Solar district heating in Europe: supplying renewable zero-emission heat

Magdalena Berberich, Dirk Mangold

Solites, Steinbeis Research Institute for Solar and Sustainable Thermal Energy Systems, Stuttgart (Germany)

Abstract

District heating is one major approach to increase the overall energy efficiency in urban areas and an important platform to increase the share of renewable energies in the heat supply. Solar thermal energy is emission-free, available everywhere and offers stable operating costs for decades. Together, they can play an important role in the energy transition of the heating sector in Europe and beyond.

The integration of solar thermal systems into district heating offers different technical solutions, whereof some are applied since decades, some others, like decentral direct feed-in, are in evaluation. Generally, solar thermal systems are sensitive to the levels of the supply and return temperature and the detailed system integration, here especially regarding the hydraulics and the control strategy.

In the case that the solar thermal system is applied to combined heat and power productions, the overall system can be designed to the best economics if the electricity market, the dynamics in the heat consumption and the solar thermal production etc. are considered. The integration of a large heat storage volume might be helpful to separate production and supply powers and therefore can lead to a system with lowest heat cost, although the investment cost can be quite high. At least such complex systems ask for dynamic system simulation during the design phase to ensure best economics and to enable a risk analysis for varying prerequisites.

Keywords: Solar district heating, large-scale solar thermal system, smart cities

1. Introduction

Solar district heating (SDH) plants are a large-scale solar thermal technology supplying renewable, zero-emission heat from large collector fields via district heating networks to residential and industrial areas. Combined with large seasonal heat storages, the solar thermal plant can contribute to more than 50 % of the yearly heat demand even in high latitudes. The main market for SDH consists of plants with a solar fraction of up to 20 % of the yearly heat demand, including the application of a short-term heat storage or even without any heat storage.

New solar district heating projects show an interesting variety of technical concepts and operator models. This underlines also the high potential of district heating and cooling with renewable energy sources as flexible technical and organizational solution for the energy transition at local level.

2. Basic systems for solar thermal integration

A solar thermal plant can be connected to the district heating system by means of central feed-in or decentralized as shown in Figure 1. Central feed-in means the solar heat is integrated in the main heating central where the heat storage is located. The schematic in Figure 1 shows a seasonal heat storage; it depends on the size of the collector area and the performance of the additional heat productions in relation to the fluctuating heat demand if a smaller short-term heat storage can be sufficient or even neglected.

In the case of decentral feed-in of solar thermal heat, the solar collectors are placed at suitable locations and are connected directly to the district heating circuit. In several large solar thermal plants in Sweden, Austria and in a few first plants in Germany, a decentral feed-in of solar heat into district heating systems has been realized.

doi:10.18086/swc.2017.06.03 Available at http://proceedings.ises.org

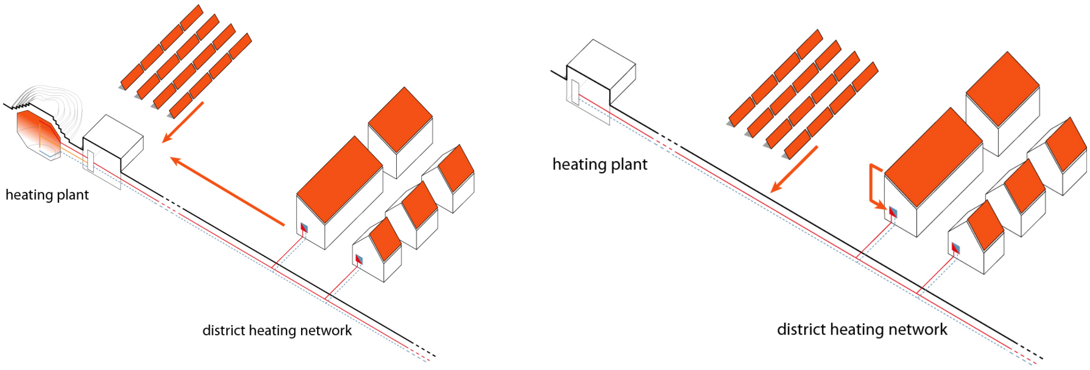

Figure 1: Schematic of central (left) and decentral (right) feed-in of solar thermal heat

For both, central and decentral feed-in of solar thermal heat in a district heating net, the solar thermal plant can be operated to produce the supply temperature or to preheat the fluid in the return flow. Figure 2 shows a basic schematic of a solar thermal plant for district heating. Usually it is applied for a solar thermal integration in the central heating plant. The broken grey line shows the system boundary for the solar system. To separate the solar circuit and the net circuit hydraulically a heat exchanger is applied. Often a heat storage is integrated into the system to store the heat from the solar collectors before it is transported to the additional heater and then delivered with the supply temperature to the district heating net.

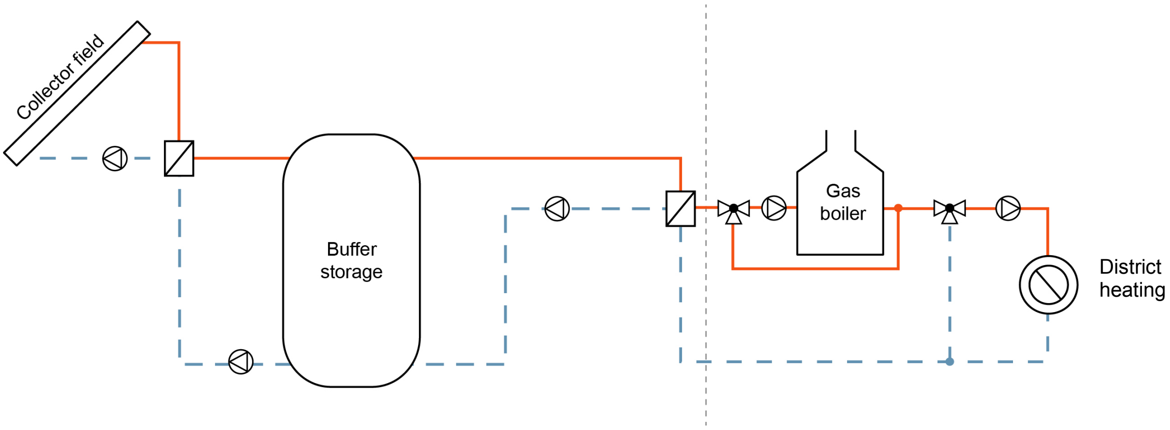

Figure 2: Schematic of a solar thermal plant for solar district heating

In case of delivering the supply temperature for the district heating net, the solar collectors only can produce heat if the solar irradiation is high enough.

In the case of preheating the return flow, the solar collectors heat up the return flow with a predefined temperature difference. For supplying the heat to the district heating net the fluid is heated up to the supply temperature by an additional heater (e.g. a gas boiler as shown in Figure 2). The variation of the solar irradiation can be balanced by a volume-flow control of the pumps in the solar circuit to keep the temperature of the preheated flow from the collector field to the buffer storage within the predesigned range.

The sizing of the buffer storage depends on several parameters like the intended solar fraction, the operation characteristics of the collector field and the dynamics of the heat demand in the district heating net and in the unload circuit of the buffer storage etc. The larger the intended solar fraction and the higher the complexity of the hydraulic system concept are, the more a dynamic simulation of the overall system is recommended.

3. Solar collector area

Within the last 30 years the technology for realizing large collector areas was developed, first by pilot plants that were supported by R+D funding. Within the last 10 years the technology is on its way to a state-of-the-art heating technology for utilities, energy companies, cooperatives etc. The developments differed due to different boundary conditions in different European countries. All developments comprise specialized collectors for district heating application. They cover up to about 12 m² of collector area per collector. Their internal hydraulic scheme is optimized to facilitate the realization of long collector rows by a simple connection of the collectors and to run these rows with low flow. This saves installation costs as well as electricity consumption of the solar circuit pumps. The following figures show different mounting systems of solar collector areas for district heating systems:

1. Ground mounted (Figures 3 and 4)
2. Roof integrated (Figure 5)
3. On roof (Figure 6)

Figure 3: Vacuum tube collectors in Büsingen, Germany

Figure 4: High-temperature flat plate collectors in Dronninglund, Denmark

Figure 5: Roof integrated solar thermal collectors on "solar@home"-building in Crailsheim, Germany

Figure 6: Solar collectors elevated on flat roof in Neckarsulm, Germany

Without regarding the cost for the ground, to mount the collectors on simple subconstructions directly on the ground offers the possibility to achieve the lowest cost for the realization of a solar collector area. The availability of ground is restricted especially in urban areas. Thus it might be also applicable to integrate the collectors in a roof. Figure 5 shows a so called "solar roof" that was realized within an energetic retrofitting of an old army building. The "solar roof" replaces the roof tiles and integrates roof windows, drip moulding, snow guard etc. Another possibility is to mount a collector field on a flat roof as shown in Figure 6. In this case, to achieve low cost for the subconstruction can be a challenge due to the statical requirements to carry especially the wind loads.

The market offers two main constructions of collectors, flat plate collectors and vacuum tube collectors (see Figure

3 and Figure 4). The specific products of the collector producing companies vary in performance and construction. To find the best suitable collector for a specific project it is recommended to invite offers from the solar companies and to decide according to the specific heat price. The solar heat price is calculated from the overall costs of the solar thermal plant in relation to the usable solar heat. To compare different offers, this usable solar heat should be calculated for all offers with the same simulation program, using the characteristic figures for every offered collector type according to test certificates like “Solar Keymark”, that is valid all over Europe (ESTIF, 2017).

4. System design

For a favorable performance of the solar thermal system, the overall system design is important. First of all the location of the solar thermal plant decides about the amount of solar irradiation that the collectors receive. The solar thermal plant is able to heat its inlet temperature only if the irradiation is high enough for that. The following Figure 7 shows the differences between the global irradiation of two cities in Germany over ten years, whereas Würzburg is a location with very good solar irradiation conditions and Hamburg is a location with quite low solar irradiation. The solar irradiation in the years 2007 to 2016 fluctuates with +4 to -6 % of the average in the ten years for Würzburg (broken line). For Hamburg, the variation comprises the range of +7 to -5 % of the average level. There is a significant difference in the global solar irradiation of the two locations, which is very variable over the ten years.

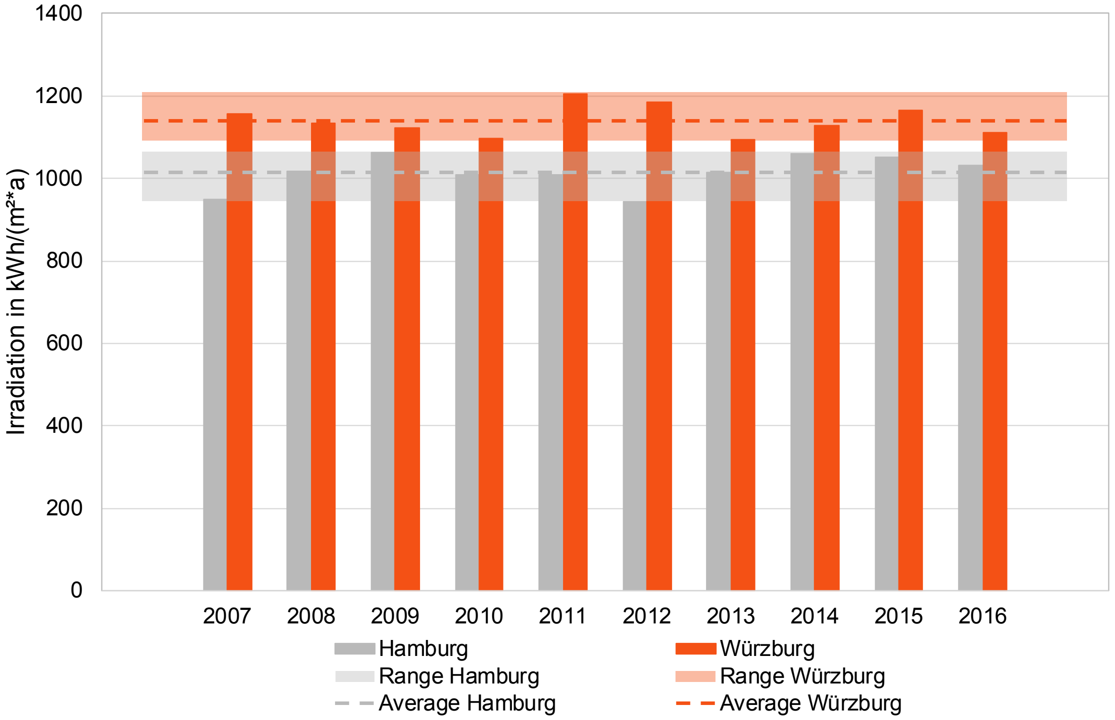

Figure 7: Yearly global solar irradiation in the years 2007 to 2016 for Würzburg and Hamburg (Deutscher Wetterdienst, 2017) on horizontal plane

Therefore, it is recommended to dimension a solar thermal plant using climate data of the location of the plant over a longer period, e.g. 10 years. By varying the solar irradiation in a sensitivity analysis within a system simulation program, its effect on the energy gain of the solar system can be analysed and valuated. If necessary, the solar thermal plant can be dimensioned with a safety factor to reach the needed solar heat gain even in years with poor irradiation.

In addition to that, the solar heat gain depends on the operation temperatures. The higher the average operation temperature of the collectors is, the lower the efficiency of the collectors gets because of higher heat losses of every collector. Therefore, the return temperature to the collector field and the needed supply temperature, which shall be produced by the collectors, are decisive for the achievable solar energy gain.

This correlation is shown in Figure 8 for high-temperature flat plate and vacuum tube collectors in the German market. The sample collector is a high-temperature flat plate collector with average specific values. The results are calculated with average climate data over 10 years (Meteotest, 2017) of the German city Frankfurt. The average net temperatures in the diagram are the yearly average for the arithmetic value of the supply and return temperatures of the regarded collector in every hour of the year.

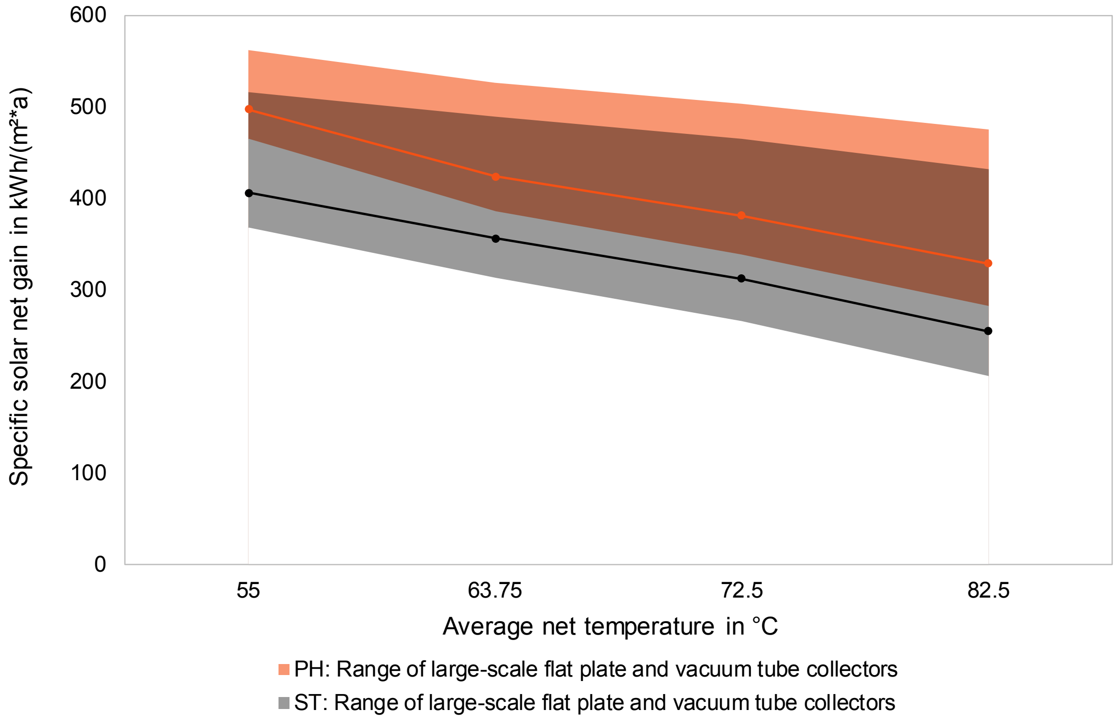

Figure 8: Usable solar heat of large-scale collectors in the German market with two different control strategies for the delivered temperature of the solar thermal plant: ST = heating up to the supply temperature, PH = preheating. The lines represent a sample collector (m²: brutto collector area)

In the preheating mode (PH, Figure 8), the solar thermal plant delivers heat at a lower temperature level than the supply temperature of the district heating net. Therefore, the solar thermal plant can produce heat even if the solar irradiation is low. The solar heat production in this mode mainly depends on the return temperature of the district heating net that should be heated by the solar thermal plant. This is visible by the strong reduction of the solar heat gain between the cases with 55 °C and 63.75 °C average temperature. The return temperature increases between these two cases from 40 to 50 °C in a yearly average.

A first idea of the performance of one single collector gives the Solar Keymark certificate (ESTIF, 2017). Each collector is tested and certified under standardized conditions with a constant average temperature in the collector. Neither the influence of the system integration nor the realistic supply and return temperatures are considered in the tests. In the certificate the performance indicators and yearly heat productions are declared for the climate data of four different locations in Europe.

As mentioned above, the solar irradiation influences the solar heat production of the collector field to a strong extend. This is shown in Figure 9 for the sample collector and with the application of the formerly mentioned climate data from Würzburg and Hamburg (see Figure 7).

The calculations of the solar heat production, whose results are shown in Figure 9, are based on a solar thermal system with a decentral feed-in and without a heat storage. This system is operated to deliver always the supply temperature of the district heating net. The average net temperature is 63.75 °C, in summer the supply temperature amounts to 75 °C and the return temperature to 55 °C. The results show the direct dependency of the solar heat gain on the solar irradiation and the strong variation from the average in single years. The variation around the 10-years-average lies in a range of +10 to -15 % for Würzburg and +20 to -14 % for Hamburg.

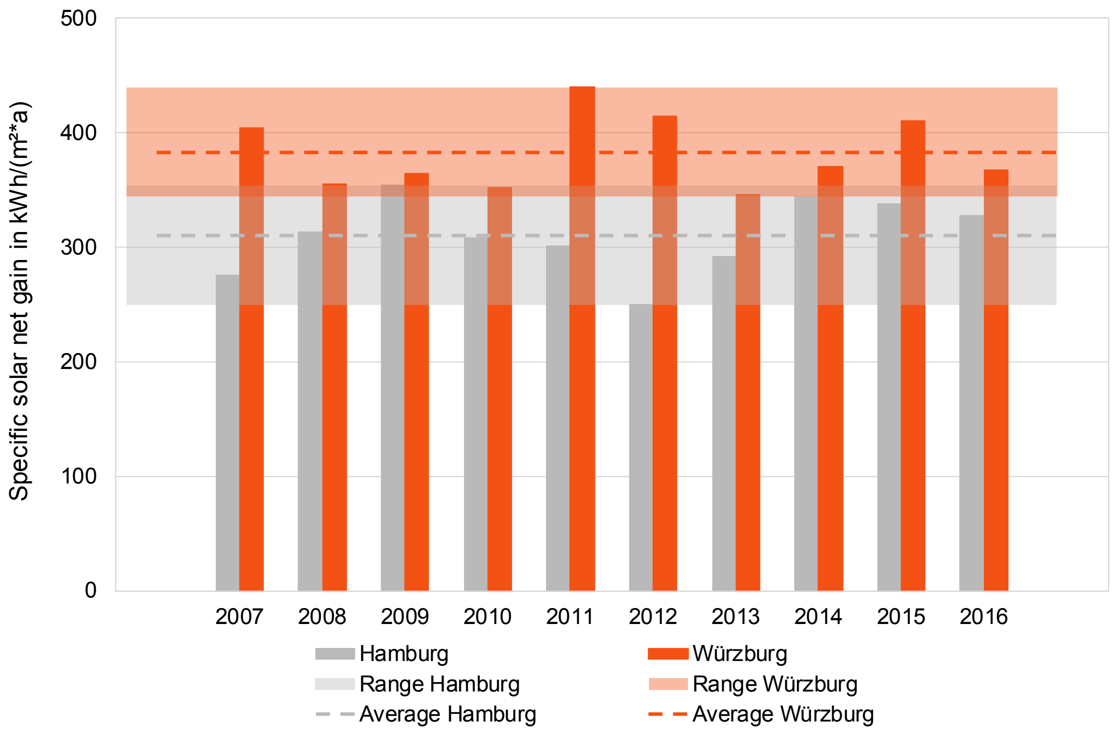

Figure 9: Calculated specific solar heat gain per m² brutto collector area of a sample collector with climatic data for the years 2007 to 2016 for the cities of Würzburg and Hamburg. The solar thermal plant is operated to always reach the supply temperature in a district heating network with 63.75 °C average temperature.

Such variations in the solar heat gain need to be considered when dimensioning a solar thermal plant. That is why the careful calculation of the solar heat gain with all available data and, in addition, based on realistic assumptions is essential for the feasibility of solar district heating systems. Compared to conventional heat producers, dynamic system behavior and the variations of the solar irradiation, the mass flow and the temperatures of the district heating net need to be considered in detail.

If a solar thermal plant is dimensioned to deliver the entire heat demand of the district heating net during the summer time, in most cases a short-term heat storage is necessary to store the heat from day to night and for the case of some cloudy days. In Europe the heat demand during summer usually is defined by tap water heating and the heat demand of industrial processes. The solar fraction of these solar thermal systems depends on the seasonal distribution of the yearly heat demand and is usually between 10 to 15 %. The higher the solar fraction, the more solar heat needs to be stored, not only for some days but for weeks. In case of high solar fractions of solar heat in the region of more than 40 % of the yearly heat demand, a seasonal heat storage is necessary, because the heat from summer has to be used in winter. Due to the longer storage time of the solar heat, the heat losses increase and the specific net solar heat gain of the collectors decreases. Figure 10 gives an example for the interrelations of the main parameters for such systems.

Therefore, it is assumed that the collector field comprises high temperature flat plate collectors of the sample type (see Figure 8), located in the city of Frankfurt in Germany. The collector field feeds in decentrally into a district heating net with a supply temperature of 78 °C in a yearly average and a yearly heat demand of 4 GWh/a. To increase the solar fraction of the yearly heat demand of the district heating net (see red line in Figure 10), the collector area has to be increased (see x-axis in Figure 10). The higher the solar fraction gets, the larger the heat storage volume has to be. The dashed grey line shows the specific storage volume in m³ water, related to the brutto collector area, that is necessary to reach the intended solar fraction. By mathematical variation, the specific storage volume was fitted to the respective collector area in a way that the storage volume is used completely and stagnation in the collector field is just avoided. For a solar collector area of 10,000 m² a solar fraction of 70 % of the yearly heat demand of the district heating net can be reached with a specific storage volume of 2.3 m³/(m² brutto collector area). In Figure 10, this specific storage volume is set to 100 % (see y-axis). The black broken line in Figure 10 gives the specific solar net gain of the entire solar thermal system (see Figure 2). The solar net gain is the usable solar thermal energy that is fed into the district heating net. Heat losses by the storage etc. are subtracted already. The maximum value of 313 kWh/(m² a), equals 100 %, is quite low and caused by the overall system layout that asks for a feed-in of the solar net heat gain always on the supply temperature of the district heating net of 78 °C in a yearly average. This specific solar net heat gain declines with rising solar fraction due to rising heat losses of the necessary storage and rising average operation temperatures in the collector field.

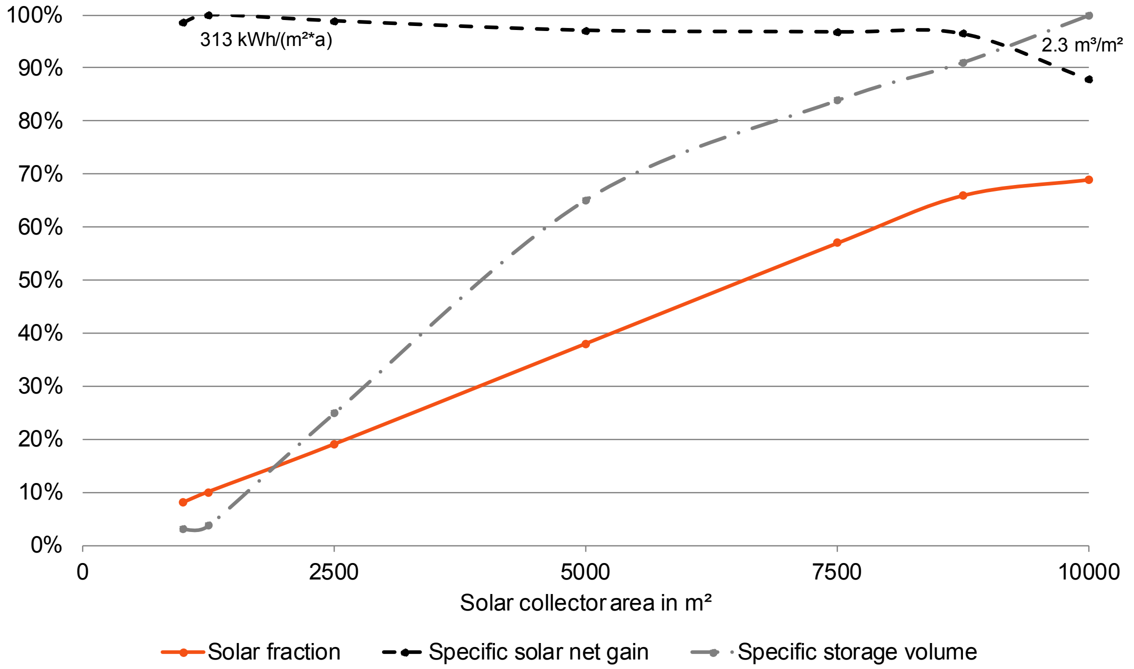

Figure 10: Correlation of solar collector area, specific heat storage volume, solar fraction of the yearly heat demand and solar heat gain for a solar thermal plant that feed in decentrally in a district heating net and always delivers the supply temperature of 78 °C in a yearly average (sample collector and weather data of the German city Frankfurt (see Figure 8))

For a real plant, possible next steps in the overall system design would be to change the system integration of the solar thermal system to a preheating mode (see Figure 8) or to integrate a heat pump into the solar system to unload the heat storage to lower temperatures. Both possibilities allow to reduce the operation temperatures of the solar collector field to reach higher specific solar net gains per year.

The results in the diagrams of chapter 4 are calculated with the Excel-calculation program SCFW ("ScenoCalc Fernwärme", in German: "ScenoCalc for solar district heating systems") which is free of charge and can be used for first assessments of SDH systems (Solites, 2017).

5. Market development in Europe

The first solar thermal plants that delivered heat to district heating nets were realized in Europe in the beginning 1980s driven by national research and demonstration programs as a reaction on the worldwide oil crises in the 1970s. Since then, the technical developments in different fields like the technologies for solar thermal collectors that are specialized for their application to district heating, the system integration of a solar collector field into district heating, the available heat stores, the possible operation modes of the solar thermal system etc. were immense. First large pilot plants were built in Sweden and Denmark, followed by a continuous development in Germany and other European countries like Austria etc.

In the last years, Denmark showed an impressive success story regarding solar district heating driven by national laws that increase the price for fossil gas if it is used only for heating. Since 2010 a capacity of more than 500 MW_{th} of solar thermal collectors has been newly installed. These solar thermal plants are connected to the heating central of a district heating net according or similar to the schematic system in Figure 2. The largest plant in operation has a total collector area of 15 hectares and a thermal capacity of 100 MW_{th}. In other European countries, the market conditions of the heating and cooling sectors significantly differ from the particular situation in Denmark. But also in Germany, Austria and in other countries with starting markets large scale solar thermal plants become an economically competitive heat generation option for district heating. Figure 11 gives an overview of the market status of solar district heating in Europe.

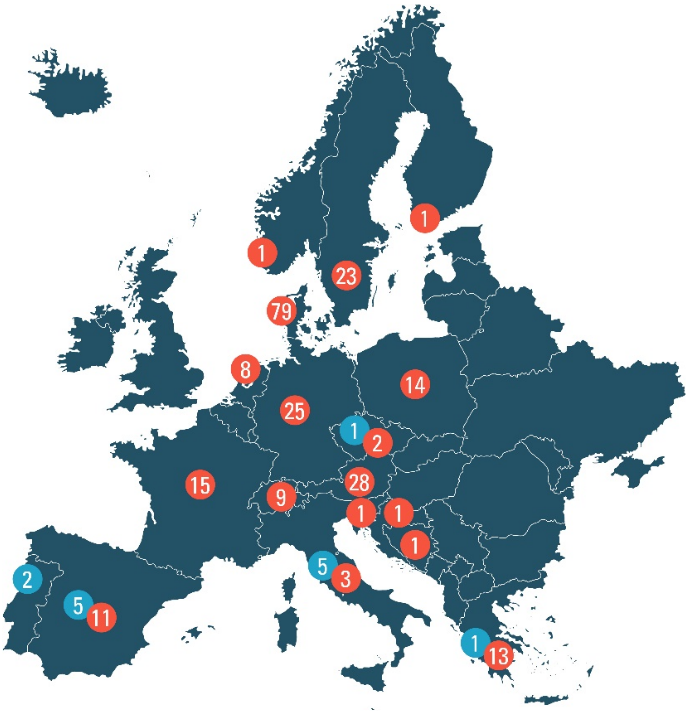

Fig 11: Solar district heating market status in Europe (May 2016) (red dot: solar thermal system for district heating, blue dot: solar thermal system for district cooling, number: amount of solar thermal systems in respective European country) (Solites, 2016)

At the end of 2015, 252 plants with more than 350 kW_{th} nominal power were in operation in Europe. The total installed capacity amounts to 750 MW_{th}. Moreover, an increasing number of countries are following this trend and new markets have started to develop, for example in Italy, France and even in South Korea.

New solar district heating projects show an interesting variety of technical concepts and operator models: So called ‘energy villages’ are a solution for rural areas, where whole villages switch from individual, often oil-based heating systems to district heating systems for larger parts of the village. Local biomass plants combined with a solar thermal system are seen as one of the applicable renewable heat sources for such systems and operators are often cooperatives, municipalities themselves or their utilities. Solar district heating is, however, also an advantageous solution for new built or retrofit districts in innovative urban development projects. In several large solar thermal plants in Sweden and Austria a decentral feed-in of solar heat into the district heating has been realized. A decentral feed-in is in particular interesting for larger city district heating systems, where sufficiently large roof or infrastructure areas are available along the district heating lines.

The energy transition with its growing part of renewable power supply in the electricity nets in some European countries leads to an additional market push for solar thermal systems in district heating nets. More and more fossil-driven CHP-plants (CHP: combined heat and power) reach a shut down during the summer months due to uneconomic operation conditions that are caused by high amounts of renewable power in the electricity grids. The missing heat can be replaced by renewable solar thermal energy.

Economical competitiveness and heat generation costs between 30 and 50 Euro/MWh are reached whenever the solar thermal plants are sufficiently large (> 1 MW_{th}), the overall concept is kept simple (e.g. ground-mounted collector fields, see Figures 3 and 4) and the district heating system is operated at suitable temperatures (< 100 °C). In addition subsidies for the introduction of renewable energy sources into district heating are available in many

European countries. The low share of operation costs leads to a long term stability and calculability of heat generation costs for the whole operation period of typically 25 years.

6. The European SDHp2m project

SDHp2m stands for "Solar District Heating and actions from Policy to Market". The project addresses market uptake challenges for a wider use of district heating and cooling systems (DHC) with high shares of renewable energy sources (RES). The action specifically focuses on the use of large-scale solar thermal plants combined with other RES in DHC systems (Solites, 2016).

The key approach of the project is to develop, improve and implement advanced policies and support measures for SDH in nine participating EU regions. In three focus regions Thuringia (DE), Styria (AT) and Rhône-Alpes (FR) the regulating regional authorities are participating as project partners to ensure a strong implementation capacity within the project. In six follower regions from BG, DE, IT, PL, SE the regulating authorities are integrated through letters of commitment. The project activities aim at a direct mobilization of investments in SDH and hence in a significant market rollout.

In each region, a stakeholder advisory group has been created, gathering market and policy actors to identify the actions that have to be taken to enable a market roll-out of SDH. A detailed action plan has been set up that the regional teams are implementing. The planning of activities by local actors at a regional level ensures the development and implementation of ideas adapted to the local framework. On the other hand, thanks to the international level of the project, know-how and experience from frontrunner regions are available and partners can exchange ideas and methods on how to tackle their challenges. Several factsheets are under development regarding the policy, financing and market development actions in each region.

Addressed market uptake challenges are: Improved RES DHC policy, business models and better access to plant financing, sustained public acceptance and bridging the gap between policy and market through market support and capacity building. Denmark and Sweden reach already today a high share of RES in DHC and are used as a role model for this project.

Some European countries supplement the market development for SDH by national market development projects. As an example, the German Federal Ministry for Economic Affairs and Energy started the project "Solnet 4.0". Within this project, eight suppliers of solar thermal plants for district heating works together with SDH specialists, the German district heating industry federation AGFW e.V. and media suppliers to increase and strengthen the growing development of the German SDH market.

7. Perspectives

The technologies for large collector fields that can be integrated into district heating systems in Europe are already offered by at minimum eight companies. Further technical developments are necessary to further adopt the solar thermal technologies to district heating for centralized and decentralized feed-in. One of the main focuses of research lies in the system integration of large collector fields into complex district heating networks with several heating centrals, several combined heat and power plants etc. The energy transition leads to fundamental changes in the district heating technologies with good opportunities to integrate solar thermal as a heating technology into these systems. The technical questions how this integration should be realized are not yet answered. Within first pilot plants this new, broad field of research and development is investigated like in the new project "renewable district heating 2020 – the multifunctional district heating network as a heat hub" in the city of Hennigsdorf in Germany. The utilities of Hennigsdorf are going to raise the amount of renewable energies up to 100 % for their district heating net of about 50 km length that delivers about 120 GWh/a heat on a temperature level of up to 105 °C supply temperature. Therefore the utilities cooperate with technical consultancies and Solites as scientific experts to develop the technical-economical optimum for the overall district heating system and its operation strategy.

Safeguarding the SDH market development to a stable and durable market still is a comprehensive task that asks for huge efforts within the coming years - with Denmark as the only worldwide exception. These efforts mainly comprises non-technical developments. Some first European countries show that if the political will to further develop the SDH market is expressed clearly and in addition finds its way into market incentive programs and long term stable market conditions, the district heating companies increasingly welcome solar thermal plants as a sustainable, future-proof heating technology and start their own way into a solar future. The possible variants are extensive: from a first small solar thermal plant to the 100 % renewable solution for whole (smart) cities.

8. References

Deutscher Wetterdienst, 07.09.2017, ftp://ftp-cdc.dwd.de/pub/CDC/observations_germany/

ESTIF – European Solar Thermal Industry Federation, 15.09.2017, http://www.estif.org/solarkeymarknew/index.php

Meteotest, Meteonorm: Einstrahlungsdaten für jeden Ort des Planeten, 22.08.2017, http://meteonorm.com/de/

Solites, 07.04.2016, Solar District Heating - The SDH projects website. http://solar-district-heating.eu/Home.aspx

Solites, 29.09.2017, ScenoCalc Fernwärme – Ertragsvorhersagetool für Solarthermie-Anlagen in Wärmenetzen, https://www.scfw.de/

The SDHp2m project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691624

Supported by:
Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

The projects "Solnet 4.0" and "renewable district heating 2020 – the multifunctional district heating network as a heat hub" has received funding from the German Ministry for Economic Affairs and Energy on the basis of a decision by the German Bundestag