SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Technology Position Paper

Efficient Solar District Heating Systems – Considering higher temperatures and digitalization measures

April 29th, 2025

Technology Collaboration Programme
by iea

Contents

Figure 1 The largest thermal solar district heating plant of the world, in Silkeborg, Denmark

This document was prepared by Klaus Lichtenegger, BEST – Bioenergy and Sustainable Technologies, Operating Agent of *SHC Task 68 Efficient Solar District Heating Systems – Considering higher temperatures and digitalization measures* of the Solar Heating and Cooling Technology Collaboration Programme with input from Magdalena Berberich, Solites, Germany, Lukas Emberger & Maria Moser, SOLID SES, Austria, Luuk Beurskens, TNO, Netherlands, Joakim Byström, Absolicon, Sweden, and other experts from Task 68.

DOI: 10.18777/ieashc-task68-2025-0001

This position paper provides an overview of **Solar District Heating Systems** (with an example plant shown in Figure 1), outlining their importance, capabilities, and required actions to reach their full potential. It addresses issues for policy and decision makers, other stakeholders, journalists and influencers and presents high-level information as a basis for the uptake and further development of Solar District Heating. It concludes by highlighting the existing challenges and the actions needed to increase the share of solar energy in district heating.

1 Introduction and Relevance

Climate change, which is being driven by our dependence on fossil fuels and the harmful Green House Gases (GHGs) they emit, is having an increasingly negative impact on both the global ecosystem and on the lives of hundreds of millions of people, mostly due to the steep increase and disastrous consequences of extreme weather events. The world energy supply, however, still mostly relies on fossil fuels (>75%) – as shown in Figure 2. Thus, there is an urgent need to reduce our use of fossil fuels and increase the share of renewable energy sources.

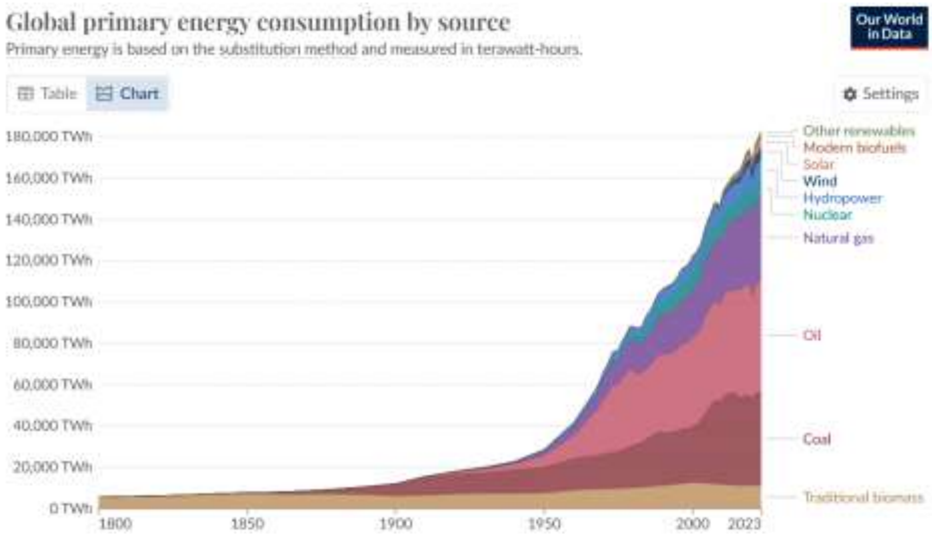

Figure 2 Historic development of global energy consumption by source, from (Ritchie, 2020)

An important lever for increasing the share of renewables is targeting the heat supply. This is because heat constitutes almost 50% of the final energy consumption globally, as illustrated in Figure 3/left. This is also emphasised by **#HeatIsHalf** (see Logo in Figure 3/right) to highlight the – often underestimated – importance of heat for the global energy demand.

Figure 3 Energy demand, including share of renewables adapted from Renewables 2023 Global Status Report, https://www.ren21.net/gsr-2023/ and #HeatIsHalf logo, https://heatishalf.com.

For decarbonization of the heating sector, two key technologies have emerged, see e.g. (Kelch, 2024):

- **Compression heat pumps,** which can be powered by renewable electric energy and are particularly well-suited for sparsely populated areas.
- **District heating (DH) systems** are ideally suited for densely populated areas (like cities and compact villages). DH systems allow for the integration of various heat sources, including combined heat and power plants, biomass plants, industrial waste heat, heat from waste incineration and heat from future key elements of the energy system (like electrolysers and methanization reactors).

An important renewable heat source to be considered and, if possible, integrated into district heating systems, is solar heat. As an abundant, and fully renewable energy source with very low operational cost, **Solar District Heating** (SDH) should be an obvious choice to increase the share of renewable energy in district heating. The structure of such a system is illustrated in Figure 4.

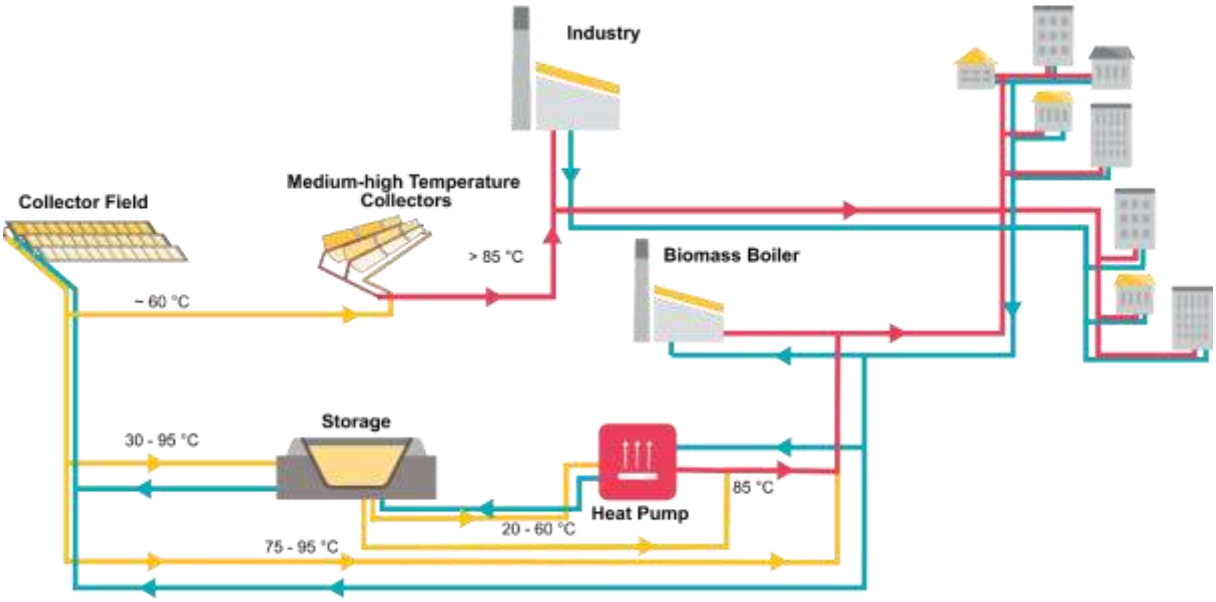

Figure 4 District heating system with integration of low- and medium-temperature collectors, thermal storage, heat pumps and a biomass boiler (as example for a different renewable heat source)

In practice, however, there are reservations against solar technology, or it is not even considered as a viable option, often due to misconceptions or the rather short-term perspective on heat planning. IEA SHC Task 68 aims to correct such deficiencies and demonstrate the benefits of solar thermal in district heating systems.

2 Current Status

Solar District Heating is a mature technology. It is currently one of the most prominent and important applications of large scale solar thermal technology. For relatively high temperatures (e.g. 100°C), modern collectors have a high heat yield, see Figure 5.

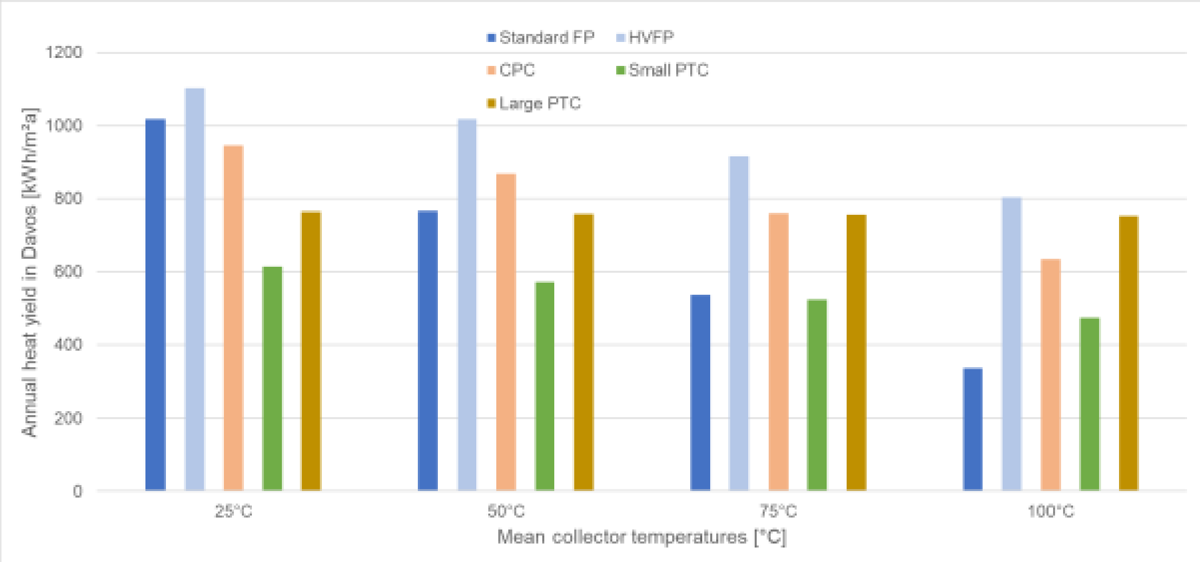

Figure 5 Comparison of gross thermal yield in Davos for different operating temperatures, based on Solar Keymark data and ScenoCalc calculations, from (Tamm, 2024), for standard flat-plate collectors (FP), high-vacuum flat plate (HVFP), compound parabolic concentrator (CPC) and parabolic trough collectors (PTC).

While, in northern climates, for small-scale solutions (like single family homes), solar solutions based on photovoltaics (PV) and heat pumps have largely supplanted solar thermal systems, solar thermal systems continue to have several advantages for district heating (as well as for other applications like industrial heat):

- **High Efficiency:** Solar thermal collectors achieve excellent performance at high temperatures, as required in most larger district heating systems. Different types of collectors available in the market can be used for different target temperatures, as shown in Figure 5.
- **Convenient Energy Storage:** Thermal energy, efficiently provided by solar thermal systems, can be stored, in large volumes, in a cost effective and environmentally friendly ways.
- **Global Market:** While the market for PV modules is almost entirely derived from China, some 90%. Solar thermal has a diversity of manufacturers from various countries. The production of solar thermal collectors also requires considerably less amounts of critical raw materials.
- **Mature Technology**: While other technologies like high-temperature heat pumps are possible heat sources for this application, they are not as easy to integrate and cannot yet be considered a mature, well-established technology.

Around the world there are several successful (technological and economical) implementations of SDH, including plants with high-performance flat-plate collectors or concentrating solar collectors and systems with seasonal heat storage. An overview of the installed systems is given in Figure 6.

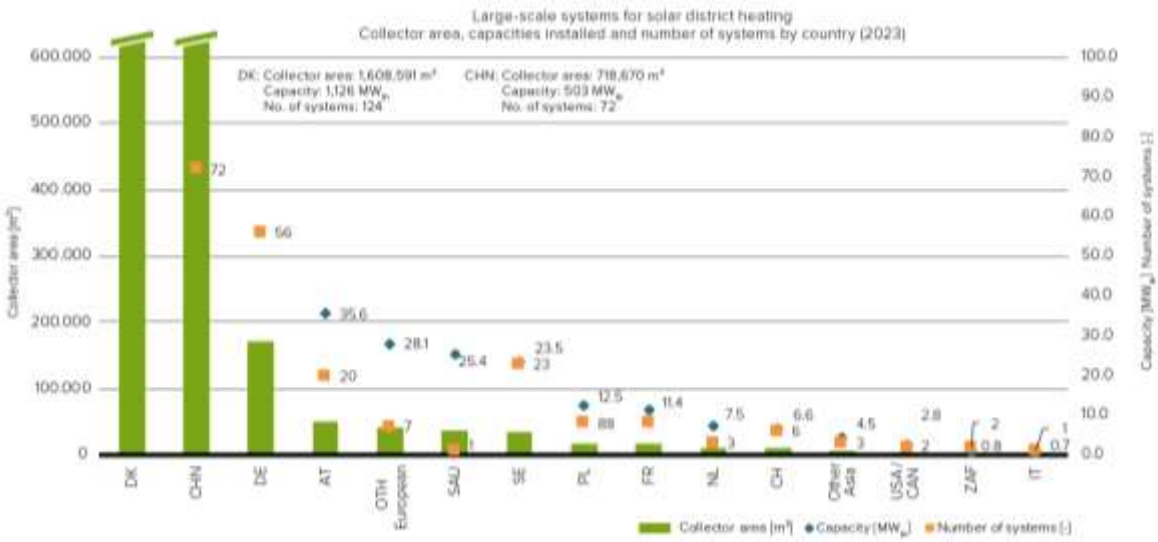

Figure 6 **Large-scale systems for solar district heating – capacities, collector area installed and number of systems by the end of 2023, adapted from Fig.~8 of (Weiss, 2024)**

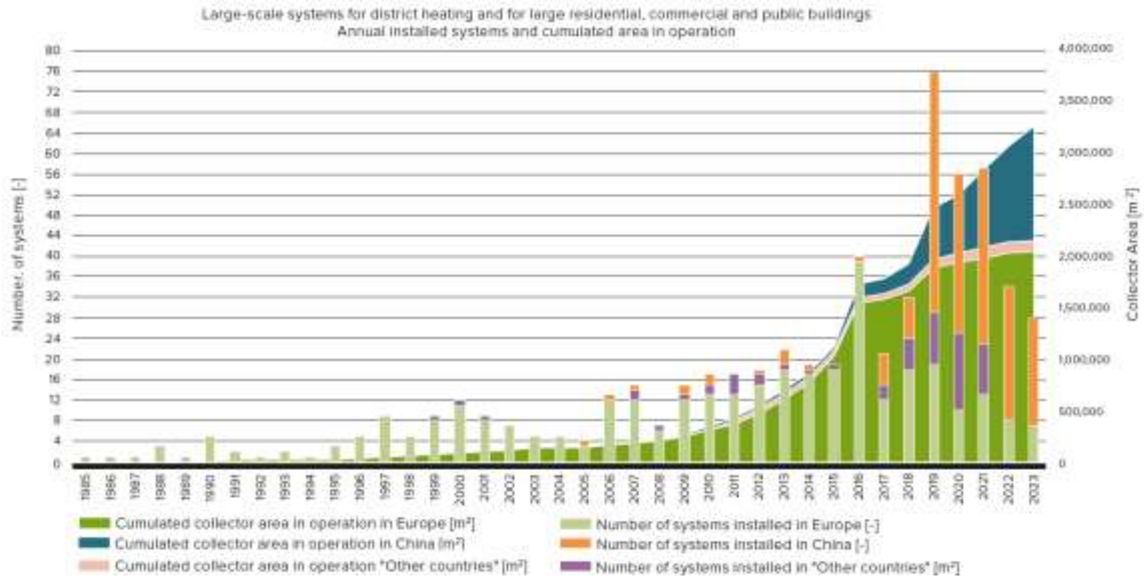

Figure 7 **Large-scale systems for solar district heating and large residential, commercial, and public buildings worldwide – annual installations and cumulated area in operation, adapted from Fig.~7 of (Weiss, 2024)**

The historic view in Figure 7, shows that the number of annual installations has – after a phase of almost exponential growth – has decreased since 2020. The increase of area in operation is driven by installations in a single country (China), while in Europe, installations have plateaued.

In many parts of the world, SDH should thrive as a reliable and cost-effective method to decarbonize the heating sector yet has stagnated or not yet managed to be properly recognized.

The reasons for this unfortunate situation are most likely not technological ones, but more related to high investment costs (CAPEX), which are often difficult to raise without public funding – though they are readily offset in operation by the very low operational expenses (OPEX) and the security of supply, guaranteed by the independence of fuel imports.

3 Potential

Of all renewable energy sources, solar energy is rated as the one with the most potential. Most analyses, from MacKay (2009, Ch. 30) to IEA (2024, Ch. 3) agree that the decarbonization of our energy system will have to rely largely on solar energy, combined in an elaborate way with other renewable energy sources.

While the demand of energy for heating is expected to drop slightly due to improved building efficiency in the form of better insulation, etc., and due to climate change, the situation depicted in Figure 3 will not change dramatically. Heat will remain a large part of the total global energy demand, and, in addition to industrial process heat, buildings will continue to account for a large percentage of total consumption. Thus, there is great potential for solar district heating.

For heating purposes, an often-cited target Solar Fraction (SF) is 20% This value can be reached by making use of solar energy during summer and on sunny days during transition periods (with little contributions during winter). In such an approach, additional heating technologies with sufficient peak power to satisfy the maximum heat demand are still required.

While the space demand for such solutions is an obstacle, it is by no means insurmountable. Figure 8 shows the space requirements for 20% SF for a few selected cities. The space demand is comparable to those of other infrastructure projects, e.g., airports, highways junctions or golf courses. In contrast to other infrastructure, the ground under solar thermal collectors is not sealed, biodiversity increases, and the area can be used twice for collectors and as grazing land for sheep (Tamm, 2024).

Figure 8 Illustration on the space demand of a solar thermal plant to satisfy 20% of the heat demand for Bratislava (1 171 280 m^2 area, 229 491 MWh/a), Klagenfurt (474 012 m^2 area, 109 205 MWh/a), Riga (6 741 504 m^2 area, 967 116 MWh/a) and Zaragoza (755 392 m^2 area, 287 793 MWh/a), from https://solardistrictheating.eu/ (currently restricted website), based on Google Maps and on an analysis done by Absolicon

Solar district heating systems with relatively high solar fractions have already been demonstrated, e.g., St. Ruprecht, Austria, with 15% SF, Silkeborg, Denmark, with 17-20% SF, and Tåårs, Denmark, with 22% SF (Fogelström, 2025).

While for most countries, aiming for 20% SF is already a bold step beyond the usual state of art, it is by no means the limit. Significantly higher solar fractions can be achieved by use of seasonal storages or smart combinations with other technologies like shallow geothermal and heat pumps. By transferring heat from summer to winter, such systems can push the limit. For the city of Dronninglund, Denmark, 40% SF was achieved using a 60,000 m^3 pit storage. While additional heat sources are usually still required to compensate for heat losses and corresponding temperature drops, solar fractions above 50% are possible, (Klöck, 2023), (SOLID, 2024).

In contrast to alternative approaches (e.g., large scale retrofit of building insulation and installation of heat pumps), these savings could be achieved within a relatively short timeframe of only a few years, as shown in (Kelch, 2024). Thus, the advantages of solar thermal plants as a renewable heat source for district heating grids are numerous. The ability to provide low cost for heat (calculated over lifetime) and price stability provided by fuel independence are particularly striking ones.

There are, however, also significant barriers that have prevented the widespread adoption of solar thermal plants for this purpose. The “high-CAPEX-low-OPEX” situation, which is characteristic for renewable energy, also exists for SDH. The estimated potential reduction of the Levelized Cost of Heat (LCoH) up to 2050, however, illustrates that solar thermal is more likely to reduce costs than that a cost increase is to be expected, which may partly mitigate the financing risk, as shown in Figure 9.

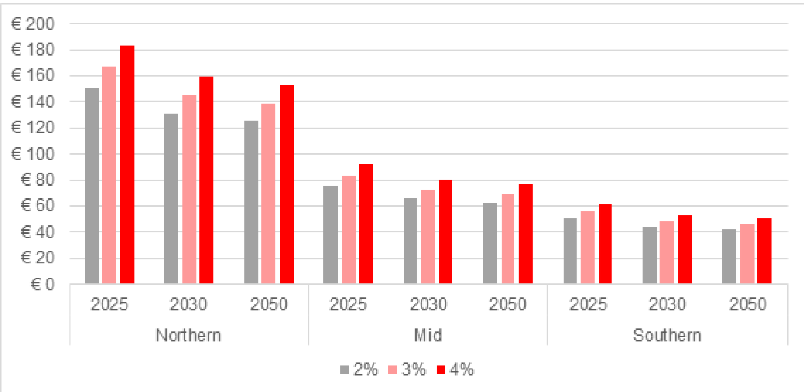

Figure 9 Estimated potential levelized Cost of Heat (LCoH) for three European regions and three interest rates (2%, 3% and 4%), from (Beurskens, 2025)

In addition, the space demand is sometimes regarded as problematic, and there is often little knowledge or understanding about the potential of this technology.

Lowering the entry barrier can be achieved by several means:

- Dissemination of successful installations of solar district heating, towards planners and investors not yet aware of the benefits and possibilities.
- Acceleration of the planning phase through standardization of processes and improved information/data flow between parties.
- Offering different options, with solutions tailored to meet the needs of the client, e.g., either as turnkey solutions or as heat purchase agreements, which reduce risk to the customer.
- New financing schemes, including crowd funding
- Governmental and general investment policies more oriented towards sustainable long-term perspective

4 Actions Needed

To support the rapid decarbonization of district heating, the table below highlights some of the challenges and the actions needed to overcome them.

Challenge	Action needed	Action by whom
Collector technologies	While high-temperature solar collectors have reached a high degree of maturity, further R&D on raising efficiency and reducing production costs would be beneficial. Also, deployment is an important driver for cost decrease.	Collector manufacturer (in cooperation with universities / research centres)
Combination of Technologies	Establish systems to combine different renewable energy production and storage technologies to establish fully renewable heating and cooling with high shares of solar energy.	System designers together with R&D partners (universities, research centres)
Monitoring, Evaluation, Control and Data Science	Raise level of digitalization of solar thermal plants and district heating systems; adopt advanced yield monitoring (e.g. by using SunPeek, https://sunpeek.org/) and fault detection software in order ensure high yield and proper operation during the service life. Implement advanced (model-predictive) control for higher system efficiency and better integration in the overall energy management system.	Plant / district heating system owner or operator (possibly in cooperation with R&D partners)
Cost reduction, and policy design	Increase public funding to renewable energy sources like solar thermal as a lever to motivate DH operators to quickly switch to renewable energy sources instead of sticking to conventional technology they already know. Reduce bureaucratic burden for project development (e.g. by speeding up routine environmental checks) Energy contracting or crowdfunding to lower the barrier posed by high investment costs	Policy/decision makers Contracting or financing institutions
Effective dissemination	Build awareness for the possibilities offered by solar thermal solutions (which are often still not very well known in the DH community), e.g. by providing easy to use calculation tools and presenting successful use cases, to reduce the average time from contact to contract.	IEA TCPs (SHC, DHC, …), ISES, universities, research centres, manufacturers

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