of CHP plants there is a surplus of electricity. The options to address this situation are 1) export of electricity and 2) to change from CHP mode to heat production only, using backup conventional boilers.

The transition from heat production to combined heat and power production implies an increased consumption of fuel, but the incremental cost of electricity is quite low and can nearly always justify electricity trade with neighbouring countries. The result is an export of electricity with a profile very close to the profile of the wind power (see Fig. 1).

Figure 1

This modelled situation corresponds fairly closely to real world operational experiences, and at 50% wind energy the peak of required electricity export in January is nearly 8,000 MW.

Furthermore, since wind power output in Denmark is closely correlated with that in Germany, it should be anticipated that the Danish need to export will coincide with and must compete with a much larger German export requirement. The electricity markets in Germany and Denmark have already accepted the consequence of this matter, and introduced negative spot prices, and in fact such prices were recorded for 71 hours in Germany in 2009. Consequently, there are good reasons for considering domestic alternatives such as new types of electricity demand. In the short term the flexible operation of district heating systems seems to be an obvious and largely satisfactory option.

CHP plants providing balancing services

Figure 2

Fig. 2 is an attempt to illustrate the production of heat at local CHP plants in January 2025, with electricity export minimized, that is to say that wind power is given priority and unfettered access to demand. In Chart A CHP production is possible only in the wind power valleys (the green areas), and the content of the hot water tanks does not go far (the yellow areas). In this scenario CHP plants have become unimportant, and probably uneconomic.

In the next scenario, described in Chart B, large heat pumps have been installed in the CHP systems. A quantity of 400 MW has been arbitrarily chosen for the group of central CHP plants and 500 MW for the small CHP plants. The chart demonstrates a reduced use of backup boilers, the content of the hot water tanks lasts longer, and the increased consumption of electricity allows a slightly increased CHP production.

In the last case (Chart C) 750 MW of large electric heaters have been installed in both central and local CHP systems. The most obvious effect in January is a further reduction of the production from the backup boilers.

Of course, whether heat pumps and electric heaters would actually be operated as shown in Fig. 2 would depend on market conditions, but the decisive point is that the CHP operators have a range of options open to them. A CHP plant can both participate in the market for balancing services by purchasing cheap surplus electricity, and, at other times, produce electricity when profitable. This vision projects an active and interesting future to imaginatively operated CHP plants.

However, the optimal capacity of heat pumps and electric heaters cannot be estimated in advance, since the average utilization will decrease with increasing capacity. In the example shown the average duration times are 2,414 hours for heat pumps and 801 hours for electric heaters, but it should be recognised that in real-world operation the export of surplus electricity might be the best choice in some cases and lead to lower duration times than in the theoretical example.

Electricity exports can be reduced

When CHP systems are using electricity for heating water it is reasonable to conclude that the need for export of electricity will decline. Fig. 3 demonstrates the possibilities.

Figure 1 showed that covering all heat demand with CHP would require export of up to an instantaneous peak of 8,000 MW. Figure 3 shows that reduction of CHP production can reduce the export peak to below 5,000 MW.

Figure 3

The 900 MW heat pumps will reduce the export peak to below 4,000 MW, and a further 1,500 MW of electric heaters can bring this down to a little more than 2,000 MW. On an annual basis electricity export can be reduced from 2.9 to 0.8 TWh. In other words, the CHP systems can absorb a significant part of the variations of the wind power.

Great opportunities for CHP systems

A selection of annual figures demonstrates the achievable improvements (Table 1). At maximum CHP production the need for export of electricity will be 39.5% of the produced wind energy, and this quantity can be reduced to less than 10%. The export can be minimized to 16.6% by conversion of 23.7% of the demand for heat to backup boilers. These two figures can be reduced to 4.4% and 5.0% by the use of heat pumps and electric heaters, and a much greater flexibility in the Danish energy system is thus achieved.

Strategy	Maximum CHP			Minimum export		
Denmark 2025 50% wind energy	Overflow	Backup boilers	Electric heated	Overflow	Backup boilers	Electric heated
	% of wind production	% of demand for district heating		% of wind production	% of demand for district heating	
40 GWh storage (ref.)	39,5	0	0	16,6	23,7	0
+900 MW heat pumps	17,9	0	14,9	10,1	8,0	14,9
+1250 MW el. heaters	9,2	0	18,4	4,4	5,0	18,4

Table 1 Heat pumps and electric heaters can reduce the need for export of electricity.

According to the statistics of the Danish Energy Authority production at the local CHP plants has been reduced by about 25% since 2005, which may already reflect tougher competition in the electricity market. If this inference is correct, the observed trend could inspire a re-evaluation of the future role of the local CHP plants, and an efficient interaction between wind power and CHP plants could be a powerful lever in Danish energy policy up to 2025. Otherwise, there is a dual risk that due to further growth in wind power Danish CHP plants will face closure and the country's electricity system will become extremely dependent on international balancing services.

At present, it will probably be difficult for individual CHP systems to produce a bankable estimate of the risk and the profitability of an investment in large heat pumps and electric heaters, but this could be addressed if energy taxes and other frameworks support this development, and if the market conditions are clear and transparent.

Calculation Details

The scenario presented here is assumed to be valid for Denmark in 2025, with a wind energy share of 50% of the traditional electricity demand. Three time series of 8,784 hours are included in the data: wind power, electricity consumption, and heat demand. The model is required to find a balance in both electricity and heat supply, with a surplus of electricity being referred to as "Export", and missing CHP heat production as "Backup Boilers".

Calculations this far into the future involve several uncertainties, and in particular the capacity of the hot water tanks has a very significant impact on the realisable flexibility of the CHP systems. A total capacity of 10 GWh for central power stations and 30 GWh for local CHP plants has been employed, and though it seems reasonable to the author, it is only an estimate.

Because data for an economic optimization is unavailable, two operational strategies have been tested: maximized CHP production, and minimized electricity export. Presumably, and depending on the conditions in the international electricity market, real world operation will be somewhere between these two extremes, but the clarity of these extreme cases permits assessment of the value of the proposal.

The first of the scenarios is important because the continued existence of CHP systems only makes sense in the long term if they are able to sell both electricity and heat.

The second matters because external demand for electricity cannot be taken for granted. Several neighbouring countries have ambitious wind power plans, the United Kingdom is the principal example, and they all anticipate the purchase of balancing services provided by Norwegian hydro. It is not clear that all demands on those services can be met, even if there is major enhancement of interconnection and there is some further expansion of Norwegian hydro. Indeed, the use of CHP as a source of balancing services may become attractive in countries other than Denmark.

(First published in Danish by “Fjernvarmen” no. 3/2011)

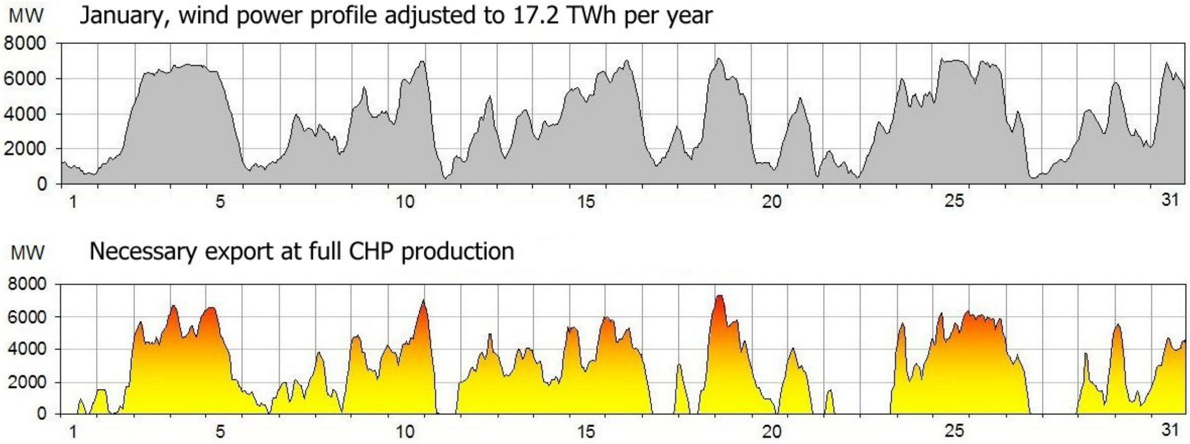

Figure 1: Calculation for Denmark in January 2025, with 50% wind energy on an annual basis. The calculated export at full CHP production is similar to the wind power profile. The small peaks reflect daily variations in electricity consumption.

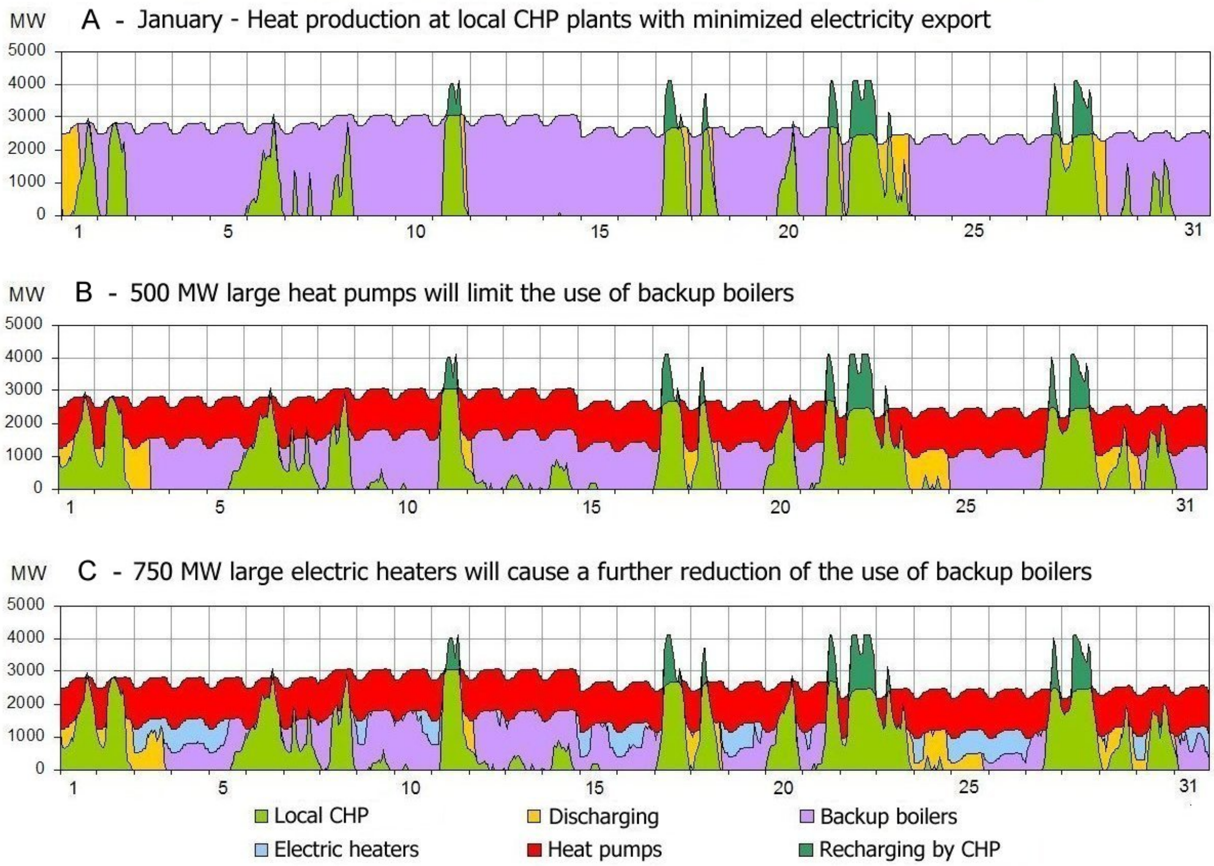

Figure 2: Demonstration of local operation of CHP plants in January 2025. If electricity cannot be exported, only the “valleys” in the wind power profile are open for CHP production. However, heat pumps and electric heaters offer new opportunities for the CHP systems.

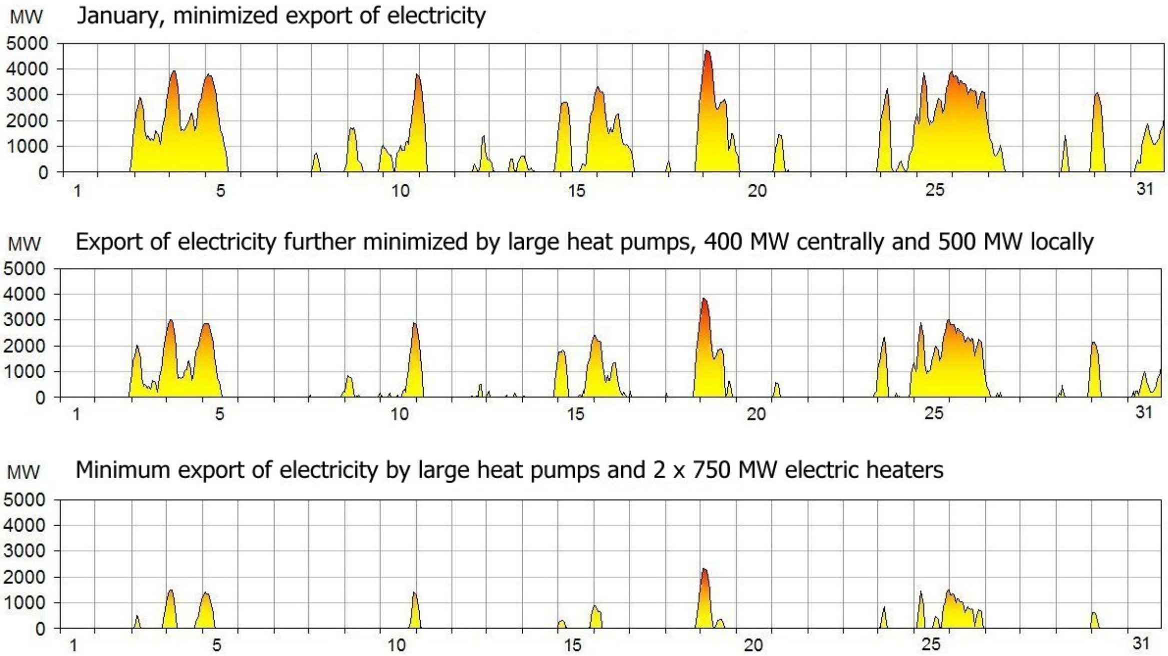

Figure 3: Heat pumps and electric heaters can make electricity surplus useful in Denmark. Export of electricity has been minimized by reducing CHP production, but without curtailing wind power.