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Status in Solar Heat from Concentrating Solar Systems

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Abstract. A survey presents the latest developments in solar process heat systems. Solar field sizes and cost data about installations commissioned between 2010 and 2020 have been raised from collector suppliers and project developers worldwide. Based on this unique database, the cost development in the last 10 years is analysed for more than 900 projects. For investigating the performance of parabolic trough systems in the moderate Central European climate, data of a full year of operation have been investigated. The results confirm former simulations on the collector performance of solar fields.

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INTRODUCTION

This survey gives an overview of the developments in solar thermal heat in terms of installations with concentrating solar systems recently erected and of costs of solar thermal systems.

For compiling the data of the number of installations commissioned, the collector producers have been contacted and their data analysed. To derive cost information, data of more than 900 commercial and industrial (C&I) solar heat projects commissioned between 2010 and 2020 in the major solar heat markets worldwide have been evaluated.

Additionally, first results of the operation of a commercial parabolic trough collector field in a moderate climate will be presented. The measured annual yield is put into relation with former simulations with the program greenius.

DEVELOPMENTS ON THE SOLAR PROCESS HEAT MARKET

Only 71 solar heat for industrial processes (SHIP) plants with a combined capacity of 91 MWth (130,745 m^2 collector area) were commissioned around the world in 2020 – compared to 86 and 99 systems in 2019 and 2018, respectively. These are the results of yearly surveys of about 80 technology suppliers listed on the SHIP Supplier World Map, created by Solrico in the frame of the international Solar Payback project.

Table 1 displays the newly installed collector area for the solar concentrating technologies in the years 2018 to 2020 for SHIP as well as for Non-SHIP applications. The main industry hubs for concentrating solar collector manufacturing were China, Germany, India and Mexico.

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TABLE 1. Newly installed concentrating collector area for heat purposes [1]

	Application	Newly installed collector area in 2018 [m² aperture]	Newly installed collector area in 2019 [m² aperture]	Newly installed collector area in 2020 [m² aperture]
Parabolic trough	SHIP applications	11,367	7,539	14,030
	NON-SHIP applications	21,220	4,051	218
	Glasspoint (Miraah)	0	257,143	0
	Total	**32,587**	**268,733**	**14,248**
Dish	SHIP applications	1,075	1,962	310
	Commercial cooking	1,576	160	1,140
	Total	**2,651**	**2,122**	**1,450**
Linear Fresnel	SHIP applications	360	636	602
	Total	**360**	**636**	**602**
	Newly installed collector area across all three technologies [m²]	**35,598**	**271,491**	**16,300**
	Total collector area in operation at the end of the year [m²]	**520,556**	**792,046**	**808,346**

Although many solar technology suppliers reported delays in plant construction and commissioning, 2020 saw several multi-megawatt plants come into operation. The five largest plants are shown in Table 2. Three of them are used in agriculture – more specifically, in the countryside, where space is usually not an issue. In addition, each plant was installed by another technology supplier, all of which chose the collector technology most suited to their product portfolio.

TABLE 2. Largest SHIP plants commissioned in 2020 [2]

Installation site	Size of solar field [m2 / kW]	Technology provider	Type of collector	Application	Commissioning date
Nibbixwoud, Netherlands	15,000 m² 10.5 MW_{th}	G2 Energy, Netherlands	Flat plate	Heating Freesia farm greenhouses	April 2020
Sanya, Hainan, China	6,645 m² 4.6 MW_{th}	Linuo Paradigma, China	Vacuum tube	Process heat for beverage industry	July 2020
Ganzhou, Tibet, China	5,500 m² 3.9 MW_{th}	Vicot, China	Parabolic trough	Preheat for agricultural drying	May 2020
Lhasa, Tibet, China	5,000 m² 3.5 MW_{th}	Sunrain, China	Vacuum tube	Heating agricultural greenhouses	September 2020
Izmir, Turkey	5,000 m2 3 MW_{th}	Soliterm, Germany	Parabolic trough	Process heat for packaging company	September 2020

DATA ON SOLAR THERMAL HEAT COSTS

A database that contains costs and yields of more than 900 commercial solar heat projects larger than 50 m² commissioned in 21 countries around the world between 2010 and 2020 has been yielded by Solrico with the aim to add solar heat for the first time in IRENA´s flagship publication Renewable Power Generation Costs. IRENA has evaluated these data and derived statistics on solar heat costs in terms of USD-cent per kW and Levelised Cost of Heat (LCOH).

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Totalling more than 930 MWth, these plants are used for a variety of applications, ranging from solar district heating and solar process heat to central hot water distribution for hotels, hospitals or housing blocks.

Average LCOH values consider SHIP projects commissioned between 2010 and 2020 with all collector types excluding air heating applications. The weighted-average LCOH for SHIP plants ranges from 3.8 to 9.7 USD-cent/kWh, depending on different cost structure and irradiation levels. . For the temperature range below 150 °C, in Asia and Mexico for example an LCOH of 8,7 USD-cent/kWh was investigated. In this calculation 140 projects were investigated with a size of average 293 kW, 731 kWh/(m² * a).. Par contrast, in Europe 82 projects were investigated which reached a weighted-average LCOH of 8.7 USD-cent/kWh (with a size of average 400 kW and an average yield of564 kWh/(m² * a)). Given the relatively small number of projects providing heat between 150 °C and 400 °C, the average is calculated on a global level. The projects reached costs at 9.7 USD-cent/kWh for an average plant size of 334 kW and a yield of 654 kWh/(m² * a). All LCOH values are calculated with a standardised Weighted Average Cost of Capital (WACC) of 5% and 25 years lifetime and consider SHIP projects commissioned between 2010 and 2020 with all collector types excluding air heating applications.

Two important drivers of solar heat cost reduction have been identified, namely an increasingly mature domestic market and growing economies of scale. The second is most evident when looking at the solar district heat market in Europe (Fig. 1). Each orange circle shows one Solar District Heating (SDH) project and each blue circle shows one of the large multi-MW SHIP plants commissioned between 2010 and 2021 in Europe. 97% of the SDH projects have been installed in three countries Austria, Germany and Denmark.

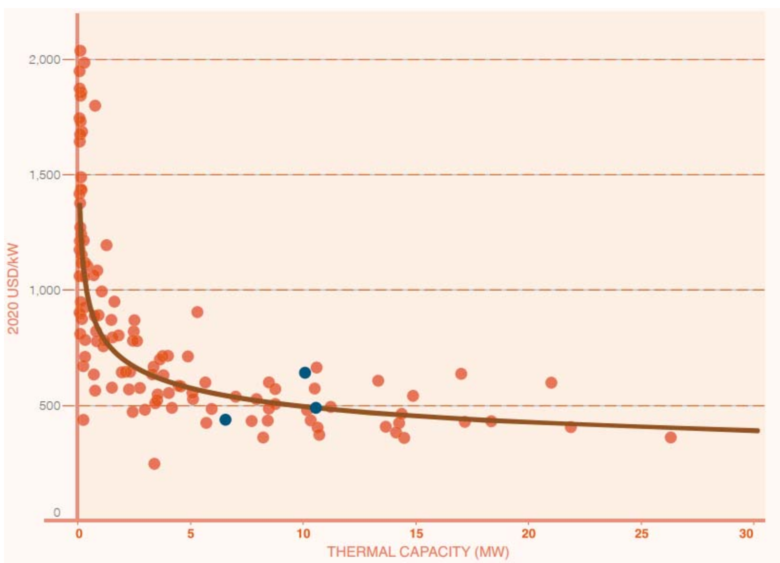

FIGURE 1. Weighted average installed costs of differently sized solar district heating projects in orange and solar process heat plants in Europe in blue. Source: IRENA/Solar Payback [3]

The cost reduction is evident for the district heating plants (orange dots) and amounts to 14% at doubling the thermal capacity. As the three process heat plants (blue dots) fall around the trend line it is assumed that the solar process plants follow the same cost reduction. The trend curve suggests that for every doubling of the size of the plant, total installed costs will decline by 14 %. This market is also addressed by suppliers from concentrating collectors.

The new IRENA solar heat project cost data base also allows the analysis of cost trends over time. First results in Figure 2 show impressive cost reductions for example for European SHIP plants between 2014 and 2020. The diameter of each circle denotes the project capacity in kW, and the centre the total installed cost in USD 2020 on the Y-axis. The bold line represents the weighted-average installed costs by year. The arrow marks the reduction between the weighted-average costs of all projects in the first and the last year of the examined period.

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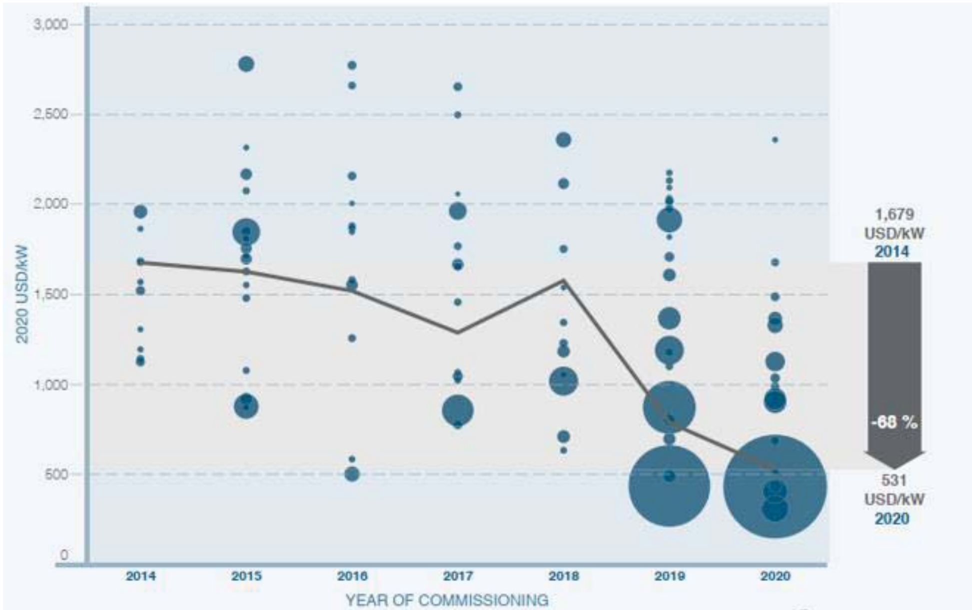

FIGURE 2. Weighted-average total installed costs of 101 SHIP plants in Europe. Source: Solar Payback/IRENA [3]

According to the investigations of Solar Payback and IRENA, economies of scale for larger plants are achieved by:

- Lower bill-of-materials
- Improved efficiency in manufacturing
- Lower fixed costs per kW for permissions, design and logistics
- Faster and more efficient installation.

IRENA plans to publish an alone-standing publication in the first quarter of 2022 focusing on C&I solar heat cost trends.

MEASUREMENT RESULTS FROM A PARABOLIC TROUGH FIELD IN BELGIUM

Only very few installations with concentrating collectors have been erected in a moderate climate and little is known about their operation. Therefore, experiences from operation of solar process heat installations are of special interest. The company Solarlite provided data [1] which are discussed in this chapter.

Solarlite is surveying online the operation of a 1107.8 m² (gross) field of collectors with the typical power plant geometry of e.g. the EuroTrough including glass/silver mirrors and vacuum receiver pipes. The plant is owned by the company Azteq which sells heat to the customer ADPO at its facility in Antwerp (Fig. 3).

After a commissioning and optimisation phase, Solarlite has gained data for a full year of operation for the period 01.08.2020 to 31.07.2021.

For the heat transfer fluid in the collectors a silicon oil, Helisol, is being operated between 200 to 300 °C as foreseen in the design. It heats a boiler where steam at 160 to 170 °C is produced. The BoP (Balance of Plant) which includes pumps steam boiler, expansion tanks and other devices, is assembled in a container, situated close to the solar field with about 10 to 15 m of piping length in between. The SCE (Solar Collector Element) have an aperture width of 5.77 m and a length of 12m. The connection line between the two collector rows has a length of 12 m. From the BoP a steam line has been installed for connecting with the consumers plant.

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FIGURE 3. Parabolic trough collectors for steam generation at ADPO plant in Belgium

The data received from Solarlite are related to the primary loop which includes the solar field and piping between the BoP and solar field. No information on detailed data or measurement equipment was transferred except for the radiation measurement which is a RSP (Rotating shadowband sensor).

For the period mentioned a thermal yield of 452 MWh was measured. For three operational days, corrupt data were found, which add up to approximately 16 MWh. This number was indirectly estimated from the steam flow meter in the secondary loop. Thus, a total yield of 468 MWh for one operational year can be assumed. With a gross aperture area of 1107.8 m², this is translating to 422 kWh/(m² * a) .

Additionally, the plant was in maintenance mode for around 8 days (from spring to autumn) which could have been operational days and the plant was additionally shut down for weather reasons (high wind speeds) and client request for 6 sunny days (from spring to autumn). If the plant would have been operated during these days, close to 450 kWh/(m² * a) could have been reached according to Solarlite [4].

The DNI/ANI total measured during this period is 834/684 kWh/m²/a. Not all radiation has been captured due to shading on the RSP sensor, missing/corrupt data and non-ideal cleaning. Solarlite estimated that a correction of 10% would be required to come to a realistic result. The DNI would then amount to 917 kWh/(m² * a) .

The cleaning of the collectors has only been performed by rain since the beginning of operation. Soiling has not been measured.

In Fig. 4 this yield is compared with calculations for a parabolic trough collector field performed with greenius from [5]. The results are not fully comparable because they are based on different climatic conditions and details in the assumptions. One aspect is that the row spacing at ADPO is only about two times of the aperture width, compared to three times of the aperture in the greenius calculations.

The DNI of the Potsdam radiation file amounts to 1017 kWh/(m² * a) , which is about 11% more than for the measured data at the ADPO site. Nevertheless, the output of the ADPO field is close to the calculated yield for the Potsdam climate and thus confirms the general idea that concentrating systems generate a significant output in most Central European climates.

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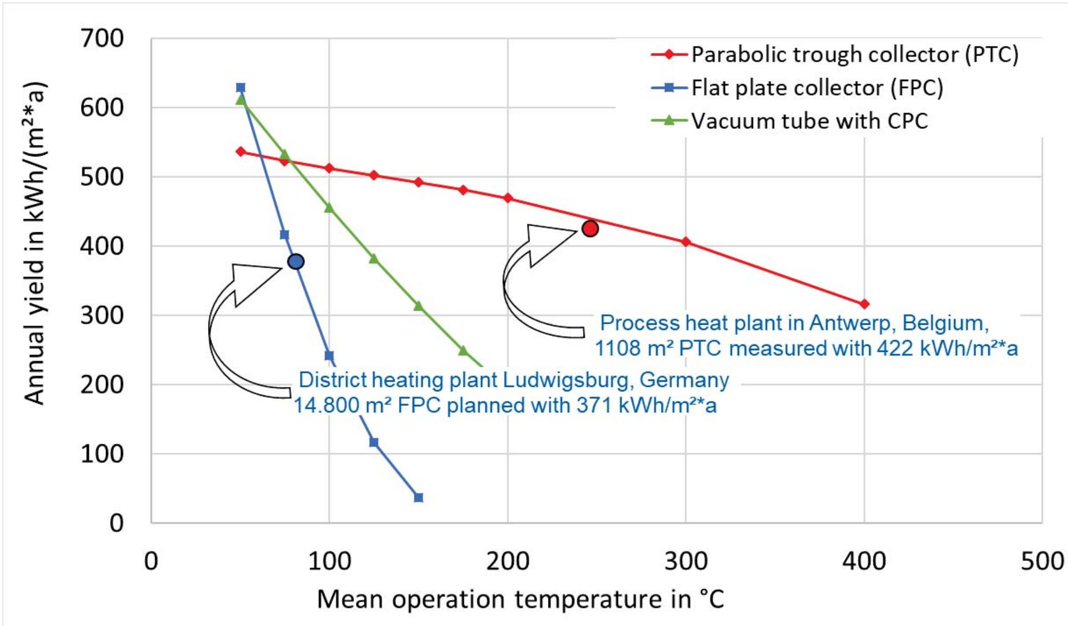

Figure 4. Comparison with former simulations with greenius (CPC - Compound Parabolic Concentrators)

The comparison in Fig. 4 also shows that the yield from a parabolic trough collector field at high temperatures is in the range of a flat plate collector (FPC) field at low temperatures if compared with planning of a district heating plant in Ludwigsburg, Germany. This also underlines that concentrating collectors are opening a further option for the heat supply in moderate climates.

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CONCLUSIONS

Due to the pandemic only 71 SHIP plants with various collector types were commissioned in 2020, even less than in 2018 and 2019. The main industry hubs for concentrating solar collector manufacturing were China, Germany, India and Mexico.

The costs of large European SHIP systems including stationary collectors have come down by 68% in the years 2014 to 2020. A main driver has been the cost reduction by economies of scale, as found within the Solar Payback project and by IRENA [3]. The cost reduction amounts to 14% at doubling the thermal capacity of a plant.

An annual yield of 422 kWh/(m² * a) was measured by the operator of a SHIP plant for a parabolic trough field in Belgium. This value has been related with simulations performed with a comparable climate. The results confirm the main statement that concentrating collectors can provide a significant amount of energy comparable to that of established collector technologies as flat plate and vacuum tube collectors, opening new options for solar heat supply also in moderate climates.

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