# Combining Smart Grid Measures

It is well known that the wind power profile does not match the profile of electricity demand. The mismatch will cause balancing problems in a future planned for 50% wind energy. "Smart Grid" is the magic word which is supposed to solve the problems.

The Smart Grid concept is often described superficially without discussion of the conflicts of interests embedded in large scale integration of wind power. It is the purpose of this paper to discuss the conflicts and to demonstrate possible combinations of measures.

## Conclusions

- Combined heat and power (CHP) and wind energy are essential elements of Danish energy policy. Both CHP and wind power depend on electricity demand. The traditional electricity demand in Denmark is frequently too small for both purposes.
- The introduction of wind power has caused an increasing amount of overflow electricity which must be dealt with somehow.
    - The main options so far have been export of electricity or curtailment of CHP heat supply.
    - With an increasing share of wind power in the neighbouring countries the dependency on export of electricity may become less attractive and harmful to the economy of new wind parks.
- This paper presents other options. The following measures have been analysed:
    - Hot water storages in district heating systems
    - Large heat pumps connected to district heating systems
    - Electric heaters connected to district heating systems
    - Small heat pumps connected to end-user installations
    - Flexible end-user demand
- The operational strategies selected for analysis are debatable. The visualization of some results in this paper is intended to encourage a debate.
- With 50% wind energy and without new measures between 17% and 31% of the wind energy must be exported or curtailed. At 17% (a minimum export strategy) 19% of the heat demand from CHP systems must be curtailed. This indicates a strong dependency on other countries.
- It is a main result of the calculations that measures based on coordination between electricity and district heating systems offer the most powerful improvements. Moreover these measures could contribute to the survival of vulnerable CHP schemes.
- Heat pumps and electric heaters based on overflow electricity from wind and CHP will have modest capacity factors depending on installed capacity. Future market conditions must determine reasonable capacity levels.
- Small heat pumps seem to be less effective than large heat pumps with the same capacity and connected to district heating systems.
- Flexible electric load can reduce the electricity overflow further, but at the cost of some increase of the unserved demand for heat from CHP systems.
- A careful redesign of market arrangements will be needed in order to encourage an economic viable composition of measures.

### 50% wind energy in 2025

The calculations in this paper are based on a traditional electricity demand in Denmark at 34.4 TWh. The production of wind energy is supposed to be 17.2 TWh or 50% of the consumption. The demand for district heating is supposed to be 50 PJ for central CHP systems and 24 PJ for local CHP systems.

### Operational options

There is a good balance between demand for electricity and heat from CHP systems in Denmark. The heat can be produced without overflow of electricity.

The introduction of wind power has caused an increasing amount of overflow electricity which must be dealt with somehow.

Export is the most natural option when there is an overflow of electricity in Denmark. So far the increasing share of wind power has been followed by a corresponding export of electricity. With an increasing share of wind power in the neighbouring countries the dependency on export of electricity may become less attractive and obstructive to the economy of new wind parks.

The second option is a reduction of electricity output from the CHP schemes by switching heat production to backup boilers. Due to the high efficiency of the CHP process this choice causes additional consumption of fossil fuel and additional operational cost.

Both main options have disadvantages. In real life market conditions will decide the compromise.

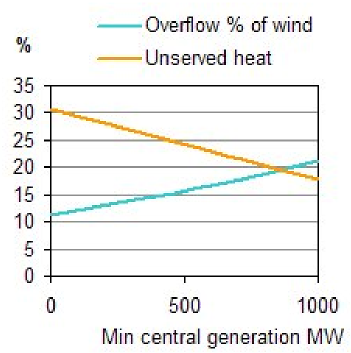
However, it is possible avoid the disadvantages to some degree by a variety of measures, including additional intelligent electricity demand and coordinated operation of electricity and district heating systems.

The purpose of this paper is to visualize the operation of possible measures and to demonstrate some conflicts between the measures.

### Conflicting targets

Certain operational reserves are required for maintaining the operational security of the power system. Currently at least 5 or 6 large units must be running in order to maintain transient stability and a minimum short circuit capacity. This rule implies a certain minimum thermal generation, but allows also a certain heat production for the central district heating systems.

In this paper the minimum thermal generation is assumed to be 600 MW. Development efforts are being prepared in order to reduce the required thermal minimum generation without jeopardizing operational security. A reduction could make domestic electricity demand available for wind power, but would at the same time transfer heat production from CHP to backup boilers.



The chart shows that the overflow of wind energy in Denmark can be reduced if the minimum thermal generation can be reduced, but only at the cost of more heat demand not being served (minimum export strategy, no measures assumed).

The calculations are based on hourly time series for wind power output and electricity demand for West Denmark in 2008. A synthetic model generates a time series for the demand for district heating. The available data and algorithms do not allow very detailed simulations (like SIVAEL from Energinet.dk), but the tool provides fair magnitudes for an overview of the interaction between some integration measures.

The model does not include the international power markets. Instead two strategies have been used. One calculation is minimizing export while a second calculation maximizes electricity output from CHP plants assuming the sufficient foreign demand is available. Real operation will be somewhere between these extremes.

The maximum CHP strategy is not challenging. With unlimited export capability and sufficient generating capacity all heat demand can be served. The presentations below are mainly focused on the minimum export strategy in order to examine self-sufficiency of Danish energy systems with 50% wind electricity.

The selected operational strategies are debatable. The visualization of some results in this paper is intended to encourage such debate.

**Overview of integration measures**

| | Strategy | Minimum export | | | Maximum CHP | | |
|---|---|---|---|---|---|---|---|
| | | Minimum electricity export | Electric heat for distr. heat | Unserved heat demand | Minimum electricity export | Electric heat for distr. heat | Unserved heat demand |
| | Case | % of wind | % of heat | % of heat | % of wind | % of heat | % of heat |
| A | Base | 17 | - | 23 | 35 | - | 0 |
| B | A + hot water storages | 17 | - | 19 | 31 | - | 0 |
| C | B + large heat pumps | 13 | 10 | 8 | 19 | 11 | 0 |
| D | C + large electric heaters | 7 | 15 | 4 | 10 | 15 | 0 |
| E | D + small heat pumps | 6 | 14 | 4 | 8 | 14 | 0 |
| F | E + flexible load | 1 | 7 | 9 | 8 | 7 | 0 |

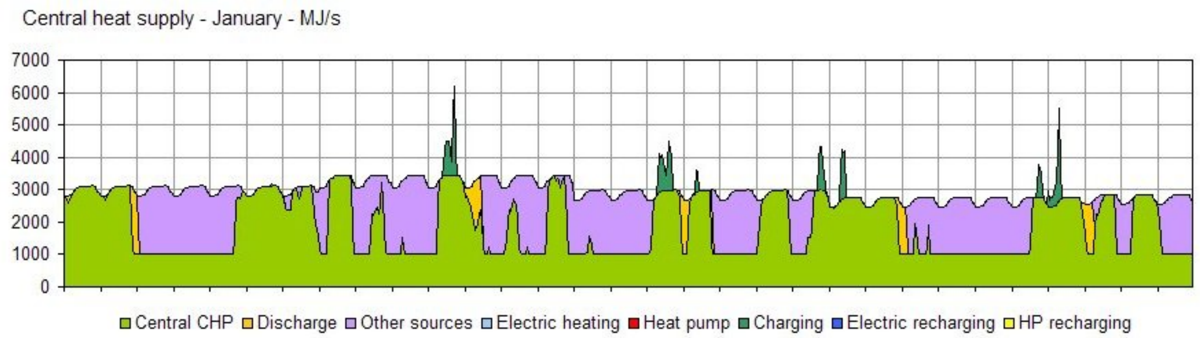
The main result of the calculations is that a combination of hot water storages, large heat pumps and electric heaters in the district heating systems and small heat pumps for consumers without district heating can reduce both overflow of electricity and unserved heat supply. A flexible electric load can reduce the overflow further, but at the cost of some increase of the unserved demand for heat from CHP systems.

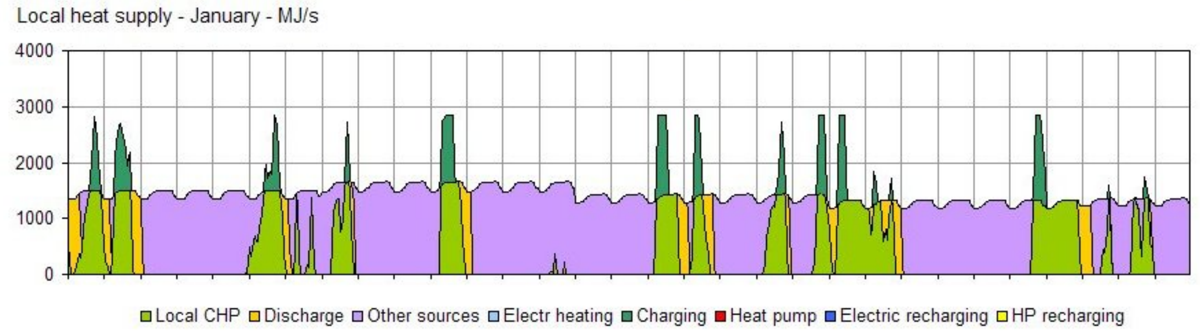
### Hot water storages

Hot water storages are already widely used in local and central CHP systems. Therefore case B could be considered as the reference case.

The problem is that publicly available data for the hot water storage capacity seems to be missing. In this paper the total Danish hot water storage capacity has been assumed to be 10 GWh (= 36 TJ) for central and local CHP systems respectively.

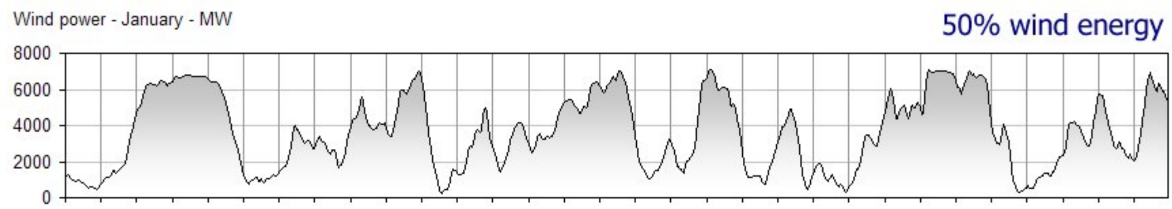
The month of January is used for the demonstration of the operation with hot water storages under the minimum export strategy:




The violet areas show unserved heat demand (to be served by backup boilers). A limited demand has been covered by discharging storages (dark yellow areas). Recharging (dark green areas) is possible during periods with low output of wind power.

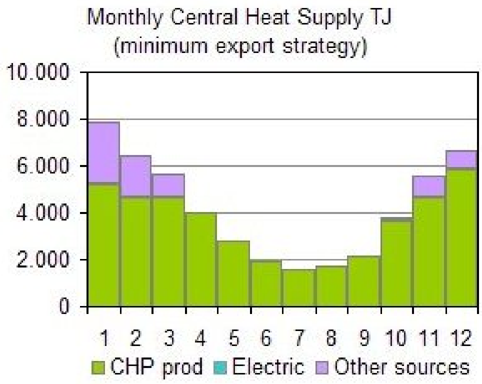
This operating pattern is not very attractive to owners of local CHP schemes who are supposed to produce a lot of heat by CHP in January.

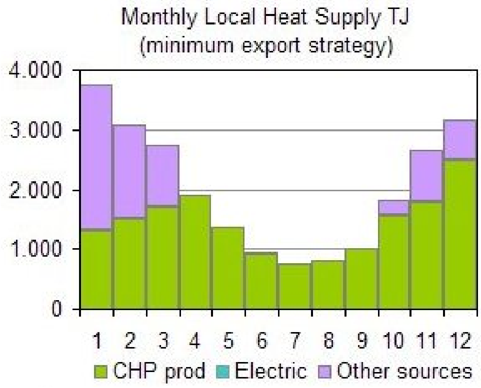



According to the charts strong wind seems to prevent operation of the CHP systems.

Larger hot water storages may be useful, but limited recharge capacity will be the bottleneck of the system.

Unserved demand for heat has been found during the cold season for the minimum export strategy. This observation demonstrates the conflict between wind power and CHP.

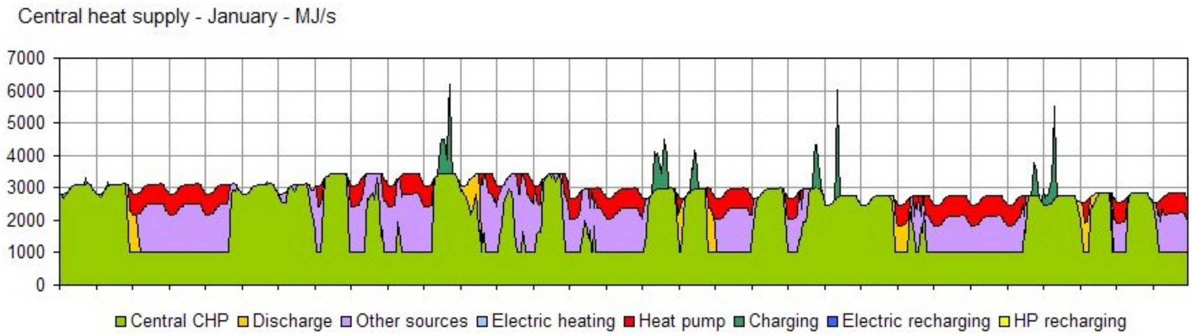


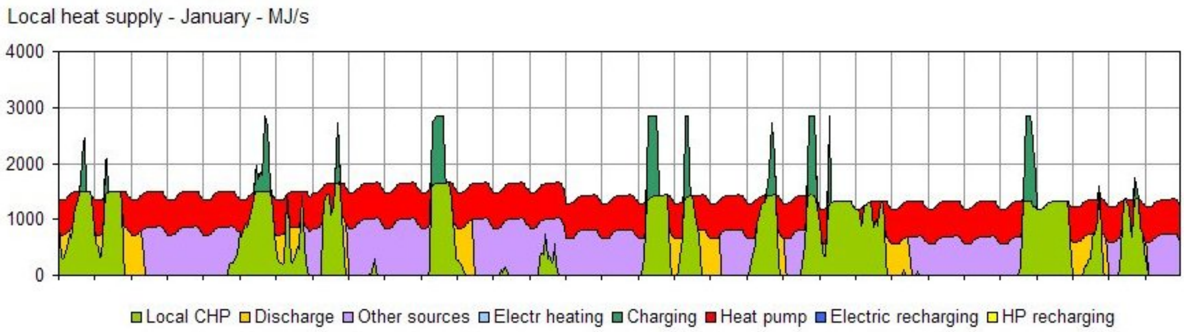




The reason for a reasonably high CHP production of heat in December is that December 2008 had a rather small wind energy output in Denmark.

**Large heat pumps for district heating**

Heat pumps for the district heating systems are supposed to contribute considerably to a better fuel economy. For the calculation the maximum electricity demand for heat pumps is assumed to be 250 MW for the local CHP systems and 250 MW for the central CHP systems. The efficiency (COP) is supposed to be 2.5 in both cases. The following chart shows the operational pattern under the minimum export strategy:

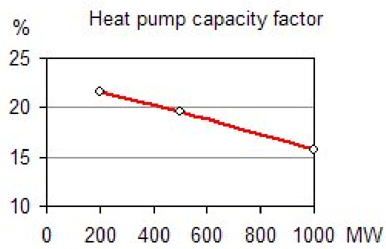



The chart shows how parts of the unserved (violet) areas have been replaced by heat pumps (red areas).

In the model heat pumps are primarily operating when there is overflow electricity available. A combination of CHP electricity and heat pumps is also considered to be acceptable because the total efficiency exceeds 1.

Higher heat pump capacities would reduce the unserved heat demand further, but also the average utilization of heat pumps would go down.




Heat pumps are expensive and should have high utilization. Calculations were made with total heat pump capacities between 200 and 1,000 MW. For this investigation a total heat pump capacity at 500 MW was chosen.

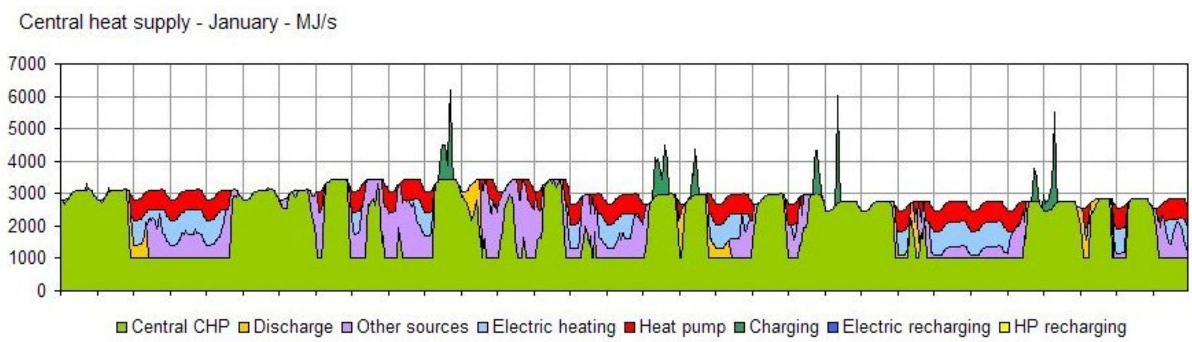
The large heat pumps add 859 GWh (or 2.5%) to the traditional electricity demand and produce 7,838 TJ heat (10.4% of the heat demand). Additional operation of heat pumps will probably be possible under market conditions. Therefore it is difficult to estimate the optimal capacity of large heat pumps.

The overview table shows that the large heat pumps are able to reduce both overflow of electricity and unserved heat.

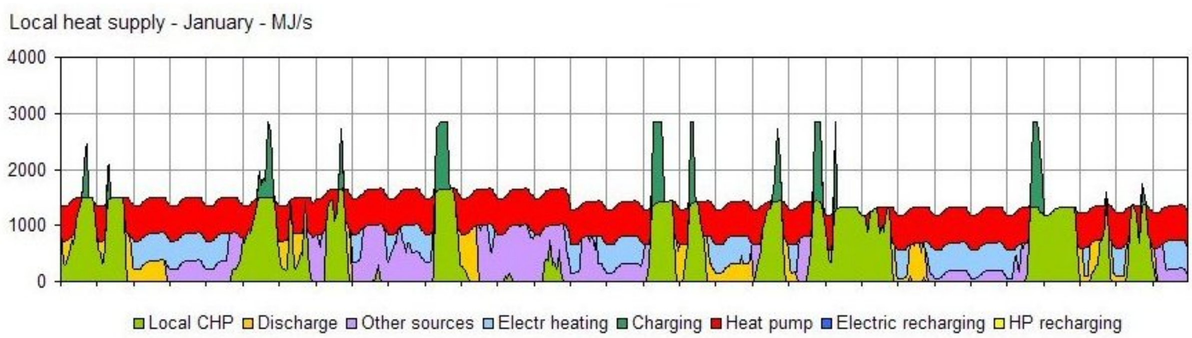
**Electric heaters for district heating**

Both heat pumps and electric heaters have already been installed in Danish district heating systems and demonstrated good results. Electric heaters are cheaper, but less efficient than heat pumps.

The capacity of electric heaters is assumed to be 500 MW locally and 750 MW centrally. The following operational pattern was found for January under the minimum export strategy:




Electric heating (light blue) offers a further reduction of the violet area.



In the model only overflow electricity is used for electric heaters. The combination of CHP and electric heaters would give a total efficiency below 1 and has therefore been ignored for this investigation.

The operational pattern for case D will be much more interesting to the operators of local CHP systems than case B and may support the long term survival of economically vulnerable schemes.

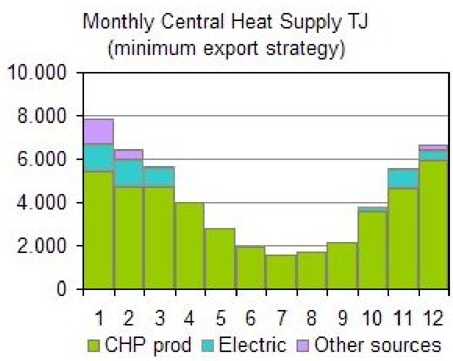
Several comments and papers have suggested that heat pumps should absorb overflow of electricity and transform it into useful heat.

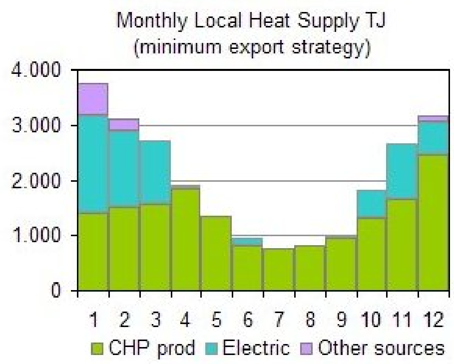
| Case D | Duration hours | Capacity factor % |
|---|---|---|
| Local heat pumps | 2,172 | 24.7 |
| Central heat pumps | 1,259 | 14.3 |
| Local electrical heat | 963 | 11.0 |
| Central electrical heat | 721 | 8.2 |

There has been reluctance to electric heating which is considered to be environmentally less acceptable.

A combination of heat pumps and electric water heaters offers a further improvement to the heat supply in an environment with a high share of wind power. Only future market conditions can tell the optimal mix.

The calculated consumption of electricity for heat pumps and electric heaters is 1,881 GWh (5.5% of the traditional electricity demand) and the heat production is 11,402 TJ (15.4% of heat demand).




The service to the district heating systems during the cold season has improved considerably in comparison to case B, particularly for the local CHP systems.

**Small heat pumps**

It is debatable if electricity demand for small heat pumps can be flexible during the cold season, but it is an advantage that the annual variation follows the demand for heat and thus provides additional electricity demand when it is desirable.

In the next case 1,800 GWh demand for small heat pumps has been added.

Compared to the previous cases small heat pumps seem to have limited effect on electricity overflow and unserved

| Case E | Duration hours | Capacity factor % |
|---|---|---|
| Local heat pumps | 1,983 | 22.6 |
| Central heat pumps | 1,121 | 12.9 |
| Local electrical heat | 854 | 9.7 |
| Central electrical heat | 613 | 7.0 |

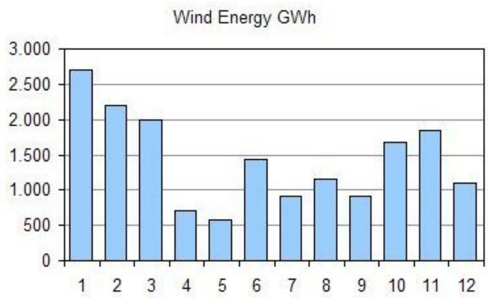
heat. The utilization of large heat pumps and electric heaters has been slightly reduced. Small heat pumps may therefore displace the large units to some degree.

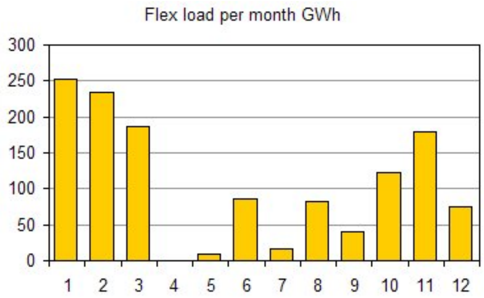
The total additional electricity demand for heat pumps and electric heaters is 3,463 GWh or 10.1% of the traditional electricity demand. If the small heat pumps are assumed to have an average COP at 2.5, the heat produced by electricity amounts to 26,378 TJ.

Small heat pumps have a better effect as the first choice (i.e. added to case B), but still more modest than other measures with comparable capacities.

**Flexible load**

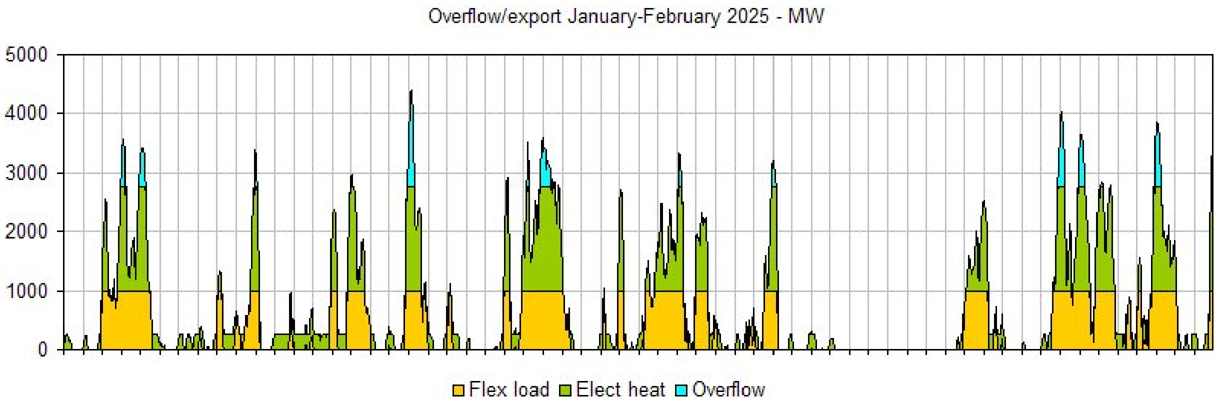
In this case overflow electricity can be absorbed by 1,000 MW flexible demands. The service for flexible customers will be quite irregular.




The supply of the flexible load depends on wind and may vary considerably from month to month. The wind power profile used for the calculations has low output in April, May and July and offers correspondingly low amount of flexible supply. Even in December the wind power output is quite low.

Flexible load customers may demand supply at normal market prices during low wind periods.




The model assumes that flexible load has a first priority to Danish overflow electricity. The supply for large heat pumps and electric heaters has been correspondingly reduced.

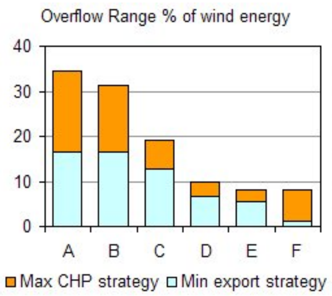
| Case F | Duration hours | Capacity factor % |
|---|---|---|
| Local heat pumps | 1,588 | 18.1 |
| Central heat pumps | 721 | 8.2 |
| Local electrical heat | 539 | 6.1 |
| Central electrical heat | 317 | 3.6 |

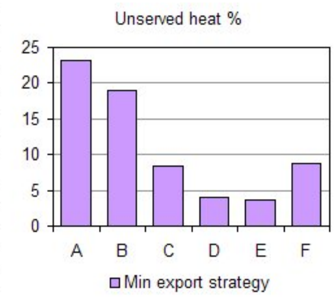
The flexible load amounts to 1,283 GWh (capacity factor 14.6%). Heat pumps and electric heaters have consumed 1,084 GWh. Export is 234 GWh or 1.2% of produced wind energy in the minimum export strategy. Unserved heat is 5,155 TJ or 7.0% of the heat demand.

Flexible load is supposed to be used for special purposes such as recharging electric cars. It may undermine conditions for heat pumps. It is an open question how an economic combination of these measures can be composed.

**Evaluation**

The traditional electricity demand I Denmark cannot absorb the electricity output from both the CHP systems and wind power capacity for 50% wind energy.

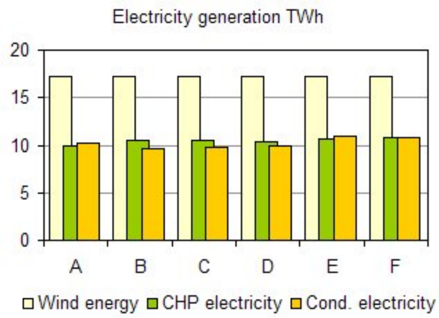



Without new measures between 17% and 31% of the wind energy must be exported or curtailed (case B).

With the selected combinations of large heat pumps and electric heaters for district heating systems this range can be reduced to between 7% and 10% (case D). The same measures will reduce the amount of unserved heat from 19% to 4% of the demand for heat from the CHP systems.

Small heat pumps seem to have a quite limited effect, and flexible demand may displace heat pumps.




All measures have only limited influence on the thermal electricity production. It is particularly interesting that condensing production in all cases covers nearly a third of the demand for electricity. The reasons are low CHP production and low wind power output during the summer season.

The essential effect of the measures will be an improved range of options for better utilization of the electricity overflow and a reduced dependency on neighbouring countries.

In the perfect self-sufficient energy system wind energy has replaced condensing production, there is no electricity overflow and all demand for heat can be served by CHP. However, due to different variability of wind, electricity demand and heat demand imbalances must be accumulated or equalized somewhere.

This paper demonstrates that coordination with the CHP system offers excellent opportunities for such functions for a wind energy share approaching 50%, but a considerable share of condensing production of electricity seems to be unavoidable.

Flexible demand may displace heat pumps. It will take a carefully prepared new market design to create an appropriate balance between coordination with the district heating systems and measures at electricity end-user level.