Task 55 Towards the Integration of Large SHC Systems into DHC Networks

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

D-D4. Market development for large scale SDH/SDC systems in country reports

IEA SHC FACT SHEET 55.D.D.4

Subject:	Evaluation of diverse global market developments for large scale SDH/SDC and country reports
Description:	Country reports about deployment, system design, typical applications and promotion policies of large-scale solar thermal systems
Date:	October 2020
Authors:	See the following country reports
Editor:	Magdalena Berberich (Solites)
Download possible at:	http://task55.iea-shc.org/fact-sheets

Introduction

This publication of IEA SHC Task 55 describes the market development of Solar District Heating and Cooling in seven countries. Within country report presentations during the eight taskmeetings, the market developments in the participating countries were presented and discussed in the international expert group and the information is summarized in this factsheet.

In these seven markets, there is a broad variety of large-scale SDH systems. The variety ranges from small collector areas on buildings, which are decentrally integrated in district heating (DH) networks to ground mounted collector areas with sizes up to 157,000 m² in Denmark, connected to large volumes of underground thermal energy storages. Denmark, China, Germany and Austria are the countries with the highest numbers in installed large-scale collector area in SDH systems in the world. Sweden has a long history of SDH applications with 25 large-scale systems now running. France and The Netherlands are in the beginning of a market development with first bigger plants with up to 4,000 m² in France and 7,000 m² in The Netherlands.

For the four leading countries, the success factors for large-scale solar thermal plants were analyzed in detail and some of the findings are transferable to other countries as well. While solar resources are a minor success factor, the heat demand and heat supply infrastructure in the countries, relative prices of solar heat to competing technologies, business models and legal regulations were decisive for the market development in the countries. Different subsidy programs have a strong impact on the market. [1]

Denmark is the leading country for SDH, mainly due to the unique role of DH utilities (non-profit, investors and operators) and policies affecting heat supply by DH utilities (high taxes on fossil fuels, energy saving points). In China, Germany and Austria, a broader variety of large-scale solar thermal applications including process heat is installed.

During the duration of Task 55, the size of the newly installed collector areas has increased significantly. In 2016, the world's largest SDH collector area was built in Denmark with 157,000 m², followed by major projects in Tibetan regions in China with high solar fractions of up to 100 % of the space heating demand and the largest German plant with 14,800 m². It is expected that the trend of large-scale SDH systems will continue in the coming years and that these systems will become increasingly important for the decarbonization of the heat supply.

Solar resources

The available solar radiation is an important factor for the solar yield of large-scale solar thermal systems. Concentrating systems track the sun both in longitudinal and transversal direction to fully use the direct normal irradiation (DNI). Non-concentrating systems with flat plate collectors usually have a fixed tilt and azimuth. The yearly irradiance on an optimally tilted and aligned surface is a good indicator for the achievable solar yield for non-tracking collectors.

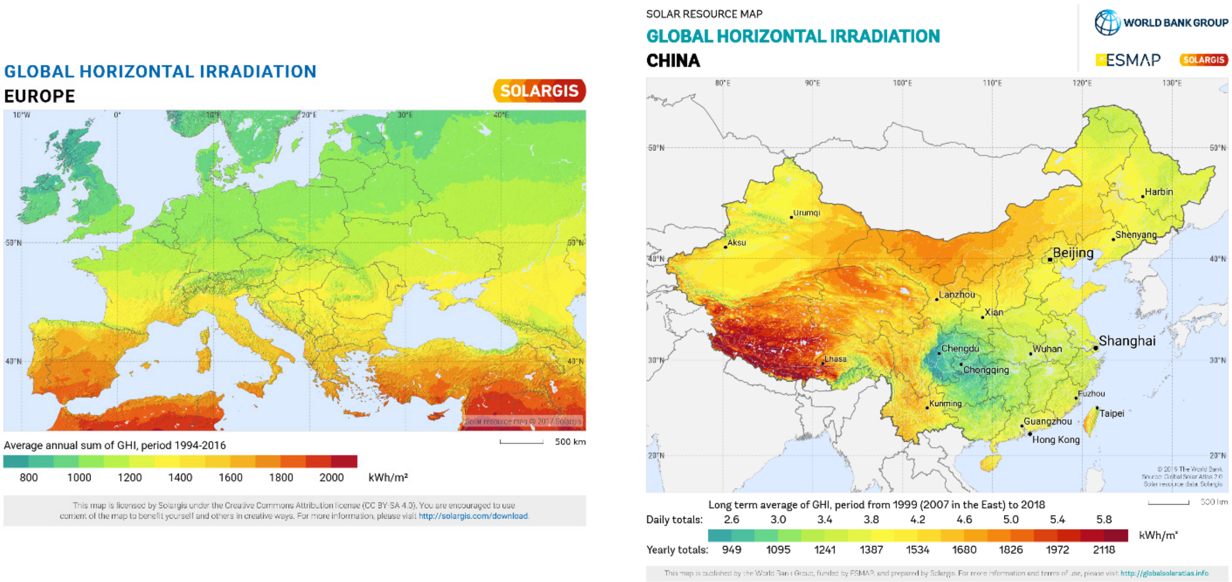


Figure 1: Global horizontal irradiation in Europe and China [2]

For all regions only data on global irradiance on horizontal surfaces (GHI) is typically available from weather stations. To compare solar resources of different regions the long-term average of GHI and DNI are used. An overview of the solar resources in the regions described in this factsheet is given in Figure 1 and Table 1. The solar radiation actually used by solar collectors lies somewhere between these two values.

Table 1: Solar resources of the regions in this country report factsheet [1] [2]

Country	Global horizontal irradiation (GHI)	Direct normal irradiation (DNI)
	kWh/m²/year	kWh/m²/year
Austria	1,150 – 1,250	1,000 – 1,200
China	950 Chuan-Yu region 2,200 Qinghai-Tibet Plateau	400 – 2,900
Denmark	1,000 – 1,150	900 – 1,100
France	950 – 1,700	950 – 1,900
Germany	1,000 – 1,200	750 – 1,150
The Netherlands	975 – 1,125	800 – 1,000
Sweden	950 – 1,100	900 – 1,200

Content

Country Report Austria

IEA SHC FACT SHEET 55.D.D.4

Subject:	Large-scale solar thermal plants in Austria
Description:	Deployment, system design, typical applications and promotion policies of large-scale solar thermal systems in Austria
Date:	September 2020
Authors:	Daniel Tschopp, Samuel Knabl, Walter Becke, Christian Fink. AEE – Institute for Sustainable Technologies (AEE INTEC).
Download possible at:	http://task55.iea-shc.org/fact-sheets

Introduction

Austria successfully established a market for large-scale solar thermal systems, ranking No. 4 in the world regarding installed collector area [3]. The first large-scale systems were built in the late 1990s. In 2010, a subsidy program for systems with a collector area exceeding 100 m^2 was established. This provided a major boost to the industry [4].

Deployment of large-scale solar thermal systems

By the end of 2018, there were 23 large-scale systems in operation with a total aperture area of 38,900 m^2 (27.2 MW). The system sizes range from 501 m^2 to 8,250 m^2 with an average collector area of 1,700 m^2. Systems in the medium range of 100 m^2 to 500 m^2 are also widespread, with around eight times more systems built in this range between 2010 and 2016 compared to large-scale systems [5]. Unlike in Denmark, for the majority of the plants – 19 out of 23 – the collectors are mounted on or integrated into the roof (usually on roofs of apartment houses or boiler houses). Most systems have diurnal storages, none of the built plants uses a seasonal storage. Except for one plant with CPC collectors, all plants use single-glazed, double-glazed or single-glazed/foil flat plate collectors. Typical tilt angles are between 30° and 45°. For the majority of the plants, the solar fraction ranges from 10% to 20%, covering the lion share of the summer load. [6]. Figure 2 shows the location of the plants.

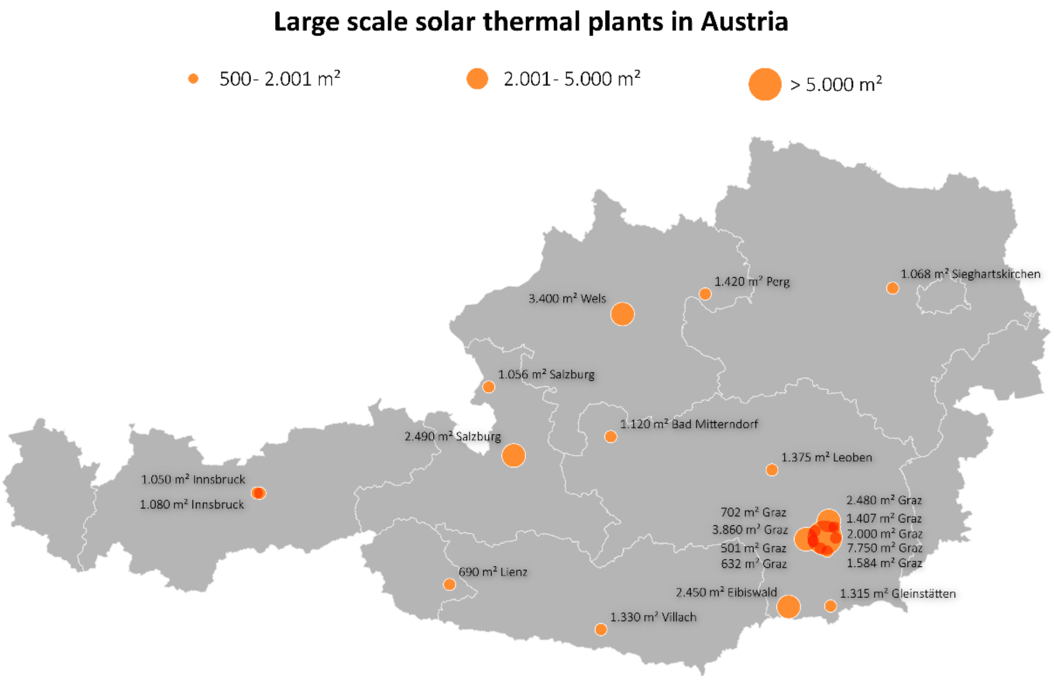


Figure 2: Geographical distribution of large-scale solar thermal plants in Austria

Typical applications

Characteristic for Austria is a broad variety of applications.

Solar heating for microgrids: With 9 systems (10,088 m^2 collector area) the most common application is the feed into a decentraliz local microgrid. Solar assisted microgrids can be found in newly built or reconstructed urban districts. Oftentimes, these networks are operated at low temperatures (< 65 °C supply temperature).

SDH for urban areas: Urban district heating networks in Austria are characterized by a high heating density, resulting from heat customers with high loads (industry, commercial housing, etc.), and multiple heat sources (CHPs, waste heat, oil and gas boiler, etc.). The potential for large-scale solar thermal plants depends on the availability of other heat sources with a low marginal cost (especially waste heat), suitable areas to mount the collectors and grid temperatures. Eight systems which feed into an urban district heating network (19,190 m^2) have been built so far.

SDH for villages and rural areas: Communal district heating networks in Austria usually have a central heat source (often biomass boilers). The majority of the heat customers are single family houses with small load shares. The main technical argument to integrate solar thermal in communal district heating is the unsatisfactory coverage of the summer load with boilers that often operate in off-peak and partial load, implying high stand-by losses and low efficiency. Up till now, 3 solar systems to provide heat to biomass district heating networks of communities (4,490 m^2) have been built.

Process heat: The possibility to integrate solar thermal in processes depends very much on the process in question. In recent years, three solar process heat systems (3,718 m^2) have been built.

Policies to promote large scale solar thermal plants

In the framework of the EU agreement on the climate-energy package, Austria committed to increase the share of renewable energy to 34% in the national energy mix until 2020 [7]. As part of a comprehensive strategy to promote the use of solar thermal energy, a program for large scale solar thermal installations was designed in 2010 [8]. Eligible are installations with a collector area of 100 to 10,000 m^2 (until 2015: 2,000 m^2). The funding is based on the additional investment costs of the solar thermal system (including piping, storage, system integration) compared to a fossil-fueled reference system. The funding percentage is 40% (> 2,000 m^2: 30%, > 5,000 m^2: 20%; +5% for SME and innovative storage solutions) with a limitation of 750,000 EUR per project. Since 2020, feasibility studies for projects with more than 5,000 m^2 collector area are also eligible for funding [9].

Peculiarities of the Austrian market

The successful deployment of Austrian large-scale systems is partly due to the *Energy Service Company (ESCo)* business model (also known as *Solar Contracting*) [1]. To overcome the burden of high investment cost and the perceived uncertainty connected to solar heating, ESCos take responsibility for the investment, design and operation of the plant and sell the heat to housing facilities owners and/or district heating utilities, which pay a contracted price.

Outlook

System concepts which combine large collector fields with absorption heat pumps and large scale (seasonal) storages, providing a significant share of the heat load of urban district heating networks, have gained increased attention recently. The energy supplier for the city of Graz is planning to build the largest solar thermal plant in the world with 220,000 m^2 (154 MW) collector area and a pit storage with a volume of 900,000 m^3 [10].

Country Report China

IEA SHC FACT SHEET 55 D-4

Subject:	Large-scale solar thermal plants in China
Description:	Deployment, system design, typical applications and promotion policies of large-scale solar thermal systems in China
Date:	December 2020
Authors:	Chenhui Jia, Solareast (the content was taken from [1])
Download possible at:	http://task55.iea-shc.org/fact-sheets

Introduction

Solar thermal supply of low temperature heat demand (not exceeding 95°C) can play a significant role in the future energy mix and could reach more than 16% of total final energy use (16.5 EJ) for low temperature heat by 2050 worldwide. There are good prospects for China as well. The Chinese government aims to reach 3.5 billion m2 space heating area using renewable energies by the end of 2020, while the area of space heating using renewable energies by the end of 2016 was only 700 million m2. The total installed area of solar thermal systems in China should be above 800 million m2 by the end of 2020. With an estimated turnover of 16.9 billion USD in 2017 and 672,000 people working on production, installation and maintenance of solar thermal systems worldwide, the solar industry is already a major economic factor.

The driving force for large-scale solar thermal systems has been SDH applications in Denmark, where by the end of 2018 a total of 118 plants with a capacity of 970 MW were in operation, making up 63% of the capacity worldwide. Denmark is followed by China (212 MW, 55 systems). China could become the leading market driver and surpassed Denmark regarding newly installed capacity in 2017 and 2018 for the first time.

Market overview

A distinct characteristic of Chinese DH networks is that they typically only provide space heating. DHW systems are mostly installed for local grids, which are not connected to DH networks. These systems can be much larger than 500 m2 collector area. In the market survey on China, only data for space heating and industrial applications were considered. According to these data, there are 55 systems with a total capacity of 212 MW in operation by the end of 2018. As there are plenty large-scale DHW systems and data for space heating and industrial process plants might still be incomplete, the Chinese large-scale market is presumably much bigger.

China has dominated the market for small-scale solar thermal systems for many years, accounting for 89% of the installed capacity by end of 2016. Large-scale solar thermal systems for space heating and industrial processes have only started to be installed in recent years. In comparison to Denmark, where most plants use FPCs, ETCs and PTCs are also widespread in large-scale applications. One 75,000 m2 PTC plant for DH supply was constructed in Inner Mongolia in 2017.

Heat demand

The Chinese DH networks currently cover around 8.5 billion m2 of building floor area (building floor area is the typical unit of measurement), having nearly tripled since 2005. As urbanization continues, the building floor area in China is projected to increase by 40% by 2050, reaching more than 80 billion m2 from 57 billion m2 today. The total building floor area covered by DH networks in Northern China tripled over the last decade, increasing nearly as much as the combined floor area growth in the northern urban heating (NUH) area (north part of China) since 2005. Solar thermal systems face extremely favorable natural conditions in these areas due to high heat demand and high solar irradiance. A characteristic of Chinese DH networks is that they often provide heat only for space heating. DHW systems are separate and not fed by the grid. Space heating systems in most places in Northern China are only put into operation for several months in winter heating seasons. For instance, the operation period of space heating systems in Beijing is November 15 to March 15 next year (4 months). There is no space heating supply in the rest of the year. Typical supply/return temperatures of new DH networks (radiator heating) in China are 75/50℃ or 85/60℃. For the floor radiant heating systems, typical supply/return temperatures are 35/30℃ or 45/40℃. Only 1% of the DH supply in China is currently covered by renewable energies. More than 80% of space heating in Northern China are supplied by coal boilers, which is a main reason for the air pollution in winter. China has a great need to lower the environmental footprint of its DH networks and the country has pursued assertive public policy decisions in recent years towards cleaner and energy-efficient DH.

Typical applications

The best practice example for China was built in collaboration with the leading Danish turn-key supplier Arcon-Sunmark A/S.

Langkazi Tibet Solar Heating is a 100% subsidy project. The project received a grant of 175 million RMB from the central government. It was realized as a turn-key solution by a consortium of Beijing Heating Project Design Co. Ltd, Suneast Arcon-Sunmark and Sunrain Group. The project adopts the internationally advanced SDH technology of the Danish company Arcon-Sunmark A/S, that is responsible for the design and technical supervision of the collector array, storage and heat exchanger station. All critical equipment of the solar collector circuit was imported from Europe. The DH network and heating terminal units were designed by Beijing Heating Project Design Co. Ltd. The whole project is coordinated by Sunrain Group.

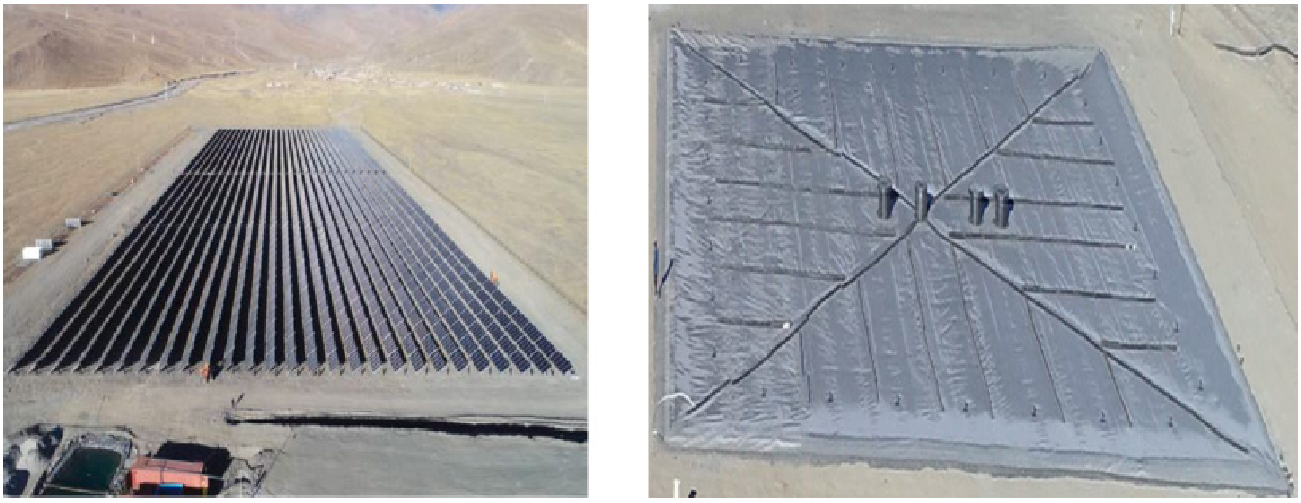


Figure 3: Collector array (left) and PTES (right) of Langkazi Tibet SDH (source: Sunrain)

Policies to promote large scale solar thermal plants

The Chinese central government set up the “Clean Heating Initiative” for the period 2017–2021 to control air pollution. By the end of 2021, the percentage of coal boilers should be reduced by more than 50%. The authority supports the exchange of oil boilers with renewable energy for space heating, including solar thermal energy. In rural areas, oftentimes there are no heating devices. The Green Energy Revolution is one of the main steps to achieve rural revitalization under the policy of the roadmap for rural vitalization (“No 1 central document” of 2018). Rural areas have very cheap land, which may be an emerging market for solar space heating in the near future. In addition, some flagship local governments, like Shandong and Hebei, have their own subsidy programs to promote large-scale solar thermal systems. Based on the national solar energy development plan (2015–2020), the number of large SDH plants should reach more than 200 and the total installed collector area for SDH plants should reach more than 4 million m2 by the end of 2020.

In China, large-scale solar thermal systems for space heating and industry process heat just started in recent years. Projects mainly rely on subsidies from the government at the current stage.

Peculiarities of the Chinese market

China has fewer installed systems than Denmark, but a broader range of applications encompassing rural and urban networks and industrial applications. This is partly due to investment-based subsidies which are not bound to a particular application and also allow for more expensive plants as subsidies usually cover a fixed percentage of the total investment cost. The conditions for solar thermal integration in DH networks in China is not as favorable as in Denmark. DH is more widespread in Germany and Austria than in China, but DH temperature levels are generally high. In China, a high heat demand in cold areas with high irradiance levels is contrasted by DH networks which are only in operation in winter and do not provide DHW. The special role of DH utilities as project developers and risk takers for large-scale solar thermal systems is addressed in these countries by special business models, e.g. bioenergy village in Germany and ESCo in Austria. Learning from the Danish experience, providing incentives to DH utilities to reduce CO_2 emissions with market-based instruments (taxes on fossil fuels, emissions trading systems) could be an effective strategy for other countries as well. Compared to investment-based incentives, market-based incentives provide a direct motivation to build the most cost-effective systems and maximize the solar yield.

China has a vast territory, with a large population in the east and a shortage of land resources, while the western regions are sparsely populated. The southernmost and northernmost regions also differ significantly. Adapting measures to local conditions is always the basic principle of renewable energy development in China. At present, the western region of China, such as Tibet, Xinjiang, Qinghai and other regions, is suitable for the development of solar energy inter-seasonal heat storage for district heating. In the east, particularly for provinces with hot summer and cold winter, it is suitable to combine solar energy with soil-source heat pump to promote solar energy inter-seasonal soil heat storage and realize heating in winter and cooling in summer. For the northeast and other extremely cold regions, solar energy inter-seasonal soil-source heat pump heating can effectively solve the frosting problem of air-source heat pump. [11]

In general, the initial investment cost of solar energy inter-seasonal heat storage is relatively high, and scale expansion as far as possible will effectively reduce the initial investment of unit heating area. Some scholars have found that the increase in the number of district heating users will help to reduce the initial investment and operating costs. At the same time, large-scale application will be expected to significantly reduce the production and manufacturing costs of related equipment and materials, and furtherly reduce the initial investment from the perspective of the market. [11]

Outlook

China has a broader variety of large-scale solar thermal applications including solar process heat, partly due to incentive schemes based on installation cost of plants rather than market-based instruments like in Denmark. Differences in the availability of solar resources are a minor factor for the success of large-scale solar thermal systems in China, but rather the heat supply infrastructure (for district heating) and relative prices to competing technologies and promotion schemes are important.

Besides low cost for solar heat provision, risk minimizing strategies are an important, often underestimated success factor to deal with the problem of high initial investment costs. Successful risk minimizing strategies are improved solar yield and heat load predictions and performance guarantees, turn-key suppliers, energy service companies and energy cooperatives. Risk-taking by district heating utilities like in Denmark can push the market. Heat supply from large-scale solar thermal systems is a mature technology with a broad field of applications. Optimized solutions for large collector arrays to realize economies of scale include hydraulic layouts leading to homogenous flow distribution and model-based plant control with frequency-controlled pump.

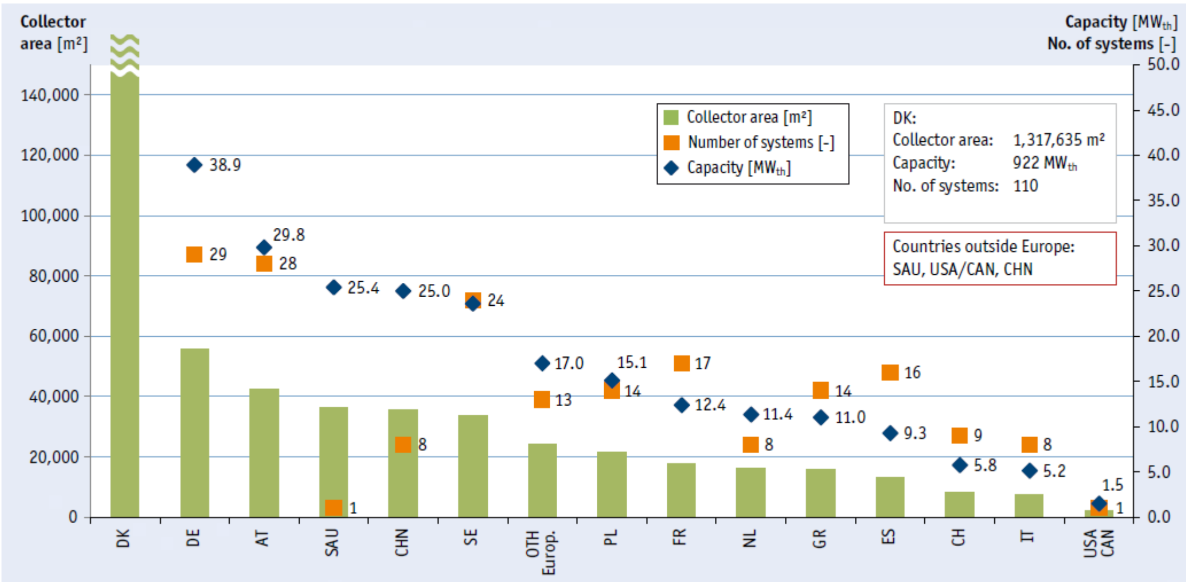
Country Report Denmark

IEA SHC FACT SHEET 55.D.D.4	
Subject:	Solar District Heating in Denmark
Description:	2019 status for solar district heating in Denmark
Date:	April 2019
Authors:	Jan Erik Nielsen, Daniel Trier - PlanEnergi
Download possible at:	http://task55.iea-shc.org/fact-sheets

Introduction

Denmark has a long-term tradition for Solar District Heating (SDH) systems; the first system was installed 1988 and is still in operation. Denmark is world leading in solar district heating regarding installed capacity as seen by figure 4.

Most systems are below 20,000 m² with a solar fraction around or below 20 %, but there are now several larger systems with seasonal storage and solar fractions of 40 – 50 %.



Solar district heating and cooling – capacities and collector area installed and number of systems in 2016
(Data source: Jan-Olof Dalenbäck - Chalmers University of Technology, SE and Sabine Putz - IEA SHC Task 55)

*Figure 4: Solar District Heating Systems around the world **by end of 2016**. [IEA SHC - Solar Heat Worldwide 2017]*

Deployment of large-scale solar thermal systems

By the end of 2018, there were 110 SDH systems in operation with a total aperture area of approx. 1.4 mill m² (approx. 1 GW). The system sizes range from 1,000 m² to 157,000 m² with an average collector area of 12,500 m². 26 systems have had one or more extension(s) during the years.

All collector fields are ground mounted. Most systems have flat plate collectors (single- and/or double-glazed), a few systems have concentrating collectors.

Figure 5: Ground mounted collector field at Trustrup-Lyngby Varmeværk. Source: ARCON-SUNMARK.

Four systems have established water pit seasonal storage of 60,000 – 200,000 m^3. One system has a demo borehole storage.

Figure 6: Water pit storage at Dronninglund Fjernvarme. Source: Dronninglund Fjernvarme

Fig. 5 shows the historical development. Fig. 6 shows the distribution of systems across the country.

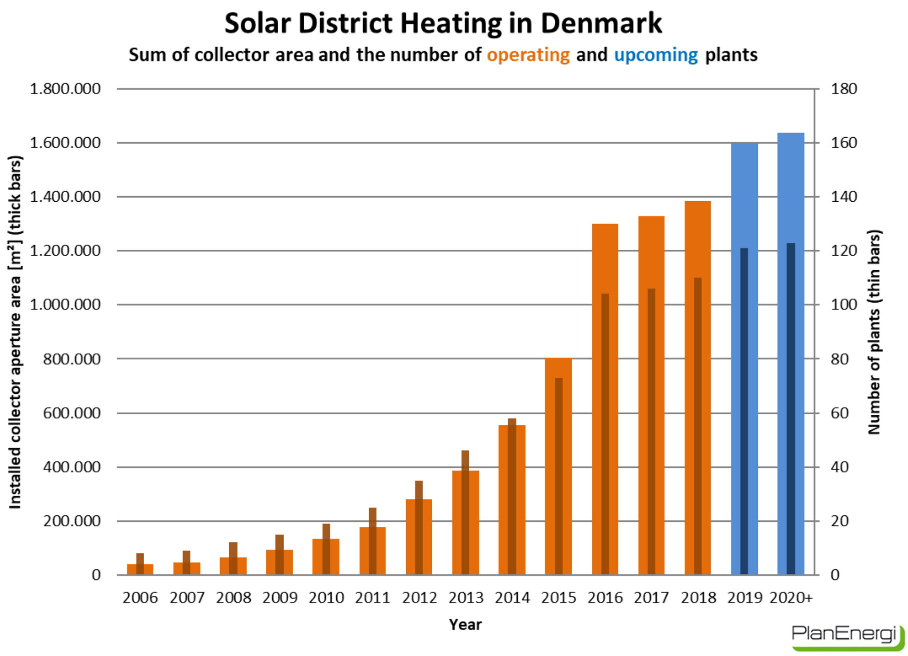


Figure 7: Historical development of solar district heating systems in Denmark Planned systems included in blue circles bars. Source: PlanEnergi.

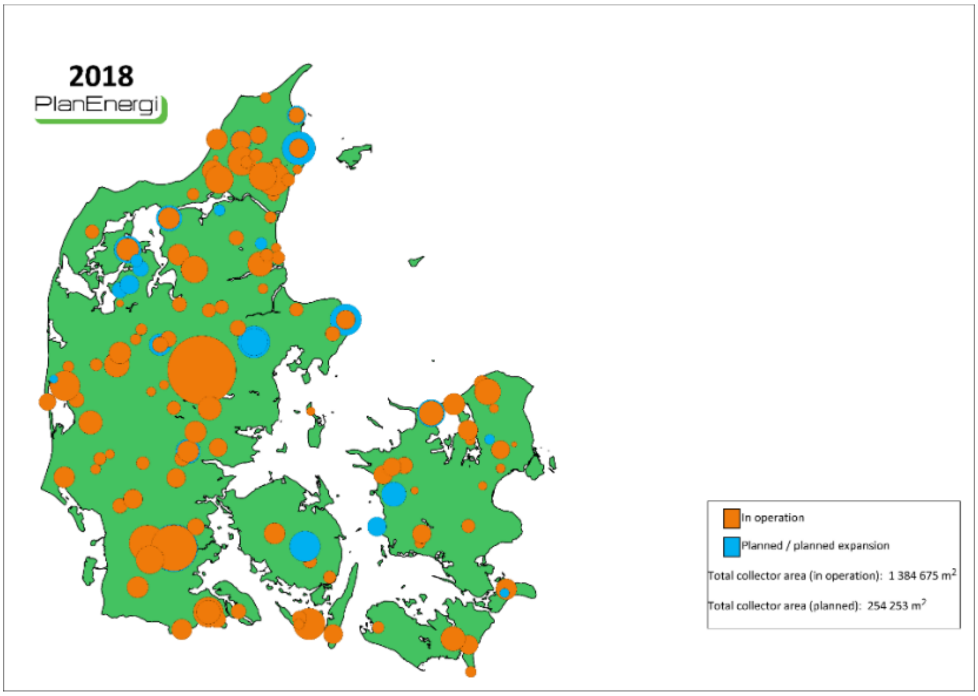


Figure 8: Solar district heating systems in Denmark by the end of 2018 (orange circles). Planned systems (blue circles). Source: PlanEnergi.

Typical applications

With a few exceptions all Danish large solar heating systems supply district heating. One system with concentrating collectors combined with an ORC[1] unit do also produce electricity[2].

Most systems are designed for covering the summer load, which corresponds to an annual solar fraction of 15 – 20 % in Denmark. A few systems have seasonal storage and solar fractions of 40 – 50 %.

Most systems are substituting natural gas and biomass[3] in smaller district heating networks in towns in the country side.

One large system of 157,000 m² is supplying a larger town with a solar fraction around 20 %.

The price of solar heat (without subsidy) is 20 - 30 €/MWh (calculated with a lifetime of 25 years and 3 % interest rate).

Policies to promote large scale solar thermal plants

In the period 2013–16 and again 2017–19, there has been an "energy saving subsidy", valid in general for energy saving projects and including solar district heating systems too. The subsidy has been approx. 10 % of the investment. In the latest period there was a limit, so only systems less than approx. 16,000 m² could have full subsidy. A new subsidy framework for the district heating sector is being considered now – it is expected to come into force for solar district heating in 2020.

Peculiarities of the Danish market

The successful deployment of Danish solar district heating systems is influenced by the following factors:

- Long time tradition for district heating (60 % of the national heat load is supplied by district heating)
- Low-medium temperature network, typical temperatures are:
- Forward temperature: 75 – 85 °C
- Return temperature: 35 – 45 °C
- Many country side villages had district heating networks established in the 1980s supplied by natural gas CHP units
- Most district heating companies are user owned or public owned companies aiming at lowest heat prices (and not highest profit)
- Danish District Heating Association gather and share good ideas through their experience-exchange-groups
- High tax on gas (and other fossil fuels)
- Attractive financing through "Kommunekredit" (credit institution for local and regional authorities)

[1] Organic Rankine Cycle (ORC)
[2] Combined Heat and Power production (CHP)
[3] Straw, woodchips and pellets

Outlook

It is expected that the use of large heat storages will increase in the near future, not only to store solar heat from summer to winter but also to accommodate coupling between the electricity sector and the heat sector. Large heat storages can level out the varying dynamic electricity production from wind and solar PV and increase use of industrial waste heat and other sources – an attempt to illustrate this has been made in figure 9.

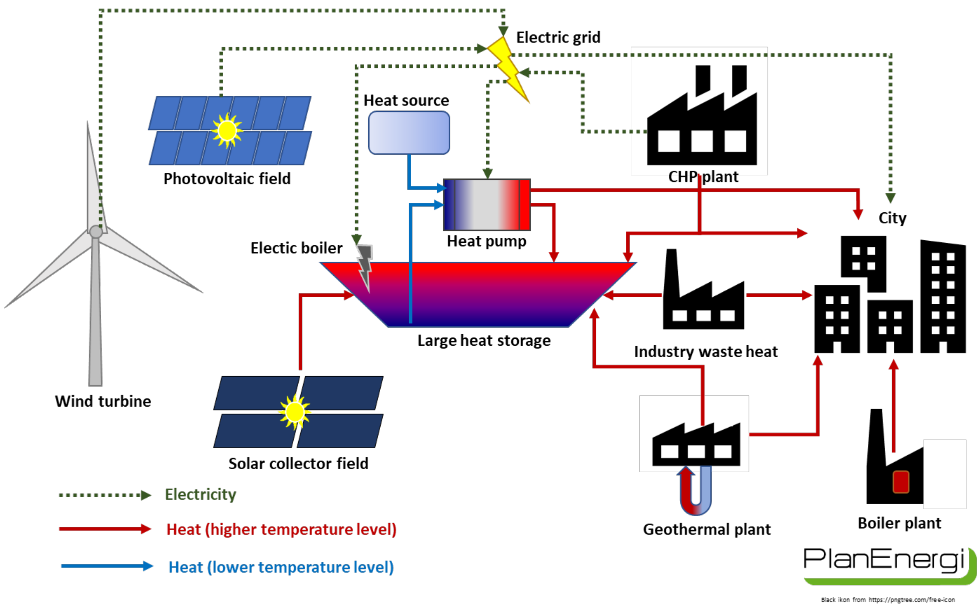


Figure 9: Connecting electricity and heat supply and load using heat pumps and CHP units and heat storage (sector coupling). Source PlanEnergi.

Country Report France

IEA SHC FACT SHEET 55.D.D.4

Subject:	Large-scale solar thermal plants in France
Description:	Deployment, system design, typical applications and promotion policies of large-scale solar thermal systems in France
Date:	September 2019
Authors:	Nicolas LAMAISON, Cédric PAULUS (CEA-INES, France)
Download possible at:	http://task55.iea-shc.org/fact-sheets

Introduction

The solar thermal market in France is dominated by individual and collective DHW installations. However, for the last 10 years, the market stagnates with a slightly decreasing total solar panels area installed each year, however still ranking No. 8 worldwide in the number of installed collector area in 2018 [12]. With an opposite trend compared to small installations, large solar installations for industry and District Heating Network (DHN) is starting and could help the French solar thermal market to expand again. Since 2015, a subsidy program [13] for large solar systems with a collector area exceeding 300 m^2 has been launched with a growing impact on the market.

Deployment of large-scale solar thermal systems

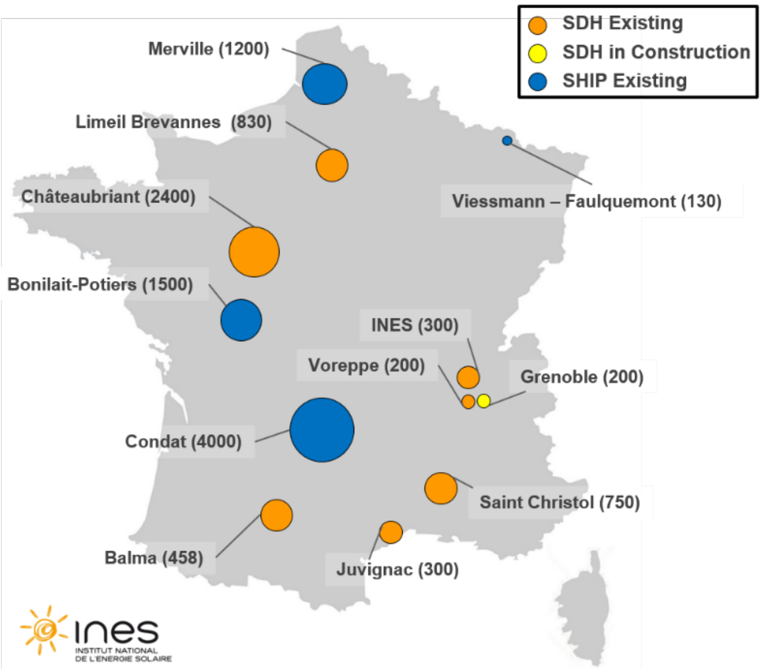


Figure 10: Solar District Heating and SHIP plants in France (SHIP: solar heat for industrial processes)

By the end of 2019, there were 11 large-scale systems in operation with a total aperture area of 12,068 m^2 (8.4 MW), as shown in Figure 10. The system sizes range from 200 m^2 to 4,000 m^2 with an average collector area of 1,100 m^2. One of the systems is an experimental one (INES on Figure 10) where various configurations of solar thermal feed into DHN are tested. Among the others, 6 are mounted on roofs (car-park, boiler house or building) and 4 are installed on the ground. Most systems have daily storages and none of the built plant has a seasonal storage. Except for one plant with CPC collectors (St Christol) and two with vacuum tubes (Balma and Viessmann-Faulquemont), all plants use single-glazed or double-glazed flat plate collectors. Innovative enough to be mentioned, the plant in Condat exhibits flat plate collector mounted on single-axis tracker. For the DHN applications, typical supply and return temperatures are 85/65°C, tilt angles are between 30° and 45°, and the solar fraction is always around 5%.

Typical applications

Even though large-scale solar thermal systems are still at their beginning in France, it seems that a broad variety of applications, similar to other European countries, already exists:

Solar heating for micro-grids: With 3 systems (1,590 m^2 collector area, Balma, Juvignac and Limeil Brevannes on Figure 10), the most common application is the feed into a decentral local micro-grid. Solar assisted micro-grids can be found in newly built or reconstructed urban districts. Oftentimes, these networks are operated in combination with a wood boiler at low temperatures (< 70 °C flow temperature), favoring solar thermal production plant.

SDH for urban areas: Urban district heating networks in France are characterized by a high heating density, resulting from heat customers with high loads (industry, commercial housing, etc.), and multiple heat sources (CHPs, waste heat, oil and gas boiler, etc.). The potential for large-scale solar thermal plants depends on the availability of other heat sources with a low marginal cost (especially waste heat), suitable areas to mount the collectors and grid temperatures. Although they are intrinsically very different, two systems in France could be characterized as urban areas SDH. The first one, Chateaubriant is for now the largest SDH in France (2,400m^2) and supplies heat in a decentralized manner to the city DHN with a solar fraction of about 3%. The second-one is currently being installed into a low-pressure loop, itself connected to the main high-pressure loop of Grenoble DHN, the second largest one in France. While Chateaubriant DHN is still rather decentralized and could be classified in next Section, the Grenoble SDH is rooftop based in the city center.

SDH for villages and rural areas: Communal district heating networks in France usually have a central heat source (often biomass boilers due to financial incentives). The majority of the heat customers are single-family houses with small load shares. The main technical argument to integrate solar thermal in communal district heating is the unsatisfactory coverage of the summer load with boilers who often operate in off-peak and partial load, implying high stand-by losses and low efficiency. Two systems providing heat to a biomass-based district heating networks are currently in operation in France (see Voreppe and Saint Cristol on Figure 10).

SHIP (Solar Heat for Industrial Processes): The possibility to integrate solar thermal in processes depends very much on the process in question. Process with quasi-constant heat demands such as breweries or cleaning industry are most appreciated process heat customers of large-scale solar thermal. In the last 2 years in France, two major plants have been built with Merville and Condat (see Figure 10) with a total installed area of 5,200 m². Large-scale solar thermal fields seem to have a promising future with new projects signed for the coming years.

Policies to promote large scale solar thermal plants

In order to respect i) the EU agreement on the climate-energy package [14] and ii) the French energy transition law [15] which states that the renewable energy share in the final energy consumption should reached 23% in 2020, the French Agency for Renewable Energy (ADEME) has launched in 2008 a program called “Fonds Chaleur”. Between 2009 and 2015, 1,590 small solar thermal installations (individual or collective) have been partly financed by this incentive, which promotes heat production using solar, biomass, geothermal, and/or district heating network. In 2015, a new program for large-scale solar thermal installations has been launched [13]. Eligible installations must have an aperture area above 300m² for SHIP applications and above 500m² for SDH ones. With 5 projects (including only 1 SDH) financed in total by the end of 2017 at a rate around 60%, this program seems to still be in its early days. For this program, ADEME targets a financial help of about 25 €/MWh in the coming years.

Peculiarities of the French market

For now, the rather low gas price and carbon tax in France lead to solar thermal project often not economically profitable. The deployment of French large-scale systems is and will be partly due to the *Energy Service Company (ESCo)* business model (also known as *Solar Contracting*). Indeed, French DHN are mostly operated by companies with a public service delegation contract from cities (about 75%) for a time span of 10 to 25 years [16]. Thus, to overcome the burden of high investment cost for the public service delegation company and the perceived uncertainty connected to solar heating, ESCos take responsibility for the investment, design and operation of the plant and sell the heat to the district heating utilities, which pay a contracted price.

Outlook

It is clear that the objective of 3.1 TWh of produced solar heat by 2030, stated by the French government in its envisioned energy program [17], is challenging with the current trends (1.2TWh at the end of 2017 [18]) and economical context .However, there are reasons to believe that large SDH installations will take off in France. First, large plants in a range above 3000m² (even though for SHIP application) have been built and are in construction in France for the first time. Second, even though the large-scale solar installations program from ADEME has not granted any SDH projects in 2016 and 2017, 2 have been awarded in 2018 and 2 additional in early 2019, sign of a new positive trend. Third, an increase of the carbon tax could also contribute to obtain a more competitive solar thermal technology.

Country Report Germany

IEA SHC FACT SHEET 55.D.D.4

Subject:	Large-scale solar thermal plants in Germany
Description:	Deployment, system design, typical applications and promotion policies of large-scale solar thermal systems in Germany
Date:	March 2020
Authors:	Magdalena Berberich, Solites Dominik Bestenlehner, IGTE University of Stuttgart
Download possible at:	http://task55.iea-shc.org/fact-sheets

Introduction

Germany successfully established a market for large-scale solar thermal systems in DH networks. With 37 systems and about 69,900 m² of gross collector area, Germany is ranking number three in the world regarding installed collector area [19] . The market in Germany got a significant boost in 2016 and performance grew by around 50 percent in 2019. Numbers are expected to double in the next years [20].

Deployment of large-scale solar thermal systems

By the end of 2019, there were 37 large-scale solar thermal systems in operation with a total gross collector area of about 69,900 m² [19]. Figure 11 shows the geographical distribution of the SDH plants in Germany, the share of the Southwest (Baden-Württemberg) is 47 percent. The system sizes range from 99 m^2 to 8,300 m^2 with an average collector area of 1,890 m^2. Flat plate collectors are used mainly, but evacuated tube collectors have a relatively high share of 34 % of installed collector area. For SDH systems, typical values for temperatures are 70-110 °C in supply and 40-80 °C in return flow [1].

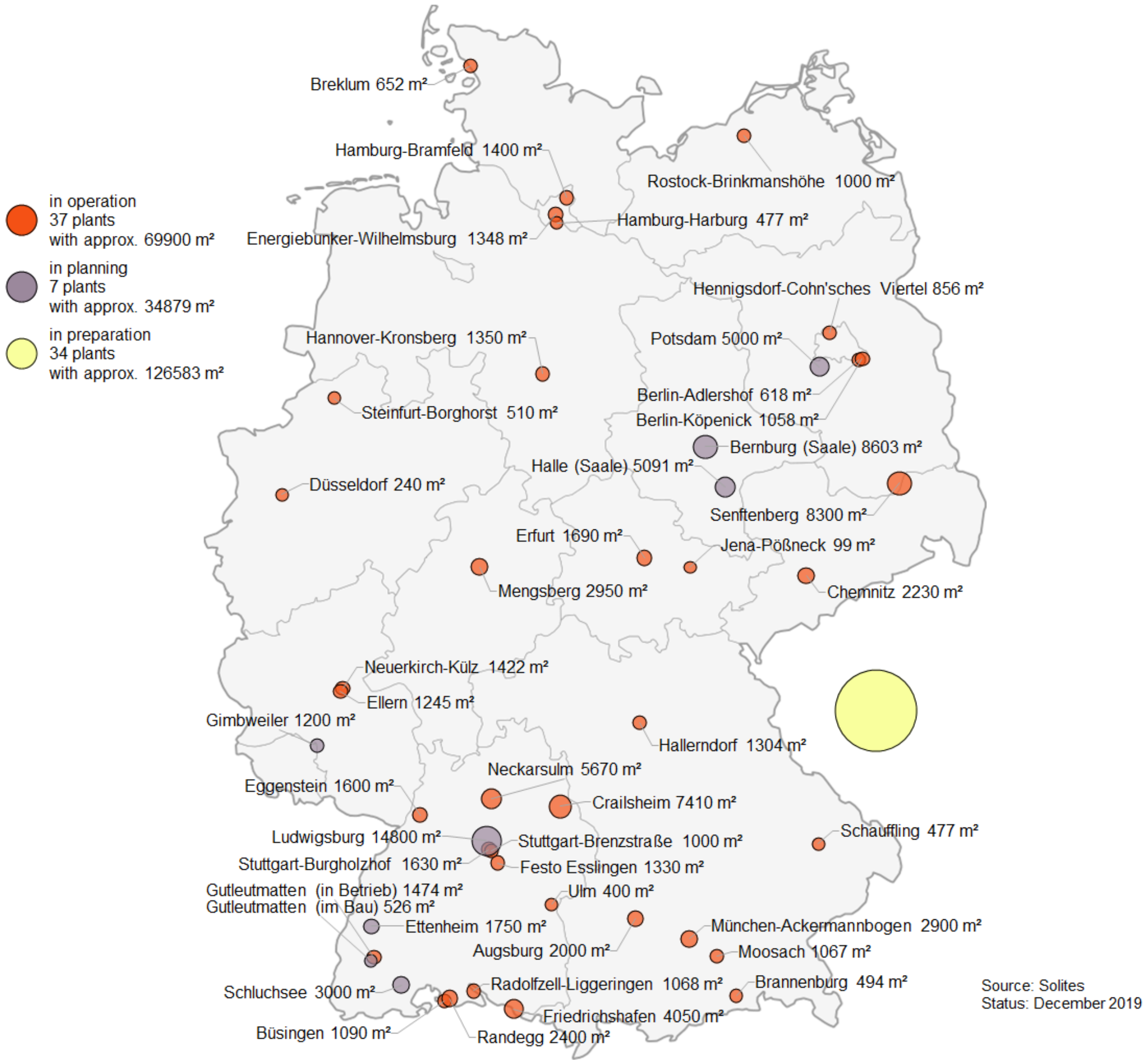


Figure 11: Geographical distribution of large-scale solar thermal plants in Germany

Typical applications

Characteristic for Germany is a broad variety of applications.

SDH applications range from small villages and rural areas, to SDH for districts and SDH in cities and urban centers. For cities and urban areas, DH are usually operated with heat from combined heat and power plants, heating plants, waste incineration or industrial waste heat. Depending on the system size and efficiency of the solar thermal plant, heat production costs below 50 €/MWh can be reached without incentives [21].

Solar thermal projects are often realized in bioenergy villages ("Bioenergiedorf"), where the main share of energy demand is produced from local renewable energies. In 2018 five new bioenergy villages started its operation. The projects are usually initiated by citizens, who cooperate with the municipality, local craftsmen, building companies and consulting engineers. Oftentimes, the citizens set up a registered cooperative to manage the energy supply and distribution, which has the aim of long-term favorable prices instead of short-term profit maximization. Furthermore, it allows a high degree of co-determination and limited liability risks. The combination of wood chip boilers and solar thermal plants turned out to be one successful system for an efficient heat supply, the bioenergy village Büsingen is a good example [22].

Another typical business strategy for large-scale solar thermal systems in Germany is the change from fossil fuels to renewable energies in DH systems. Especially for DH networks with a relatively high thermal load, a solar thermal system can directly feed into the network without additional storage system. This allows for a cheap heat production but only for limited solar fraction of the entire heat demand of the DH network. One regulatory reason for this effort is the reduction of the primary energy factor of the DH network. With a reduced primary energy factor, new customers meet the legal requirements for using renewable energies in new buildings by connecting to the DH network [23]. Furthermore, DH companies as well as industries benefit from long-term cost stability of solar heat.

Policies to promote large scale solar thermal plants

Germany's transformation strategy to renewable energies ("Energiewende") targets a share of renewable energies of the final energy consumption of at least 18 % in 2020 and 30 % in 2030 [24]. In the heating sector, the final energy consumption is to be reduced by 20 % and the heat from renewable energies is to be increased to 14 % until the year 2020. To reach these shares, one possible scenario "Erneuerbare Energien" aims to increase the heat supply by district heating networks to 75 TWh/a in 2050. Meanwhile, the contribution from solar thermal energy to the final energy consumption should increase from 3 TWh/a in 2008 to 80 TWh/a [25].

In 2009, an incentive scheme ("Marktanreizprogramm") was put in place for solar thermal systems [26]. Solar thermal plants with collector areas larger than 20 m^2 receive a subsidy of up to 50 % of the investment costs. Plants larger than 40 m^2 feeding into DH networks receive up to 40 % of the investment costs. Alternatively, a performance-based incentive can be chosen, where a rate of 0.45 €/kWh of the yearly collector yield (according to the Solar Keymark certificate) is paid once. The subsidy is limited to 45 to 65 % of the total investment cost. Additionally, incentives for DH networks and heat storages are paid. Since 2009, active market development is done by Solites together with the German district heating association AGFW and other partners in the international SDH projects as well as in the German projects SolnetBW I and II and Solnet 4.0 [19]. In July 2017, the German Ministry for Economic Affairs and Energy has established a new subsidy scheme for feasibility studies and realization of innovative "District Heating Pilot Projects 4.0" ("Wärmenetze 4.0"), which supply at least 50 % of their annual heat consumption from renewable energy sources or industrial waste heat and have a maximum supply temperature of 95 °C [27].

In parallel to promote the installation of large SDH systems, Germany has a long history of research on large solar thermal systems, mostly in combination with seasonal thermal energy storage (STES). In eleven pilot plants, built between 1996 and 2001, with the aim of reaching 50 % solar fraction, different seasonal heat storage technologies (underground aquifer, borehole, pit and tank storage) were developed and monitored. Multifunctional short- and long-term storages for all heat producers have also been integrated into some systems [28]. This research on large solar thermal plants is still ongoing. The latest research projects are about the extension of a SDH-plant already several years in operation [29], and the analyzation and identification of future potentials of SDH systems with STES [30] [31].

Peculiarities of the German market

In Germany, the realisation of large-scale solar thermal plants is accompanied by various bottlenecks like the availability of land, incomplete knowledge or lack of trust of stakeholders, and acceptance on site. In addition, the district heating itself is the basis for the use of solar thermal energy.

Germany has significantly less DH networks than other European countries. Especially in the Western part of Germany, DH networks are not very common. This results in an economic boundary for large solar thermal systems since the DH network is often not (yet) available and has to be installed additionally. At the same time, natural gas is broadly available and therefore, is usually the most cost-effective solution in terms of investment costs for heat supply.

Nevertheless, a rethinking process has begun, which is also reflected in the increasing number of bioenergy villages. In addition, the market incentive program and the strongly expanded promotion of DH and SDH in the last few years are also having an effect. Many municipalities are now converting their energy supply in the city centers to district heating, and new development areas are increasingly being planned with district heating networks. This suggests that in future solar district heating will play an increasingly larger and more important role in urban energy supply.

Outlook

Large-scale solar thermal technology is technically mature. The good operating results of the first commercial plants have meanwhile got around among the utilities. The disadvantage of high investment and corresponding capital service are now well offset by governmental subsidy programs. This means that the advantage of permanently low operating costs is all the more important. The agreed CO_2 price also contributes to the growing market prospects for large solar thermal systems.

The collector area of realized SDH systems became larger in the last years and it is expected that this trend will be continued and that more SDH systems will be implemented (see Figure 12). With the installation of a 14,800 m² solar collector field integrated in the district heating system of the city of Ludwigsburg, the biggest SDH plant went in operation in spring 2020 [32]. Thermal energy storages will be further developed regarding the construction methods and materials, eg. [31] [33].

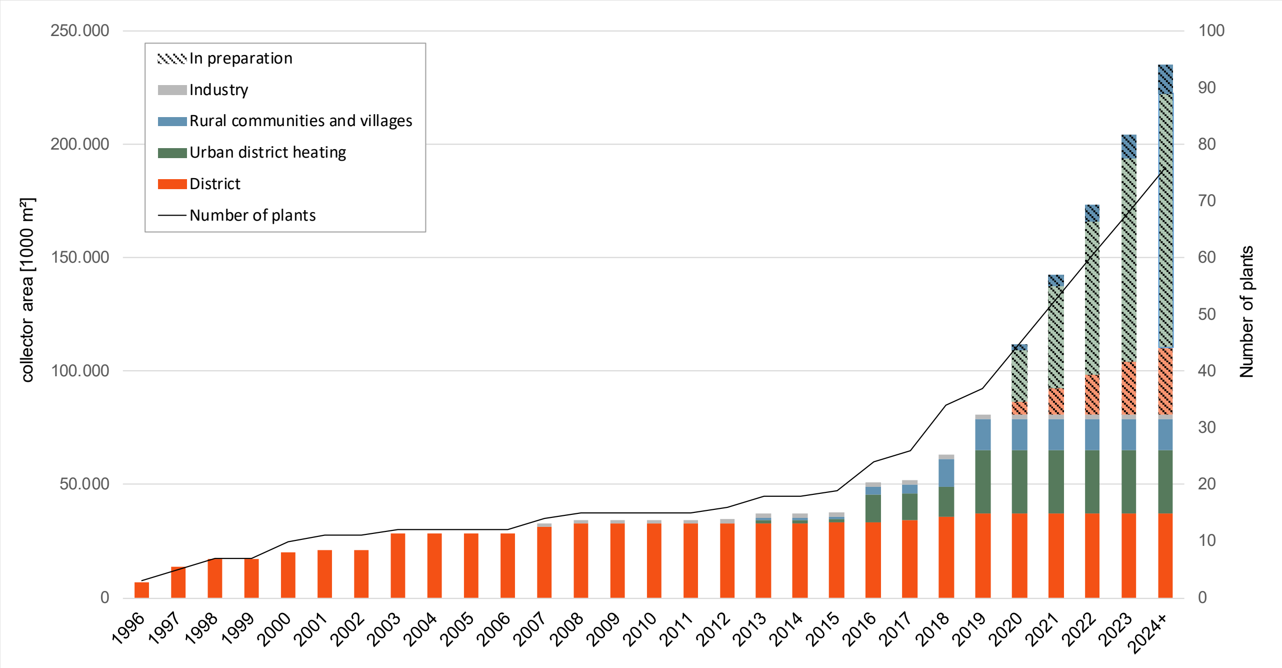


Figure 12: Market figures for SDH in Germany [19]

Country Report The Netherlands

IEA SHC FACT SHEET 55.D.D.4	
Subject:	Large-scale solar thermal plants in the Netherlands
Description:	Deployment, system design, typical applications and promotion policies of large-scale solar thermal systems in the Netherlands
Date:	October 2019
Authors:	Luuk Beurskens, ECN-TNO
Download possible at:	http://task55.iea-shc.org/fact-sheets

Introduction

The Dutch solar thermal market is small. While the market doubled from roughly 300,000 m^2 around the year 2001 to 600,000 m^2 in 2011, currently the market stagnates at around 650,000 m^2. The largest part of the market concerns domestic systems (<6m^2, 66% in 2018), followed by larger systems (>6m^2, 20%) with the remaining part unglazed collectors (14%) [34]. Within the glazed collectors, the market for vacuum tubes covers around 18% (data for 2015) [35]. Small scale solar thermal benefitted from multiple consecutive support schemes [36], while currently there are two main financial incentives: the investment grant ISDE for systems up to 200 m^2 [37], and the energy production subsidy SDE++ for systems above 200 m^2 [38]. Regarding per capita collector area, the Netherlands is certainly not a frontrunner (0.038 m^2 collector area per capita compared to 0.413 m^2 for Austria [39]).

Deployment of large-scale solar thermal systems

Very few large-scale systems are in operation in the Netherlands, two are introduced here. One system is connected to a district heating system: Zoneiland Almere (2010), with an area 7,000 m^2 (4.9 MW_{th}) and an annual heat production of 9,750 GJ (2,700 MWh). To the grid 2,700 households are connected, no heat storage is in place and the solar fraction is 10% [40].

In 2018 a large solar thermal drain-back system was connected to a greenhouse in Heerhugowaard. Total area is 9,300 m^2 (6.5 MWth) and the annual heat production is 18,000 GJ (5,000 MWh). Heat is used either directly or indirectly after an underground thermal energy storage. A small water storage tank is in place (1000 m^3). The solar fraction of this system is unknown [41]. This system operates at relatively low temperature (around 40°C), reason for which the annual yield in relative terms is higher than the Almere system, which is connected to a heat network that requires higher temperatures.

Figure 13 shows the realised solar thermal plants under the SDE+ scheme, based on info from a public database [42]. Based on an average of 18 plants, the average thermal capacity is 260 kW_{th}.

Figure 13: Geographical distribution of realized solar thermal systems in the Netherlands, supported under SDE+ subsidy scheme. The Almere and Heerhugowaard installations as described in the text are not in the SDE+ database. Source: [42].

Policy to promote large scale solar thermal plants

The above-mentioned SDE+ scheme, written out as Stimulation of Sustainable Energy Production, is an operating grant. Eligible are companies, institutions and non-profit organisations. Solar thermal systems above 200 m^2 are supported. Annual opening occurs in phases with an (increasing) maximum phase amount on a first-come-first-served base. The annual budget is around B€ 10 and the production subsidy is paid during 15 years. Renewable energy producers are compensated for a fixed 'unprofitable component' defined as the difference of renewable energy costs and conventional energy (in the case of solar thermal: natural gas is the reference). Solar thermal below 1 MW_{th} receives 9.8 minus 3.2 = 6.6 €c/kWh (provisional data for 2019) and solar thermal above 1 MW_{th} receives 8.5 minus 2.6 = 5.9 €c/kWh (provisional data for 2019) [43].

Outlook

Although solar thermal systems in the Netherlands currently contribute little to the gross final energy consumption (0,7% in 2018 [44]), support schemes are available, targeting all system sizes. In energy terms, electricity generation from Solar PV has exceeded solar thermal heat generation by a factor ten (data 2018). As the energy transition towards a more sustainable system, among which heat supply, is seriously addressed in the Netherlands, it is possible that solar thermal energy will see an increase in future.

Country Report Sweden

IEA SHC FACT SHEET 55.D.D.4

Subject:	Large-scale solar thermal plants in Sweden
Description:	Deployment, typical applications and promotion policies of large-scale solar thermal systems in Sweden
Date:	February 2020
Authors:	Benjamin Ahlgren – Absolicon Solar Collector AB Jan-Olof Dalenbäck – CIT Energy Management
Download possible at:	http://task55.iea-shc.org/fact-sheets

Introduction

Sweden has a history of being the forerunner in solar thermal by building the worlds, at the time, largest plants during the period 1982 to 1992 [45]. Some of the plants installed during that time has for varying reasons been dismantled after 5-25 years of operation but the now oldest plant Åsa (1 030 m^2, 1985) is still in operation after 35 years. In 2010, Sweden was a leading large-scale (> 500 m^2) solar heating country in Europe with 20 plants in operation [46]. When environmental concerns increased and taxing of Swedish district heating for CO_2 and NO_x started, district heating reduced its oil dependency mainly by introducing biofuels and waste into its fuel mix [47]. The last 10 years, development of the Swedish solar thermal market have been slow and it now totals 544,814 m^2 (381 MW_{th}) including not only large scale systems, that is number 33 worldwide [48]. Parts of the Swedish flat plate technology, first developed within state funded research, was moved in late eighties to the company which is now Arcon-Sunmark in Denmark. Recent years, research and business connected to concentrating solar technology is the most active field within large-scale solar thermal in Sweden with Absolicon Solar Collector playing a key role among manufacturers.

Lately, there has been two regional projects aiming to raise attention for district heating with large scale solar thermal in Sweden. First during 2016-2018 in Västra Götaland within the EU project *Solar District Heating and actions from policy to market (SDHp2m)* [49]. Second, a similar project financed by Region Västernorrland is currently carried out by Absolicon and it is called *District heating of the future*. It is spreading Danish solar district heating experience whilst providing pre-feasibility studies for new plants in the region. It has been found that many district heating boilers are at the end of their lifespan, making solar thermal compete not only with fuel costs but with investments for new boilers [50]. This is a good opportunity for solar thermal.

Deployment of large-scale solar thermal

In Sweden, solar heat was estimated to account for 140 GWh in annual heat supply during 2016 [51]. 25 solar thermal systems above 500 m^2 are in operation, the latest of which was deployed in 2016 in Haninge, Stockholm, with roof mounted solar collectors and ground source heat pumps for seasonal storage. The latest one connected to district heating was Ystad, which is a 540 m^2 roof mounted decentralized plant. Most of the solar district heating plants in Sweden would classify as either feed-in or secondary systems and many are roof-mounted on multi-dwelling buildings. Table 2 is listing the biggest solar heating plants that were in operation 2017. For some, e.g. Kungälv, the complete field is however not in operation. The map in Figure 14 is an attempt to gather solar thermal installations bigger than 200 m^2. It shows the plants from the Solar District Heating plant database [52], the ones mentioned in the evaluation in [45] along with installations deployed by Absolicon [53] during the last 10 years.

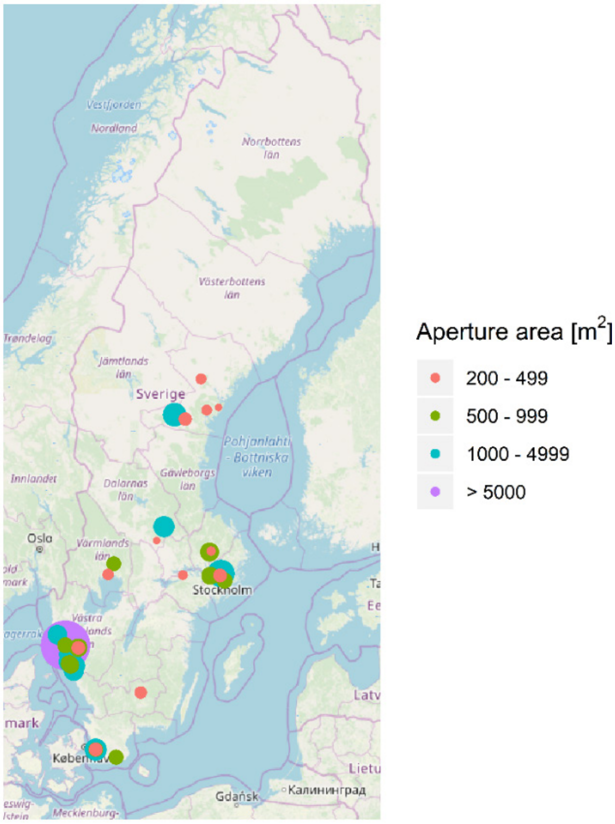


Figure 14: Operating Swedish solar thermal installations bigger than 200 m2, totalling 38 installations [45], [52], [53]. Cartography licensed as CC BY-SA, © OpenStreetMap contributors [54].

Table 2. Swedish solar heating plants > 1000 m^2 in operation 2017 according to the Solar District Heating plant database [52].

Plant	Operation since	Aperture area [m^2]
Kungälv	2000	10 000
Anneberg	2002	2 400
Fränsta	1999	1 650
Gårdsten, Angered	2000	1 410
Bo01, Malmö	2001	1 400
Säter, Hedemora	1992	1 250
Kullavik	1987	1 185
Kockum Fritid, Malmö	2002	1 100
Heleneholm, Malmö	2006	1 100
Haninge	2016	1 050
Åsa	1985	1 030
Odensbacken	1991	1 000
Ellös	2010	1 000

As one can see in Figure 15 – sales of solar collectors have had a negative trend during the past ten years since the support for solar thermal ended in 2011 and policy focus shifted towards solar PV (see below).

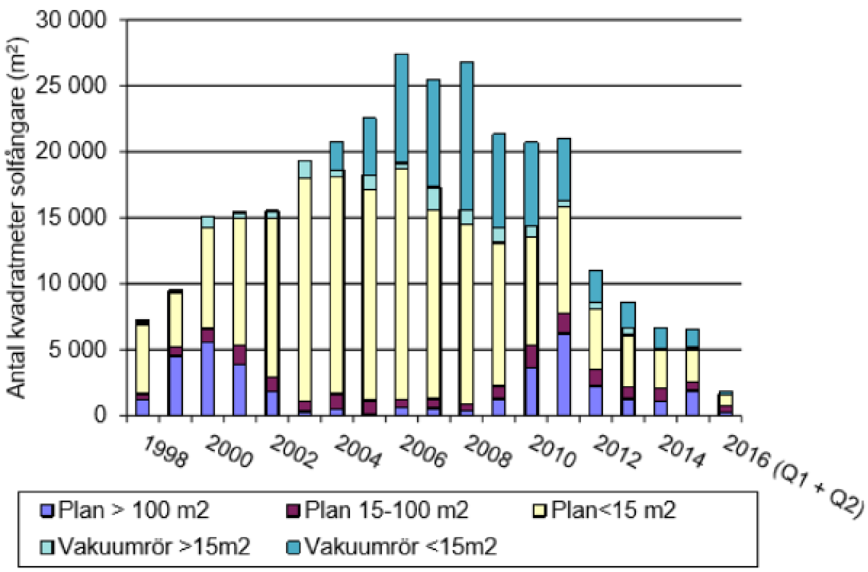


Figure 15: Sales of glazed solar collectors during 1998-2015 measured in m2 and divided by flat plates ("Plan") and evacuated tube collectors ("Vakuumrör") of different field sizes [51].

Policies to promote large scale solar thermal plants

There are currently no policies that directly support solar heating in Sweden. The support for solar thermal (SFS 2000:287 and SFS 2008:1247) ended in 2011 and amounted to approximately 130 MSEK during 2000-2011 and during that time the sales of solar collectors increased around three times [55], see Figure 15 above. The support was based on collector performance in connection to Solar Keymark in order to support collector development [55]. For comparison, the granted support for solar PV (SFS 2009:689) has amounted to a total of 2.9 BSEK since 2009, see Figure 16 [56]. As apparent from Figure 17, solar PV is currently seeing an exponential increase in Sweden [57].

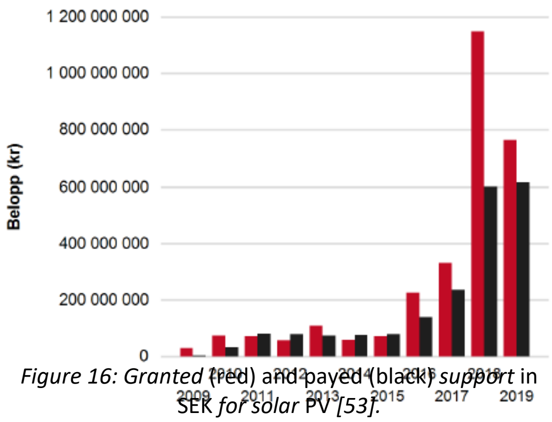


Figure 16: Granted (red) and payed (black) support in SEK for solar PV [53].

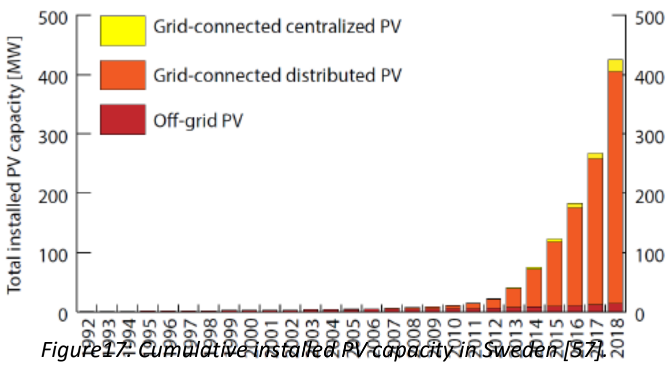


Figure 17: Cumulative installed PV capacity in Sweden [57].

In Swedish Building regulations [58], district heating is currently weighted with a primary energy factor of 1 compared to electricity 1.6. However, there is an ongoing debate on whether a factor of 1 is low enough [59] since the current system has been favoring heat pumps by making it easier for a building with heat pump to fulfil requirements in primary energy consumption than one with district heating [60]. New regulations, using weighting factors instead of primary energy factors, where the weighting factors are instead 0.7 for district heating, 0.6 for district cooling and 1.8 for electricity, are now submitted for comments. They are proposed to come into effect 1st of July 2020 [60]. Energy produced within a real estate and is used by its buildings is not included in the energy usage of the building [58], hence supporting e.g. solar energy. However, only the energy directly used in the building counts, not the energy sold to the grid.

Environmental assessment of the district heating in Sweden is carried out by *Värmemarknadskommittén* (*VMK*) that report publicly e.g. primary energy factor, fuel mix and emission factors for all grids so that customers can get insight into its district heating grid. Solar heating is currently not present in the assessment and performance factors are not reported in the overview of different heat sources in the report [61]. The inclusion of solar heat into the annual environmental assessment of district heating is suggested to highlight its environmental benefits and how it affects the total performance of a district heating grid.

The Swedish government recently approved a stepwise increasing tax on waste incineration starting from April 2020 [62] that indirectly favors deployment of solar district heating. Future increase in costs connected to waste incineration could be a market driver for solar, currently however, burning waste is cheaper.

Peculiarities of the Swedish market

During 2015 district heating accounted for 58 % of the total energy usage in households and facilities in Sweden [47]. The heat price for multi-dwelling customers has increased by around 50 % during the last 20 years, partly due to increased fuel costs [47]. The large penetration of district heating is positive for the deployment of solar district heating and stable energy costs is a selling point towards both utilities and end customers.

The stakeholders in the Swedish district heating market changed from district heating utilities being owned and run by municipalities to more and more private companies [63]. This affects the required rate of return as well as the time horizon in decision making and can have a negative effect on energy sources requiring large initial investments, such as solar heat.

Outlook

The increasing attention regarding climate protection is a strong market driver for all renewable energy systems. An expected growing competition for biomass to reduce climate impact is expected to challenge the extensive dependency of biomass in district heating [64]. Attention has already been put on occasions where lack of biomass has increased the emissions of district heating due to the backup being fossil fuels [65]. Here, solar district heating can play an important role by reducing biomass dependency during the summer months. Sweden could hereby save its biomass resources for winter or for new demands in transportation fuels, chemicals and plastics.

Several system benefits have been identified for deploying solar district in bio-based district heating grids. Boiler efficiencies tend to increase and boiler lifetimes are expected to increase due to less usage on partial load [66]. Some utilities are not able to run their biomass boilers on the low summer loads and must use oil or electricity boilers instead. In addition, with solar district heating there is less emissions from combustion during summer and less transportation of biomass [66].

The shortly ending lifespans of existing district heating plants discovered by the *District heating of the future* project along with the discussion above yields strong arguments for the deployment of solar district heating in Sweden. Introducing solar heat along with heat storages in smaller district heating grids without waste incineration is suggested as the most feasible way forward. That because heat storages can then both increase performance of the existing system (less partial load operation) and store solar thermal energy on daily and weekly basis. In addition, increased storage capacity can reduce fossil fuel use during demand peaks in wintertime.

References

[1] D. Tschopp, Z. Tian, M. Berberich, J. Fan, B. Perers und S. Furbo, „Large-scale solar thermal systems in leading countries: A review and comparative study of Denmark, China, Germany and Austria," 2020. [Online]. Available: https://doi.org/10.1016/j.apenergy.2020.114997.

[2] Solargis, „Solar resource maps and GIS data for 200+ countries," [Online]. Available: https://solargis.com/maps-and-gis-data/overview. [Zugriff am 8 December 2020].

[3] W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide. Global Market Development and Trends in 2017. Detailed Market Figures 2016. 2018 Edition." AEE - Institute for Sustainable Technologies, Gleisdorf, Austria, 2018.

[4] C. Fink et al., "Aggregierte Ergebnisse zum Projekt WISSENSCHAFTLICHE BEGLEITFORSCHUNG ZUM FÖRDERPROGRAMM „SOLARTHERMIE – SOLARE GROßANLAGEN " 2010-2014," AEE - Institute for Sustainable Technologies, Gleisdorf, 2015.

[5] C. Fink, S. Knabl, R. Stelzer, B. Windholz, and F. Helminger, "Aggregierte Ergebnisse aus der wissenschaftlichen Begleitung des Förderprogramms „Solare Großanlagen" in Österreich," presented at the OTTI 27. Symposium Thermische Solarenergie, Bad Staffelstein, Deutschland, 2017.

[6] AEE INTEC, "Data collected in Begleitforschung by AEE INTEC." AEE - Institute for Sustainable Technologies, Gleisdorf, Austria, 2017

[7] E. Union, "Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC," Off. J. Eur. Union, vol. 5, 2009.

[8] C. Fink, T. Müller, and W. Weiss, "Solarwärme 2020. Eine Technologie- und Umsetzungsroadmap für Österreich."

[9] Klima- und Energiefonds, "Leitfaden Solarthermie – solare Großanlagen. Jahresprogramm 2020," Klima- und Energiefonds, 2020.

[10] "Steiermark plant weltgrößte Solarthermie-Anlage," 14-Jun-2018. [Online]. Available: https://steiermark.orf.at/news/stories/2918765/. [Accessed: 01-Oct-2018].

[11] Beijing Solar Energy Research Institute, China Academy of Building Research, DTU, Planenergi, RED, „Large Scale Solar District Heating Systems: A Handbook and Practical Guide" 2014.

[12] W. Weiss and M. Spörk-Dür, "Solar Heat Worldwide. Global Market Development and Trends in 2018. Detailed Market Figures 2017. 2019 Edition," AEE INTEC AEE - Institute for Sustainable Technologies 8200 Gleisdorf, Austria, May 2019.

[13] ADEME, "Appel à projets national: Grandes Installations Solaires Thermiques," 2019. [Online]. Available: https://appelsaprojets.ademe.fr/aap/AAPST2019-20. [Accessed: 15-Sep-2019].

[14] European Union, "Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC," Off. J. Eur. Union, vol. 5, p. 2009, 2009.

[15] Ministère de la Transition écologique et solidaire, “LTECV: Loi de Transition Energétique pour la Croissance Verte,” Aout-2015. [Online]. Available: https://www.ecologique-solidaire.gouv.fr/loi-transition-energetique-croissance-verte.

[16] SNCU, “Les réseaux de chaleur et de froid, Résultats de l’enquête annuelle - édition 2018,” 2018.

[17] République Francaise, “Programmation Pluriannuelle de l’Energie,” Journal Officiel de la République Française, Oct-2016.

[18] Y. Coltier and C. Plouhinec, “Chiffres clés des énergies renouvelables. Édition 2019,” 2019.

[19] P. Geiger, T. Pauschinger, M. Sandrock, C. Maaß, H. Westholm, M. Stehle, M. Blesl, H. Huther, K. Sercan-Çalışmaz and H. Böhnisch, SolnetBW II - Solare Wärmenetze für Baden-Württemberg, Stuttgart, 2020.

[20] L. Deschaintre, O. Miedaner and T. Pauschinger, “The many faces of solar district heating in Germany,” 5th international SDH Conference, Graz, 2018.

[21] M. Berberich and D. Mangold, “Solar district heating in Europe: supplying renewable zero-emission heat,” in Proceedings of IEA SHC, Abu Dhabi, UAE, 2017.

[22] Solites, “SDHplus Bioenergy villages Germany,” Solites, Stuttgart, 2013.

[23] BMWi, “Erneuerbare-Energien-Wärmegesetz - EEWärmeG,” 2018.

[24] BMWi, “Zweiter Fortschrittsbericht zur Energiewende - Die Energie der Zukunft. Berichtsjahr 2017,” BMWi, Berlin, 2017.

[25] BMWi, “Energieeffizienzstrategie Gebäude,” BMWi, Berlin, 2015.

[26] BMWi, “Richtlinien zur Förderung von Maßnahmen zur Nutzung erneuerbarer Energien im Wärmemarkt,” BMWi, Berlin, 2015.

[27] BMWi, “Förderbekanntmachung zu den Modellvorhaben Wärmenetzsysteme 4.0 (‘Wärmenetze 4.0’),” Bundesanzeiger, 2017.

[28] Solites, “Saisonalspeicher,” [Online]. Available: http://www.saisonalspeicher.de/. [Accessed 15 August 2019].

[29] N. Gohl, D. Bestenlehner and H. Drück, “Extension of Germany’s Largest Solar District Heating System with Seasonal Thermal Energy Storage,” 2017.

[30] N. Gohl, H. Drück and D. Bestenlehner, “Evaluation of Germany's Largest Solar District Heating System with Seasonal Thrmal Energy Storage,” in Eurosun 2018 International Conference on Solar Energy for Buildings and Industry, Rapperswil, 2018.

[31] N. Gohl, D. Bestenlehner and H. Drück, “Analyzation and Identification of Future Potentials of Solar District Heating Systems with Seasonal Thermal Energy Storage in Germany,” in Solar District Heating conference, Graz, 2018.

[32] Stadtwerke Ludwigsburg, “Kommunales Klimaschutz-Modellprojekt SolarHeatGrid,” [Online]. Available: https://www.swlb.de/solar-heat-grid. [Accessed 17 February 2020].

[33] T. Urbaneck, F. Findeisen, J. M. Mücke, S. Lang, M. Gensbaur, D. Bestenlehner, H. Drück, R. Beyer and K. Pieper, Oberirdische Speicher in Segmentbauweise für Wärmeversorgungssysteme - OBSERW, Chemnitz: Technische Universität Chemnitz, 2018.

[34] Statistics Netherlands (CBS), Zonnewarmte, https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82003NED (September 2019).

[35] Statistics Netherlands (CBS), Afzet afgedekte zonnewarmte systemen, uitgesplitst naar type systeem, https://www.cbs.nl/nl-nl/maatwerk/2016/20/afzet-afgedekte-zonnewarmte-systemen-naar-type-systeem (September 2019).

[36] Menkveld, M. and Beurskens, L.W.M., Renewable heating and cooling in the Netherlands, ECN Policy Studies, June 2009, ECN-B--09-013, https://publicaties.ecn.nl/ECN-B--09-013

[37] RVO, Investeringssubsidie duurzame energie ISDE, https://www.rvo.nl/subsidies-regelingen/investeringssubsidie-duurzame-energie-isde (September 2019).

[38] RVO, https://www.rvo.nl/subsidies-regelingen/stimulering-duurzame-energieproductie (September 2019).

[39] EurObserv'ER Solar Thermal Barometer (June 2018) https://www.eurobserv-er.org/category/all-solar-thermal-and-concentrated-solar-power-barometers

[40] Nuon, https://www.nuon.nl/duurzame-energie/zonne-energie/zonnestralen-uit-uw-douche.

[41] Tesselaar Freesia, https://www.tesselaarfreesia.nl/2019/02/01/groene-freesias-uit-heerhugowaard-het-grootste-zonthermische-project-van-nederland.

[42] SDE public viewer, realised solar thermal installations under SDE+ (anonymised data), https://www.rvo.nl/subsidies-regelingen/stimulering-duurzame-energieproductie/feiten-en-cijfers/feiten-en-cijfers-sde-algemeen

[43] RVO, https://english.rvo.nl/subsidies programmes/sde.

[44] Statistics Netherlands (CBS), 'Hernieuwbare energie in Nederland 2018' (September 2019), https://www.cbs.nl/nl-nl/publicatie/2019/40/hernieuwbare-energie-in-nederland-2018

[45] J. O. Dalenbäck, G. Lennermo, P. E. Andersson-Jessen, and P. Kovacs, Solvärme i Fjärrvärmesystem - Utvärdering av primärkopplade system. 2013.

[46] J. O. Dalenbäck, 'SDH WP2 D2.1 Success factors in Solar District Heating', CIT Energy Mangement AB. Göteborg, 2010.

[47] Swedish Energy Agency, 'Energiläget', 2017.

[48] W. Weiss and M. Spörk-Dür, 'Solar Heat Worldwide: Global Market Development and Trends in 2018', 2019.

[49] 'SDHp2m from policy to market'. Solar District Heating, 2019.

[50] 'Nu startar projektet Framtidens Fjärrvärme om lagring av solvärme från sommar till vinter | Absolicon Solar Collector'. [Online]. Available: http://www.absolicon.se/nu-startar-projektet-framtidens-fjarrvarme-om-lagring-av-solvarme-fran-sommar-till-vinter/. [Accessed: 03-Jan-2020].

[51] Energimyndigheten, 'Uppföljning av utvecklingen för investeringar i solenergi', 2016.

[52] ‘Plant database – Solar District Heating’. [Online]. Available: https://www.solar-district-heating.eu/en/plant-database/. [Accessed: 22-Jan-2020].

[53] ‘Absolicon Solar Collector AB’. 2020.

[54] ‘OpenStreetMap’. [Online]. Available: https://www.openstreetmap.org/copyright/en. [Accessed: 23-Jan-2020].

[55] Boverket, Utvärdering av solvärme- bidraget och solvärmestödet. 2012.

[56] Boverkets statistiksystem, ‘Stöd för installation av solceller’, 2019.

[57] IEA/PVPS, J. Lindahl, C. Stolts, A. Oller Westerberg, and B. Jeffrey, ‘National Survey Report of PV Power Applications in Sweden’, 2018.

[58] Boverket, ‘BFS 2011:6’, 2011.

[59] G. Ingelhag and M. Gullberg, ‘Primärenergifaktorer för fjärrvärme : Analys och beräkning av primärenergifaktorer för svensk fjärrvärme’, 2017.

[60] Boverket, ‘Konsekvensutredning BFS 2020 : XX’, 2020.

[61] Värmemarknadskommitén, ‘Fjärrvärmens lokala miljövärden’, 2018.

[62] Finansdepartementet, ‘Lagrådsremiss Skatt på avfallsförbränning, Prop. 2019/20:32’, 2019.

[63] D. Magnusson, ‘Ägarförändringar På Den Svenska Fjärrvärmemarknaden – En Översikt Över Förvärv Och Avyttringar 1990-2014’, no. 353, 2015.

[64] K. Ericsson and S. Werner, ‘The introduction and expansion of biomass use in Swedish district heating systems’, *Biomass and Bioenergy*, vol. 94, pp. 57–65, 2016.

[65] ‘Brist på biobränslen och kall vinter syns i fjärrvärmestatistiken - Energiföretagen Sverige’. [Online]. Available: https://www.energiforetagen.se/pressrum/nyheter/2019/juni/brist-pa-biobranslen-och-kall-vinter-syns-i-fjarrvarmestatistiken/. [Accessed: 21-Jan-2020].

[66] P. A. Sørensen and J. O. Dalenbäck, ‘SDHp2m from policy to market - Implementering av solvärme i befintliga biovärmecentraler’, 2017