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Towards District Heating With 80-100 % Solar Fraction

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Abstract

The implementation of a large scale solar heating system to supply a district heating network which stands in front of an upcoming expansion (to cover three more villages) has been investigated. This includes the feasibility study of aiming for large solar fractions. The result is that a solar heating system which can supply the entire heat demand of the expansion will be more feasible than only operating with biomass boilers. The study also investigates the possibility of going one (big) step further to reach solar fractions in the range of 80 % not only for the expansion, but for the entire district heating network with an annual heat demand of approximately 60,000 MWh. The results indicate that the cost of having a heat supply with a solar fraction of around 80 % would match the cost of a biomass based supply if a new tax on biomass would have been approved. It has later been decided to drop the implementation of this tax and without it the most feasible solar fraction is significantly lower for the specific case. However the average heat price for a system with high solar fractions is in the range of typical district heating production costs for other fuels than biomass (e.g. natural gas) thus making it a potential option for future district heating solutions.

Key-words: Solar district heating, large scale, solar fraction, business model.

1. Introduction

On the Danish island Bornholm in the Baltic Sea the local utility are planning to expand one of their district heating networks which at the moment are supplying the villages Nexø, Balka and Snogebæk from a straw fired district heating plant in the outskirts of Nexø. The extension consists of establishing district heating in the nearby villages Listed, Svaneke and Aarsdale, and coupling them to the same district heating plant while increasing the boiler capacity. The utility also considers using a solar heating system to supply some of the demand. The feasibility of different solar fractions has been investigated in a case study focusing on this situation.

2. Business model

It is well known that a barrier for large scale solar heating systems can be the big up-front investment costs. The business model for the utility at Bornholm is to keep the up-front costs as low as possible and to get the income from the heat bill. This is possible because the district heating utilities in Denmark are able to get loans with a very low interest rate and thereby spread out the payment over a long period of time (up to 25 years). This strategy can be applied for investments in the capacity of the district heating plant as well as for the network. The result is that investments in renewable energy implementation and efficiency improvements of the heat production system are not held back by large investment costs.

Most of the investments required to supply district heating for a new area is paid back by the customers over a number of years (i.e. included in the heat bill). For a house with an oil boiler the customer has to pay approx. 2,200-2,300 € for the district heating connection. This includes the pipe connection to the house incl. installation, a heat meter, district heating unit with hot water tank installed and shunt regulation, removal of oil boiler, old hot water tank and oil tank.

For electric heated houses there is no connection fee. On the other hand these customers need to install a

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water based heating system in their houses.

When the transition is completed, the customer is left with 30-40 % reduction in annual heat costs knowing that also the environment benefits from the solution.

The offer only applies for a limited period of time and only if a certain share of the potential customers sign up for being connected to the district heating network before the utility begins the construction. This way the utility do not risk installing a network where only a few customers want to be connected. Customers who choose to connect to the district heating network at a later time will have to pay a higher connection fee.

3. The district heating plant units

The present heat production in the case study is based on straw boilers and this will also be the supply of some or all of the expansion of the network. The fuel is available from the local farmland.

Besides the boilers the utility are looking towards introducing a large scale solar thermal system which – for large solar fractions – could include a seasonal heat storage and a heat pump. In that case the system could be constructed as shown in figure 1.

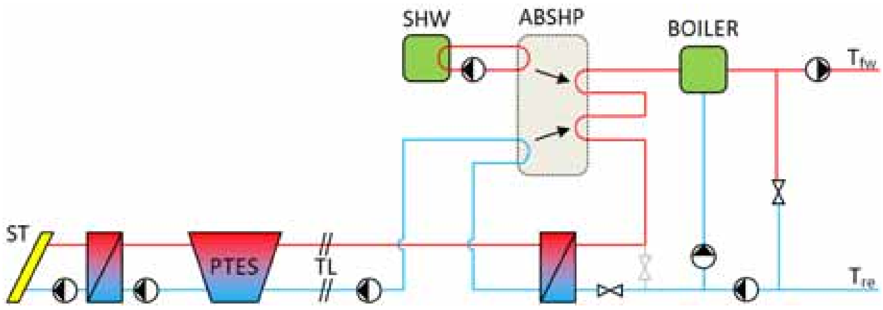

Fig. 1: Principle diagram of a solar heating system combined with seasonal heat storage, absorption heat pump and boiler(s).

The solar heat is supplied to the heat storage from where it is supplied to the district heating network by means of a heat exchanger (directly), by using a heat pump or a mix of these. The heat pump makes it possible to extract heat from the storage at lower temperature levels than the return temperature of the district heating network. This means that the storage volume is utilised more efficiently compared to a storage which can only use heat by means of a heat exchanger (i.e. only down to the return temperature level). In other words it is possible to store a larger amount of energy in a storage connected to a heat pump than if there is no heat pump. Another benefit is that the lower temperature in the storage improves the efficiency of the solar collectors. (However one should be aware not to "count the solar heat production twice" when assessing the performance of the heat pump since the heat extracted from the storage is not freely available like in air-to-water heat pumps – it has to be paid for as the investment in the solar collectors.) By simulating the system with different sizes of collector field, storage and heat pump, different scenarios can be investigated.

4. Feasibility calculation method

The district heating plant has been modeled in the software tool TRNSYS (version 17.01) in order to evaluate flows and temperatures in the energy system hour by hour during a year. The simulation runs for a period of two years (17,520 hours) and the results from the second year are used in the calculations. This way the effect of the start-up preconditions in the beginning of the simulation is minimised.

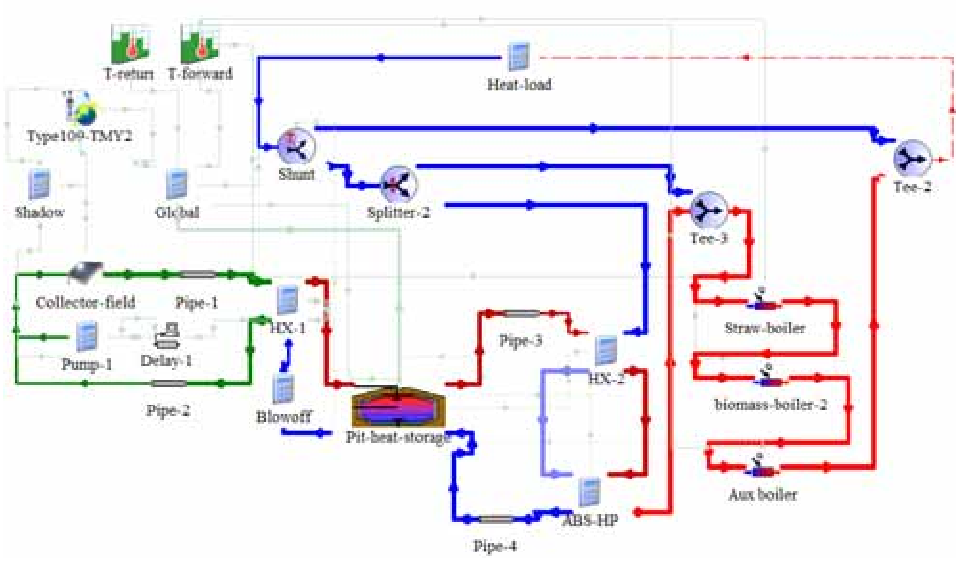

Figure 2: User interface of TRNSYS model for a system with solar collector area, seasonal storage and absorption heat pump.

The average heat price is calculated as the sum of annual operation & maintenance costs (e.g. fuel costs) and annual repayments of the loan for the district heating plant units (solar collectors, storage etc.) divided by the annual heat demand. This number needs to be as low as possible for the utility which is why it can be used to optimize the system component sizes.

A software tool called GenOpt is used to perform a numerical optimisation of the system. This is done by varying different (user specified) parameters (e.g. the total solar collector area) in the TRNSYS model in order to find a configuration which provides the lowest possible heat price. This can be done with several different parameters in the same optimisation.

When both operation & maintenance costs and the repayment of the loan is included in the overall calculation of the total annual costs for the utility, the result is that the potential savings provided by a solar heating system (and/or other energy technologies) is highlighted and that the focus is thereby moved from the large up-front investment costs to the potential benefits of the investment.

5. Solar fraction: 100 % of network expansion ~ 23 % of total demand

To supply 100 % of the heat demand associated to the expansion of the network (on an annual basis) a solar collector area of approx. 33,000 m^2 is required. This share corresponds to approx. 23 % of the future entire network demand. The solar district heating system will benefit from the interaction with the rest of the network thus in practice supplying solar heat to the entire network in summer and in turn being supplied by biomass boilers in winter. This way there is no need for a seasonal storage and absorption heat pump. Instead of a pit heat storage as shown in figure 1 a cylindrical steel tank of 3,000 m^3 is used. The district heating supply in this scenario is seen in figure 3. The resulting heat price is below the heat price for operation solely based on biomass boilers.

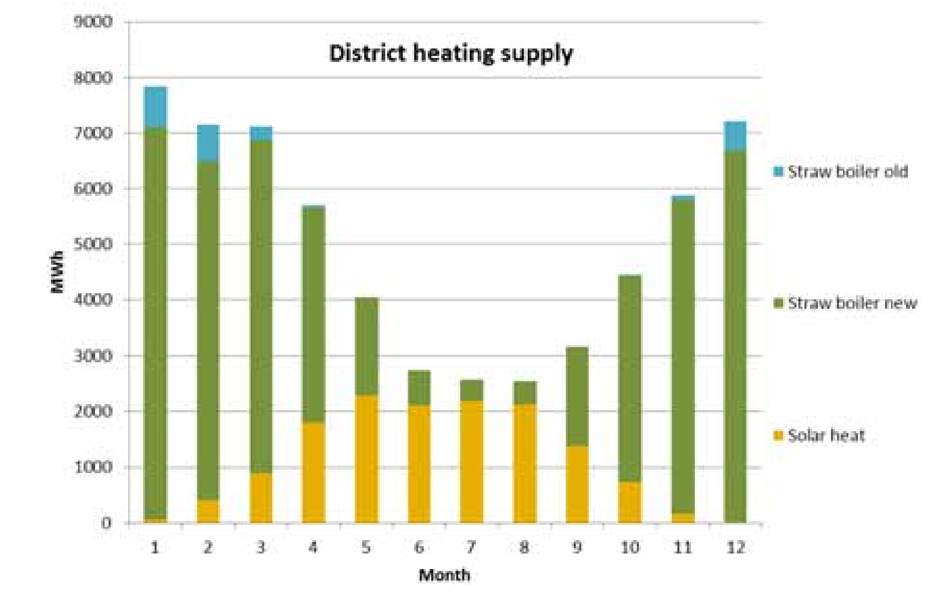

Figure 3: Heat supply for the different heat producing units for a solar heating system covering 23 % of the total demand.

6. Solar fraction > 80 % of total demand

A solar fraction of more than 80 % can be reached by several combinations of solar collector area and storage volume. In figure 4 is seen the variations in a) heat price and b) the solar heat supplied to the storage per m^2 of collector area for four different combinations of collector area and storage volume. All combinations result in a solar fraction of approx. 82 %.

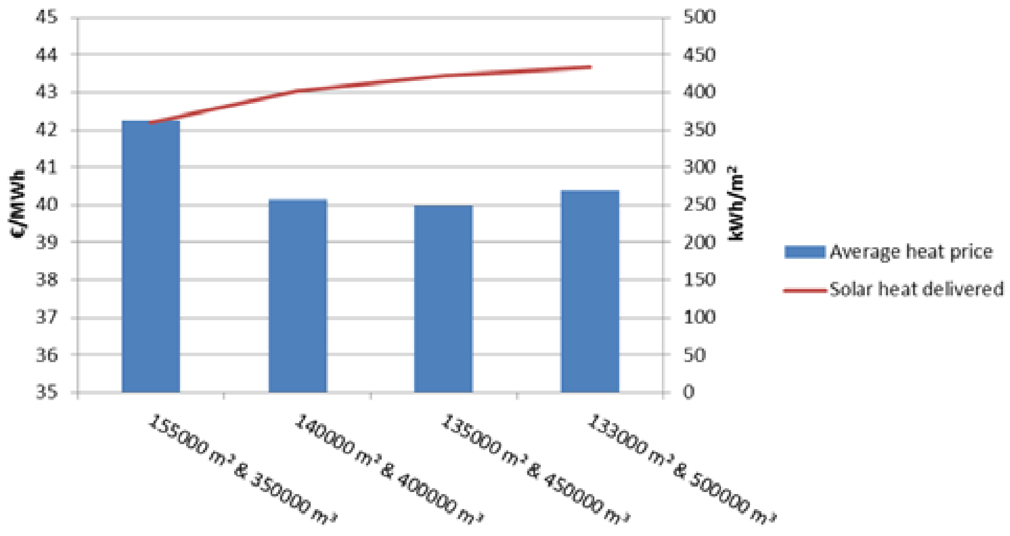

Figure 4: Variations in heat price and solar heat supplied to the storage per m^2 of collector for different combinations of collector area and storage volume all resulting in a solar fraction of 82 %.

The lowest average heat price for this solar fraction is for a 135.000 m^2 solar collector field and a pit heat storage of 450.000 m^3 (along with a large scale absorption heat pump as described in section 3). Using these figures in the simulation model the heat supply becomes as shown in figure 5.

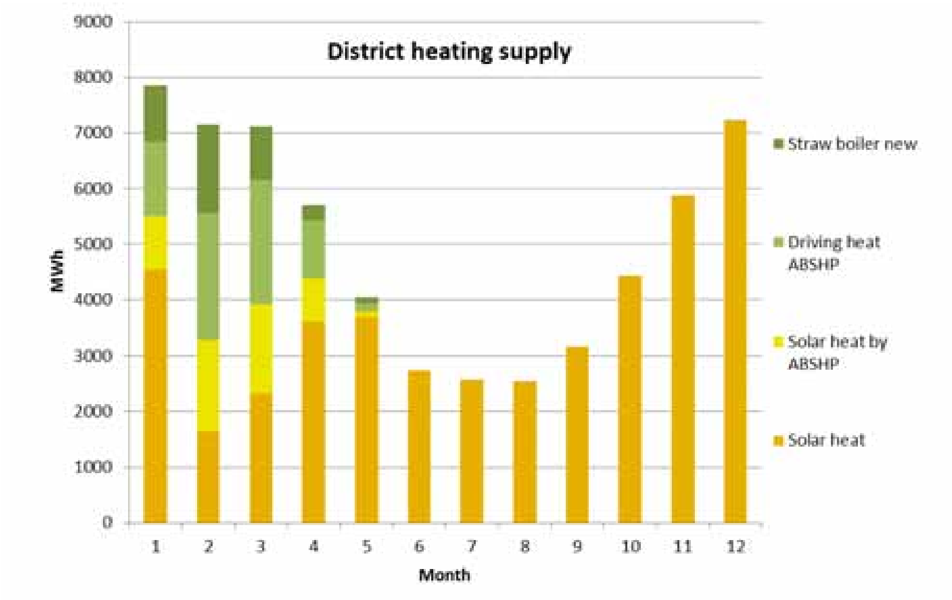

Figure 5: Heat supply for the different heat producing units for a solar heating system covering 82 % of the total demand.

In figure 6 is seen the supply of energy to the system (being solar heat from the collector field as well as fuel). Comparing figure 5 and 6 it is seen that the storage is charged mainly in spring and in summer and that this heat is enough to cover almost all the demand the rest of the year.

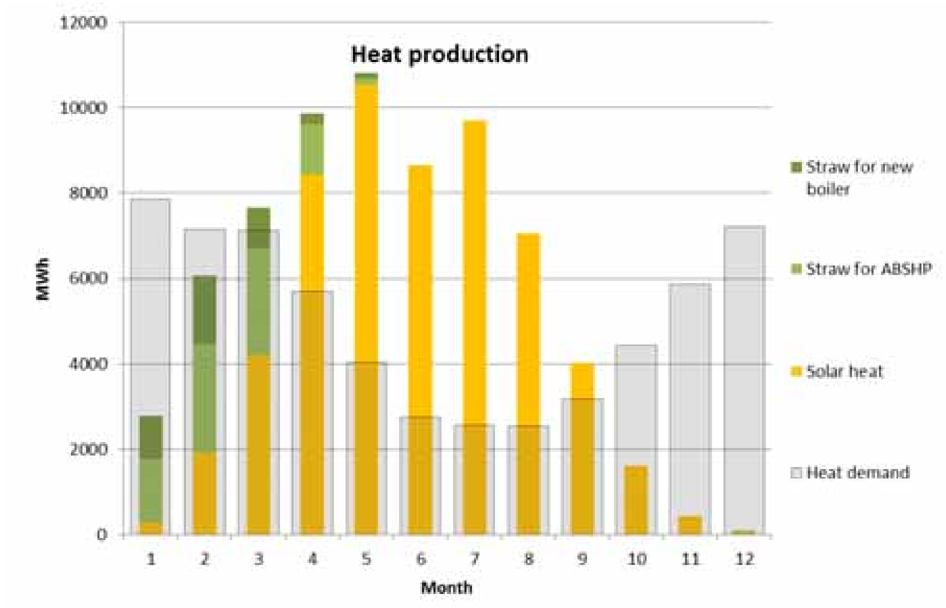

Figure 6: Solar heat and straw based heat used in a solar heating system covering 82 % of the total demand.

7. The influence of politics

A new tax on biomass fuels was introduced in 2012 which should have been in effect from the beginning of 2014. After a long period of discussions the Danish parliament later decided to drop this specific tax. Since this tax would gradually become a large part of the total biomass price it favoured solar thermal systems in the ‘competition’ against biomass boilers in the case study. Hence the optimisation varies significantly depending on whether or not the tax is included in the economic calculations.

In general this political change underlines the argument for solar district heating based on the fact that the cost of solar heat is fixed throughout the lifetime of the solar heating system. In principle a utility becomes more independent from the politic decisions regarding taxation on the different fuels when the solar fraction is increased.

8. Financial results

Including the above mentioned tax – as it was done initially in the case study based on the financial expectations – results in a heat price for the 82 % solar fraction system which can compete with the heat price of a system only using biomass. Without this tax the large solar fraction configurations are no longer the most feasible solution for the case in question. However a system supplying the entire demand for the three villages forming the expansion of the network (described in section 5) will still be more feasible than to base the operation only on straw boilers.

9. Conclusions

When being an available option, biomass has in general been the hardest competitor for solar district heating in Denmark because of the low costs and almost no taxes compared to other fuels. Even without the previously expected tax, large solar fractions can be feasible for a number of district heating plants – especially if they are based on fossil fuels.

Though the preconditions for the specific case study have changed against the favour of very high solar fractions, the study shows that even at large solar fractions the heat can be produced at reasonable costs (e.g. comparable to natural gas CHP plant heat prices). There is a national tendency towards larger solar district heating systems and larger solar fractions. Several systems aiming for 50 % solar fraction have been realised or planned for the coming years and this development could indicate the next step for solar district heating in Denmark: Moving from widespread awareness of the reliability and feasibility of systems for solar fractions up to 25 %, to more complex systems interacting with several other units in order to supply the majority of the annual heat production.

10. Abbreviations

CHP Combined heat and power

ST Solar thermal collector field

PTES Pit thermal energy storage

TL Transmission line

SHW Superheated water circuit

ABSHP Absorption heat pump

T_{fw} District heating network forward temperature

T_{re} District heating network return temperature

S_f Solar fraction

11. Acknowledgement

This work has been carried out as part of the Solar District Heating Plus project (SDHplus) co-funded by the Intelligent Energy Europe Programme of the European Union.