Wind Power and CHP: Conflict or Interaction?

While participating in the EcoGrid.dk project[1] I noticed abundance of electricity when the district heating systems demand more heat. I claimed that heating water in the district heating systems by surplus electricity could add the necessary flexibility to the Danish spot market, particularly for high wind energy penetrations. I demonstrated the possibility by a few charts on an hourly basis, but I was unable to quantify the potential.

In 2009 I made an analysis for the Renewable Energy Foundation in London of wind power and spot markets in Denmark and Germany for the years 2006 to 2008. The work revealed extreme market situations created by accidental wind power combinations, but the work did not include heat supply, and it was not forward looking.

It has been claimed that utilising overflow electricity is no problem because it can be stored in Norway. This solution should be chosen when it is profitable, but congestion or economy may suggest other solutions. The Norwegian service has a cost and the price depends on the Danish alternatives. Therefore domestic alternatives can be of great value.

In order to be able to study the interaction between wind power, electricity demand and heat demand during a full year I have made a model as a spreadsheet on an hourly basis.

The model in brief

Hourly values for wind energy production and electricity consumption have been downloaded from the Energinet.dk web site. The data concerns West Denmark which had so far the largest penetration of wind power. The time series can rather easily be exchanged for other data, if desirable.

The heat demand is distributed over the hours of the year in accordance with a profile. The total heat consumption supplied from central and local power plants respectively have been estimated from the statistics published by the Danish Energy Agency[2]. Only data for the entire country has been published. For this work the district heat consumption in West Denmark has been assumed to be 60% of the corresponding national figures. The heat model cannot be more accurate than this assumption.

It is well known that combined production of heat and power (CHP) is saving fuel. Consequently it also saves money and reduces environmental impact compared with separate productions. But the combined production is only advantageous if there is a simultaneous demand for both products.

It took several years to obtain general acceptance of this simple logic and subsequently to bring about a revised legislation for prevention of unnecessary electricity production and useless fuel consumption.

The model does not include economic data and it does not make economic choices. A specified minimum of thermal generation of electricity is maintained as a stabilising measure. Apart from that the wind power has the first priority. After wind power the next priorities are

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[1] Sponsored by the Danish Transmission System Operator, Energinet.dk, see http://www.energinet.dk/en/menu/R+and+D/EcoGrid/EcoGrid.dk.htm

[2] Danish Energy Agency: Energistatistik 2008, page 14.

central CHP, local CHP and condensing power (thermal generation of electricity without heat).

Hot water storages already exist in the district heating systems. Therefore it is possible to turn up production on local CHP plants if there is an uncovered electricity demand and available room in the hot water storage. Uncovered heat demand is assumed to be supplied from the boilers which have been installed for peaks and as reserve capacity.

Surplus electricity from wind power is assumed to be exported.

This operational strategy is simplified. It could be improved, but the necessary data for this purpose is not available.

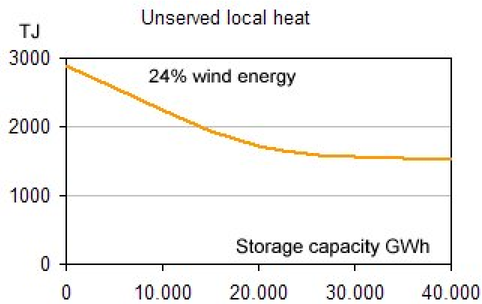
The model includes two programs (VBA, Visual Basics for Applications).

A preparatory program creates time series based on the following additional data:
- Central CHP: annual heat consumption, minimum electricity production and c_M[3].
- Local CHP: annual heat consumption and c_M.
- Factor for scaling wind energy up or down

A simulation program creates annual results based on the following additional data:
- Total capacity of hot water storages at local CHP plants
- Total capacity of electrical water heaters at local CHP plants
- Total electrical capacity of local CHP plants

A case with data section (left) and main results (right) is shown as annex 1.

Hot water storages improving overall efficiency



The district heating systems can store energy as hot water. In the model only local CHP systems have energy storages, but also the central CHP systems do have storages.

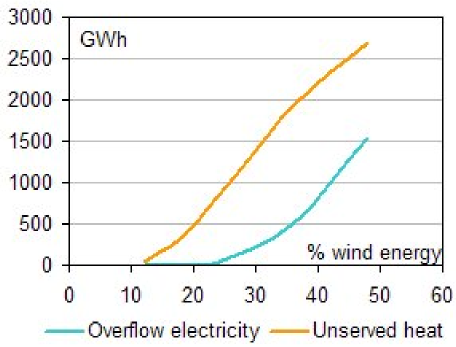
In 2008 the wind energy produced in West Denmark amounted to 24% of the electricity consumption. As a starting point it is assumed that only domestic electricity demand is available and that the wind energy is displacing electricity from CHP plants. The corresponding heat demand must be supplied from boilers. The chart suggests that hot water storages at the local CHP plants were able to half the amount of heat produced on boilers under these circumstances.

Unless otherwise specified the calculations assume hot water storages utilised up to 40 GWh.

Insufficient electricity demand for both wind power and CHP

A series of calculations with varying amounts of wind power and without use of electric water heaters demonstrates the impact of wind power on the combined production of heat and electricity.

[3] c_M is electricity production in MW divided by heat production in MJ/s at counter pressure operation



On the chart (next page) surplus electricity and heat from peak boilers have been shown in the same unit (GWh) in order to facilitate the comparison.

The chart demonstrates how wind energy is displacing combined production from a wind energy penetration at 10%. At 48% about 1,500 GWh wind energy (or 14% of the produced wind energy) must be exported. More than 2,500 GWh heat (or 18% of the heat demand of the CHP systems) must be supplied by peak boilers, because the electricity demand is insufficient for combined production of electricity and heat.

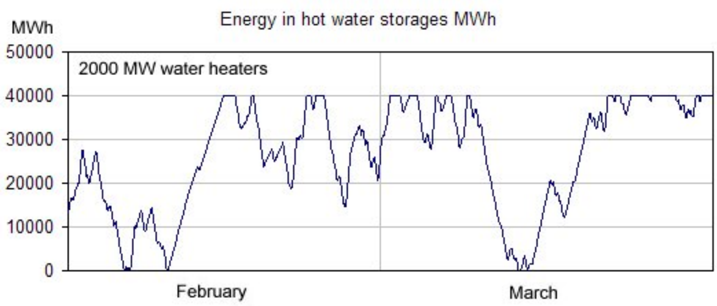
One important message is that electricity demand is an essential condition of both wind power and combined heat and power production. When both wind power capacity and CHP systems are extended these activities are competing for the insufficient electricity demand.

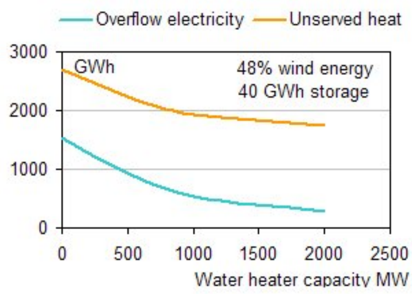
Export is the solution in real life. Due to low variable costs and the possibility of cogeneration of electricity and heat very cheap electricity can be offered for the international market. In the case with 48% wind energy about 3,250 GWh must be exported (1,500 GWh wind energy and 1,750 GWh CHP electricity or about 15% of the electricity consumption) in order to have full utilisation of both wind power and cogeneration of electricity and heat. I consider that to be an inconvenient binding for Danish market participants and for Energinet.dk.

The next section demonstrates the effect of use of water heater for conversion of electricity into hot water.

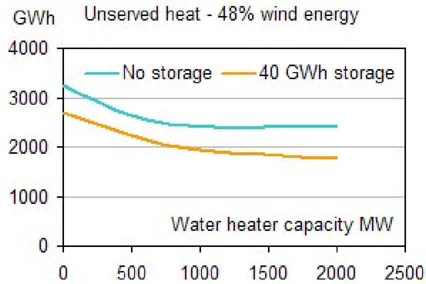
More efficient wind power and cogeneration due to electric water heaters

At 48% wind energy surplus electricity can replace about a third of the heat production from peak boilers (‘unserved heat’ on the chart).





The chart shows that nearly all surplus electricity can be utilised for heat supply. It also shows how water heaters take market shares from peak boilers.



The use of heat storages can be demonstrated. The abundance of electricity causes the storage to be filled during the hot season. A more advanced operational strategy may improve the use of the storages.

Both water heaters and storages contribute to reduced use of peak boilers, but the water heaters seem to provide the major contribution.

In the case shown the 2,000 MW water heater capacity is fully utilised, but the effect of installing water heater capacity beyond about 1,000 MW seems to be limited.

Better choices to Danish market participants

It has been the purpose of these calculations to demonstrate the magnitude of the improvements which can be achieved by simple and inexpensive measures.

Wind energy and cogeneration are competing for the electricity demand. Wind energy will displace CHP. Saving electricity will add to the problems.

If the wind energy penetration is increased from 10% to 48% at the present electricity demand about 20% of the heat demand in the CHP systems will move from CHP plants to peak boilers. It is assumed that the existing heat storages are utilised in an optimal way. Otherwise the peak boilers may take over up to 24%. In spite of the priority of wind power about 15% of the wind energy cannot be sold in Denmark.

1,000 MW electric boilers will be able to reduce the contribution of peak boilers to about 13%, and the overflow of electricity will be reduced to a third. The electric boilers will have a capacity factor about 11%. This makes less convincing case for the use of heat pumps.

Solving the problems by export will require about 3,300 GWh export at times with surplus of electricity or about 15% of the annual electricity consumption.

Though the model is far from perfect I am convinced that considerable advantages can be achieved by the coordination between electricity and heat supply. This measure alone can solve about half of the problems created by 50% wind energy.

However, this promising opportunity should not cause delays of the development of other measures.

Some people seem to believe that the Danish balancing problems will disappear in the big European ocean. I consider this to be ostrich policy. I expect a massive international demand for regulating services in the future. The market will determine the price depending on available alternatives. Therefore simple and efficient domestic measures can give Danish market participants better choices to the benefit of Danish economy and environmental policy.

Top left: Data for input time series
Bottom left: Data for simulation

Top right: Main results for demand models and wind power
Bottom right: Main results of simulation

Central power plants		
Heat demand	TJ/year	33.000
Min electric generation	MW	350,00
Counter pressure cM	MW/MJ/s	0,60
Local CHP plants		
Heat demand, local	TJ/year	16.000
Counter pressure cM	MW/MJ/s	0,70
Wind power		
Correction	Factor	2,00

Observed hours	Residual demand GWh	Net exchange Import GWh	Export GWh	Thermal generation GWh	Electr. demand GWh
8.784	16.430	1.655	2.682	17.457	21.622

Heat model hours	Central heat TJ	Max MJ/s	Min MJ/s	Local heat TJ	Max MJ/s
8.784	33.000	2.278	583	16.000	1.105

Adjusted hours	Wind power GWh	Residual demand > 0 GWh	< 0 GWh
8.784	10.384	12.264	1.025

Hot water storages		
Capacity	MWh	40.000
Local electric heaters		
Capacity	MW	1.000
Local CHP plants		
Capacity	MW	800

Simulation hours	Thermal prod. GWh	Wind prod. GWh	Electr. heat GWh	Stored energy GWh	Overflow export GWh	Balance electr. GWh	Cond. electr. GWh
8.784	12.771	10.384	834	132	567	0	6.007

Central CHP TJ	heat Other TJ	Central CHP-el. GWh	Local CHP TJ	heat Electr. TJ	Other TJ	Storage ultimo TJ	Local CHP-el. GWh
27.321	5.679	4.553	11.368	3.478	1.298	144	2.211

Max el. to heat MW	Max charge MW	Max discharge MJ/s	Max demand MW	Max thermal MW	Max wind MW
1.000	849	955	3.748	3.616	4.353