Update on SHIP Technology Costs

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SHIP Business and Financing Models

IEA SHC TASK 64 | IEA SolarPACES Task IV | Solar Process Heat

Technology Collaboration Programme

by iea

Update on SHIP Technology Costs

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SHIP Business and Financing Models

This is a report from SHC Task 64 / SolarPACES Task IV: Solar Process Heat and work performed in Subtask E: Guideline to Market

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The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency.

Our mission is *To bring the latest solar heating and cooling research and information to the forefront of the global energy transition.*

IEA SHC members carry out cooperative research, development, demonstrations, and exchanges of information through Tasks (projects) on solar heating and cooling components and systems and their application to advance the deployment and research and development activities in the field of solar heating and cooling.

Our focus areas, with the associated Tasks in parenthesis, include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54, 69)
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- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64, 72)
- Solar District Heating (Tasks 7, 45, 55, 68)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63, 66)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61, 70)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, Test Methods and LCA/LCoH (Tasks 14, 24, 34, 43, 57, 71)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42, 58, 67)

In addition to our Task work, other activities of the IEA SHC include our:

- ➢ SHC Solar Academy
- ➢ *Solar Heat Worldwide*, annual statistics report
- ➢ SHC International Conference

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To realize this mission, SolarPACES coordinates and advances concentrating solar technology research, by focusing on the next generation of technologies, by providing information and recommendations to policy makers and by organizing international conferences, workshops, reports and task meetings.

Our focus areas are organized in six tasks:

- Task I: Solar Thermal Electric Systems
- Task II: Solar Chemistry Research
- Task III: Solar Technology and Advanced Applications
- Task IV: Solar Heat Integration in Industrial Processes
- Task V: Solar Resource for High Penetration and Large Scale Applications
- Task VI: Solar Energy and Water Processes and Applications

In addition to our Task work, other activities of the IEA SolarPACES include:

- SolarPACES International Conference.
- Review of CSP market and cost data with the International Renewable Energy Agency (IRENA).
- Joint project on solar resource for high penetration and large scale applications in collaboration with the TCP on Photovoltaic Power Systems (PVPS TCP).
- Project in solar process heat in collaboration with the TCP on Solar Heating and Cooling (SHC TCP).

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Contents

1 Executive Summary

Solar Heat for Industrial Processes (SHIP) is a ready-to-market technology that can provide renewable heat to industry. Subtask E "Guideline to Market" of the Task 64/IV "Solar Process Heat" aims to support faster and broader market rollout by demonstrating that SHIP technologies are innovative, affordable and profitable.

This report contains two deliverable reports within Task 64/IV Solar Process Heat, Subtask E. After a short introduction in Chapter 2, Chapter 3 presents an update of Solar Heat for Industrial Processes (SHIP) technology costs **(Deliverable E2)**, followed by Chapter 4 presenting new trends on business models and financing schemes for SHIP plants **(Deliverable E3)**. In Chapter 5, additional information supporting the main text is annexed.

Chapter 3 emphasizes the importance of evaluating SHIP as a long-term heat source for industrial companies. Calculating the levelized cost of heat (LCOH) allows for a comprehensive assessment of the long-term benefits of SHIP plants, considering both capital and operational expenses. A recommended conversion factor of 0.7 kWth/m2 facilitates proper representation of concentrating solar thermal (CST) technologies in statistics on solar heat.

Data from solrico's solar heat cost analysis reveal significant reductions in total installed cost and levelized cost of heat for SHIP plants, driven by factors such as a maturing supply chain and economies of scale. Reductions in total installed costs and LCOH are observed, attributed to factors such as production optimization and economies of scale, illustrated by examples from Austria, Germany, and Mexico.

Forecasts based on a survey among SHIP project developers indicate a significant increase in SHIP capacity by 2026, with concentrating collectors expected to dominate the market. Heat delivery contracts are poised to become the dominant framework for large-scale SHIP projects.

A qualitative comparison of solar thermal systems with other renewable heating solutions highlights their advantages, positioning solar thermal systems as a compelling choice, particularly for process heat below 100°C but also for applications up to 400 °C, which is readily available and reliable.

In summary, Deliverable E2 provides valuable insights into the current state, trends, and outlook of SHIP technology cost, along with its comparison and integration options with other renewable heating solutions and its role in the industrial heat transition.

Chapter 4 delves into new trends in financing schemes and business models for SHIP plants, highlighting their value propositions, presenting a SWOT (Strengths, Weakness, Opportunities, Threats) analysis, and various business models and financing options available.

The value proposition of SHIP encompasses addressing industrial heat demand, offering a well-proven and CO_2-free technology, ensuring security of heat supply, and providing additional benefits such as flexibility, reliability, and emissions savings. Moreover, SHIP systems offer significant advantages in reducing Greenhouse Gases (GHGs) and particulate matter (PM) emissions, contributing to environmental sustainability.

The SWOT analysis identifies strengths like clean heat production and higher efficiency, weaknesses such as higher initial costs and complexity, opportunities including GHG emission reduction and marketing factors, and risks like a possible perception of a high-risk investment and limited information.

Different business models for SHIP installation are discussed, including the traditional sale of the plant to the heat consumer and the evolving Energy Service Company (ESCO) model, which offers heat as a service to end users. The ESCO model, also known as "heat supply contracting," relieves end users from upfront investment burdens, presenting a significant potential for future adoption.

Financing models for SHIP projects vary, based on the chosen business model. Traditional plant sale models require upfront investment from both suppliers and customers, whereas the ESCO model shifts the financial burden to the ESCO, providing customers with a cost-effective alternative. A medium-term trend towards ESCO models in announced and planned SHIP projects has been identified.

Overall, Deliverable E3 shows that understanding the evolving landscape of business models and financing options is essential for leveraging the full potential of SHIP technology and promoting its widespread adoption in industrial processes.

2 Introduction

Within Task 64/IV Solar Process Heat, Subtask E “Guideline to Market” is aiming to support a wider penetration of solar thermal technologies in the supply of heating (and cooling) in industry, demonstrating Solar Heat for Industrial Processes (SHIP) to be an important contribution to the decarbonisation of the industrial sector. This requires not only to overcome technical and/or technological barriers, but it is crucial to also address non-technical barriers. Whereas well suited system integration strategies, design tools, standardized procedures or modular components are all in all paramount for the development of reliable and prompt “off the shelve” solutions, experience shows that often non-technological barriers might have a critical role in the decision making process. Above all, competitiveness and investment/financing related barriers prove in many cases to be the bottleneck for the adoption of solar thermal technologies in the industrial framework.

Thus, Subtask E aims at drafting the guidelines of a market approach more prone to be successful among industrial end-users. Closing the circle of strategies tackling technical and non-technical barriers to market penetration, in this subtask Solar Heat for Industrial Processes (SHIP) is to be delivered to industrial end-users as an easy-to-implement, reliable, innovative, affordable, and profitable technological solution for the decarbonization of heating (and cooling) supply to industry. By this, SHIP shall be seen as one of the core technologies of a hybrid industrial supply system, well optimized and integrated to the demand.

Whereas “simple” and “reliable” technical and technological solutions are already addressed in the other Subtasks, Subtask E builds upon the remaining aspects of how Solar Process Heat should be perceived by industrial end-users:

- **“Innovative”:** demonstrating that the use of solar thermal technologies in industrial applications is recognized as a potential innovative technological solution for industrial decarbonization; investigate how it is reflected in innovation strategies at regional, national or trans-national levels; fostering the dissemination and use of available research funding for the development of R&D projects aiming at technology cost reductions and demonstration activities;
- **“Affordable”:** defining suitable indicators enabling a levelled comparison of CAPEX driven investments in SHIP to the OPEX driven investments of competitor technologies (e.g. boilers or heat pumps); gathering updated information and disseminating the technology cost reduction trends; defining suitable energy cost evolution scenarios enabling a due perception of future heat production costs and a quantification of the “hedging effect” of SHIP towards other energy sources; apply the findings to position SHIP as a core part of a hybrid industrial energy system;
- **“Profitable”:** demonstrating that a “Payback driven” appraisal of SHIP is short sighted as it does not capture the NPV potential of these CAPEX driven investments; gathering updated information and disseminating new trends on SHIP financing models; developing suitable scenarios demonstrating that SHIP based LCOH is competitive with other (conventional and/or renewable) energy sources; pooling available SHIP financing possibilities among potential project promoters and/or end-users.

Information on technology costs is key for evaluating the profitability. Thus chapter 3 covers ***Deliverable E2*** and gives an update on SHIP technology costs, cost reduction trends and an Outlook to the market until 2026.

Secondly, the imminent need for adjusted financing solutions for SHIP is satisfied by giving an overview on trends on business models and financing solutions in chapter 4 – covering ***Deliverable E3***.

3 Update on SHIP Technology Costs (Deliverable E2)

Full Title: Update on technology costs, statistics and cost reduction trends, including suitable energy cost evolution perspectives and promoting the use of LCOH as benchmark for the comparison of innovative heating/cooling production systems

High capital expenditure (CAPEX) for the initial investment and long-time savings on energy cost, two characteristics of SHIP installations, are not supporting investment decisions based on short-term considerations. Instead of only relying on Return-Of-Investment and payback times, it is important to evaluate SHIP as a long-term heat source for the industrial company. Calculating the levelized costs of heat (LCOH) is an established method to communicate the long-term benefit of a SHIP plant. Current cost trends and a future outlook of SHIP like Heat Supply Contracts are presented in this chapter as well as the synergies with other technologies in a fully decarbonized industrial system.

3.1 Relevant Methods and Materials for Technology Costs Assessment and Statistics

Levelized costs of heat (LCOH) is a method used to assess the cost of producing heat energy, while considering both capital and operational expenses. Its importance lies in its ability to provide a standardized means of evaluating various heat generation technologies. LCOH is used in different studies to compare different technologies and markets as shown in chapter 3.2 (cost trends), chapter 3.5 (comparisons with other technologies) and chapter 4.3.2 (heat supply models).

3.1.1 LCOH calculation methods

LCOH facilitates fair comparisons among different methods, allowing informed decisions by policymakers, investors, and energy planners. It aids in efficient resource allocation, guiding governments in shaping energy policies, promoting sustainability, predicting long-term costs accurately, and adapting to market dynamics. In essence, LCOH is a valuable tool for assessing and comparing the economic viability of heat production options, essential for effective resource allocation, policy formulation, and transitioning to more sustainable and cost-effective heat generation.

There are different assumptions for the definition of the variables of the equation for the calculation of LCOH (levelized costs of heat) available and to be able to compare various results, it is important to know which method was utilized in the calculation. Table 3-1 gives an overview of applied methods of LCOH calculations.

Table 3-1: Comparison of the formula for the calculation of LCOH for solar thermal systems

Solar Payback[1]	**Solar Heat Worldwide (SHW)** [2]	**IEA SHC Task 54**[3]
$\boldsymbol{LCOH_{SP} = \frac{I_0 + \sum_{t=1}^{n} \frac{M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Y_t}{(1+r)^t}}}$	$LCoH_{SHWW} = \frac{I_0 + \sum_{t=1}^{t_{ges}} \frac{A_t}{(1+r)^t}}{\sum_{t=1}^{t_{ges}} \frac{SE}{(1+r)^t}}$	$LCoH_{Task54} = \frac{I_0 - S_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}}$
$LCOH_{SP}$ = Levelized Cost of Heat in USD/kWh I_0 = investment expenditure in year zero M_t = operation and maintenance expenditure estimated by IEA SHC Task 64 experts	$LCoH_{SHWW}$: levelized cost of heat [€/kWh] I_0: specific solar thermal system costs incl. installation (excl. VAT, subsidies not considered in the statistics) [€/m²gross] A_t: fixed and variable O&M expenditures in the year t [€/m²gross] SE: solar energy yield in the year t [kWh/m²gross]	$LCoH_{Task54}$: levelized cost of heat in €/kWh I_0: initial investment in € S_0: subsidies and incentives in € C_t: operation and maintenance costs (year t) in €

[1] Epp, Bärbel, Oropeza, Marisol, Taylor, Michael, August 2021, "*Cost Trends Of Solar Energy For Heat In Industry*" Source: https://www.solrico.com/fileadmin/solrico/media/doc/Solar_payback/Flyer_SHIP_Cost_Trends_August_2021.pdf
[2] IEA-SHC, 2017. *"Solar Heat Worldwide".* Source: http://www.iea-shc.org/solar-heat-worldwide
[3] Veynandt,et.al. "*Comparison of the levelized cost of heat calculation methods for solar thermal applications in IEA-SHC Task 54 (LCoHs) and in Solar Heat Worldwide (LCoH)."* Source: https://task54.iea-shc.org/Data/Sites/1/publications/A13-Info-Sheet--LCOH-Comparison-SHWW.pdf

• 1 % of total installed costs per year (≤ 1,000 m² aperture area of field) • 0.5 % of total installed costs per year (>1,000 m² aperture area of field) *Y* = project-specific annual heat generation [MWh/a] *r* = discount rate (WACC) = 5 % (real) … fixed for the comparison *n* = system lifetime	r: discount rate in % t: year within the period of use (1,2,…$tges$) $tges$: period of use (solar thermal system life time in years) [a]	E_t: saved final energy (year t) in kWh r: discount rate in % T: period of analysis in years

How the solar energy contribution is considered, presents the biggest difference between the three approaches: While Solar Payback and Solar Heat Worldwide include the solar energy yield in a year, the Task 54 formula only considers the “usable” part of the generated energy, e.g. factoring in any thermal losses and stagnation on summer weekends. Only the Task 54 assumptions consider subsidies and incentives as it is developed on a project-to-project basis, while SHW is for statistical purposes and thus subsidies are not subtracted. Finally Solar Payback calculates the LCOH in USD/kWh, not in €/kWh like the others.

The LCOH method represents a good basis for comparison between possible technologies and energy sources that can be used in the application. Most processes and energy supply systems are operated until the end of their service life, which means that the LCOH approach appears to be more suitable than methods based on payback period requirements. This is particularly true from the perspective of the public funding provider, also because the longer-term LCOH approach means that the CAPEX, which are highly relevant to solar systems, have a smaller impact on the kWh costs. The risk-averse, short-term calculations of industrial payback period requirements do not reflect the lower life cycle costs of solar systems.

3.1.2 Conversion Factor (Collector Area to Thermal Capacity) for Concentrating Collectors in Statistics

To increase the visibility of a technology and thus contribute to its further promotion, it is essential that the technology is represented in available statistics alongside with other, comparable renewable energy technologies. In the field of solar thermal technologies, one example for statistics is the report “Solar Heat Worldwide”, issued annually by the IEA SHC (for the 2023 Edition, see[4]). One main key figure used in statistics on renewable energy technologies is the total installed capacity.

For solar thermal installations, often only the installed collector area is given and no value for the installed capacity is provided. In order to still have solar thermal technologies represented in statistics on installed capacity, in 2004, international solar thermal experts agreed on a methodology to convert installed collector area (in m²) into solar thermal capacity (kW_{th}) for the use in statistics. For unglazed collectors, flat plate collectors and evacuated tubular collectors and their use in statistics, they recommended a conversion factor of 0.7 kW_{th}/m^2 in a publication[5] by the IEA SHC Programme.

In recent years, also many projects using concentrating collectors have been installed and the international expert group in Task 64/IV / Subtask E identified the lack of a conversion factor for concentrating collectors as a gap impeding the proper representation of concentrating solar thermal (CST) technologies in statistics. Following intensive discussions and several draft documents discussing technical aspects of such a conversion factor, the expert group eventually published another technical note and recommended a conversion factor of 0.7 kW_{th}/m^2 for the use in statistics on concentrating collectors[6]. This factor shall be used uniformly for one-axis tracking parabolic troughs, one-axis linear Fresnel collectors, and two-axis tracking systems like parabolic dishes and Fresnel lens collectors. The publication also contains detailed explanatory notes on technical aspects, relations to the

[4] Werner Weiss, Monika Spörk-Dür, “*Solar Heat Worldwide*“, 2023 Edition, Source: https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2022.pdf DOI: 10.18777/ieashc-shw-2022-0001

[5] Technical note: “*Recommendation: Converting solar thermal collector area into installed capacity (m2 to kWth)*”, Source: https://www.iea-shc.org/Data/Sites/1/documents/statistics/Technical_Note-New_Solar_Thermal_Statistics_Conversion.pdf

[6] Solar heating and cooling, “*Calculation method for the conversion of aperture area into thermal power for tracked concentrating solar thermal systems for statistical purposes”*, Source: https://task64.iea-shc.org/Data/Sites/1/publications/technical_note_conversion_factor_m2tokW_final_April2023.pdf

standardisation on solar thermal technologies and the reasoning behind the recommended factor and addressed collector technologies.

With this recommendation published by the IEA SHC, the proper representation of solar thermal technologies including concentrating technologies (CST) is supported and facilitated.

3.2 Update on Technology Costs

The cost data utilized in this report is taken from two main sources. The first source constitutes data from the solar heat cost analysis done by solrico[7] through Solar Payback and in cooperation with IRENA, which results were presented in the heat generation cost chapter of the “Renewable Power Generation Costs in 2020” report by IRENA. The second source is the SHIP database[8] run by AEE INTEC for the last ten years, which contains an extensive account of SHIP plants throughout the world and gathers data on the economic parameters of the various plants.

In the first part, the insights learned through the cost analysis done by solrico and IRENA will be presented and then compared to the results of the data from the SHIP database.

Large-scale solar heat plants have experienced cost reductions within three distinct market segments. These segments serve various types of clients, such as industries with high heat energy demands (known as SHIP), utility companies managing district heating networks (referred to as SDH), and a range of service sector facilities, including hospitals, hotels, sports centers, and multi-family houses. The choice of collector type in solar thermal systems hinges on the client's specific temperature requirements, significantly influencing equipment costs. Analyses were conducted on weighted-average total installed costs and the levelized cost of heat for commercial and industrial solar heat plants across major markets. These analyses reveal important trends in cost reduction.

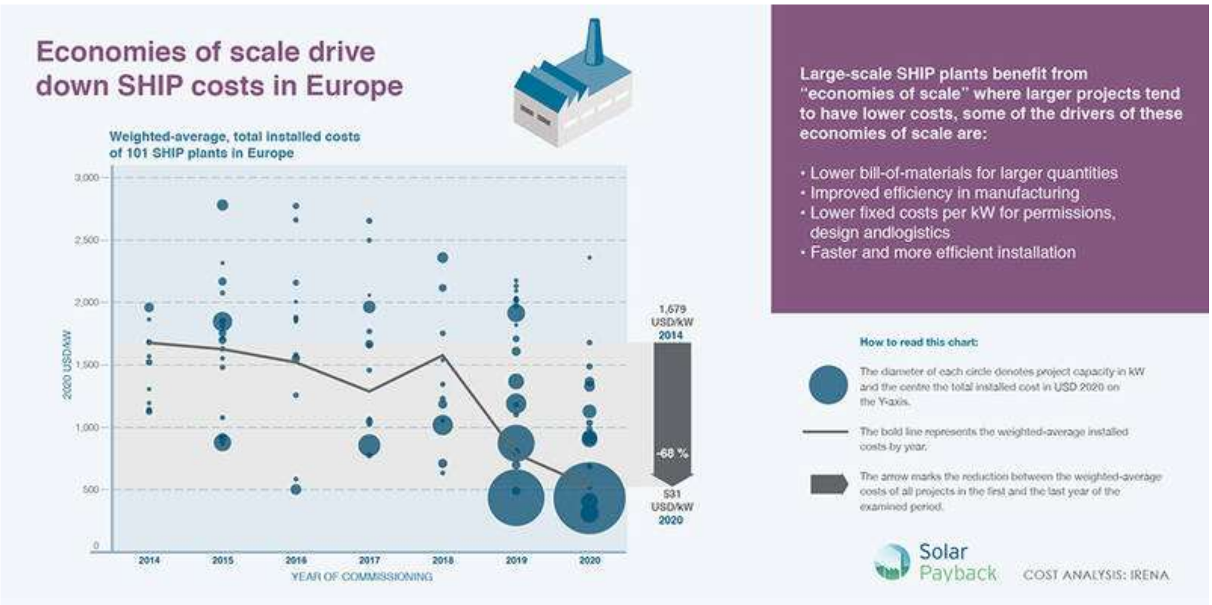

Figure 3-1: Economies of scale drive down SHIP costs in Europe[9]

One noteworthy finding is that the total installed costs of solar thermal systems in the industrial sector tend to be higher when compared to those in the building or energy sectors. Moreover, an examination of 101 SHIP plants in Europe, commissioned between 2014 and 2020, highlights the advantages of larger SHIP plants due to the economies of scale they offer. Regional average levelized costs of heat for SHIP plants vary, ranging from 3.9 USD-cent/kWh in Asia to 9.2 USD-cent/kWh in Western Europe. These differences are influenced by economies of scale, variations in cost structures, and local irradiation levels. It's noteworthy that the most prevalent applications for SHIP plants worldwide are those that require heat up to 150°C, accounting for 30% of the global industrial heat demand. Solar heat is generally more cost-competitive in this segment. In fact, the lowest weighted-average levelized costs

[7] Solrico Website: https://www.solrico.com/

[8] SHIP Database Website: https://energieatlas.aee-intec.at/index.php

[9] *Solar Payback/IRENA* 2022, Source. https://www.solrico.com/fileadmin/solrico/media/cost_assessment/Cost_trend_of_SHIP_in_Europe.jpg

of heat for solar heat up to 150°C, at 3.8 USD-cent/kWh, are found in factory applications in Asia and Mexico, underscoring the economic viability and potential of solar heat in these regions.

3.3 Cost Reduction Trends

To show the cost reduction trends of the last years, the IRENA and Solar Payback collaboration for the part of "Renewable Heat Costs in Commercial and Industrial Solar Thermal" in their "Renewable Power Generation Costs" in 2020 report is utilized. There the costs of systems in Germany, Austria and Mexico are compared.

Over the past few years, significant reductions in total installed costs have been observed in mainly non-concentrating solar thermal systems in Austria (55% decrease from 2013 to 2020), Germany (45% decrease from 2014 to 2020), and Mexico (17% decrease from 2010 to 2020) as already shown in Figure . However, data for 2020 and 2021 remains limited, especially in Austria. By 2020, total installed costs in these countries had started to converge, with larger projects in Austria showing slightly lower average costs during that period compared to Germany and Mexico (Figure 3-2).

Figure 3-2: Total installed costs and LCOH for commercial and industrial-scale solar thermal plants in Austria, Germany, and Mexico, 2010-2020[10]

In terms of the levelized cost of heat (LCOH), Mexico displayed a distinct advantage due to its superior solar resources, with a weighted-average LCOH of just USD 0.039/kWh in 2020. In contrast, Germany's 2020 LCOH increase was influenced by a single outlier with exceptionally high installed costs and reductions are generally attributed to a maturing supply chain, while Austria's decline in weighted-average LCOH from 2018 to 2020 was mainly due to the deployment of larger systems in the latter period, highlighting the cost-efficiency benefits of economies of scale.

This, however, has not been the case in Mexico, as the average plant size for the 108 projects illustrated in Figure 3-3 remains relatively small at 139 kW. Here, the mature market has been the driver of reduced costs of commercial and industrial solar heat plants – by 17% over the past decade. These cost reductions were primarily achieved through production optimization, more efficient logistics, and intense competition among well-established project developers.

[10] IRENA (2021), "*Renewable Power Generation Costs in 2020"*, International Renewable Energy Agency, Abu Dhabi. Source: https://www.solrico.com/fileadmin/solrico/media/cost_assessment/IRENA_Renewable_Heat_Generation_Costs_2010_to_2020.pdf

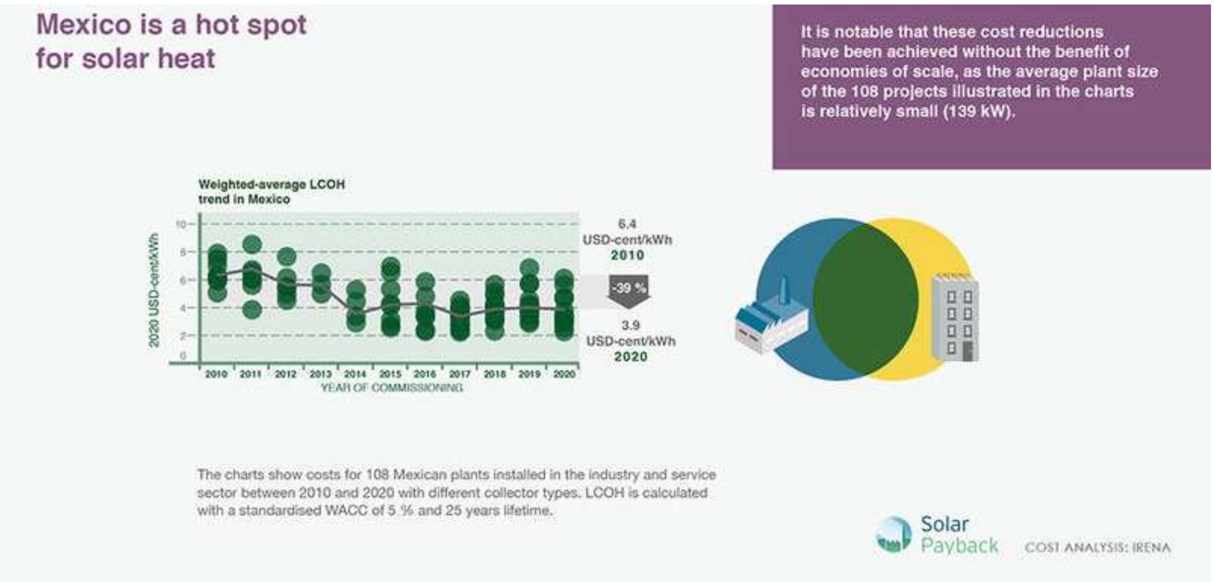

Figure 3-3: Mature markets accelerate cost reductions of large solar heat plants[11]

Figure 3-4 shows the learning rate for a related sector of SHIP: The solar district heat (SDH) sector. The chart shows the percentage of reduction of costs for every doubling of cumulative installed capacity.

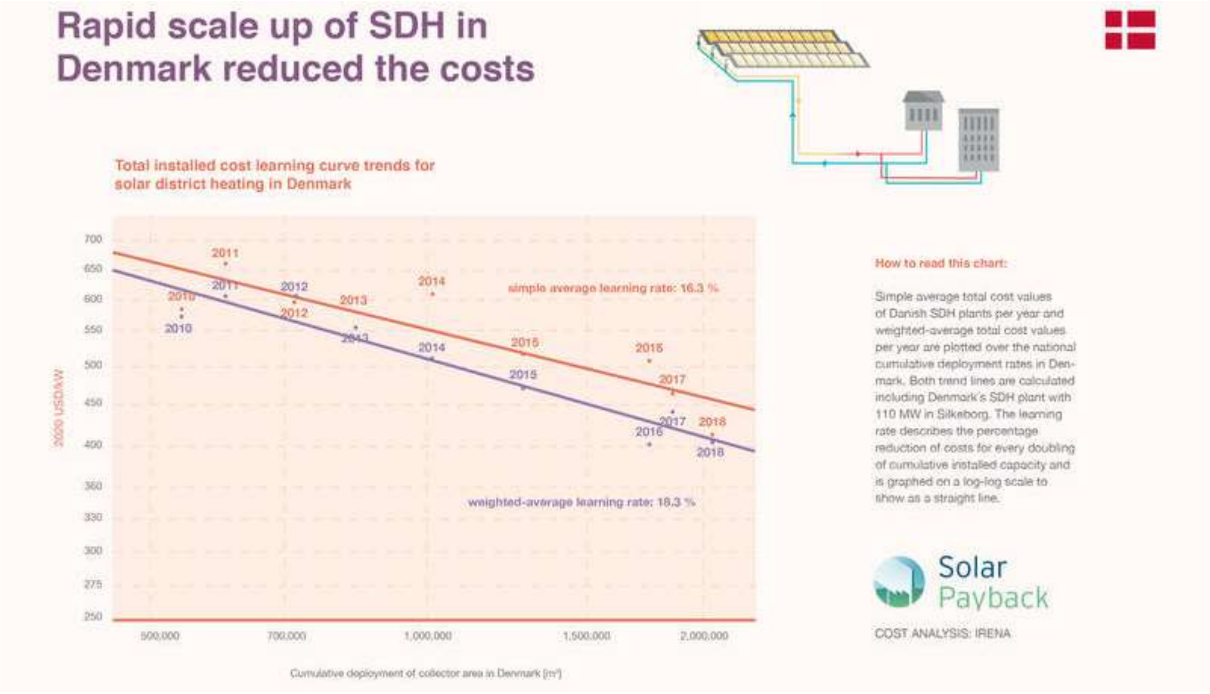

Figure 3-4 Learning rate for solar district heating in Denmark[12]

Similarly, the example of Denmark's SDH market shows the effect of economy of scale. This also can be assumed for SHIP systems at larger scales. Figure 3-5, shows a sharp decline of costs for systems larger than 5 MW_{th} of installed capacity.

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[11] IRENA (2021), "*Renewable Power Generation Costs in 2020"*, International Renewable Energy Agency, Abu Dhabi. Source: https://www.solrico.com/fileadmin/solrico/media/cost_assessment/IRENA_Renewable_Heat_Generation_Costs_2010_to_2020.pdf

12 Solrico*, "Learning rate for solar district heating in Denmark", Source:*
https://www.solrico.com/fileadmin/_processed_/csm_Learning_rate_for_solar_district_heating_in_Denmark_d023dfd42e.jpg

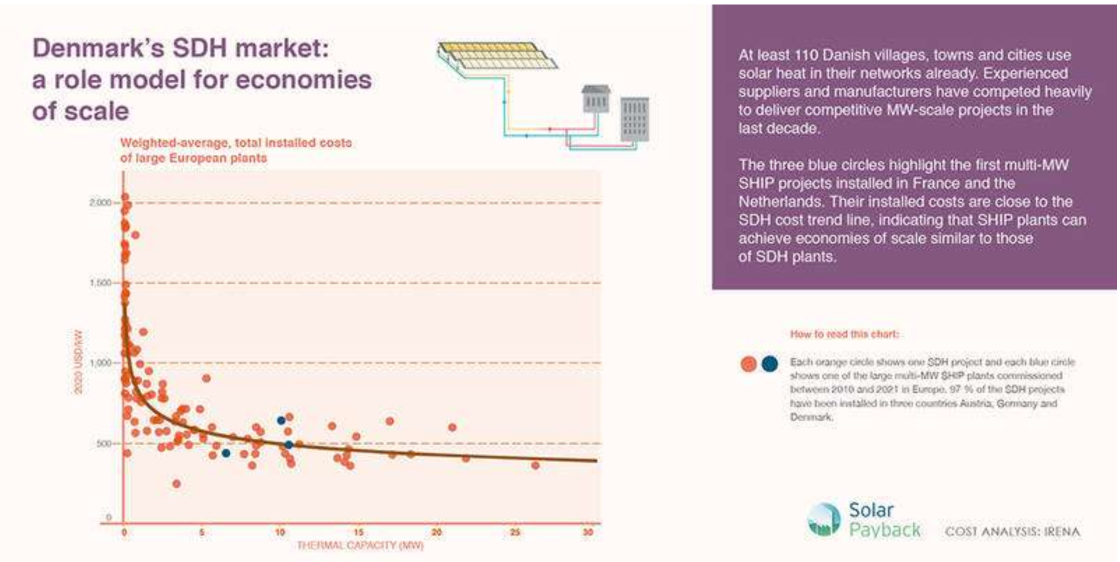

Figure 3-5 Denmark's SDH market: a role model for economies of scale[13]

3.4 SHIP Market Outlook until 2026

This chapter is based on the work done by the solar market research organization solrico. In September 2023 the status was published based on a survey among SHIP project developers worldwide[14].

It shows a significant increase in forecasted capacity. The survey considers the likelihood of implementation based on the project stage of the various projects. Figure 3-6 shows that the forecast for 2023 showed an increase by 71 MW and until 2026 an increase of 260 MW.

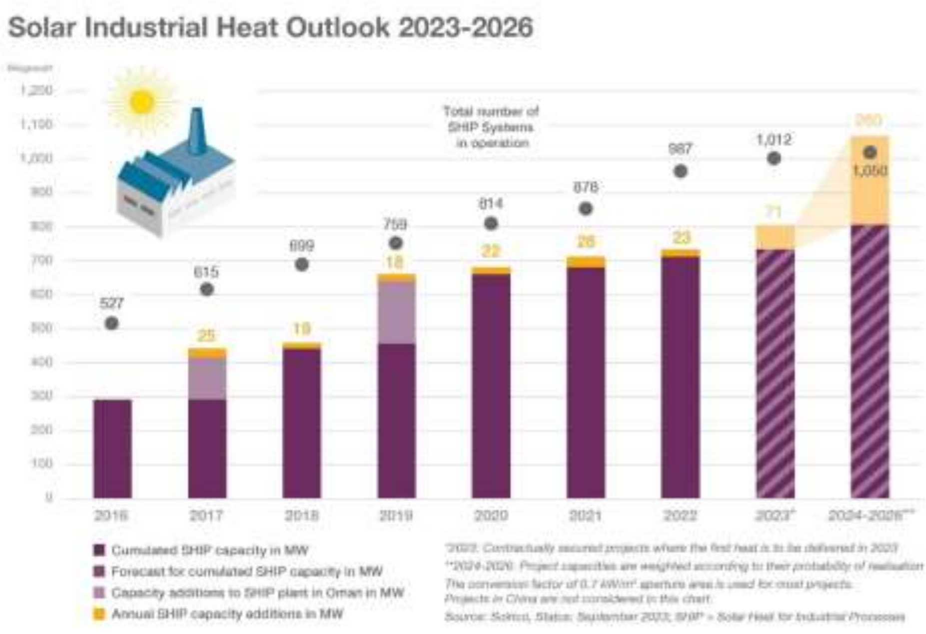

Figure 3-6: Solar Industrial Heat Outlook 2023-2026. [15]

[13] Solrico, "Denmark's SDH market: a role model for economies of scale", Source: https://www.solrico.com/fileadmin/_processed_/csm_Economies_of_scale_for_SDH_in_Europe_b1860d89f0.jpg

[14] Solrico (2023) Launch of Solar Industrial Heat Outlook 2023-2026. Accessed 15. Nov. 2023; www.solrico.com

[15] Solrico (2023) Launch of Solar Industrial Heat Outlook 2023-2026. Accessed 15. Nov. 2023; www.solrico.com

Two main trends have been identified. Figure 3-7 shows that the share of concentrating collectors was below 25% in 2021/22 but is expected to raise to above 75% by 2026.

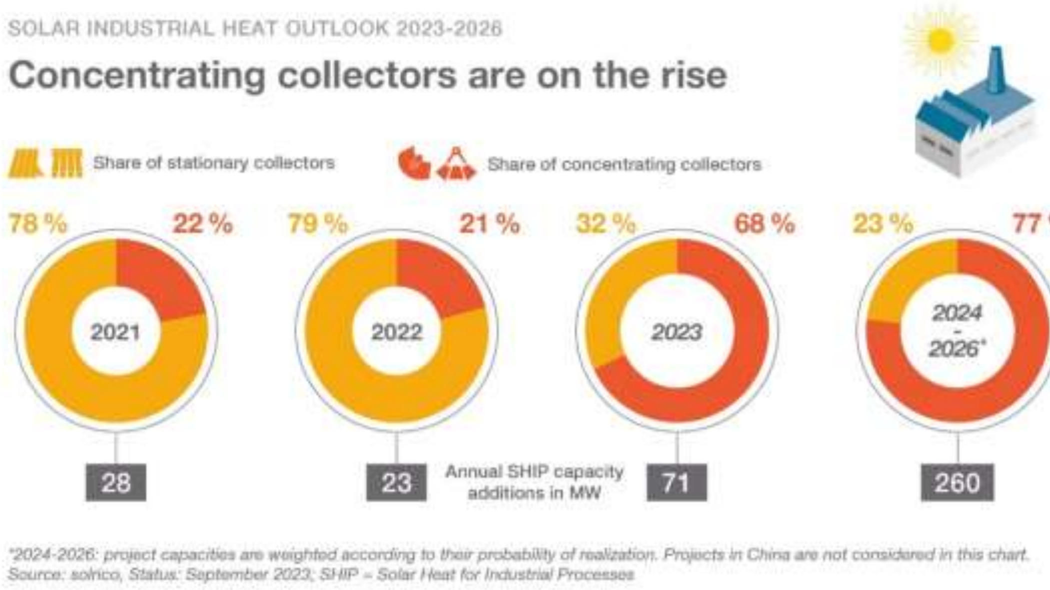

Figure 3-7: Share of stationary and concentrating collectors in Solar Industrial Heat Outlook 2023-2026 (Source: solrico 2023 – see previous footnote)

The second trend is the rapid increase of heat delivery contracts, which are poised to become dominate the future SHIP market. Despite notable fluctuations in the share of heat delivery contracts observed in 2021 and 2022, as well as in the projected outlook, it is evident that this trend has yet to attain full stability. Nonetheless, the outlook suggests a surge in the development of large-scale SHIP projects within this framework. These initiatives address the imperative of industrial clients for enduring, predictable heat pricing over the long term while mitigating technological risks by entrusting experts with the operation of SHIP plants.

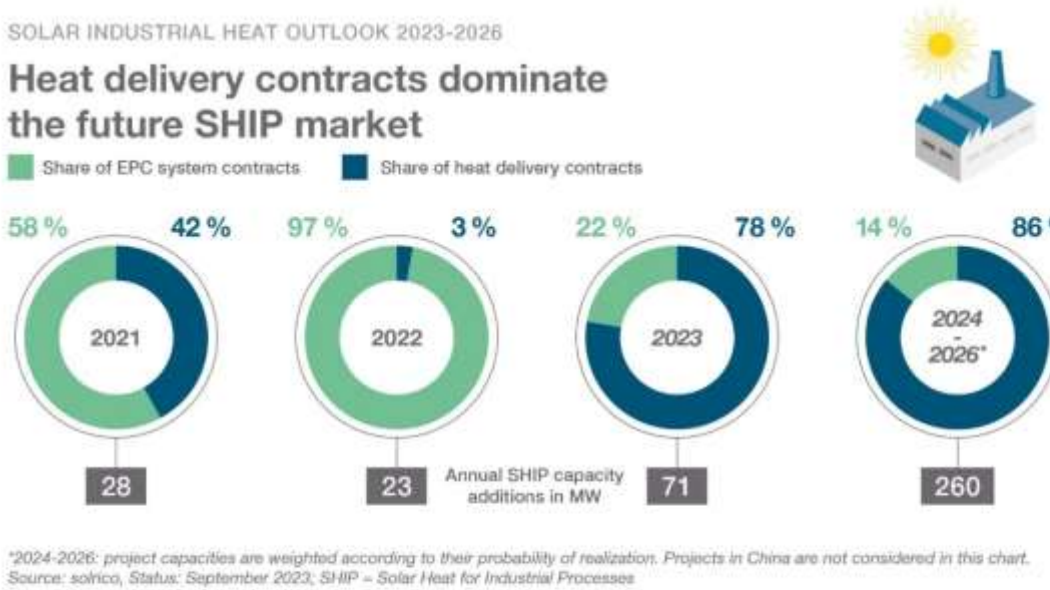

Figure 3-8: Heat delivery contracts and their share in recent years and in the projected outlook. (Source: solrico 2023 – see previous footnote)

3.5 Comparison and Synergies with Other Renewable Heating Solutions

SHIP solutions are always designed as fuel saver, so they have to be combined with other technologies to reach reasonable reductions of CO2-emissions. Furthermore, the analyses of Subtask A showed that also in industry, ambient temperature dependent heat has a relevant share of the overall heat demand (Link to Deliverable A1). This is due to the space heating demand in production halls as well as the mostly existing ventilation units and high air exchange ratios. Nonetheless, a summer heat demand that can be addressed with SHIP solutions could be identified in nearly all Industries.

3.5.1 Comparison and Synergies with Heat Pumps

While the LCOH of SHIP solutions are mainly CAPEX-driven, the LCOH of heat pump (HP) solutions are significantly dependent on the cost of electricity[16]. So far, HPs are often designed with respect to the base load enabling a constant operation throughout the year with a high number of full load hours. With respect to the climate targets, higher shares of the renewables have to be achieved highlighting the need for new design guidelines. As indicated in Figure 3-9, increased capacity ratio (capacity of heat pump in relation to maximum demand load) leads to higher LCOH, but also to higher renewable fractions.

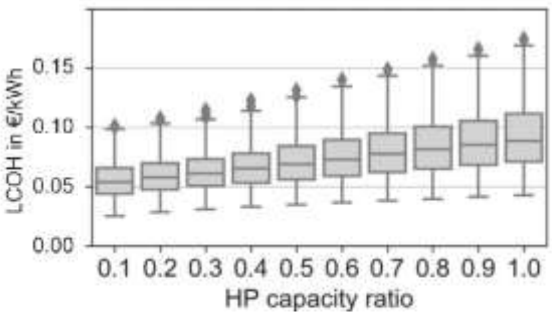

Figure 3-9 Capacity ratio linked to the LCOH of HP [18]

A study[17] by the University Kassel showed that a reduction of the full load hours of the HP also reduces its LCOH, but only to a very small extent up to around 3000 full load hours. For hybrid SHIP and heat pump solutions this implies the possibility to integrate solar heating plants into heat supply solutions for industry to cover the summer heat demand whereas the heat pump design is focused on the winter heat demand. While the LCOH of the heat pump should not be increased significantly, as long as the heat pump reaches at least around 3000 full load hours, it is avoided that the heat pump shows many start-stop-cycles during low heat demand summer periods. Furthermore, the heat pump can profit of the big solar buffer storage also enabling smoother operation in winter months which brings additional positive effect on the LCOH due to reduced maintenance costs.

[16] Jesper et. Al (2023), "*Hybrid solar thermal and heat pump systems in industry: Model based development of globally applicable design guidelines*", Solar Energy Advances, Source: https://doi.org/10.1016/j.seja.2023.100034

[17] *Mateo Jesper, Felix Pag, Klaus Vajen, Ulrike Jordan: Effects of energy price inflation on the economic evaluation of large-scale industrial waste heat pumps, Symposium for solar heating and innovative heating solutions, 9.-11. May 2023, Bad Staffelstein, Germany (in German)*

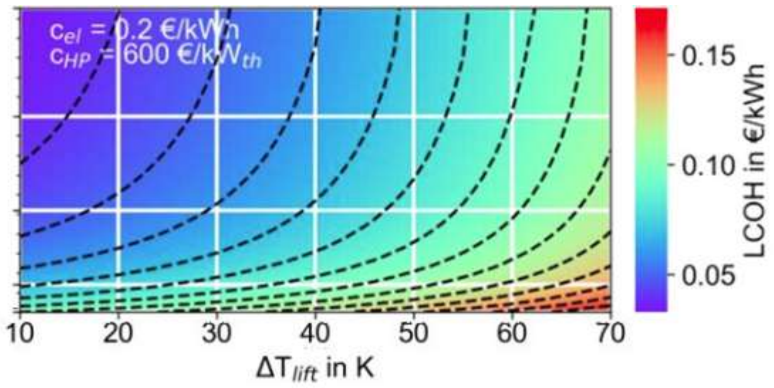

Figure 3-10 LCOH of a HP as a function of the temperature lift [18]

In contrast to SHIP, recent studies showed that economies of scale cannot be seen for heat pumps in the MW-range so far (Figure 3-11). In case that this can still be achieved in the future, this will have an even more positive effect on such hybrid systems in which SHIP covers the summer base load and heat pumps supply the major share of the residual heat demand.

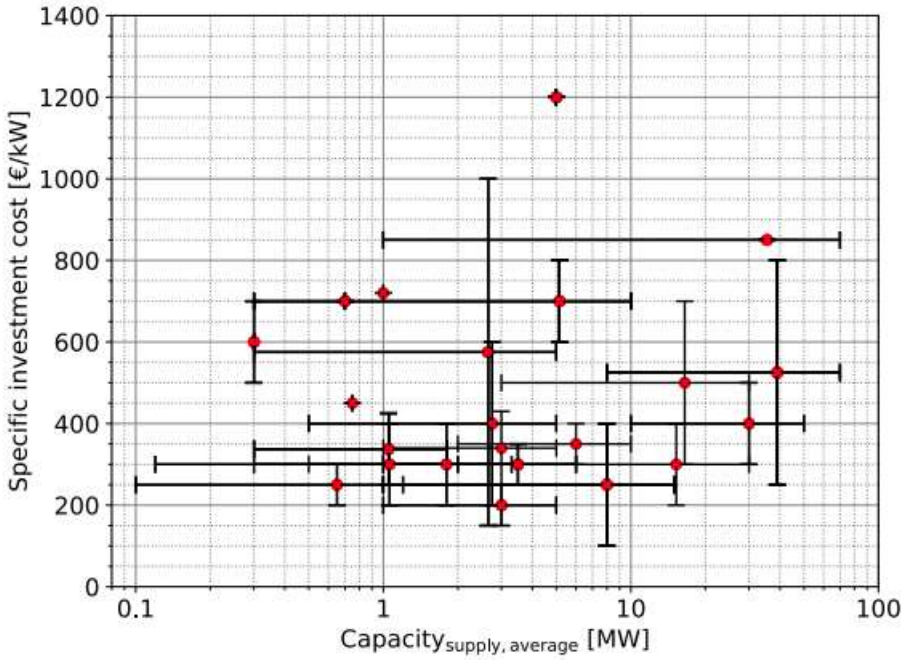

Figure 3-11 Specific Investment cost of HPs as a function of capacity[19]

[18] Jesper et. Al (2023), "*Hybrid solar thermal and heat pump systems in industry: Model based development of globally applicable design guidelines"*, Solar Energy Advances, Source: https://doi.org/10.1016/j.seja.2023.100034

19 Zühlsdorf et. al., *"High-Temperature Heat Pumps. Task 1 – Technologies.: Task Report* Source: https://findit.dtu.dk/en/catalog/65118468e1b8eb12188eed7c

3.5.2 Comparison with other Renewable Heating Solutions

The best renewable heating solution for a particular industrial application depends on several factors, including (local) resource availability, technical complexity, reliability, capital expenditure, operational expenditure, achievable temperatures, scalability and demand-side specific heating requirements.

Solar thermal systems stand out as a compelling choice when compared to other renewable heating solutions. Using solar thermal systems to generate heat for industrial processes offers various opportunities to reduce the reliance on fossil fuels, particularly at temperatures below 100°C. This level is essential for numerous industrial, commercial, and service-related processes. However, there are also various industrial heating processes which require temperatures >100°C or >200°C. While renewable heat sources such as biomass, biogas and heat pumps as well as electrification of processes are quite well established, solar thermal heating for industrial applications is still rare, despite a growing number of known installations (see SHIP Plants database[20]).

Thus, to identify potential barriers and opportunities for industrial solar thermal applications, a comparison of different renewable heat sources and solar thermal heating systems was carried out on a qualitative level. When advantages and disadvantages of solar thermal energy systems are compared to other renewable heat sources, a variety of available technologies (collector types) needs to be considered due to the different application areas (temperatures, cost, scalability, local conditions such as solar irradiance and incidence angles etc)

In Table 3-2 below, a comparison between solar thermal and other renewable heating solutions is presented. The method followed and information is mainly based on the Austrian project "Industrial Excess Heat INXS". The findings and method were adapted to facilitate the comparison between solar thermal and other renewable heating solutions.

Method:

In order to shed more light on the topic of industrial solar thermal applications, a literature review was conducted. Focusing on the question which advantages and disadvantages of solar thermal heat utilization apply from the point of view of a manufacturing company compared to other renewable energy sources.

In each case, a general comparison was made between solar thermal and each other technology/heat source, and advantages and disadvantages were listed. In the case of similar conditions (e.g. need for a buffer storage due to fluctuating energy production from solar energy), no explicit mention was made. Note that for real installations and investment decisions an individual (pre-)feasibility based on local conditions and applications needs to be made to identify the most feasible solution.

Following alternatives were analysed:

- 1). Electric resistance heating using power generated from an onsite photovoltaic (PV) system
- 2). Electric resistance heating with grid power
- 3). Heat pumps
- 4). Electrolysis hydrogen (green hydrogen)
- 5). Biogas
- 6). Biomass
- 7). Geothermal
- 8). Internal Utilization of Waste Heat

Note: with regard to waste heat utilization, a detailed comparison was conducted within aforementioned "Industrial Excess Heat INXS". Based on the comparison of “solar thermal heating” and other process heat sources a condensed version of the collected information is shown in Table 2. In the Annex (section 5.2) the detailed tables with more detailed information on the advantages and disadvantages of these technologies compared to solar thermal are shows.

[20] SHIP Plant database, Source: https://energieatlas.aee-intec.at/index.php/view/map?repository=ship&project=ship_edit *or* www.ship-plants.info

Table 3-2 Comparison of different renewable technologies with solar thermal ("-" means disadvantage, "+" means advantage compared to solar thermal) [21]

Electric resistance heating with PV	Electric resistance heating with grid	Heat pumps	Electrolysis hydrogen	Biogas	Biomass	Geothermal	Internal utilisation of Waste Heat
- exergetic inefficiency - **dependent on coupled renew. energy**	- exergetic Inefficiency - **Not entirely renew.** - **High OPEX** - **Dependency on electricity as sole energy source** - **Higher LCOH**	- Price negotiations with electricity provider - **Energy price dependency** - **High CAPEX & OPEX** - Environmental Impact - **GHG depends on electricity mix** - **Electricity dependency** - Complexity + **100°C < (efficiency)**	- **High CAPEX & OPEX** - Development dependency - Partner countries dependency - Economic profitability impact - **High cost infrastructure** - Scalability (cost) - **Resource need** - **Complexity** - **Local availability** - 100°C < (efficiency)	- Difficult operation - Sector competition - Limited supplies/er - Implementation - **Higher CAPEX**	- **Not CO_2 neutral** - Not fully sustainable - **Sector competition** - Pricing - **Finite resources** - **Emissions** - **Higher CAPEX** - **Higher var. costs** - Storage space - Supplier dependency - Integrability	- **Local availability (high temperature)** - Additional technology needed (low temperature) - Possible environm. impacts - Scalability - **High CAPEX** - **Complexity** - Cost efficiency (high temperature)	- **Not fully sustainable** - Difficult with low quality waste heat - Internal interdependencies - Equipment maintenance - **New permits needed** - Accessibility of equipment - **Error potential** - Price dependency on heat source - Local availability depends on heat source - **<200°C more <100°C**
+ **High flexibility** + **Easy conversion** + Possible grid distribution + Plannable volatility + **More versatile** + **Diffuse light utilisation.** + Direct usability, no transfer medium + Easier scalable + **Longer lifespan** + **Simplicity** Availability and accessibility	+ **Geographic flexibility** + Cost-effectiveness + **High flexibility** + **Peak demand** + **Easy conversion** + Easy deployment + **Possible low CAPEX** + **No backup needed** Various supplier	+ Simplicity + **Reliable** + **Local availability** + Scalability + **Combination with solar** + **Flexibility** + Use waste energy + **Various Energy sources** + **Peak demand** + **No backup** + More reliable + Financial viability + **Local availability** + **<100°C possible** Scalability	+ **Versatility** + **Achievable high temperatures** + Waste heat usable + **Storability** + Supplier availability + **No backup** + **Reliability** - **Not CO_2 neutral** - Not fully sustainable - **Higher var. costs** - **Emissions** - **Finite resources** Expensive technology	+ **Circularity** + Accessibility though gas network + Local production + Distribution + **Flexibility** + **Storage** + **High temp. possible** + Established technology + Centralized heat + **Heat availability** + Substitution possibility (nat. gas) + **No backup** + **Peak demand** Simplicity	+ Reliability functional + Local availability + **Temp. control and reliability** + Scalability + **Storage** + **Multiple provider** + Centralized **No backup**	+ **Peak demand** + High temperature + **Simplicity** + Reliability functional + Local availability + **Temp. control and reliability** + Scalability + **Low OPEX (waste heat)** + Reduces dependencies + **Minimal land use** + Less downtime + **Stable pricing** **No backup**	+ 100°C< possible + Scalability + Enhance compliance with environmental regulations + Condition improvement + **Lower emission** + Heat availability + **Usability** + Energy transmission + Space efficiency + **Consistency** + **Reliability** + **Energy waste prevention** + Simplicity + Cost efficiency (depends) + **Local availability**

[21] Hammer et al. 2022 (Final report of the project "Industrial Excess Heat INXS").

In July 2022, the German industry association for concentrating solar power (Deutsche CSP, DCSP) published a policy position paper[22] discussing different technologies available to support the heat transition in German industry. The various technology options for providing heat must be combined and integrated, emphasising that solar heat can be integrated with any other heat supply technology. For the medium temperature range, which is particularly important to address e.g. industrial steam networks, solar heat from concentrating solar thermal (CST) technologies can make an important contribution to decarbonizing the industry. In the position paper, concentrated solar thermal and other low-CO2 technologies are briefly introduced and discussed, highlighting which of the options can already be implemented quickly and cost-effectively today, and how integration and interaction of the various technologies can contribute to rapid replacement of fossil fuels. A qualitative overview on technological options is given by means of a table which is shown below.

Table 3-3: Assessment of low-carbon technologies for the industrial heat transition, status July 2022 (Source DCSP, see footnote below)

	Temperature level (commercial)	Technical availability	Availability in time	Economic efficiency (today)	Land requirements (incl. energy generation)	Integration	Potential Germany /EU
Solar thermal	80°C – 420°C	🟢	5000 – 6500 Full load hours	🟢	🟢	🟡	🟡
Thermal storage	60°C - 560°C	🟢	Generates flexibility / replaces electricity storage	🟢	depending on heat source	🟢	🟢
	Options for hybridization						
Electric direct heating	Up to 420 °C	🟢	depending on availability green electricity	🟢	🟡	🟢	🟢
Heat pump **Steam compressor**	70 °C – 100°C 100-150°C 150-250 °C	🟢 🟡 🟢	depending on availability green electricity	🟡	🟢	🟡	🟢
Storage power plant	100 °C- 550 °C	🟡	4000 h with thermal storage	🟡	🟡	🟡	🟡
Deep geothermal	Up to 200°C in DE	🟡	7000- 8000 h Full load hours	🟡	🟢	🟡	🟡
Biomass (residual, old, damaged wood)	Up to 500°C	🟢	7000 – 8000h Full load hours	🟢	🟢	🟡 Transport	🟡
Biogas (Waste materials)	All temperature ranges	🟢	7000 – 8000h Full load hours	🔴	🟢	🟡	🟡
Green hydrogen	All temperature ranges	🟡	7000-8000 Full load hours	🔴	🔴	🟡 Transport and storage	🟡

🟢 Commercially available / competitive / low complexity
🟡 Limited availability / competitive in niches / medium complexity
🔴 Not available / not competitive / high complexity

[22] Deutsche CSP, "*Accelerating the Heat transition in the Industry*", July 2022, available from https://www.deutsche-csp.com/en-gb/mediathek

4 New Trends on Business Models and Financing Schemes

Full Title: E3 - New trends on financing schemes and business models to SHIP and collection of available SHIP financing possibilities

Solar heat plants for industrial processes (SHIP plants) represent a ready-to-use **technology** that provides a unique selling proposition which is described in the ***value proposition*** and SWOT analysis in the first subchapters (4.1 and 4.2).

Providers of this new technology (Engineering companies, manufacturers, general contractors etc.) who want to make money together with their customers must use specific ***business models*** to organize their value creation process. Besides the **traditional business model of selling this technology** or the design or components of it to industrial customers (chapter 4.3.1), there is an evolving **new business model of selling energy and other services of SHIP plants** instead of selling the plant itself. This new business model which we call the **ESCO model** is described in more detail below (chapter 4.3.2).

Specific and innovative financing schemes and subsidized **financing possibilities** enable and facilitate the build-up of business models of technology providers and are also supporting customers to pay for SHIP plants or the produced energy and other services (chapter 4.4).

4.1 The Value Propositions of SHIP

Besides purely monetary and economic aspects, SHIP offers added value in many other respects as listed below. These value propositions should be taken into account when comparing with other options for heat supply and may influence decision-making in industry towards the implementation of SHIP into their processes and heat supply systems. Mostly independent of the applied business model, SHIP can provide additional benefits and competitive advantages against other heat supply technologies (see also chapter 3.5). The Value Proposition of SHIP:

- directly addressing the heat demand in industry, representing the highest share of final energy demand in industry, with significant shares in the low to medium temperature ranges addressable by SHIP
- a well-proven technology widely demonstrated (for examples, see projects in the SHIP database[23])
- CO_2 free, "green" heat supply, contributing to a decarbonisation strategy of a company/customer and/or green product quality labels.
- security of heat supply at predictable cost, thus no dependency on volatile energy markets, increased resilience of heat supply for production
- no dependency on future development of CO_2 pricing
- additional backup/redundancy/flexibility/resilience of heat supply through thermal storage (TES)
- low dependency on future electricity price spikes
- SHIP can cover a wide range of temperatures with the right design and the combination with other technologies
- highest conversion efficiency (solar irradiance to useful heat), resulting in lower area requirements as compared to photovoltaics
- increased reliability, and resilience through scalable and modular solutions
- emissions savings leading to quantifiable health improvements[24,25]

Beyond the value proposition referring to the technical side of heat supply, cost and fuel savings, green labels and product qualities, SHIP systems also offer significant benefits in reducing Greenhous Gases (GHGs), and particulate matter (PM) emissions. Studies have found, for example, that in the U.S. fine pollution (PM 2.5 microns), can affect those most who live in proximity to industrial sites. This tends to disproportionately affect people of colour (POC) such as Black, Hispanics and Asians[26].

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23 SHIP database, Source: https://energieatlas.aee-intec.at/index.php/view/map?repository=ship&project=ship_edit

24 EEA, *"Improving air quality improves people's health and productivity"*, Source: https://www.eea.europa.eu/signals-archived/signals-2020/articles/improving-air-quality-improves-people2019s

25 EPA, *"Progress Cleaning the Air and Improving People's Health"*, Source: https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health

26 Tessum et al., 2021, *"PM2.5 polluters disproportionately and systemically affect people of color in the United States"*, Source: https://www.science.org/doi/10.1126/sciadv.abf4491

4.2 SWOT - Analysis

The SWOT analysis is a matrix used to clarify the strengths, weaknesses, opportunities and threats/risks of the SHIP technology. The individual categories were analyzed and corresponding factors identified in the framework of the EU project SHIP2FAIR [27].

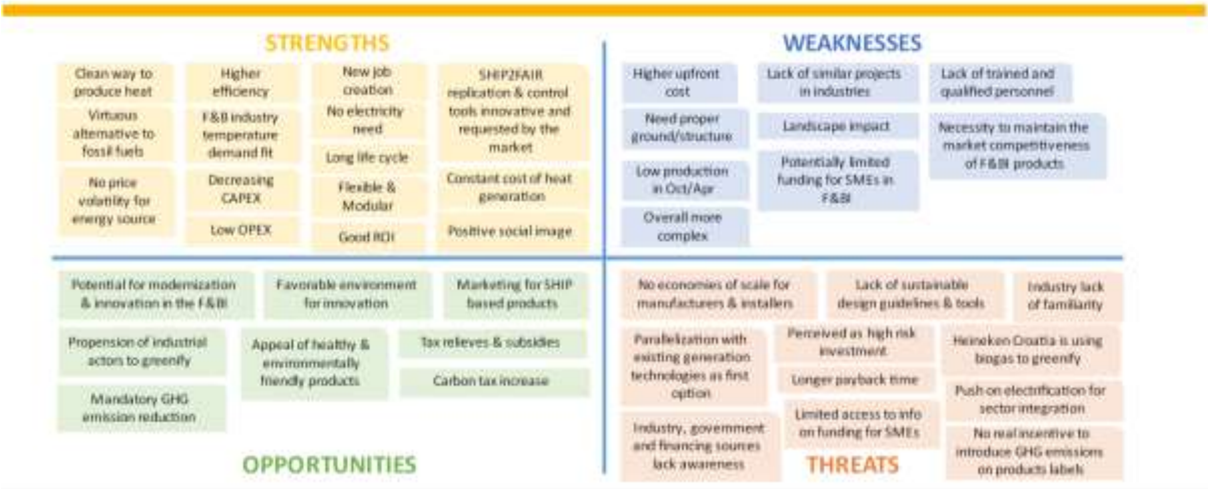

Figure 4-1 SWOT-Analysis of SHIP by the SHIP2FAIR project [27]

Among the strengths, clean way to produce heat, higher efficiency, or no price volatility as well as low OPEX and good ROI were identified. Weaknesses that can be associated with SHIP are higher CAPEX, irradiation dependency or complexity. The opportunities are GHG emission reduction, tax relives & subsidies, as well as marketing factors. Additionally, the risks of SHIP application have also been analysed. These are perceived as high-risk investment, limited information, or the industrial pushing towards electrification.

4.3 Applied Business Models for SHIP

To use solar heat in industrial processes, a solar installation has to be built and connected to the heat user. The solar installation typically consists of a solar field (an ensemble of hydraulicly connected solar thermal collectors), piping and an interface to the heat user (e.g. a heat transfer station with a heat exchanger between solar circuit and user circuit, sometimes also called solar station, solar central or balance of plant (BoP)). Usually, thermal storage is added for flexibility and heat use at times without solar irradiance.

Typically, the integration of renewable energy sources in general and of solar heat in particular is facilitated in a design of a new plant, where all components can be optimised and designed for optimal technical performance at lowest cost ("greenfield" installation). However, most industrial sites have a technical infrastructure including a heat supply system, grown over years and decades. Here, the challenge is to identify the best way to integrate solar heat into the existing infrastructure ("brownfield" installation) at highest efficiency and lowest cost, which usually requires limited changes to the existing infrastructure. At the same time, the installation of a SHIP plant and an optional thermal storage also provides an opportunity and trigger to simultaneously apply additional efficiency measures and assessing possible changes in the existing infrastructure, typically resulting in a good SHIP integration into a slightly modified and more efficient heat supply system.

From the point of view of the customer, the acquisition of a SHIP plant requires a comparably **high upfront investment** (capital expenditure, CAPEX) in technical infrastructure, while the amortization of the initial expenditures only emerges over the lifetime of the solar installation through low operational expenditure (OPEX) for the heat supply in conjunction with the corresponding fuel savings. These specific financial conditions don't meet

[27] EDF, "*Business models for the deployment of Solar Heating for Industrial Processes*" Source: http://ship2fair-h2020.eu/wp-content/uploads/2023/09/SHIP2FAIR_D8.1_Business-models_Final.pdf

the usual short payback time expectations for investments in industry. Thus, it is encouraged complement the payback time calculation with LCOH calculation to highlight the advantage of having a constant heat delivery price over the lifetime of the SHIP plant.

There are different business models applied when installing SHIP plants, which have specific advantages and disadvantages with respect to the cost structure and financial setup, which are briefly explained in the following. In particular, an ESCO model (section 4.3.2) relieves the end user from the burden of a high upfront investment, therefore offering a large potential for future rollout.

4.3.1 Sale of a SHIP plant

Figure 4-2 symbolically shows the procedure for the model in which the SHIP plant is sold to the heat consumer, who becomes the system owner and operator. In this case, a legal contract is drawn up with a turnkey supplier, i.e. the end user basically buys a SHIP installation. The turnkey supplier shall engineer the entire system. Depending on the nature of the order, the customer commissions several partner companies or a project management company, which coordinates the construction and commissions the subcontractors. The project is handled jointly with the customer and the turnkey supplier. Once the plant has been completed, it becomes the property of the customer. The customer pays the purchase price to the turnkey supplier. If available, additional incentives or subsidies, are used to reduce the total cost for the customer.

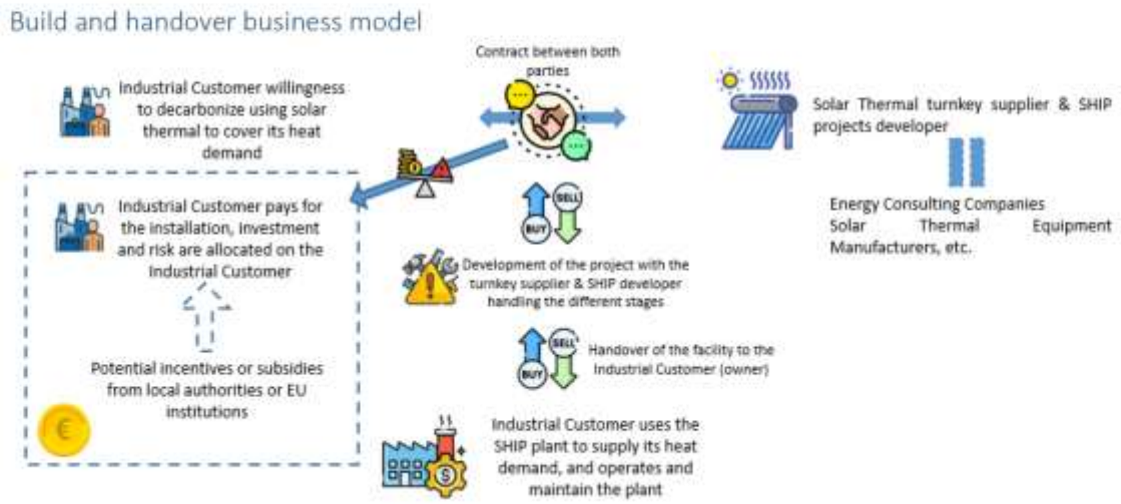

Figure 4-2 Aspects of the plant sale model [28]

The key feature of this business model is that the customer bears the risk and all OPEX costs, which are not covered by contractual warranties and guarantees of the turnkey supplier. The customer is responsible for the functionality of their system and for commissioning suitable companies to carry out maintenance, inspections and repairs.

4.3.2 Heat supply models by energy service companies (ESCO)

Energy service companies (ESCOs) offer energy savings and replacement of fossil energy through designing, financing, and installing energy-efficient equipment and building retrofits and/or deliver heat from own heat generation sources, thereby avoiding the need for customers to provide significant up-front CAPEX [29]. ESCOs use energy service performance contracts, which guarantee annual financial savings in reduced utility bills or other added value and/or supply renewable energy at periodical payments that cover the equipment financing and installation costs and remunerates ESCOs based on metered performance and heat delivery.

[28] EDF, "*Business models for the deployment of Solar Heating for Industrial Processes*" Source: http://ship2fair-h2020.eu/wp-content/uploads/2023/09/SHIP2FAIR_D8.1_Business-models_Final.pdf

[29] McMilan et al., 2023, *"Renewable Thermal Energy Systems: Systemic Challenges and Transformational Policies (Report 2)"*, Source: https://www.nrel.gov/docs/fy23osti/83020.pdf

In contrary to the plant sale model, where the customer / end user buys and owns the SHIP installations, in an ESCO model the ownership of the SHIP plant stays with the ESCO. This also means that the ESCO also bears the entire investment (CAPEX), which can promote decision-making in the industry because a high upfront investment by end user is avoided. Maintaining the general idea underlying the ESCO model, for larger projects sometimes a project company is established as a "Special Purpose Vehicle (SPV)" by the ESCO for the actual financing, installation, and operation of the plant (see also section 4.4.1).

The here called "ESCO model" is sometimes referred to using other terms like "heat as a service", "heat purchase agreement (HPA)" in analogy to the known power purchase agreements (PPA), "heat supply contracting" and others. While they are sometimes used synonymously and thus somewhat imprecisely, we here try a clarification of the terminology: In this type of business model, an ESCO (the company) is offering to sell "heat as a service" or "heat delivery" (the service, the product) through a "heat supply contract" or "heat purchase agreement" (the type of contract).

Figure 4-3 gives an overview of the functional aspects and contractual relations between the different parties in a SHIP ESCO model.

Figure 4-3: Functional aspects of an ESCO model [30]

The ESCO business model has been widely used in the United States. First and foremost, ESCOs have primarily served institutions in the public sector (e.g., federal and state government, schools, and universities); public and institutional markets composed 94% of U.S. ESCO revenues in 2018 [31]. Initial formation of the U.S. ESCO industry was supported using financial incentives offered by electricity and natural gas utilities, which helped address customers' initial concerns about the financial and technical performance of energy-efficient equipment [32].

As the ESCO model has evolved, it has gone from primarily electricity projects to more complicated projects involving fuel. This increase in complexity has come with increases in payback periods, which grew from 1.9 to 3.2 years for private sector projects and 5.2 to 10.5 years in public sector projects over the course of about 10–15 years [33].

Initially, the concept of using the ESCO model to support renewable energy was rare and not well understood [34]. Although the model's features of reducing risk and uncertainty and avoiding customer capital investment would seem to address barriers for SHIP adoption in industry, there are challenges in industry that may limit ESCO success. For example, manufacturers may be wary of providing energy and process information that they feel is

30 EDF, *"Business models for the deployment of Solar Heating for Industrial Processes"* Source: http://ship2fair-h2020.eu/wp-content/uploads/2023/09/SHIP2FAIR_D8.1_Business-models_Final.pdf

31 Stuart et al., 2021, "*U.S. ESCO Industry: Industry Size and Recent market Trends*", Source: https://doi.org/10.2172/1788023

32 Carvallo et al., 2019, "*Evaluating project level investment trends for the U.S. ESCO industry: 1990–2017*", Source: https://doi.org/10.1016/j.enpol.2019.03.061

33 Larsen et al., 2012, "*Evolution of the U.S. energy service company industry: Market size and project performance from 1990–2008*", Source; https://doi.org/10.1016/j.enpol.2012.08.035

34 S.Putz, 2025, "*Task 45: ESCo models-general*." Source: https://task45.iea-shc.org/data/sites/1/publications/IEA-SHC-T45.C.2.1-TECH-ESCo-Models-General.pdf

confidential, and large, energy-intensive industries may already have the financial and technical resources to implement projects on their own [34].

In order to act as ESCO, i.e. to offer and contract heat purchase agreements between the ESCO and the end user, a legal and financial framework needs to be established that can provide sufficient technical, legal and financial safety for both the supplier / ESCO and the end user. Despite these additional efforts, a heat supply contract (HPA, ESCO model, …) mitigates some of the main obstacles and barriers for SHIP installations, which is primarily the high CAPEX at installation, while cost savings are realized only during operation over the technical lifetime of the plant. But it should be emphasized that the ESCO mode is not just a financial model to avoid high upfront investments by the customer, but a real business model with different arrangement of contractual relations between supplier and customer and a different operational setup. End users are usually reluctant to operate and maintain a SHIP plant or lack the respective know-how or staff, while in a HPA the O&M is typically ensured by the ESCO. Accordingly, several larger SHIP projects have been installed in the last years or are currently being installed that use HPA as legal framework.

The recent **SHIP Market Outlook** (already highlighted in chapter 3.4) shows that the majority of projects planned in the near to medium future (2024-2026) will be using ESCO/HPA models as contractual framework (Figure 3-8). This emphasis again the perceived advantages and benefits as compared to other project constellations.

A list of providers offering heat supply contracts (ESCOS) can be found among the list of suppliers and technology providers for solar process heat on the website of the German project SolarPayback [35]. This website is regularly updated by solrico [36]. As part of the supplier data listed there, information is provided whether a respective supplier offers heat supply contracting („Service: heat supply contract“ stated with the supplier details), either themselves or with partner companies, and whether a supplier has references (reference commercial SHIP plants already built).

Annex 5.1 shows a list of SHIP suppliers offering heat supply via an ESCO model. The list is based on the above-mentioned SHIP supplier database and lists all companies which reported to offer heat supply as a service with their database entry (status: August 2023).

Please note that many other companies active in heat supply for industry may offer heat supply contracts and act as ESCO, where SHIP could be part of an overall heat supply offer. Therefore, we explicitly want to point out that the mentioned list is not claiming to provide a complete list of ESCO companies, but lists only those who are SHIP technology providers and are registered in the above quoted database.

4.4 Financing Models

Independent on the chosen business model for a SHIP installation, the investing party (be it the customer in the plant sales model, or the ESCO in the ESCO/HPA model) will usually require financing for the initial investment (capital expenditure, CAPEX) and – in the ESCO case – for financing working capital requirements. A comparison with customary financing approaches for wind power and PV as well as available models and instruments for financing SHIP installations are discussed in the following.

4.4.1 A comparison of financing approaches for renewable energy plants – risk and risk management instruments

For wind power and photovoltaic solar power projects, the financial markets offer well established financing models on a very large scale. Investment in such projects is regarded as a separate asset class by banks, investments funds and capital markets. Most projects are financed based on the cash flow they are generating and not on the balance sheet of the asset owner.

Cash-flow based financing is possible because the parameters for cash flow generation by wind power and PV projects are calculated in standardized ways and are well understood by banks and other financial investors. The large investment size of most projects (especially wind power) is favourable to implement them by a project company which is established as a Special Purpose Vehicle (SPV) and financed with equity and long-term loans structured by typical project financing principles.

[35] SolarPayback Source: https://www.solar-payback.com/suppliers/

[36] Solrico Source: https://www.solrico.com/

Performance risks and technical risks of wind power and PV projects are seen as calculable and manageable. For wind power projects, available meteorological data, wind measurement on site, independent yield studies based on the power curve of the selected turbine to determine energy yield with 50%/90%/99% probability (“P50/P90/P99”) provide a reliable basis for energy production. Additionally, the mature technology and the high quality of wind turbines (worldwide market size 2020: 54 billion USD), a mandatory certification system, and well controlled O&M costs by online predictive maintenance systems are limiting technical risks, which are even covered by payment guarantees of turbined manufacturers for reaching 97% availability of production. For PV, there are equally reliable data bases and technical performance risk management possibilities in place.

Technical performance risks of solar thermal power production can be managed in a similar way. Irradiation and meteorological data, the performance characteristics of the solar thermal installations and guarantees by the manufacturers of these technologically mature technologies, are available.

But solar thermal technologies are produced for comparatively small markets and with small numbers of projects. In most cases, thermal energy is not generated for a thermal power grid, distributing energy to a multitude of customers, but for a single customer. Heat generation has to be integrated into the production facility of the customer as a customized technical solution. It is therefore difficult to standardize product offers.

Risk managers in banks and other financial institutions know little about the technology of solar thermal in industry. Instead of relying on a broad base of experience as for PV and wind power, the risk analysis has to be done case by case by technical performance assessment.

The most important difference is caused by the offtake side. While electricity is fed into the power grid and can be sold on the electricity markets, the thermal energy generated in the solar thermal plant typically has only one customer. If this customer does not or cannot pay for the delivered energy, there is no alternative for tapping another source of cash flow by selling to someone else. Credit risk – instead of market risks – is of primary importance.

These differences have to be considered for structuring financing models for the solar thermal energy business. Some important performance risk and credit risk management instruments (like e.g. credit ratings of big companies or utilities as contract partners of PPAs) which are the basis for the deep financial markets for renewable electricity generation and are available for wind power and PV, are not applicable at all or are not yet deployable for solar thermal energy generation.

Table 4-1 gives an overview of risk types of solar thermal systems in comparison to wind power and PV.

Table 4-1 Risks and risk management matrix

risks and risk management	**energy source availability**	risk management	**technical performance**	risk management	**market risk**	risk management	**credit risk**	risk management
Wind power	wind resource	meteo data, wind measurement, *insurance*	power curve of wind turbine; "P50/ P90" energy yield	certification, manufacturer guarantee, availability guarantee	spot market price	price curve studies, forward trade, feed- in tariffs, contracts for difference	PPA with offtaker	credit ratings, guarantees by offtaker, banks or public guarantees
PV	solar resource and climatic ambiance	meteo data, *insurance*	power curve of PV installation; "P50/ P90" energy yield	certification, manufacturer guarantee, availability guarantee	spot market price	price curve studies, forward trade, feed- in tariffs, contracts for difference	PPA with offtaker	credit ratings, guarantees by offtaker, banks or public guarantees
solar thermal for single offtaker	solar resource and climatic ambiance	meteo data	performance curves of installation; load profile of off taker	certification, manufacturer guarantee	n.a.	n.a.	Energy service contract/PPA with offtaker	credit ratings, guarantees by offtaker, banks or public guarantees

4.4.2 Overview on current and new Financing Models for SHIP

How a project is financed from planning until start of operation depends on the business model (see Chapter 4.3).

The traditional business model of selling a technical installation to a customer (“Plant Sale model”, see chapter 4.3.1) requires working capital for the seller to plan, buy components, manufacture, and install the assets. The buyer has to finance the investment in the amount of the purchase price.

The ESCO model of selling energy services or energy supplies to the customer (see chapter 4.3.2) requires financing only on the side of the ESCO. The customer has to take care of the cash for the regular service or energy payments to the ESCO.

4.4.2.1 Financing the Plant Sale model

For the supplier: In the case of the traditional business model of selling the SHIP plant, the manufacturing and installation cost are covered by the working capital of the manufacturer or the contractor. The sources to fund these expenses are shown as equity or debt on the balance sheet of the manufacturer. The seller then gets paid by the customer. The receipts of the sale can be used to reduce the debt for financing the working capital the seller needed for the production of the assets. Financing of working capital for the manufacturing process is a customary commercial banking product. Long project lead times, shaky credit ratings of customers or fast order growth can make it difficult to get working capital financing, but in principle financing models are well established. Publicly assisted financing possibilities exist for export sales in many countries.

For the buyer: The buyer needs cash at hand or in the bank to pay the purchase price for the solar thermal installation. If the buyer does not have enough liquid funds, he can inject equity or fund the additional cash need by debt, e.g. by a short term or long-term bank loan. Many investment subsidy schemes do exist, which are also listed in the last subchapter. Also, a leasing option via a leasing company might be available.

As an alternative to a bank loan or to leasing the seller can offer trade credit to the customer to facilitate financing of the sale. In the case of an export sale such a trade credit can also be provided by export credit instruments or export credit guarantees.

4.4.2.2 Financing aspects of the ESCO business model

The benefits of the ESCO model for the customer have been discussed above. **For the customer**, the ESCO model can also be seen as a financing model, as it avoids the high upfront investment expenses. When instead of the assets, energy savings or energy supplies are provided to the customer, only the manufacturer or the general contractor or the ESCO has the burden of financing substantial amounts of capital. In other words: The ESCO model is the perfect financing model for the customer because he does not have to take care of raising capital.

But for the ESCO, the financing needs are even more challenging than in the case of the sales model if he wants to grow his business. By selling an installation which has been previously manufactured, the manufacturer reduces his net debt position by the receipts of the purchase price and – unless he makes losses on the installation sale – the debt/equity ratio of his balance sheet does not deteriorate, enabling him to continue the financing cycle for new business.

This is not the case in the ESCO model. As borrowing of working capital is not followed by a corresponding cash inflow from the receipts of selling, but only by a periodical, but comparatively small payments for energy or energy service, the debt position on the balance sheet is inflated with each new project, leading to balance sheet ratios which are not sustainable.

Energy service contracts or energy supply contracts which remain on the balance sheet can therefore only be offered by very large companies with excellent credit ratings.

The ESCO business model needs cash-flow based (and not balance-sheet based) financing which enables off-balance-sheet business or to offload project-related debt from their balance sheet.

The classical and well-established off-balance sheet financing model is **project financing**, where a single project is implemented by a separate company as a special purpose vehicle (SPV). The main elements of project financing structures are reliable cash flows, long term senior loans which can be repaid by the cash flow with a high safety margin and sufficient equity allowing for the corresponding debt sizing. Such a project financing structure requires extensive legal and technical due diligence efforts and complex legal and contractual documentation. The costs for setting up a project financing structure are high and can only be supported by very large projects.

One of the key leaders in this area is Kyotherm [37]. Kyotherm has financed and contracted approximately 100 MW_{th} of renewable heat and energy efficiency projects, mainly in Europe, leading to the generation of approximately 250 gigawatt hours thermal (GWh_{th}) of renewable heat per year [38]. One relevant example is the SHIP plant at a maltery in Issoudun, France with 14,250 m² or 11 MW_{th} [39]. Energy efficiency projects make up approximately 24% of the Kyotherm portfolio, with approximately 76% for financing solar thermal, geothermal, and biomass heat generation and integration projects. [40]

ESCOs can also use **the emission of bonds** to finance its activities, like Kyotherm has already done. Such **Green Bonds**, which are in compliance with the sustainability criteria of the EU Taxonomy help to increase the funding for renewable heat projects.

Few companies today offer or issue green thermal bonds. For example, the company "Energy From Waste GmbH" issued in 2021 a €400 million green bond to finance and refinance waste heat recovery projects [41]. Kyotherm is currently also the only renewable heat generation finance institution that has utilized a corporate green thermal bond for renewable heat and efficiency projects. The company has developed and issued a green bond to Edmond de Rothschild Asset Management and Johes for €30 million [42] or $35 million as of 2020 [43]. This type of bond then allows specific renewable heat and energy efficiency projects to be funded.

For smaller projects some investment funds offer the financial technique of **forfeiting** as an alternative. Forfeiting means a long-term true sale of future receivables against a customer. By selling future receivables, the ESCO receives the present value of the future cash flow of a specific project and uses it to repay the debt it has raised for its implementation. Specialized funds, like SUSI [44] or Solas Capital [45] are offering this financial instrument not only for single projects, but as a framework-agreement based facility for ESCOs which allows them to build their business model on it.

4.4.3 Available SHIP Funding and Financing possibilities

In many countries worldwide, the rollout of renewable energy supply and also the installation of SHIP plants is promoted and supported by funding schemes and incentives. In April 2021, a Deliverable Report [46] has been published by Subtask E of the SHC/SolarPACES joint Task 64/IV, discussing different funding and incentive schemes and providing a list of funding programs available at the time of preparation of the report.

Policy recommendations

The international expert group strongly recommends politics to install funding schemes to accelerate technology rollout and facilitate decision-making based on purely financial aspects. Since then, the worldwide energy markets have seen severe disruptions by conflicts, putting a stronger focus on other aspects and potential added value of RE/SHIP installations (see section 4.1), but financial viability will stay one main aspect for decision-makers. Also, from discussions in the expert group, the report strongly recommends installing a funding scheme based on a CAPEX funding, i.e. direct subsidy to the initial investment, which has been seen favorable against other schemes like tax incentives, OPEX subsidies, loans and others.

Actual funding schemes

Since funding schemes and incentives are usually financed through programs with a limited duration and based on specific political decisions, any listing of existing funding schemes is probably outdated by the time it is published.

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37 Kyotherm Website: https://www.kyotherm.com/de/

38 Issuance of 30 Million Euro Green bond by Kyotherm. Source: https://kyotherm.com/en/issuance-of-30-million-euro-green-bond-by-kyotherm/

39 https://kyotherm.com/en/commissioning-solar-thermal-plant-issoudun/

40 Kyotherm Green Bond Framework. Kyotherm. https://www.kyotherm.com/en/wp-content/uploads/sites/3/2020/10/Green-BondFramework-Kyotherm-June-2020.pdf

41 Recycling Magazine, 2021 Source: https://www.recycling-magazine.com/2021/07/01/eew-first-green-bond-issued-by-a-thermal-waste-recovery-firm/

42 Kyotherm Green Bond Framework. Kyotherm. https://www.kyotherm.com/en/wp-content/uploads/sites/3/2020/10/Green-BondFramework-Kyotherm-June-2020.pdf

43 X-Rates, 2020. EUR Historical Exchange Rates (Euro) - 2020. https://www.xrates.com/historical/?from=EUR&amount=30&date=2020-09-02.

44 SUSI, Source: https://www.susi-partners.com/

45 Solas Capital, Source: https://www.solas.capital/

46 Deliverable Report D.E1 by Subtask E of IEA SHC/SolarPACES joint Task 64/IV, Source: https://task64.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Task64-SolarPACES-TaskIV-D.E1--Collection-of-solar-process-heat-related-research-and-funding-programs.pdf

This also applies to the report quoted above (with a database originating from a survey pursued in 2020/2021). Yet, the list published there may serve as a starting point when searching for funding programs, even though the specific programs listed may be outdated.

However, it is **strongly recommended to investigate on current conditions and potential funding schemes** in the country of a planned installation and/or from other sources that may be applicable in the respective country. While most funding programs originate from national programs, there are also programs which are not limited to one country. One recent example is the EU Innovation Fund[47], which provides funding options for innovative projects in the EU and is one of the world's largest funding programs for the demonstration of innovative low-carbon technologies.

[47]EU Innovation fund, Source: https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund

5 Annex: Additional information

5.1 SHIP suppliers offering ESCO services

Table 5-1: Suppliers of SHIP technology which at the same time offer heat supply contracts, either themselves or with partners[48]. The listing is sorted alphabetically by country of company base; ESCO services may be offered for/in other countries as well. Further information on the data source and selection procedure are given in the end of section 4.3.2. of this report. Please note that this list may not be exhaustive. In addition, many companies which are not SHIP suppliers offer ESCO services.

COUNTRY	COMPANY NAME	STATUS OF COMPANY	OFFERS ESCO	TYPE OF COLLECTOR PRODUCED INHOUSE OR ON SITE	WEBSITE
Austria	Heliovis	demonstration plants	yes	parabolic trough	https://heliovis.com/
Austria	SOLID Solar Energy Systems	with references	yes | with partner companies	no	
Belgium	Rioglass Solar	with references	yes	linear fresnel	
Brazil	Enalter Engenharia Indústria e Comércio	ready to offer	yes	flat plate	
Canada	Phoenix Solar Thermal	ready to offer	yes	parabolic trough	https://phoenixsolarthermal.com/
Canada	Solarsteam	ready to offer	yes	enclosed ultra-lightweight parabolic collector	https://solarsteam.ca/
Chile	Thenergy	ready to offer	yes	no	
China	Himin Solar	with references	yes	vacuum tube, flat plate, parabolic trough, linear Fresnel	http://www.himinsun.com/
China	Solareast Group (major brands are Sunrain and Micoe)	with references	yes	vacuum tube	http://en.sunrain.com/
China	Vicot Solar Technology	with references	yes	parabolic trough	
Denmark	Heliac	ready to offer	yes	point focus Fresnel	https://www.heliac.dk/utility-scale/
Finland	Meriaura Energy (former Savosolar)	with references	yes	flat plate	
France	Idhelio	with references	yes	linear fresnel	https://idhelio.com/

48 Suppliers of SHIP technology, Source: https://www.solar-payback.com/suppliers/

France	New Heat	with references	yes	no	https://newheat.com/en/
France	Sunti	ready to offer	yes	no	
France	Alto Solution	demontration plants	yes in partnership	parabolic trough	
Germany	Protarget	with references	yes	parabolic trough	
Germany	Solarlite (part of Azteq Group)	with references	yes	parabolic trough	
Germany	Soliterm	with references	yes	parabolic trough	
India	Quadsun Solar	with references	yes	concentrating dish	http://www.quadsuntechnology.com/
India	Sunrise CSP	with references	yes	dish concentrators	
Israel	TIGI	with references	yes	flat plate	
Jordan	Millennium Energy Industries (MEI)	with references	yes	no	
Mexico	Citrus Solar	with references	yes	no	https://citrus.mx/wp-content/cache/all/index.html
Mexico	Flemming Jorgensen Sa de CV	with references	yes	no	
Mexico	In-Situ Energia	ready to offer	yes	no	
Mexico	Inventive Power	with references	yes	parabolic trough	
Mexico	Módulo Solar	with references	yes	flat plate	
Mexico	Tecnosol	with references	yes	no	http://www.tecnosolmexico.com/
Mexico	Sunnergy	with references	yes	no	
Netherlands	G2 Energy	with references	yes	flat plate	http://g2energy.nl
Netherlands	Infinity Solar	with references	yes	no	
Netherlands	R&R Systems De Energieverdieners	with references	yes	PVT	https://www.energieverdieners.nl/
South Africa	Holms and Friends	with references	yes	no	
Spain	Covalersa	with references	yes	linear Fresnel	
Spain	Solarwall Spain	with references	yes	PVT	https://www.solarwallspain.com/
Spain	Solatom	with references	yes	linear Fresnel	https://solatom.com/
Spain	TCT True Solar Power	with references	yes	concentrating dish	https://www.truesolarpower.es/
Switzerland	TVP Solar	with references	yes	flat plate evacuated	

USA	Artic Solar	with references	yes	vacuum tube collectors	https://articsolar.com/
USA	GlassPoint Solar	ready to offer	yes	parabolic trough in greenhouse	
USA	Skyven Technologies	with references	yes	no	http://skyven.co/
USA	Solar Dynamics	ready to offer	yes	parabolic trough	https://www.solardynllc.com/
USA	Sunvapor	with references	yes	parabolic trough	
USA	Winston Cone Optics	ready to offer	yes	vacuum tube collectors	https://www.winstonconeoptics.com/

5.2 Detailed outlined advantages and disadvantages of different technologies compared to solar thermal.

This part of the appendix contains tables with detailed information from the summary of Table 3-2. The information for this matrix was taken from these tables. Each table represents one technology, as can be seen in the table header.

Table 5-2 Detailed outlined advantages and disadvantages of different technologies compared to solar thermal [49]

Disadvantages of electric resistance heating with PV	Advantages of electric resistance heating with PV
>The use of electricity for heating is inefficient from an exergy perspective. >The generation of electricity for the electric boiler is heavily dependent on coupled renewable energy sources, potentially resulting in significant seasonal variations. **>Achievable temperatures:** For temperatures under 100 degrees, both electric resistance heating with PV and solar thermal heating can be suitable. For temperatures between 100 and 200 degrees, specific solar thermal systems are quite efficient. For temperatures above 200 degrees, concentrating solar thermal systems are suitable	>The electric boiler offers high flexibility and is suitable for meeting peak demands. > Generally, electric boilers efficiently convert electrical energy into thermal energy. >Electric boilers can be easily distributed throughout the grid. >Depending on the size, an electric boiler can have low capital expenditures (CAPEX). >In this scenario, the electric boiler system operates entirely on renewable energy. >Using self generated power for the electric boiler system allows planning for the volatility of renewable energy sources. >PV systems are generally more versatile than solar thermal systems. >PV systems are more efficient in regions with lower direct sunlight due to their ability to better utilize diffuse light. **>Complexity:** Electric resistance heating powered by on-site PV systems is relatively straightforward, the electricity generated can be used directly for resistance heating elements, bypassing the need for complex heat transfer fluids, collectors, or storage systems. **>Scalability:** Solar thermal systems are less scalable due to their complexity and the need for costly modifications when expanding, making large-scale projects more challenging to implement. **>Reliability**: Electric resistance heating with PV is more reliable due to the longer lifespan of PV panels (less maintenance) and the simplicity of the electric resistance heaters. **>Local availability:** PV systems are typically more readily available and accessible, as they can be installed in various locations and are less dependent on specific geographic conditions. Especially high-temperature solar thermal systems (e.g. concentrating solar) needs direct sunlight, thus, is not suited for some geographic regions. **>Price:** Resistance heating with on-site PV systems can often be more cost-effective due to the declining cost of PV technology and the simplicity of the setup

[49] Hammer et al. 2022 (Final report of the project "Industrial Excess Heat INXS").

Disadvantages of electric resistance heating with grid	Advantages of electric resistance heating with grid
>The use of electricity for heating is wasteful from the exergy perspective. >Electric resistance heating operated with regular grid power is not entirely renewable. >Electric resistance heating have high operational expenses (OPEX) due to electricity prices. >Electric resistance heating creates a high dependency on the availability of electricity. >Solar thermal heat has lower operational expenses (OPEX) and thus a lower levelized cost of heat (LCOH). **>Achievable temperatures:** For temperatures under 100 °C, both electric resistance heating with PV and solar thermal heating can be suitable. For temperatures between 100 and 200 °C, solar thermal systems are generally more efficient. For temperatures above 200 °C, solar thermal systems are the more appropriate choice due to their capacity to generate high temperatures efficiently, which electric resistance heating is not well-suited for in most cases.	>Electric resistance heating offers high flexibility. >Electric resistance heating is suitable for peak demand. >Electric resistance heating efficiently converts electrical into thermal energy. >Electric resistance heating can be easily deployed throughout the entire grid. >Depending on the requirement, electric boilers can have low investment costs. >Integrating solar thermal heat potentially involves higher investment costs. >Solar thermal heating typically does not provide the ability to cover peak loads. >Solar thermal heat has lower continuous availability >Backup capacities must be maintained for solar thermal heat. Various electricity suppliers are available for electric resistance heating. **>Complexity:** Electric resistance heating with grid power is relatively straightforward. It involves connecting the heating element to the existing electrical grid, which is a well-established and standardized system. **>Reliability:** Electric resistance heating using power generated from the grid is typically more reliable than solar thermal heat generation. **>Price:** Solar thermal systems require significant upfront investment and may have longer payback periods **>Local availability:** Grid power is readily available **>Achievable temperatures:** Electric resistance heating with grid power is more locally available, thanks to established grid infrastructure, while solar thermal heat depends on specific geographic conditions, limiting its universal availability. >**Scalability:** Solar thermal systems are less scalable due to their complexity and the need for costly modifications when expanding, making large-scale projects more challenging to implement.

Disadvantages of heat pumps	Advantages of heat pumps
>Heat pumps require regular price negotiations with the electricity provider. >High costs during periods of high electricity prices. >Heat pumps can have high upfront (e.g., ground source heat pump) and operational costs (electricity). >Heat pumps have potential environmental impacts on water/soil due to heat extraction and storage. >The greenhouse gas intensity of Combined Heat and Power (CHP) depends on the electricity mix. >Solar thermal heat is less reliant on electricity or the power grid. >Solar thermal technologies and heat pumps can potentially work well together. **>Complexity**: Heat pumps can be complex due to various types and components, while solar thermal systems' complexity varies based on design and installation. **>Achievable temperatures:** For temperatures between 100 and 200 °C and above 200 °C, solar thermal systems are generally the better choice due to their design capabilities for high-temperature applications.	>Ambient energy is locally available in various forms. >Heat pumps allow for flexible operation. >Heat pumps enable the use of renewable energy from utility companies. >Ground-source heat pumps can utilize the Earth as a heat store (seasonal storage). >Solar thermal heat is less suitable for peak load coverage. >Backup generation capacity is needed for solar thermal heat. **>Reliability**: In general, heat pumps are considered more reliable due to fewer components, longer lifespans, and lower maintenance requirements. **>Price:** Heat pumps often offer better financial viability due to higher energy efficiency and lower maintenance costs. >Local availability: Heat pumps are generally more locally available because they are a widely used and standardized technology for both heating and cooling. **>Achievable temperatures:** For temperatures under 100 °C, both systems can work, but heat pumps may have an efficiency advantage. **>Scalability:** Heat pumps are more scalable than solar thermal systems, as they can easily be adjusted to meet changing demands without significant design modifications.

Disadvantages of electrolysis hydrogen	Advantages of electrolysis hydrogen
>Hydrogen production is costly with high upfront and ongoing expenses. >Solar thermal offers reduced reliance on international developments. >Hydrogen production depends on other countries. >Costs: Green hydrogen production may impact economic profitability. >Energy Losses: Electrolysis for green hydrogen involves energy losses. >Infrastructure: Significant investments are needed for the hydrogen infrastructure. >Scalability: Mass green hydrogen production requires substantial investments and time for cost-effective manufacturing. >Water and Resource Requirements: Electrolysis for green hydrogen needs large water and resources like platinum catalyst, which might strain resources **>Complexity**: Solar thermal systems generally have simpler components and mechanisms. **>Price:** Solar thermal systems are usually more financially viable due to lower upfront costs, simplified infrastructure, and a shorter payback period **>Local availability:** Solar thermal systems are more widely available than green hydrogen systems for heat generation due to their established technology and broader infrastructure, while green hydrogen infrastructure is still developing and less prevalent. **>Achievable temperatures:** For achieving temperatures under 100 °C, both green hydrogen and solar thermal systems can work, but for temperatures between 100 and 200 °C and above 200 °C, solar thermal systems are generally more efficient and suitable.	>Hydrogen is more versatile than solar thermal heat, it finds diverse applications in transport, industry, and energy storage, diversifying energy sources. >Hydrogen enables high-temperature heating without being dependent on geographic location. >From Hydrogen combustion waste heat can be used for low-temperature processes. >Hydrogen is easily storable (short to long term). >Multiple suppliers for hydrogen are available. >Solar thermal energy offers lower continuous availability, requiring backup capacity. >Hydrogen serves as a storage solution for excess renewable energy, convertible to electricity and/or heat as needed. **>Scalability:** Green hydrogen systems are generally more scalable because green hydrogen can be produced and stored at various scales, and the infrastructure for hydrogen distribution is versatile and can be expanded to meet changing demands. **>Reliability:** Green hydrogen is considered a reliable option for heat generation because it can theoretically provide a consistent supply regardless of weather conditions, seasons, or geographic location.

Disadvantages of biogas	Advantages of biogas
>Biogas is not CO2 neutral despite being biogenic. >Slow growing biomass is considered not fully sustainable. >Solar thermal heat has low variable costs. >Solar thermal heat doesn't require combustion, resulting in no emissions. >Organic waste resources in the market are not infinite. >Biogas plant technology is relatively expensive. >Operating biogas plants can be technically challenging. >Solar thermal heat doesn't compete with other sectors (Energy-Water-Food Nexus), which will gain importance in the future. >Regional suppliers of large biogas quantities are often limited. >Sunshine is readily available. >Solar thermal technology may be easier to integrate than a new gas boiler (and possibly a biogas plant), leading to lower infrastructure costs. >Biogas production and combustion emit CO2, even if it's mostly biogenic. >Solar thermal technology is less CAPEX intensive.	>Biogas utilizes plant and animal waste, reducing environmental impact from agricultural operations by waste reduction and improving remaining material for agriculture (fertilizer...). >Multiple Biogas providers are theoretically accessible through the gas network. >Local biogas production is possible. >Biogas can be injected into the gas network (biomethane) or used directly. >Biogas CHP (Combined Heat and Power) is as flexible as natural gas CHP. >Processed biogas is storable (short to long term) - similar to natural gas. >Heat quality (water temperature, steam pressure...) is easily adjustable. >High temperature levels are attainable with biogas. >Gas CHP and biogas plants are well established technologies. >Large biogas CHP systems allow for centralized heat generation. >Solar thermal heat has lower continuous availability. >Biogas can be substituted with natural gas when needed. >Solar thermal heat requires a backup. >Solar thermal heat is less suitable for peak load coverage. **>Complexity:** Solar thermal systems require a variety of components, these components must be carefully designed and installed in order to operate efficiently and safely. Solar thermal systems can be complex to control, as they must be able to respond to changes in sunlight availability and heat demand. **>Reliability:** Biomass systems can generate heat on demand, regardless of the weather conditions, they are typically simpler and less complex, with fewer components that can fail and are typically easier to control. **>Price:** Gas-fired systems are typically less expensive to install and maintain. However, the cost of natural gas can fluctuate. Solar thermal systems have a higher upfront cost, but they can save money on energy bills over time. **>Local availability:** Biogas is more locally available because it can be produced from a variety of organic materials, including agricultural waste, food waste, and sewage. Solar thermal systems, on the other hand, require sunlight, which is not always available in the required intensity. **>Achievable temperatures:** Both technologies can achieve the required temperatures under 100°C, between 100°C and 200°C and above 200°C. But biomass systems are typically more reliable and easier to control. **>Scalability:** Solar thermal requires sunlight to produce heat. This can limit its scalability, as solar panels cannot be installed in all locations and the amount of sunlight available can vary depending on the time of day, the weather conditions, and geographical location.

Disadvantages of biomass	**Advantages of biomass**
>Biomass, although biogenic, is not carbon-neutral. >The use of slow-growing biomass is not entirely sustainable. >Solar thermal heat does not compete with other sectors (Energy-Water-Food Nexus), which will become more relevant in the future. >Biomass prices have recently risen due to the Ukraine conflict, and storm wood is nearly depleted. >The market and resources for combustible biomass are limited. >Solar thermal heat doesn't require combustion, resulting in no ash or emissions. >Sunshine is already available (no new CO2). >Integrating solar thermal technology is less capital-intensive (CAPEX). >Solar thermal heat has low variable costs, as no (road) transport is needed. >Biomass requires storage space. >High dependence on biomass suppliers. >Solar thermal technology may be easier to integrate than a new biomass boiler (infrastructure cost).	>Biomass is easy to store (short to long term). >There are multiple providers for biomass. >In biomass Combined Heat and Power (CHP), heat quality (water temperature, steam pressure...) is easily regulated. >Biomass CHP enables centralized heat generation. >Solar thermal heat requires a backup. >Solar thermal heat is less suitable for peak load coverage. >Biomass CHP can achieve high temperature levels. >Biomass provides independence through self-generated heat. **>Complexity:** Solar thermal systems require a variety of components, these components must be carefully designed and installed in order to operate efficiently and safely. Solar thermal systems can be complex to control, as they must be able to respond to changes in sunlight availability and heat demand. **>Reliability:** Biomass systems, can generate heat on demand, regardless of the weather conditions, they are typically simpler and less complex, with fewer components that can fail and are typically easier to control. **>Price:** Biomass systems are typically less expensive to install and maintain. On the other hand, Biomass prices have recently risen due to the Ukraine conflict. **>Local availability:** Biomass is more locally available because it can be produced from a variety of organic materials, including agricultural waste, food waste, and sewage. Solar thermal systems, on the other hand, require sunlight, which is not always available in the required intensity. **>Achievable temperatures:** Both technologies can achieve the required temperatures under 100°C, between 100°C and 200°C and above 200°C. But biomass systems are typically more reliable and easier to control. **>Scalability:** Solar thermal requires sunlight to produce heat. This can limit its scalability, as solar panels cannot be installed in all locations and the amount of sunlight available can vary depending on the time of day, the weather conditions, and geographical location.

Disadvantages of geothermal	Advantages of geothermal
>Local availability of (high temperature) geothermal energy depends entirely on the geographical area and geological profile. >Additional technology (high temperature heat pump) is needed if geothermal temperatures are too low. >Environmental impacts of geothermal energy use must be carefully assessed. >Scalability of geothermal energy systems may be limited (regulation, other consumers...). >Geothermal energy utilization is associated with high CAPEX (Capital Expenditure). >Waste heat has low OPEX (Operating Expenditure). >Complexity: Solar thermal technology is typically less complex. **>Price:** Proving the availability of (high temperature) geothermal energy requires costly drilling (high risk). Solar thermal technology utilization is generally more cost effective in procurement. **>Local availability:** Overall, the availability of geothermal and solar thermal systems varies depending on the location. Geothermal systems are more locally available in regions with geothermal resources, while solar thermal systems are more locally available in regions with abundant sunlight. >Achievable temperatures: Both geothermal and solar thermal systems can be adapted for temperatures under 100°C, making them suitable for lower-temperature applications.	>Geothermal energy reduces or eliminates dependencies on other technologies. >Geothermal energy has minimal land use (heating plant). >Solar thermal heat carries a higher risk of downtime (site closure, process changes). >Deep geothermal energy is suitable for direct injection without the need for additional temperature-raising technology. >Geothermal energy has stable pricing during operation. >Low OPEX for geothermal energy when the locally available conditions are right (same for solar thermal heat). **>Reliability:** Geothermal energy allows continuous supply and it does not need a backup. **>Achievable temperatures:** Geothermal systems are generally more efficient and better suited for achieving temperatures between 100 and 200°C and above 200°C because they tap into naturally occurring high-temperature reservoirs. Solar thermal systems can achieve even higher temperatures using concentrating solar thermal (CST) however, these systems are much more complex and expensive to maintain. **>Scalability:** Geothermal systems are typically more scalable than solar thermal systems. Geothermal scalability is achieved because it depends on the drilling of additional wells or boreholes, allowing for the expansion of the heat source. In contrast, solar thermal systems require additional collector arrays and storage capacity, which can be less straightforward and more expensive to scale up.

Disadvantages of internal utilization of waste heat	Advantages of internal utilization of waste heat
>Depending on the energy source used in industrial processes, waste heat utilization may not be entirely renewable. >Utilizing low quality waste heat is challenging to achieve efficiently and may potentially necessitate larger waste heat treatment systems. >Waste heat systems can lead to internal interdependencies among processes, creating the potential for lock in situations. >Implementing waste heat systems may require equipment maintenance and result in downtime during renovation periods. >The installation of waste heat systems could lead to space constraints if additional machinery needs accommodation. >Adapting waste heat systems may necessitate new permits for modifications to existing facilities. >Waste heat systems may reduce the accessibility of equipment. >Waste heat systems can increase the potential for errors. >Price: cost of waste heat utilization is highly dependent on the heat source and heat specifications >Local availability: Waste heat availability depends on availability of waste heat sources >Achievable temperatures: Waste heat temperatures depend on the source, often temperatures are <200 or <100 °C limiting the direct utilization opportunities >Scalability: Waste heat utilization scalability depends on the available amount, power and temperature of waste heat, eventually only preheating or 2-step utilization via HP is possible	>Waste heat utilization can enhance compliance with environmental regulations by lowering heat emissions. >Waste heat utilization improves conditions, particularly in cases of very high waste heat temperatures. >Waste heat utilization lowers heat emissions into the environment, affecting air and water. >Waste heat is available consistently, while solar thermal energy relies on weather conditions. >Waste heat can be harnessed in various industrial settings, offering deployment versatility. >Waste heat is often readily available in urban and industrial areas, reducing energy transmission needs. >Waste heat systems are more space efficient than large solar collector areas. >Depending on source waste heat maintains consistency without seasonal fluctuations. >Waste heat systems efficiently capture and utilize excess energy, preventing waste. **>Complexity:** Waste heat systems can be integrated into existing processes with minimal additional infrastructure. **>Reliability:** Waste heat utilization systems used within an industrial context remain unaffected by weather conditions. **>Price:** Depending on the waste heat source, its utilization might be more cost efficient than a solar thermal system (direct + indirect cost) **>Local availability:** Solar thermal collectors need outdoor space, e.g. on roofs or free-standing with suitable light incidence, for high temperature direct sunlight is needed depending on collector type **>Achievable temperatures:** solar thermal collectors can achieve low and high temperatures depending on system type and location, however, for high temperature systems commonly high cost apply