12th IEA Heat Pump Conference 2017

Flexible heat supply and sustainability

Version 22 June 2017

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Abstract

Because of the growing share of wind and solar energy in our electricity supply the electricity rates will be more volatile. In Germany, even negative rates occur regularly (Fraunhofer, 2016). Industrial companies can benefit from fluctuating electricity prices by using combined heat and power (CHP) during high rates and heat pumps and vapor recompression at low electricity rates. This hybrid energy supply leads to a robust energy supply system with heat pumps whereby companies are less vulnerable to fluctuations in the electricity market and are more attractive for shareholders with long term focus.

Flexibility; heat supply; heat pumps; vapor recompression; industry; sustainability;

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Nomenclature

c_el	One year forward commodity tariff electricity	€/MWh_{el}
c_fuel	One year forward commodity tariff natural gas	€/MWh_{th}
COP	Coefficient of Performance Heat Pump system	MW_{th}/MW_{el}
Δc_chp	Thermal Spread Combined Heat and Power system	€/MWh_{th}
Δc_hp	Thermal Spread Heat Pump	€/MWh_{th}
η_b	Thermal efficiency reference boiler	
η_el	Electrical efficiency Combined Heat and Power system	
η_th	Thermal efficiency Combined Heat and Power system	

1. Sustainability and politics

Almost the whole scientific community recognizes our CO_2-emissions lead to unacceptable environmental impact with huge economic and demographic consequences. In Western Europe politicians decided to price CO_2-emissions with the Emission Trade System* in order to phase out fossil fuels. This emission trade system does function (Petric & J., 2014) thought the low tariffs and the volatility don't give much trust in the system (Dijksma, 2016). The cu rrent CO_2-tariffs are only a small part of the energy costs and do hardly effect investment decisions to replace fossil fuel by sustainable alternatives. For achieving their reduction targets countries stimulate replacing of fossil fuels by sustainable alternatives by subsidies on investments and feed-in tariffs. These last instruments are more successful as shown in the spectacular growth of sustainable electricity in European countries (fig. 1).

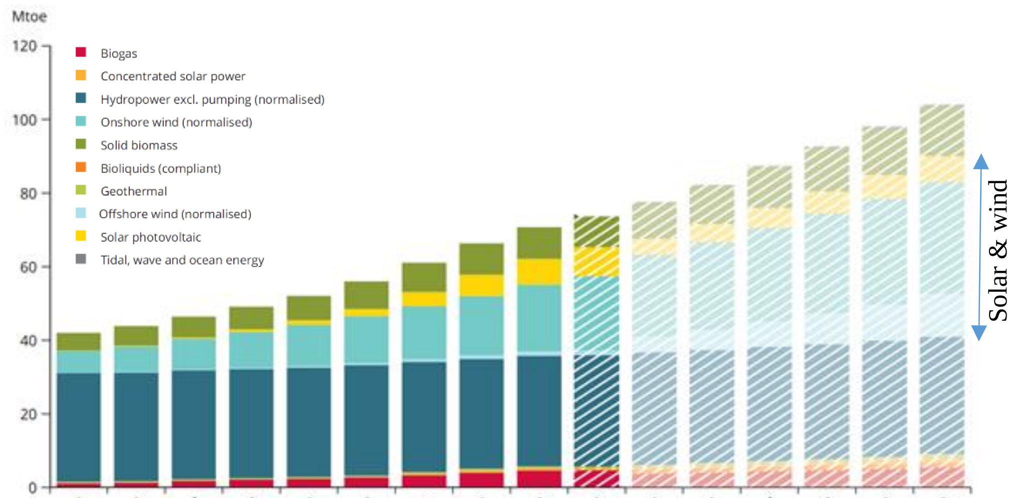

Figure 1. Renewable electricity in European Countries in Million tonne of oil equivalent. In 2014 26,9% of the total production (Tomescu, Moorkens, & e.a., 2016)

* See for explanation : https://ec.europa.eu/clima/policies/ets/index_en.htm

1. Volatility of prices

Especially the growth of wind and solar energy lead to challenges how to balance production and consumption. With a surplus of production of wind- and solar the electricity tariff drops to even negative values in a country as Germany (fig. 2). With a sudden shortage the electricity tariff increases.

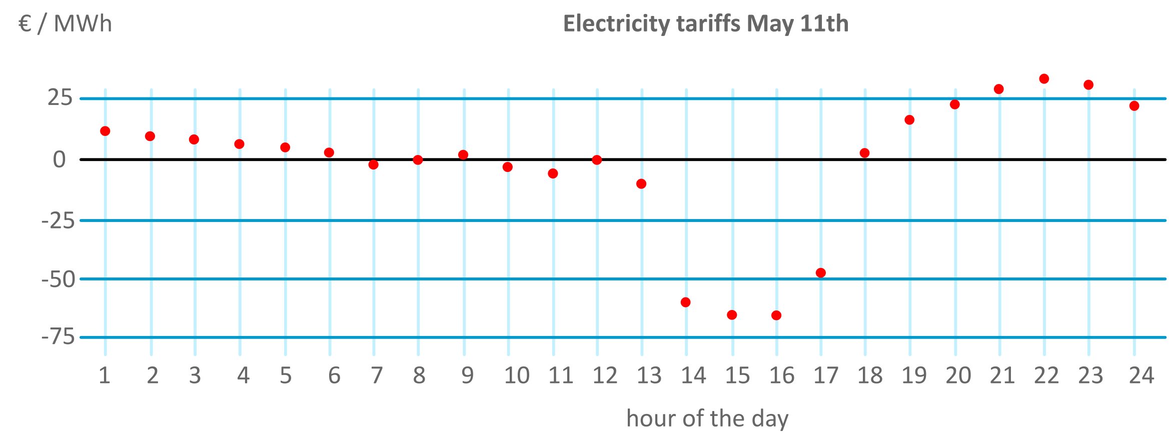

Figure 2. Electricity tariffs in Germany May 11th 2014 (Morris, 2014).

Not only Germany but also countries with a large share of hydro power have to handle surplus of electricity, for example by resistance heating in a steam boiler as seen in Norway (fig. 3).

Figure 3. Electric steam boiler 1 ton/h in Norway (photo Energy Matters)

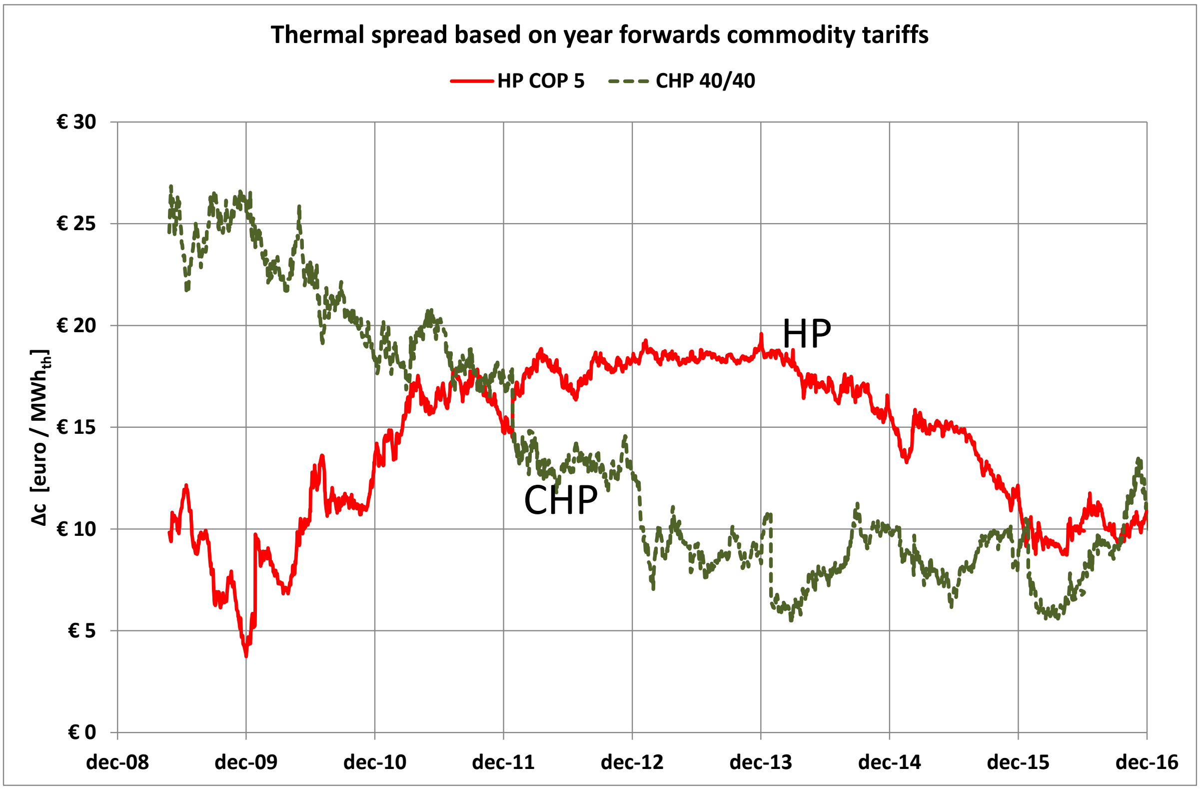

Figure 4. Thermal Spread in the Netherlands with 40% electrical efficiency, 40% heat efficiency and a reference boiler efficiency of 95%. The heat pump with a COP of 5.

Electrical driven heat pumps only can be attractive if the costs of electricity are lower than the costs of fuel saved. For evaluation of the market situation Energy Matters developed the "Thermal Spread" in analogy with the "Spark Spread". The "Thermal spread" is defined as the profit (costs minus savings) of a MWh of heat produced based on the year forwards of commodity tariffs only. For heat pumps this is the quotient of the electricity tariff and the COP minus the quotient of the fuel tariff and the boiler efficiency.

$$\Delta c\_hp = 1/COP \ \times c\_el - 1/\eta\_fuel \times c\_fuel$$

For CHP this is the cost of fuel minus the savings of electricity and heat.

$$\Delta c\_chp = 1/\eta\_th \ \ \times c\_fuel - \eta\_el/\eta\_th \times c\_el - 1/\eta\_b \times c\_fuel$$

For the Dutch situation the thermal spread of a heat pump with a COP of 5 is has been attractive compared with a gas engine (Fig. 4) from 2012 but the advantage disappeared in 2016 due the changing tariffs.

2. Hybrid energy systems

The volatility of the tariff of electricity leads to a situation where industrial companies are challenged to develop a hybrid energy supply. In situations with high power prices CHP is an attractive system. In situations with low or even negative tariffs electrical heating with resistance heating or electrical heat pumps is preferable. The switch between heat pumps and CHP must be possible within hours because the availability of wind and solar changes over daytime as does the energy consumption. Flexibility is key.

Though the share of wind and solar will increase the expectation is that the negative tariffs will vanish because market parties invest in storing cheap electricity in batteries, cold stores or heat buffers. Also, in some industries, the production of (semi-finished) products is possible if a production line has overcapacity (Krebbekx & e.a., 2015).

3. Shareholder value

Shareholders with long term targets prefer companies with a high level of sustainability (Schaltegger & Figge, 1998). Companies depending too much on fossil fuels are vulnerable or sudden increase in energy tariffs. Uncertainty leads to lower shareholder value. In addition, consumer markets are sensitive for environmental aspects (Boztepe, 212). So most multinationals operating in the Netherlands have ambitions to go sustainable (corporate social responsibility). Examples are AkzoNobel, Cosun, DSM, FrieslandCampina, Fujifilm, Heineken, Johnson&Johnson, Philips and Unilever. Some of them seize opportunities and initiatives nearby like heat of waste incinerators or steam of exothermal processes. Examples are AkzoNobel Hengelo, Chemiepark Delfzijl, Dupont Dordrecht, Shell Pernis. The long term availability of cheap biomass is uncertain because of the use as feedstock for products instead of energy production (Hennig & e.a., 2016). In addition, biomass leads to environmental problems in cultivation, transport, during storage and locally burning bio-mass causes emission of fine dust (Kluts & e.a., 2017). Geothermal sources for steam production are extremely expensive if the wells are deep and seen as high risk investments (Boxem & e.a., 2015). In addition, the capacity of tens of MW's does not fit in most of the industries. Some companies invest in wind-farms to allocate green electricity (for example the project with AkzoNobel, DSM, Google and Philips) (Jessayan, 2016). Other companies buy green electricity with certificates (For example PostNL, ABN Amro, KPN, NS and Landal GreenParks). The purchase of green gas made of biogas has much more financial implications because of the price and the energy needed for cleaning and compression (Pertl & e.a., 2009). In addition, the availability is restricted. Other fuels like green hydrogen and bio-liquid are not produced on an industrial scale yet. For the short term green electricity is the only serious way to go sustainable. Probably the community develops to an all-electric society!

4. Closing loops

Do we have an energy or an exergy problem? Most industrial companies produce products with ambient temperature using feedstock of ambient temperature as well. So in principle you don't have to supply heat for production. So why do we need so much fuel for production? The answer is that processes are developed with the idea high pressure steam and high temperature flames are the basis for processes. All systems are developed with a cascade of temperature levels (fig. 4). Waste heat of high temperature processes is fed to lower temperature processes. Why don't we close loops at every temperature level (fig. 5)? The only thing we have to do is to compensate exergy losses. And exergy losses can be compensated with electricity. So if an industrial firm wants to go sustainable, it is best to redesign the process with the exergy approach in mind.

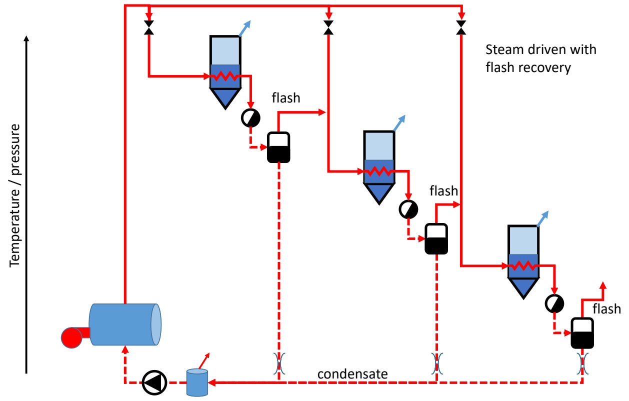

Figure 6. Steam driven system in cascade with steam trap flash recovery. Flash steam of the evaporators can be recovered with thermal vapour recompression (not shown).

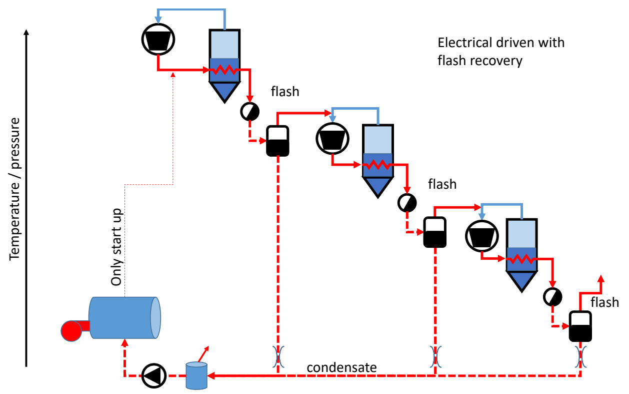

Figure 5. All electric solution. Steam is only needed for starting up the production.

For example : by re-arranging the evaporators of a sugar industry we supported a design based on a full electric situation with vapor recompression only. For starting up boiler steam is still needed.

5. Challenge for the heat pump society

On short notice all waste heat should be evaluated to reuse at a higher temperature level to minimize the losses at the end of the cascade. Based on the former analysis the development of affordable heat pumps for every temperature level and affordable mechanical vapor compression is the challenge for the heat pump society.

In the Netherlands the heat pump development is concentrated at ECN (Kleefkens & Spoelstra, 2014) and Technical University Delft.

- A high temperature heat pump (130 ºC) is developed and demonstrated by ECN, Bronswerk Heat Transfer and IBK (Kremers & Brink, 2016).
- A thermal acoustic heat pump for temperatures up to 250 ºC (Spoelstra, 2016).
- A chemical heat pump fully fed by waste heat in cooperation with Q-pinch (heat transformer) (De Boer, 2016).
- In Delft the Technical University develops an isothermal compressor for improving the COP of a water – ammonia heat pump (>100 ºC) with a Lorentz cycle (Infante Ferreira & Gudjonsdottir, 2016).

The price of all these systems must be made attractive for the market by standardizing and cooperation in development.

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