Balancing an Energy System with Wind, PV and CHP

Three-quarter wind energy and one quarter photovoltaic
seems to be a suitable mix

Summary
Previous analyses have shown that 50% wind energy penetration together with the present CHP[1] demand would cause electricity overflow in Denmark during the cold season. This paper demonstrates that a suitable combination of wind energy and photovoltaic (PV) can reduce overflow and fuel consumption.

Unfortunately Danish time series for PV output are not yet available. Better data could give more accurate results.

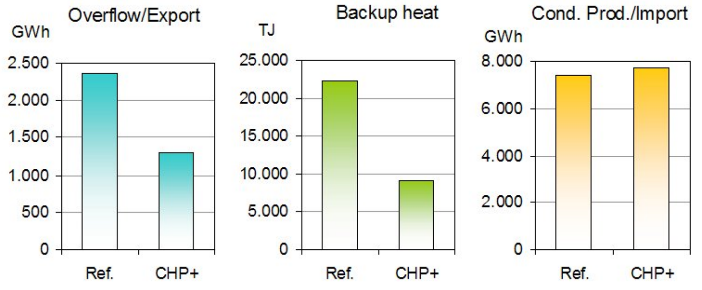
The three imbalances
An energy system in perfect balance would cover all demand for electricity and heat by wind, PV and CHP systems. Such perfection cannot be achieved in real life. For this analysis the imbalance is characterized by three quantities: **electricity overflow** (usually sold for export), **electricity deficit** (usually covered by condensing power and import) and **heat deficit** (usually covered by backup boilers).

The simulation model minimizes the electricity overflow in order to aim at self-sufficiency. No attempt was made to find a common denominator for the three imbalances and no economic evaluation was made. However, an estimate of total fuel consumption can be seen as an overall indicator.

Flexibility provided by the CHP systems
CHP systems can provide flexibility for power systems with variable production such as wind power and PV. Hot water tanks are the basic storage elements. Electric boilers and large heat pumps add to the flexibility.

Danish CHP facilities		Ref. Estimated 2012	CHP+ Assumed 2020
Hot water tanks	TJ	144	144
Electric boilers	MW_e	300	800
Large heat pumps	MW_e	0	600

A comparison can demonstrate the possible impact of these elements on the three imbalances. The produced wind energy is 50% of the electricity demand in both cases. The reference case includes an estimate of the CHP facilities in 2012. It is expected that more electric boilers and heat pumps will be installed before 2020. The CHP+ case includes an assumed capacity of electric boilers and heat pumps.



The charts demonstrate the effect. The overflow has been reduced by 45%. The heat deficit has been reduced by 59% while the electricity deficit has increased by 5%.

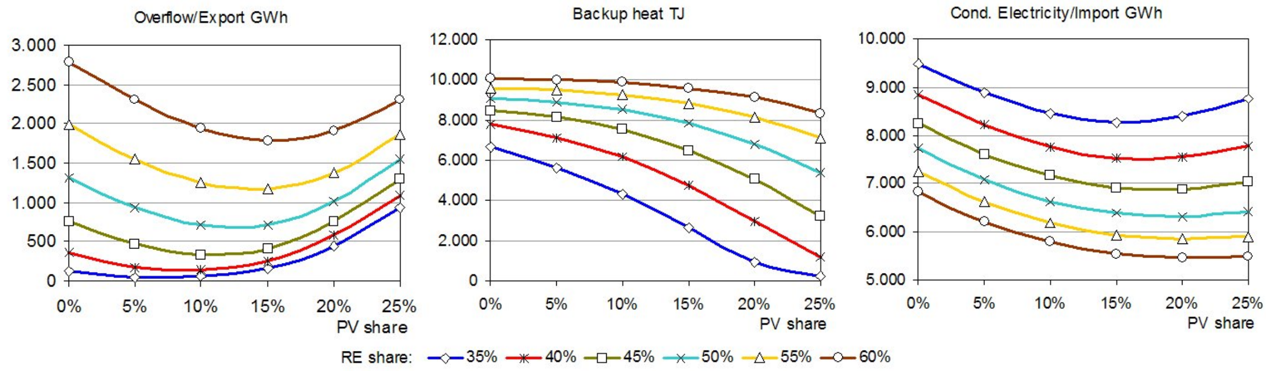
The CHP facilities are kept constant at the CHP+ level for all following

[1] CHP: Combined Heat and Power

calculations in this paper. The level may be debatable but for simplicity wind power capacity and PV capacity will be the only changing parameters in the following calculations.

The main results

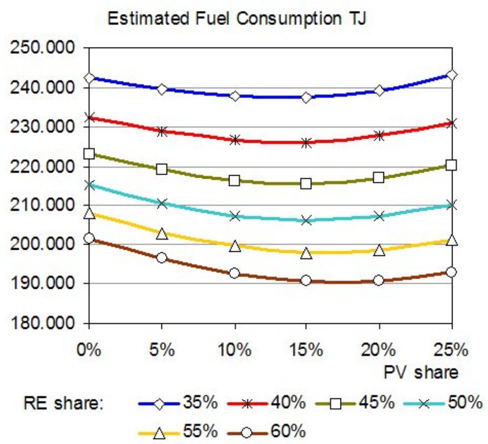
The calculations include combinations of wind energy between 35% and 60% of the traditional electricity demand and PV production between 0% and 25%. The corresponding shares of renewable energy (RE[2]) are between 35% and 60%.



With 50% RE the overflow can be reduced by further 46% by replacing about a fourth of the wind energy by PV. The reason is the different profiles of the wind power and PV time series. However, a further increase of the PV share would cause a steep overflow increase. The reason is that the lower PV load factor begins to dominate the resulting time series.

PV has a different impact on the need for heat production from backup boilers. The reason is that replacing wind energy by PV implies less electricity production during the cold seasons and more electricity production in the summer. This leaves more electricity demand for the CHP systems.

It is less obvious why the need for condensing production or import is increasing for PV shares exceeding about 20%. Replacing wind power by PV creates higher production peaks and deeper valleys. The peaks cause increasing overflow. The valleys must be filled by something else. The CHP production is steadily growing with the PV production, but for the high PV penetrations not enough for filling the valleys.



The total fuel consumption has been estimated based on the assumptions that the efficiency of CHP units and heat boilers is 0.9 and that the efficiency of condensing electricity production is 0.4.

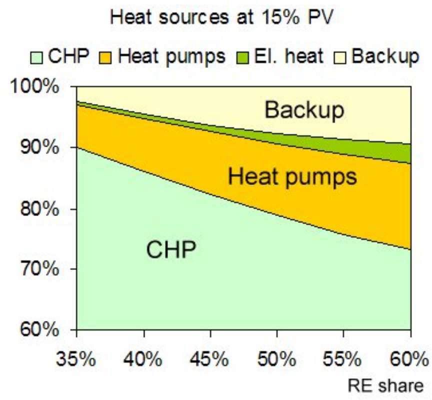
This image suggests an optimal PV share about 15% of the traditional electricity demand.

It also suggests an extension of the RE share beyond 60%. However, the CHP production will fall correspondingly and the CHP capacity might be reduced. This could become a problem.

[2] In this paper the abbreviation RE includes only wind and PV. However, even CHP units can use renewable fuels.

PV share locked at 15% of electricity demand

In this section the PV share will be locked at 15%. In normal operation energy from wind and PV will displace CHP electricity. Therefore the CHP production will fall when the total RE share increases from 35% to 60%.



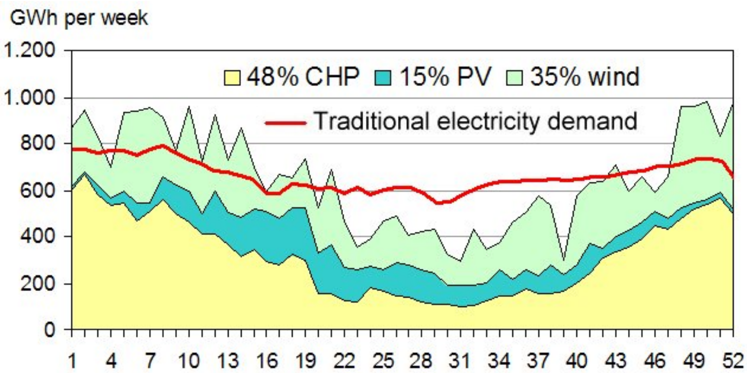
The results are valid only with the CHP production capacity and the additional facilities, specified above.

It is a question how and when the CHP operators will respond to the falling production.

As demonstrated above the CHP systems provide vital flexibility for balancing the power system. It will depend on the economic framework if the capacity can be maintained for CHP systems with decreasing production. Without knowing the future economic framework, particularly regarding heat pumps, the future capacity of the CHP systems cannot be estimated.

15% PV plus 35% wind energy (= 50% RE)

The calculations suggest a combination of about 15% PV and 35% wind energy as the best compromise.



The traditional electricity demand is defined as 100%. There will not be room for the 48% CHP electricity but rather for 38%. Condensing production and import cover 19%.

Large heat pumps and electric boilers convert electricity to heat. This *new electricity demand* is about 5% of the traditional demand in this case. 2% overflow is exported.

The corresponding distribution of heat supply is 79% from CHP, 12% from heat pumps, 2% from electric boilers and 8% from backup boilers.

The results represent a minimum export case. Conversion of electricity to heat will depend on the price level in the international electricity markets. There will be different break-even prices for heat pumps and electric heaters. Potential investors in heat pumps and electric heaters may have more or less confidence in a stable future, particularly regarding the energy balances in Denmark‘s neighbouring countries. Therefore it is difficult to estimate the future capacity of these facilities.

The data problem

The analysis is based on one year hourly time series for wind power, PV, electricity demand and heat demand. Recorded time series for electricity demand and wind power are published by Energinet.dk. However a time series for Danish PV is missing. Therefore a time series was downloaded from TenneT in Germany. The German load factor is 13%. For Danish conditions 10% would be more realistic.

More accurate calculations would be possible if hourly estimates of Danish PV output were publicly available. Separate time series for offshore wind power would allow creation of a future wind power profile depending on the assumed distribution between onshore and offshore wind. TenneT in Germany publishes separate hourly production for offshore wind farms, but the installed capacity is not yet sufficient for a realistic profile.

Hopefully Energinet.dk will expand its excellent data service by PV estimates and offshore wind.

A synthetic model has been used for generation of a heat demand profile.

The simulation model

One year is simulated, hour by hour. The essential input is time series for wind power, PV, electricity demand and heat demand. For each hour the best possible balance must be found for heat and for electricity. There are two types pf production capacity. Counter pressure units (mainly small units) produce electricity and heat in a constant proportion. For extraction units the proportion is variable because they can combine the CHP mode with the condensing mode.

Heat pumps and electric heaters are mainly used for converting surplus electricity from wind and PV into hot water. Even CHP electricity can be used by a heat pump. The combination CHP and electric heaters is blocked because a backup boiler could have at least the same efficiency.

The hot water tanks are essential for the operational flexibility during the cold season. They offer a large variety of operational options.

Due to lack of credible economic data the program does not include economic evaluations.

Conclusion

The operational interaction between wind power, PV and CHP has been demonstrated.

From an operational point of view a three to one combination of wind energy and PV energy seems to be appropriate.

The CHP system can provide necessary flexibility for balancing the variations in wind power and PV. Therefore it is important to maintain a certain CHP capacity, even in the long term. Furthermore CHP systems can contribute to a green future by switching into non fossil fuels.

Unfortunately Danish time series for PV output are not yet available. The publication of hourly time series with Danish estimates of PV output and separate records of offshore wind power would allow more accurate calculations.