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THE ROLE OF SOLAR HEATING IN THE FUTURE HEAT SUPPLY PORTFOLIO: A TECHNO ECONOMIC ASSESSMENT FOR TWO DIFFERENT DISTRICT HEATING GRIDS

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Abstract – In this paper the integration of solar thermal energy into two different district heating networks is assessed. In the first case the integration of larger scale solar thermal heat into an existing coal fired district heating network is assessed. In the second case the integration of small scale solar heat into a new settlement area with low energy buildings that will be entirely supplied by a new biomass based district heating system is assessed. For both analyses the levelized costs for different combinations of solar thermal collectors and thermal storages are calculated with the optimization tool energyPRO and the achievable solar fractions are compared. In general the analysis showed that levelized costs of solar thermal heat tend to be slightly higher than current supply portfolios but can compete with other renewable heating options and integrate a significant share of solar heat and thus reduce the use of valuable combustibles.

1. INTRODUCTION

The objective of this work is to identify possible design options of integrating solar energy in district heating systems and to assess their economic feasibility for the cities of Ansfelden in Austria and Herten in Germany. For these cases, a thorough analysis of the heating and cooling sector has been carried out (Büchele and Popovski, 2017a and 2017b) and heating and cooling strategies have been derived in close cooperation with the local authorities. The work has been carried out in the frame of the Horizon 2020 project progRESsHEAT (www.progresssheat.eu). The project included an intensive analysis of stakeholders, barriers and drivers, techno-economic modelling and the role of policies on the local, regional and national level. All these activities were embedded in an intensive stakeholder dialogue. The research question of the analysis presented in this paper is: What are the costs and opportunities for the integration of small and large scale solar heat in new and existing district heating systems in the two cities under investigation?

2. METHOD

2.1 Overall Method

To answer the research questions the following steps were carried out for each case study city: (1) Documentation and quantitative description of the current state of the district heating system in particular regarding heat supply, CO_2-emissions and costs of delivered heat. (2) Discussion of possible technological alternatives for the respective district heating system integrating solar heat. (3) Set up of a model of the current system and of the technological alternatives for the selected case studies in the modelling software energyPRO. (4) Performance of various calculations with the developed model for several settings of the supply portfolio, for solar thermal in particular regarding collector and storage size. (5) Analysis of the results in terms of resulting energy demand, share of renewable energy, CO_2-emissions and levelized costs of heat. (6) Derivation of conclusions regarding the overall feasibility of integrating solar energy in district heating based on a comparative discussion of the results.

Although this key approach was similar for both case studies, the specific questions and challenges were different due to the very different initial setting, which will be explained in the following:

2.2 The case study of Herten

For the case study of Herten the assessment focused on integrating large scale solar thermal fields with flat plate collectors from 1 000 to 50 000 m² in steps of 1 000 m² and two possible heat (pit) storages with 2 000 m³ and 10 000 m³ into the existing northern district heating subnetwork of the city, which is currently mainly supplied by coal. For this case no investments into network infrastructure or additional supply units would be needed, but the availability and costs of land and land-shaping for the solar thermal fields are important to be taken into account.

In the first step we calculated an hourly profile for the district heating network based on given annual data. The hourly demand profile was used to assess a realistic solar fraction as well as levelized costs of heat (LCOH) of solar thermal generation, which is only available at certain times of the year and particularly during summer. The hourly demand profile has been generated by fractioning the annual demand of the district heating network into hourly demand values. To do so 80% of the district heating demand has been modelled to be linear dependent on ambient temperatures accounting for space heating. A threshold value of 15°C ambient temperature was used. Above this threshold no space heat is demanded. The residual 20%-share of the district heating demand is modelled independent from ambient temperatures, assuming that it mainly results from residential hot water demand.

In order to find the solar thermal system with the lowest cost of heat the size of the solar field and the thermal storage were varied for all combinations as described above. Technical and economic assumptions such as efficiencies for the solar fields as well as capital costs for solar thermal plants including storage were taken from solar district heating guidelines (Sørensen, 2012) and are stated in Table 1. The lifetime has been assumed to be 30 years for the solar plants including storages.

With regard to land area necessary for the solar thermal fields nearby locations to the sub-systems connections have been assessed applying Geographic Information Systems. It has been assessed if the area for the fields chosen is available and if it is marked as agricultural area. This was based on the reason that agricultural land has served as area for solar thermal fields in several other projects. Thus, to allow the use of agricultural land for solar thermal fields is not uncommon. Furthermore, the price of agricultural land is by far lower than for areas dedicated for trade and industry. Costs of land are derived from a Geographical Information System from the state North Rhine- Westphalia (BORISplus, 2015), the values used are given in Table 1.

Table 1: Assumptions for the Herten case study

Parameter	Description
Solar thermal supply system	Solar thermal collectors: • Collector area 1 000 m² to 50 000 m² • Collector temperatures: 80°C/40°C • Start efficiency: 0,827 • Pipe losses: 4% • Investment costs including equipment: Cost function ranging from 200 €/m² to 400 €/m² • Fixed operation costs: 0.5 €/MWh
Thermal pit storage	• Storage Temperature top/bottom: 80°C/ 40°C • Storage volumes: 0 m³/ 2 000 m³/ 10 000 m³ • Storage capacities: 0 MWh/ 88 MWh / 440 MWh • Investment costs storage: 0 €/ 416 000 €/ 1 070 000 €
Cost of land	5.8 €/m²
Cost land shaping	6 €/m²
Economic Parameter	• Interest rate: 7% • Lifetime solar plants: 30 years • Lifetime heat storage: 30 years

2.3 The case study of Ansfelden

For the case study of Ansfelden possible supply options for a new settlement area without existing infrastructure were analysed. A 100% renewable district heating network supplying the entire settlement area by a biomass boiler with different combinations of solar thermal collectors and also solar PV in combination with a heat pump were considered. For this case study the levelized costs of heat (LCOH) included all costs arising from the installation and operation of all the components of the future district heating system.

The new settlement area under investigation includes an area of around 120 000 m² and according to current planning it will be covered by different types of mainly residential buildings and will have a plot ratio[1] of 0.45 to 0.55 per building lot. The expected buildings could consist of around 100 single-family houses, 200 row houses and 10 small multi-family houses. All of them are foreseen to be built as nearly zero energy buildings and therefore will have a very low heating demand. For each of the three building groups, the hourly demand and resulting heat load for space heating and domestic hot water is calculated.

All of the buildings in the new settlement area are assumed to be connected to a small low-temperature district heating network. The length of the network to connect all buildings is estimated to 1 500 m based on a rough calculation with a Geographic Information System. The expected supply and return temperatures are 65°C and 40°C, respectively. These low supply and return temperatures can be achieved because of the highly efficient buildings (low heating demand) and low-temperature radiators. Due to the low temperatures and pre-insulted pipes of the latest generation, the network losses are assumed to account for 10% of the annual transported heat.

According to the heat load of the buildings and the network losses a future demand profile for the district heating network was calculated smoothening the load over 4 hours. Still the high number of similar buildings with similar user profile lead to relatively high peaks of up to 2.9 MW and an annual total demand of 2.2 GWh.

Because no infrastructure exists yet, the network can be built from the scratch. Thus, synergies with other infrastructures like power lines and water channel can be used leading to lower installation costs of around 300 EUR/m of network.

The analysed district heating supply systems consists of a biomass-based boiler in combination with different sizes of solar thermal collectors and thermal storages as well as a heat pump and different sizes of photovoltaic collector fields.

The wood chip biomass boiler is the main supply device and with 2 MW of thermal output it is dimensioned to

1 Plot ratio is defined as the building floor area to the land area in a given territory

supply the demand in 98.3% of the hours (97.8% of energy). This means that in less than 7 days per year additional heating capacity is needed. An oil-fired boiler with 3 MW of thermal output works as back-up and peak load unit.

The area of solar thermal collectors is varied from 0 m² to 2 000 m² in steps of 200 m². They are combined with heat storages of 0 m³, 10 m^3, 100 m³ and 500 m³. The solar thermal collectors are planned to be installed on the district heating station and the surrounding buildings in order to avoid spreading the solar collectors over all buildings of the settlement area.

The photovoltaic panels are varied from 0 kW$_{peak}$ to 1 000 kW$_{peak}$ in steps of 200 kW$_{peak}$ and are used to drive a heat pump installed together with the PV panels. The heat pump is designed to support the system only in times when the PV system is generating electricity. Generated electricity, which cannot be used in the heat pump, is lost. The heat pump is designed to 500 kW of thermal output at an electrical input of 150 kW resulting in a COP of 3.3.

Therefore, 11 different sizes of solar thermal collectors and 4 different sizes of thermal storages together with 6 different sizes of photovoltaic panels make in total 264 combinations calculated for the case of Ansfelden. Table 2 summarizes all assumptions made for the calculation.

Table 2: Assumptions for the Ansfelden case study

Parameter	Description
Buildings	100 Single family houses, 200 Row houses and 10 Multi-family houses • Total built are: 56 300 m² • Specific space heating (SH)demand: 19 -24 kWh/m²y • Specific hot water (DHW)demand: 17 kWh/m²y • Total demand SH&DHW: 2 237 MWh • Maximum smoothened load: 2.9 MW
Network	• Length of DH network: 1 500 m • Losses: 10% of annual production • Capacity heat exchangers: 3.3 MW • Specific invest costs network: 300 €/m • Specific invest cost heat exchangers: 300€/kW
Supply Systems	Wood chip boiler • Thermal output power: 2 MW • Average annual efficiency: 85.3% • Specific investment cost: 250 €/kW • Fixed operation costs: 5 €/MWh • Cost wood chips: 66.8 €/t (25.6 €/MWh) Solar thermal collectors: • Collector area from 200 m² - 2000 m² • Collector temperatures: 70°C/40°C • Start efficiency: 0,80 • Pipe losses: 4% • Investment cost including equipment: Cost function ranging from 874 €/m² to 606 €/m² • Fixed operation costs: 0.5 €/MWh Ground source compression heat pump: • Rated electrical input power: 150 kW • Maximal thermal output power: 500 kW • Rated coefficient of performance: 3.3 • Investment costs: 1 000 €/kWth Photovoltaic cells • Installed areas 200 kWp – 1000 kWp • Aggregated losses module to grid: 5% • Investment costs including equipment: Cost function ranging from 1056 €/kW to 1041 €/kW Peak load and back up oil boiler • Thermal output power: 3 MW • Average annual efficiency: 85.3% • Investment cost: 100 €/kW • Fixed Operation Expenditures: 5 €/MWh • Cost of oil:0.7 €/l (71.4 €/MWh)
Thermal Storage	• Storage Temperature top/bottom: 65°C/ 40°C • Storage volumes: 0 m³/ 10 m³/ 100 m³/ 500 m³ • Storage capacities: 0 / 0.28 MWh / 2.75 MWh / 13.76 MWh • Investment costs storage: 0 € / 11 664 € / 39 000 € / 94 500 €
Economic Parameters	• Interest rate: 3% • Lifetime supply units & storage: 20 years • Lifetime network: 30 years

3. RESULTS

3.1 Results for Herten

The results for the district heating system in Herten show that the LCOH of the solar thermal collectors in combination with the pit storage can almost compete with the current heat supply from coal, but would slightly increase the cost of heat. In this case of course the solar heat would replace coal and therefore contribute to a significant CO_2 reduction. Furthermore in the case of Herten the integration of solar heat was the cheapest of the possible options to integrate renewable energy.

A visualisation of the evaluated cases is given in Figure 1 showing levelized cost of heat (LCOH), solar field size and storage size and the solar fraction representing the share of heat demand covered by the solar field during a year in the analysed district heating sub-system. It shows that the lowest LCOH for different field sizes can be achieved with corresponding storage sizes. Accordingly, systems without thermal storage have the lowest LCOH for small systems below 4 000 m² field area. However, with less than 5% the solar fraction is also very low for this system design. Between 5 000 and 22 000 m² of collector area systems with a relatively small storage of about 2 000 m³ have lowest LCOH achieving almost 20% solar fraction. Above 25 000 m² systems with 10 000 m³ storage become more cost-effective and can achieve a more than 5 percent higher solar fraction. The lowest LCOH of all calculated system configurations ranges between 40 and 50 EUR/MWh.

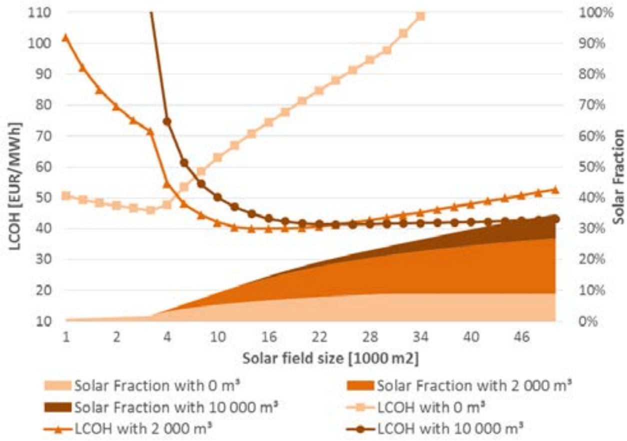

Figure 1: LCOH [EUR/MWh] of the large scale solar thermal system for the case of Herten

3.2 Results for the case of Ansfelden

Figure 2 shows the LCOH of the overall district heating network for the new settlement area in Ansfelden when integrating solar thermal collectors into a biomass based system. The results show that the cheapest heat supply for the new district heating grid would be achieved with the biomass boiler without additional solar thermal collectors but with a heat storage of 100 m³. This means that the resulting levelized costs of heat (LCOH) from the solar thermal system are higher than the heat generation costs of the assumed biomass boiler. However additional solar thermal collectors would only slightly increase the LCOH for the calculated system but could reduce the demand for biomass and therefore also reduce the risk for future price volatility of biomass. Futhermore costs and negative effects of transportation, which were not taken into account in the calculations could be reduced.

In our case for example the integration of 800 m² of solar collectors together with 100 m³ heat storage would increase the LCOH by around 10 EUR/MWh (+9.5%) and could reach a solar fraction of 15%.

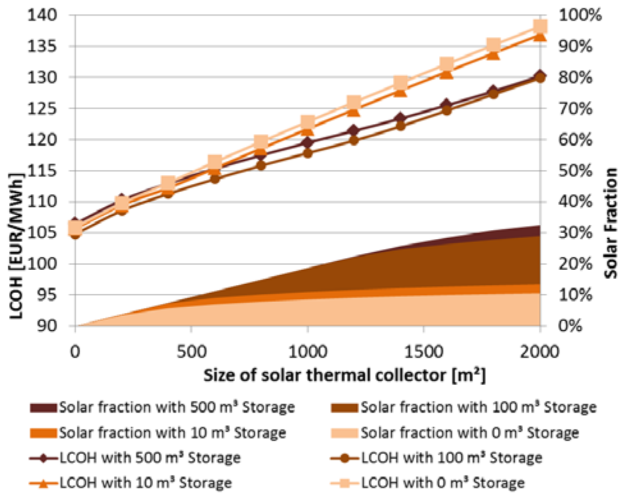

Figure 2: LCOH [EUR/MWh] of the overall district heating system for the new settlement area in Ansfelden when integrating solar thermal collectors into a biomass based system

Although the results seem to be different from the case of Herten, they show a very similar behaviour when only considering the costs for the solar thermal equipment and not for the overall district heating system: Figure 3 shows the results for the solar thermal system only, including solar thermal collector and heat storage but no investments into network nor other supply units. In this case the lowest LCOH for different collector field sizes can be achieved with different storage sizes. Up to around 200 m² of solar thermal collector the system without storage achieves the lowest LCOH resulting in solar fractions below 5%. For systems between 200 m² and 500 m² the combination with 10 m² of storage achieves the lowest LCOH resulting in solar fractions up to 10%. For systems between 500 m² and 1500 m² the combination with 100 m² of storage achieves the lowest LCOH resulting in solar fractions up to 25% and collector areas over 1500 m² achieve the lowest LCOH in combination with 500 m² of storage and can reach solar fractions above 30%. For small scale solar thermal systems the lowest LCOH of all system configurations are in the range of 80 EUR/MWh

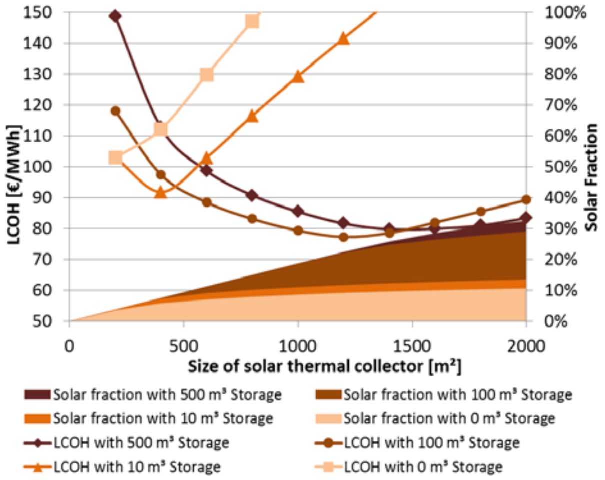

Figure 3: LCOH [EUR/MWh] of the solar thermal system only for the new settlement area in Ansfelden

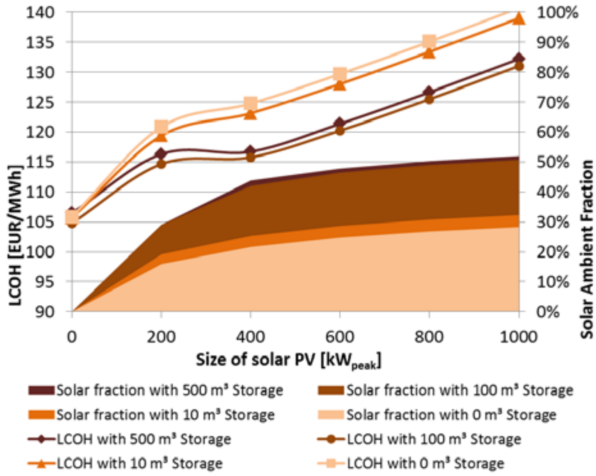

Figure 4: LCOH [EUR/MWh] of the overall district heating system for the new settlement area in Ansfelden when integrating solar PV and heat pump into a biomass based system

Alternatively for the case of Ansfelden the integration of solar PV together with a heat pump was investigated. In this calculation the heat pump can only be driven by the local PV field and no connection to the grid is assumed. Hence the solar fraction in this case is defined as the share of total heat produced by the heat pump including the electricity from the solar PV and the ambient heat. Figure 4 shows the LCOH of the overall district heating network for the new settlement area in Ansfelden when integrating solar PV together with a heat pump into a biomass based system.

The results show that also in this case the cheapest heat supply for the new district heating grid would be achieved with the biomass boiler without additional solar PV but with heat storage of 100 m³. Compared to the integration of solar thermal collectors higher fractions of solar heat (including electricity from solar PV and ambient heat) can be reached at the same costs with the combination of solar PV and heat pumps. For example the integration of 400 kW_{peak} of solar PV together with a 150 kW_{el} heat pump and 100 m³ heat storage would also increase the LCOH by around 10 EUR/MWh (+9.5%) but could achieve a solar fraction of 42%.

4. DISCUSSION AND CONCLUSIONS

For the case of Herten a big scale solar thermal system turned out to be an economically feasible solution for the integration of renewable heat into the existing coal based district heating grid. According to the calculation the integration of solar thermal heat would increase the current overall levelized cost of heat (LCOH) but reduce the CO_2 emissions significantly due to replacing coal by integrating a solar fraction up to 30%. However, the results also depend on several assumptions and input data, in particular the technical parameters and assumed investment costs. One of the biggest challenges for big scale solar systems near cities is the availability and price of land and land shaping. Moreover, for the decision also uncertainties regarding the future energy price development need to be considered

The case of Ansfelden shows similar findings in terms of effectiveness of integration of solar heat: Although the portfolio containing solar thermal collectors is not among the options with the lowest costs, a significant share of solar heat can be integrated at only moderately higher costs replacing combustibles that might be needed in other sectors like industry for higher temperature heat demands, and would also decrease the risk of price volatility of these energy carriers in the future. An integration of PV, heat pumps and a heat storage leads to higher shares of solar energy at similar costs than including solar thermal collectors. This result of course highly depends on the coefficient of performance of the heat pump and can be reached only with low flow temperatures and a well-designed heat pump. However, if this is the case, higher shares of solar energy can be integrated even if the heat pump only runs with local PV collectors not connected to the grid and economics would even improve, if excess electricity could be feed into the grid or purchased when electricity prices are low.

REFERENCES

BORISplus (2015), Aktuelle Informationen zum Immobilienmarkt in NRW: http://www.boris.nrw.de/ (last checked: 07.10.2015)

Büchele R. and Popovski E. (2017a) Assessment of local feasible renewable energy-based heating/cooling utilisation for Ansfelden and Herten. *Part of the reports D2.2 of the progRESsHEAT project*, Online available: http://www.progressheat.eu/Reports-publications-69.html.

Büchele R. and Popovski E. (2017b) Results of the quantitative assessment of selected policy packages for development area "Teilraum 31" (Ansfelden) and for Herten. *Part of the reports D4.1 of the progRESsHEAT project.* Online available: http://www.progressheat.eu/Reports-publications-69.html.

Sørensen P. A. (2012): Solar district heating guidelines. Introduction to SDH – from idea to operating system. Internet: www.solar-district-heating.eu (last checked: 17.08.2015).