SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Solar District Heating: Measures to Reduce Costs

Subtask C report RC3

IEA SHC TASK 68| Efficient Solar District Heating Systems

Technology Collaboration Programme
by iea

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Solar District Heating: Measures to Reduce Costs

This is a report from SHC Task 68: Efficient Solar District Heating Systems

Subtask C: Business Models

Authors: Luuk Beurskens (TNO, NL), Niels van der Veer (PlanEnergi, DK), Lukas Emberger (SOLID SES, AT)

Date September 2025
Report RC3, DOI: 10.18777/ieashc-task68-2025-0005
TNO report number 2025 P11710

Solar Heating & Cooling Technology Collaboration Programme (IEA SHC)

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 t*o 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)
- Solar Cooling (Tasks 25, 38, 48, 53, 65)
- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64)
- 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

Our members

Australia	France	Slovakia
Austria	Germany	South Africa
Belgium	International Solar Energy Society	Spain
Canada	Italy	Switzerland
CCREEE	Netherlands	Türkiye
China	Norway	United Kingdom
Denmark	Portugal	
EACREEE	RCREEE	
ECREEE	SACREEE	
European Commission	SICREEE	

For more information on the IEA SHC work, including many free publications, please visit www.iea-shc.org

Contents

1 Executive Summary

This report, developed as part of the International Energy Agency's (IEA) Technology Collaboration Program (TCP) Task 68 on *Efficient Solar District Heating Systems*, presents an expert-based analysis of cost reduction mechanisms (CRMs) for Solar District Heating (SDH) systems. The focus is on quantifying future reductions in capital expenditures (CAPEX), operational expenditures (OPEX), and the Levelised Cost of Heat (LCoH), while considering the impact from technological development, scientific development, and yield improvements across different project phases.

The target audience for this report is quite broad: all players in the energy transition should become aware of the potential role that solar thermal district heating may play. Special focus is on policy and decision makers, city planners, energy modellers, local, regional and national governments and technology specialists. One of the underlying reasons to be transparent on SDH costs is that this report is designed to be an aid to decision makers who need to make robust plans, projections and energy transition policies. It may help energy modelers in determining the competitiveness of solar thermal and to see the effect of policy measures.

Through various expert meetings within Task 68, 46 CRMs across six SDH systems were identified. Following this, a survey has been developed and was answered by Task 68 participants and other industry experts. Results show that the largest potential future cost reductions are expected to be realised during the construction phase, which includes the CAPEX costs, primarily through prefabrication, smart procurement, and process standardization. The planning and preparation phases also offer notable opportunities for cost reduction, especially through financing optimization, economies of scale, and design standardization.

By 2030, average CAPEX might decrease by 6.5% and OPEX by 7.7%, with further reductions expected by 2050: 10.9% and 9.3%, respectively. These potential cost savings, combined with potential yield improvements of up to 14.9%, would contribute to a significant reduction in solar thermal LCoH across Europe. The resulting LCoH estimates for SDH are listed below. For this estimate European solar collectors have been used as a reference, with discount rates of 4%, and an assumed lifetime 25 years. Monetary data throughout this report are in euros of the year 2024:

- Possible SDH LCoH reduction in Northern Europe from €154/MWh to €119/MWh (2025 to 2050, -22%)
- Possible SDH LCoH reduction in Central Europe from €77/MWh to €60/MWh (2025 to 2050, -22%)
- Possible SDH LCoH reduction from in Southern Europe €51/MWh to €40/MWh (2025 to 2050, -22%)

The expert inputs furthermore show that the cost reduction potential can be unlocked by a combination of deployment of solar thermal and research-based cost reduction measures.

2 Introduction

2.1 Solar thermal heat in district heating networks

District heating refers to generating heat in a centralised location and then distributing it to residences, businesses and industry in a local area. District heating networks offer the potential for efficient, cost-effective and flexible large-scale use of low-carbon energy sources for heating [2]. One of the pre-eminent low-carbon technologies available is solar thermal, followed by geothermal energy, the use of ambient energy through heat pumps and biomass technologies.

All district heating systems equipped with solar heating utilise them as a supplement to other heat generating units, thereby ensuring that all consumers' heat demands are met, when there is insufficient solar irradiation available [3]. Generally, multiple heat generating units are installed. A district heating network with a solar thermal installation is called a Solar District Heating (SDH) system.

Typically, solar thermal heat covers 10% to 25% of the annual heat demand (based on systems with a short-term heat storage of 0.1 - 0.3 m^3 per m^2 solar collector), whereas solar thermal in combination with a seasonal heat storage can increase the share of solar heating to 30%-50 % (and in theory up to 100%) of annual heat demand.

This report from IEA SHC Task 68 zooms in on the costs of solar thermal installations that are connected to a district heating network.

2.2 Costs and the SDH business case

Solar thermal installations offer the opportunity to reduce CO_2-emissions cost-effectively in district heating systems, while at the same time reducing the fuel price risk by substituting fossil fuels. However, large solar thermal is still not very well represented in many countries, and certainly not in district heating.

Transparency on costs and performance may pave the way to make solar thermal more prominently present in the debate on energy transition. Note that design aspects may have a direct and indirect influence on the business case, as shown in Table 1.

One of the underlying reasons to be transparent on SDH costs is that this is an aid to decision makers who need to make robust plans, projections and energy transition policies. It may help energy modelers in determining the competitiveness of solar thermal and to see the effect of policy measures.

2.3 Target audience

The target audience for this report is quite broad: all players in the energy transition may become aware of the potential role that solar thermal district heating may play. Special focus is on policy and decision makers, city planners, energy modellers, local, regional and national governments and technology specialists.

2.4 Reader's Guide

The upcoming chapters elaborate on technology development (Chapter 3), the methodology applied in this report (Chapter 4) and the outcome of the analysis (Chapter 5). Finally, conclusions and an outlook are presented (Chapters 6 and 7).

Table 1 - Factors influencing the solar business case both directly and indirectly, and with a positive or negative effect [3]

	Factors influencing the solar business case	
	Directly	**Indirectly**
Positive effect	Simple, robust and proven technology	No continuous presence of operation personnel required during operation
	Long technical lifetime	Heat production price not sensitive to variable costs of fuel
	Absence of fuel costs (low operational expenses)	Easy decommissioning
	Relatively low maintenance costs	Synergy with heat pumps
	Low electricity consumption required (for pumping only)	Competitive market because of multiple suppliers
Negative effect	Production dependent on solar radiation and weather conditions	Seasonal Variability in Heat Demand
	Low energy yield per occupied land-area, resulting in high land lease	Lack of industry/technology standardization
	High initial investment	Dependency on back-up energy generation

3 Technology development stages

Cost reduction in energy technologies is commonly driven by the process of technology learning, a principle that explains how cumulative experience and innovation can lower production and operational costs over time. For energy-generating technologies, this is often expressed through a declining Levelised Cost of Heat (LCoH), which represents the average cost per kilowatt hour (kWh) of heat delivered over the system's lifetime, incorporating both capital expenditures (CAPEX) and operational expenses (OPEX). In the context of solar thermal systems, the LCoH is calculated for a specific temperature level and geographical location, relevant to the application.

The competitiveness of renewable energy technologies, such as solar thermal for district heating, hinges on their ability to reduce costs relative to conventional fossil-based alternatives. Cost reductions can occur alongside increasing costs for competing technologies, but achieving lower LCoH through targeted improvements remains critical for market uptake.

Solar thermal technologies progress through several development stages, each with distinct cost-reduction mechanisms. Figure 5 illustrates a conceptual model of technology development, in which different drivers dominate at different stages. In the early stages, public and private support are often necessary to stimulate research and deployment. However, as technologies mature, the reliance on financial support should decrease. Ideally, once externalities such as carbon pricing are internalised, solar thermal systems can compete on a level playing field with fossil fuel-based heating technologies.

Four main categories of cost-reduction drivers are identified in this model:

1. Learning by researching,
2. Learning by deployment,
3. Economies of scale, and
4. Market influence.

These are briefly explained below and form the analytical foundation for the expert-based evaluation presented in the next chapters.

Learning by Researching

This involves cost reductions through technological innovation, such as improving efficiency, materials, or manufacturing processes. For SDH, this includes advances in collector design, coatings, or automation in production.

Learning by Deployment

Gains in this category result from hands-on experience with real projects. As more SDH systems are built, best practices emerge, and processes improve. Shared learning across projects also accelerates development.

Economies of Scale

Larger projects reduce unit costs by spreading fixed expenses and enabling bulk purchasing. In SDH, this may include scaling up collector fields, procurement of materials, and more efficient project execution.

Market Influence

Policies, regulations, and industry standardisation can support cost reductions indirectly. Incentives, carbon pricing, or streamlined permitting can improve competitiveness, while mature supply chains lower coordination and transaction costs.

All four mechanisms above may play a role in advancing solar district heating. Their influence is reflected in the cost reduction mechanisms (CRMs) evaluated by experts in Task 68, as discussed in the next chapter and Annex A.

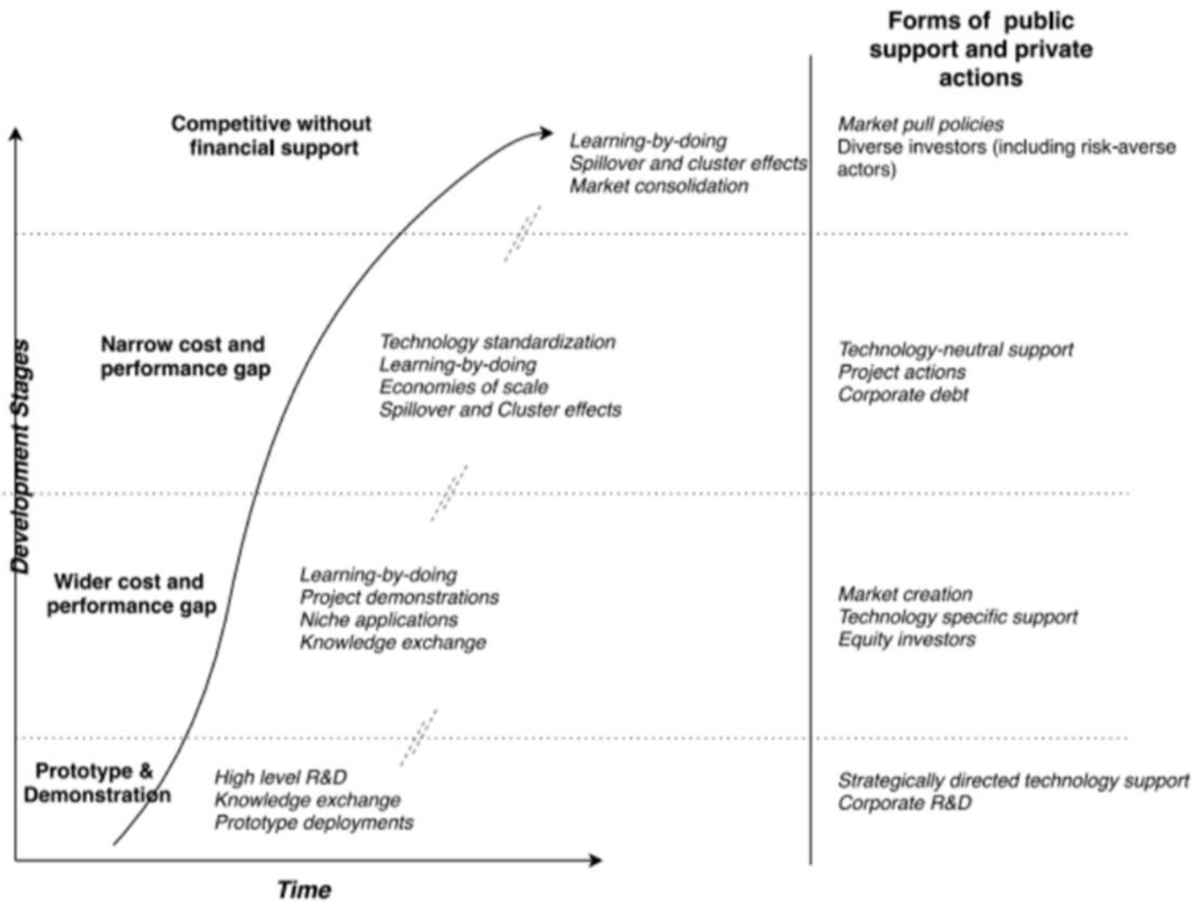

Figure 1 - Energy technology development process model, borrowed from [7]

4 Methodology

4.1 Survey Design

To estimate the potential for cost reduction in solar district heating (SDH), a survey was developed and completed by participants of IEA SHC Task 68. The survey was designed during multiple live and online sessions with solar thermal experts, resulting in a comprehensive list of 46 cost reduction mechanisms (CRMs). These mechanisms, cover all stages of an SDH project, and are listed in full in Annex A.

4.2 Project phases and expert knowledge

The total lifetime cost (TLC) of an SDH system was broken down into six distinct project phases, as shown in Table 2 below. Experts participating in the survey were asked to estimate the cost reduction potential within each phase. In total, eight completed questionnaires were received. Due to the financial nature of the task, some participants, particularly those with a technical background, chose not to provide detailed estimates.

To account for differences in expertise, respondents were also asked to self-assess their knowledge level per project phase. These self-ratings were used to weigh the cost reduction estimates, with greater weight assigned to input from respondents with higher declared expertise. The scoring ranged from 1 (“I don’t know much”) to 5 (“I know a lot”). The average expertise level across all phases was 3.3.

Table 2 - Scores on expert levels (n=8). Value 1 is low, value 5 is high expert knowledge.

SDH phases	Minimum	Average	Maximum
Phase 1 (project Idea)	2	3.9	5
Phase 2 (planning)	2	3.6	5
Phase 3 (project preparation)	2	3.1	4
Phase 4 (construction)	2	3.0	4
Phase 5 (operation over lifetime)	2	3.6	5
Phase 6 (decommissioning)	1	2.6	4

4.3 Collector types

In the survey four collector types were targeted, but the response rate was too low and the variety in estimates provided too wide to make a distinction between the various options. We therefore used a standard flat plate of European standard with a fixed tilt angle as the reference. For the cost reduction mechanisms, we therefore assume all estimates to refer to the flat plate. For completeness we list the originally targeted types below:

- **Flat plate standard (reference in this report)**
- Flat plate high efficient (not considered in this report)
- Vacuum tubes (not considered in this report)
- Concentrating solar (not considered in this report)

4.4 Project phases and costs

In the survey, CAPEX and OPEX over the entire project lifetime were estimated for the reference year 2025. A total lifetime cost range of 400–600 €/m² was used, with an average value of 500 €/m². This value represents the full system cost over a 25-year lifetime, with OPEX referring to the cumulative operational and maintenance costs during that entire lifetime period. The assumed system size is 10,000 m² of solar collector area. The estimate excludes costs for storage (both short- and long-term), land lease, and subsidies.

The collector type assumed is a south-oriented, fixed-tilt European standard flat plate collector. Central supply temperatures to the district heating network were assumed to range between 40°C and 80°C, with an average of 60°C. These parameters are necessary for estimating both yield and cost of the solar thermal plant. A solar fraction of 20% was assumed.

This cost estimate serves as the basis for evaluating potential cost reductions across the project phases. The weighted average distribution of costs is presented in Table 3. Note that phases 1, 2, 3, 4, and 6 are attributed to CAPEX. Phase 6 (decommissioning) is attributed to CAPEX because it represents a once-only expense. Phase 5 represents the OPEX over the system's lifetime (a period of 20 years was used for this purpose). Note: this approach was kept simple on purpose, so no time preference has been considered (no discounting was applied).

Table 3 - Cost weights for the various project phases as resulting from the questionnaire

	Average (weighted)	**Cost in 2025 [$€_{2024}/m^2$]**	**Minimum**	**Average**	**Maximum**
Phase 1 (project Idea)	1,1%	5	1,0%	1,1%	2,0%
Phase 2 (planning)	1,9%	9	1,0%	1,8%	3,5%
Phase 3 (project preparation)	3,1%	16	2,0%	3,0%	5,0%
Phase 4 (construction)	75,9%	380	72,0%	75,6%	84,0%
Phase 5 (operation over lifetime)	16,5%	83	9,0%	16,9%	20,0%
Phase 6 (decommissioning)	1,5%	7	0,5%	1,6%	5,0%
Total lifetime costs		**500**			

4.5 Energy yields

To calculate the Levelised Cost of Heat (LCoH), typical annual solar thermal yields were defined for different climatic zones in Europe. These system-level yields refer to the heat delivered to the district heating network. The assumed values, validated through the expert survey, are listed in Table 4.

Table 4 - Indicative heat yield (delivered to district heating system) as assumed and confirmed in the questionnaire

Estimates refer to yields on system level (delivery to the DH network)		
Typical northern yield (approx. Stockholm) [$kWh/m^2/year$]	Typical mid-region yield (approx. Würzberg) [$kWh/m^2/year$]	Typical southern yield (approx. Athens) [$kWh/m^2/year$]
200	400	600

4.6 Survey methodology

The survey was conducted through a spreadsheet, allowing participants to validate or adjust predefined assumptions and provide customised input. After confirming the initial cost levels and the collector type (most respondents opted for flat plate European standard), the respondents were asked to score 46 cost reduction mechanisms (CRMs), each allocated to a project phase. These CRMs were defined in Task 68 during various project meetings. Several aspects needed to be defined for each:

- The relevant project phase(s),
- The share of phase costs it could influence,
- The estimated cost reduction for 2030 and 2050 (relative to 2025),
- Potential impacts on annual yield (if applicable),
- The estimated contribution from deployment versus research.

The input gathered forms the foundation for the cost reduction analysis presented in the next chapter.

In order to score the CRMs in an unbiased manner pre-defined qualitative cost, reductions were presented, each of which translated to a quantitative cost reduction percentage, as indicated in Table 4 below. All experts could modify the pre-defined values if needed.

Table 4 – Qualitative and quantitative cost reductions as presented in the questionnaires

Cost reduction estimate	Corresponding quantitative cost reduction
No cost reduction	0%
Hardly any cost reduction	-0.5%
Very little cost reduction	-1%
A bit of cost reduction	-2%
Some cost reduction	-5%
Quite some cost reduction	-10%
Considerable cost reduction	-20%
Much cost reduction	-50%
Minor cost INCREASE	+1%
Little cost INCREASE	+2%
Quite some cost INCREASE	+5%
Major cost INCREASE	+10%

4.7 Levelised Cost of Heat

The levelised cost of heat (LCoH) is a measure expressing the net present cost of heat over the lifetime of a heat generation technology. It incorporates the costs during the expected lifetime of a plant and the amount of heat that is estimated to be produced over the plant lifetime. Financing costs are not considered in this approach. We apply the following simple expression (no fuel costs) to calculate the LCoH as presented further in this report.

$$\text{Levelised Cost of Heat} = \frac{\text{Capex+Opex during lifetime}}{\text{Yield during lifetime}}$$

For both Opex and Yield discounting is applied, resulting in the following detailed expression:

$$\text{LCoH [€/kWh]} = \frac{\text{Capex [€/m}^2\text{]} + \sum_{t=1}^{N} \frac{\text{Opex [€/m}^2\cdot\text{yr]}}{(1+r)^t}}{\sum_{t=1}^{N} \frac{\text{Yield [kWh/m}^2\cdot\text{yr]}}{(1+r)^t}}$$

In this expression r is the assumed discount rate, N is the expected lifetime and t indicates the time interval.

5 Outcome of the analysis

This chapter presents the results of the expert evaluation of cost reduction mechanisms (CRMs) across the different phases of Solar District Heating (SDH) projects. Experts from IEA SHC Task 68 assessed 46 CRMs by estimating their cost-saving potential in both 2030 and 2050, relative to a 2025 baseline. Each measure was categorised by its relevance to one of six SDH project phases and its anticipated impact on the cost reduction in that specific phase.

5.1 Cost Reduction Measures per Phase

This section highlights the most impactful cost reduction measures (CRMs) for each project phase, based on expert evaluations gathered through the survey. Each CRM was assessed for its cost-saving potential in both 2030 and 2050. As experts were free to assign CRMs to the phase they believed most appropriate, the resulting reductions may be distributed differently than initially defined. The overview below reflects the aggregated outcomes of expert judgement per project phase.

The full list of CRMs, including detailed descriptions, is provided in Annex A.

Phase 1: Project Idea

Five CRMs were identified in the project idea phase. Among these, the use of competitive tendering (e.g., auctions) was considered the most effective measure, offering potential savings of approximately 3.51 €/m^2 in 2030 and 5.59 €/m^2 in 2050. This mechanism encourages cost efficiency and lays the foundation for more competitive project execution.

Phase 2: Project Planning

This phase showed a relatively high cost-saving potential, with a total estimated reduction of 11 €/m^2. The most influential measures include:

- Financing improvements (e.g., securing lower interest rates or better risk-sharing): 3.71 €/m^2 in 2030 and 3.77 €/m^2 in 2050.
- Economies of scale through larger project sizes: 2.22 €/m^2 in 2030 and 2.63 €/m^2 in 2050.
- Design optimization for reduced energy losses, material use, and increased yield: 1.66 €/m^2 in 2030 and 1.67 €/m^2 in 2050.

Collectively, standardization of design and early strategic decision-making also play important supporting roles.

Phase 3: Project Preparation

Measures in this phase focus on improving logistical efficiency and project clarity. Key CRMs that individually present cost reductions above 1 €/m^2 include:

- Clear work descriptions,
- Local sourcing of materials and services, and
- Accuracy in execution planning.

Together, these contribute to cost reductions of 4.87 €/m^2 in 2030 and 6.82 €/m^2 in 2050.

Phase 4: Construction

The expert evaluations of this phase show the highest cost-saving potential, with estimated reductions of 15 €/m^2 in 2030 and 30 €/m^2 in 2050. The most impactful CRMs include:

- Prefabrication of modular components: 4.91 €/m^2 (2025) to 9.89 €/m^2 (2050).
- Smart procurement and ensuring compliance with material standards: 4.00 €/m^2 (2030) to 9.34 €/m^2 (2050).
- Process standardization and streamlining: 4.39 €/m^2 (2030) to 8.60 €/m^2 (2050).

Other beneficial measures involve hydraulic design simplification and optimised commissioning strategies.

Phase 5: Operational Expenses

Operational cost (OPEX) savings over the total lifetime of the plant, while smaller in magnitude, are still significant. Total reductions are estimated at 4 €/m² in 2030 and 5 €/m² in 2050. The leading measures include:

- Monitoring systems to ensure fault-free operation.
- Advanced control mechanisms such as predictive control and optimization tools.

Phase 6: Decommissioning

Although relatively limited in scope, this phase still offers potential savings. Life extension strategies, including plant design for reuse or recycling, can reduce decommissioning costs by 1.40 €/m² in 2030 and 1.48 €/m² in 2050, according to the experts.

5.2 Deployment vs. Research

In addition to estimating the cost-reduction potential, experts were asked to indicate whether deployment or research was the primary enabler for each CRM. Note that the indications results presented here are quite approximative, as the assessment approach is rather soft. Results show that deployment accounts for a slight majority of cost reduction potential:

- In 2030, 58% of cost savings (25 €/m²) stem from deployment, with 42% (18 €/m²) driven by research.
- In 2050, this split remains the same, with 38 €/m² (58%) from deployment and 27 €/m² (42%) from research.

Deployment-related gains are linked to broader market adoption, replication of best practices, and increased industrial experience. Research remains essential for unlocking longer-term improvements, such as better materials, system integration strategies, and circularity approaches. The latter being a topic that does not yet have a large number of experts.

However, deployment is the most significant contributor to cost reduction, provided that indeed the uptake of solar thermal district heating is prosperous.

5.3 Reduction of CAPEX

The accumulated survey results show an average CAPEX reduction of 6.5% from 2025 to 2030 and 10.9% by 2050, compared to 2025. Depending on the assumed extreme values, capex reductions range between 5.2%-13.6% (2030) and 5.3%-32.2% (2050), compared to 2025.

Figure 2 shows the CAPEX reduction from 2025 to 2030 and 2050 in absolute terms. Starting from an indicative 2025 value of 416 €/m², established through the expert meetings and general discussions in Task 68. In 2030 and 2050 the average values may drop to 389 €/m² and 370 €/m², respectively. As can be seen from the figures, experts estimate wide ranges around these average estimates.

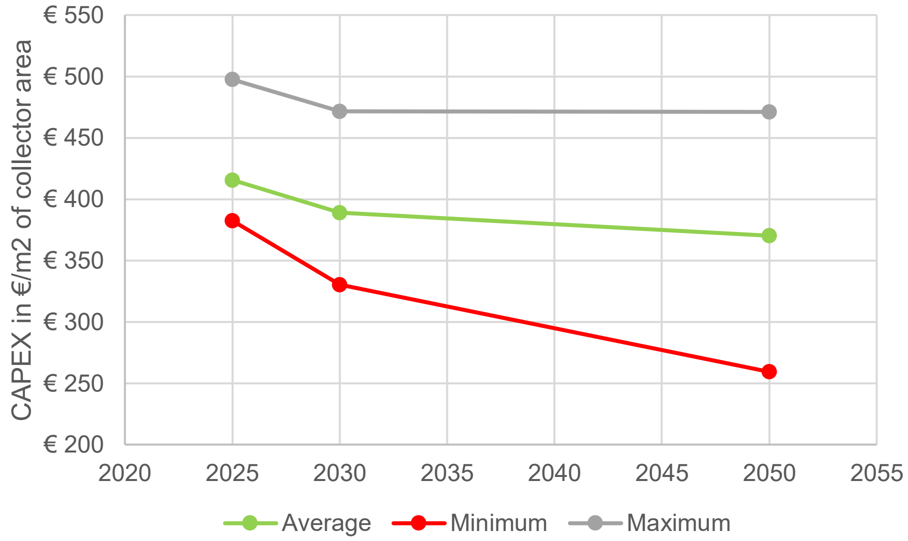

Figure 2 – CAPEX reduction in absolute values summarised. Costs are expressed in €$_{2024}$.

5.4 Reduction of OPEX

The accumulated survey results show an average OPEX reduction of 7.7% from 2025 to 2030 and 9.3% by 2050, compared to 2025.

The OPEX expenses are given as the percentage of the CAPEX per year. Figure 3 shows the OPEX reduction from 2025 to 2030 and 2050 in absolute terms, relative to the CAPEX values presented in the previous section. Assuming a starting value of €4.19 €/m^2/year in 2025, the OPEX may drop to €3.87 €/m^2/year in 2030 and €3.80 €/m^2/year in 2050.

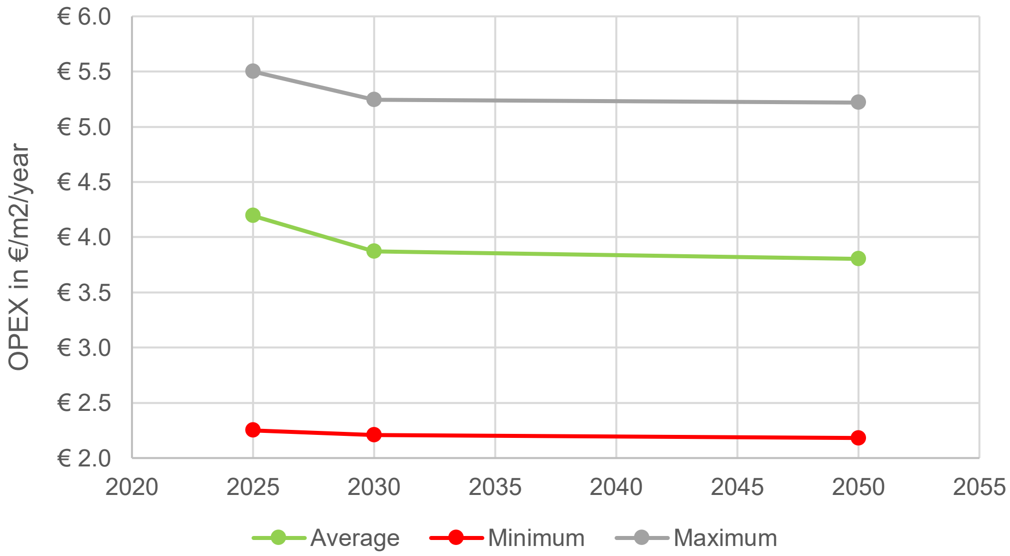

Figure 3 – OPEX reduction estimated in absolute terms, summarised. Costs are expressed in €$_{2024}$.

5.5 Solar thermal yield

Although primarily focused on cost reductions, the analysis also acknowledged interactions between CRMs and solar thermal yield. Some measures not only affect cost but also increase performance and/or yield. In some cases, the experts associated a cost *reduction* to a CRM as well, as often a cost-benefit trade-off is sought to optimise the Levelised Cost of Heat (LCoH).

Figure 4 below shows the change in the absolute annual yield of a solar collector, given all the CRMs. Experts believe the yield to increase with around 7% and approximately 15% in 2030 and 2050, respectively. The maximum cumulative value observed from the expert estimates was as high as 20% in 2030 (the combined yield effects of 24 individual cost reduction measures) and 28% in 2050 (the combined yield effects of 13 individual cost reduction measures). Note that simply adding all yield increase values may overestimate the total, as some effects may be double counted.

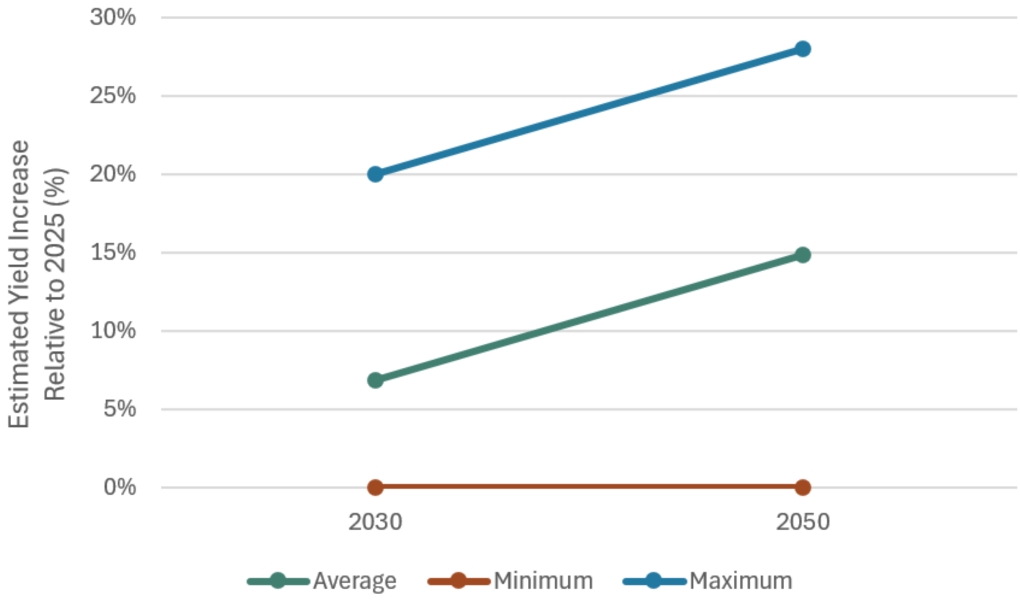

Figure 4 - Estimated Absolute Yield increase Relative to 2025

5.6 Levelised Cost of Heat

By combining the future costs and yields, it becomes possible to see their combined effect in the Levelised Cost of Heat (LCoH). Figure 5 below shows the LCoH for three different (European) locations, interest rates and time horizons.

Starting with Northern Europe, a baseline (2025 and 4% discount rate) of €154/MWh is found. In 2030, it is estimated the LCoH may drop to €134/MWh, possibly reaching €119/MWh in 2050. Depending on the discount rate, the LCoH for the Northern European location in 2050 may vary between €109/MWh and as high as €131/MWh. The LCoH is calculated using the true Total Lifetime Costs (including for example project planning and decommissioning), and the costs for these Northern locations are relatively high because of the relatively low yield. Cost reduction and yield improvement would be very beneficial in the Northern European regions, which is possible according to the expert judgements described in this report. However, the effect of the financing parameters likewise has a significant impact on the LCoH.

For the central European locations, the LCoH has a baseline of €77/MWh, but may be €70/MWh, given a lower discount rate from more beneficial financing. In 2030 and 2050, the LCoH using a 3% discount rate to the LCoH may drop to €67/MWh and €60/MWh, respectively. In absolute terms, the combined effect of estimated cost reductions and yield improvements weigh less in the mid European region, but they are cross-fertilising the situation in Northern Europe.

For a solar plant in a Southern European location, the current baseline for the LCoH is €51/MWh. In 2030 and 2050, this price may drop to €45/MWh and €40/MWh, respectively. In 2050 the observed range due to financing may be €36/MWh to €44/MWh.

Note that the values presented here have been based on the average estimates. As shown in Figures 2 to 4, applying minimum and maximum values may influence the extreme values.

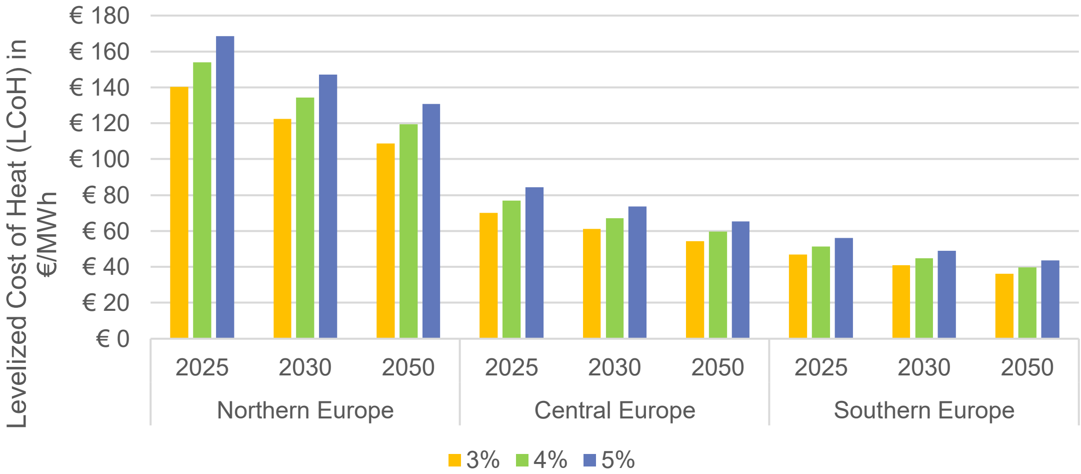

Figure 5 - Levelised Cost of Heat (LCoH) for three different regions in Europe, with varying discount rates (3% to 5%) and a time horizon of 25 years. All bars use the average values of the CAPEX and OPEX estimates, and the yield increases by 7% in 2030 and 15% in 2050. Costs are expressed in €$_{2024}$.

5.7 Correlation between respondents

In order to quantify the reliability of the respondent's cost reduction estimates we calculate the correlation between the various respondents answers for both target years. The result is shown below: R1 to R8 represent the different respondents. For the year 2030 the correlations between the respondents vary between -23% and +47%, with an average correlation of +11%. For the year 2050 the correlations between the respondents vary between -16% and +62%, as well with an average correlation of +11%. This means that the agreement between the respondents is not very high, in other words, the respondents have quite diverging opinions.

Table 5 – Calculated correlations between the series of estimates provided by the eight respondents for both target years in the questionnaire

2030	R1	R2	R3	R4	R5	R6	R7	R8
R1	100%	3%	29%	21%	26%	2%	28%	39%
R2		100%	11%	-2%	7%	0%	-23%	28%
R3			100%	-17%	17%	-5%	47%	26%
R4				100%	45%	13%	-10%	0%
R5					100%	20%	8%	5%
R6						100%	12%	1%
R7							100%	30%
R8								100%

2050	R1	R2	R3	R4	R5	R6	R7	R8
R1	100%	1%	44%	27%	26%	-3%	43%	35%
R2		100%	11%	-3%	7%	0%	-16%	28%
R3			100%	-7%	7%	-5%	42%	7%
R4				100%	62%	19%	-1%	-5%
R5					100%	11%	11%	0%
R6						100%	12%	-3%
R7							100%	6%
R8								100%

6 Conclusion

Solar District Heating (SDH) can supply heat to residences, businesses and industry. Solar thermal heat is a low-carbon technology, that has considerable potential to contribute to an efficient, cost-effective and flexible large-scale heat supply. Typically, solar thermal heat covers 10% to 25% of the annual heat demand without seasonal storage and up to 30% to 50% of annual heat demand with seasonal storage, depending on climate conditions and demand profile.

One of the hurdles SDH is facing is its competitiveness, and consequently its costs. It can be expected that further learning and upscaling of the technology will result in a future cost reductions. In this report an analysis is presented on possible cost reduction mechanisms, in quantitative terms. Based on a starting point around 2025 an extrapolation is made of SDH costs towards 2030 and 2050. The underlying cost reduction assumptions are also explained. All monetary data are expressed in euros of the year 2024 ($€_{2024}$).

To find the cost projection the partners in IEA-SHC Task 68 first made an inventory of 46 cost reduction mechanisms (CRMs), which subsequently were scored by eight solar thermal experts (the expert levels ranged from 'I know little' to 'I know a lot'). In order to come from a qualitative assessment to a quantitative cost reduction various assumptions needed to be made by the experts.

Generally speaking, a slight majority of the anticipated cost reduction is to be expected from deployment: from the questionnaires it follows that 58% of the cost reduction is expected to be driven by further developing new SDH systems. Research-driven cost reduction is expected to be around 42%. Given the soft approach of the assessment, this means that both deployment and research and development are important when cost reduction is to be achieved.

Further, it follows from the questionnaires that a trade-off exists between cost reduction versus an increased yield. This discussion is essential about the aspect of design quality. When cost reduction is carried too far it may affect the quality of the plant, resulting in excessive outages or expensive repairs. After many years of developing SDH systems, one of the strengths of solar thermal design is simplification of installations and integration with district heating systems. Preservation of solar thermal design knowledge and experience is critical to building better, less expensive systems. In order to do this, solar thermal technology needs to continue to be implemented into district heating systems around the world.

Zooming in on the cost reduction mechanisms, the greatest reduction is expected in the construction phase: prefabrication reduces labour and construction time. Additionally, standardisation, smart purchasing and streamlining of processes may contribute significantly. Together with other relevant measures such as simplifying and optimising field hydraulics and better planning of commissioning stages, these can yield a cost reduction in the construction phase of approximately 26.2 €/m² (-7.0%) in 2030 and 44.2 €/m² (-11.9%) in 2050.

In the project planning phase, several early decisions significantly impact cost reduction potential. These include financing, achieving economies of scale, optimising plant layout for energy and material efficiency, and standardisation of design. The total estimated reduction from this phase is approximately 11 €/m² (-2.9%) in 2030 and 13 €/m² (-3.1%) in 2050.

Other phases also contribute meaningfully, albeit with smaller absolute values. In the project idea phase, introducing auctions or tendering procedures can reduce costs by around 3.51 €/m² (-0.9%) in 2030 and 5.59 €/m² (-1.5%) in 2050. In the preparation phase, improvements such as clear work descriptions, local sourcing, and efficient logistics are expected to result in savings of 4.87 €/m² (-1.3%) in 2030 and 6.82 €/m² (-1.8%) in 2050.

Operational expenditures can also be reduced. The most impactful measure is plant monitoring to ensure fault-free operation, followed by control-related optimisations. In total, this phase accounts for a cost reduction of 4 €/m² (-0.8%) in 2030 and 5 €/m² (-1.0%) in 2050.

In the decommissioning phase, extending plant life and optimising for end-of-life processes provide modest savings of 1.40 €/m² (-0.4%) in 2030 and 1.48 €/m² (-0.4%) in 2050.

Table 6 below displays for each of the phases the absolute and relative cost reduction based on the 2025 reference costs. This is – different than the measures discussed above – the effect on the level of the final Capex value and not looking at the measures in each phase. It can be observed that most cost reduction can be achieved in the phase of construction.

Table 6 – Absolute and relative cost reduction relative to the 2025 reference costs, as found for each of the project phases

	Investment cost reduction compared to 2025			
	2030	**relative**	**2050**	**relative**
Project Idea	-€ 0.10	-1.6%	-€ 0.18	-2.8%
Planning	-€ 0.48	-4.2%	-€ 0.64	-7.0%
Project Preparation	-€ 0.93	-5.9%	-€ 1.19	-7.4%
Construction	-€ 26.20	-7.0%	-€ 44.20	-11.9%
Operation over lifetime	-€ 6.36	-7.8%	-€ 7.74	-9.4%
Decomissioning	-€ 0.95	-5.6%	-€ 1.02	-6.8%

To conclude, the key outcomes with the 2025 reference prices, as well as the estimated prices for 2030 and 2050, are presented in Table 7 down below.

Table 7 – Summary of all study results. Percentages in parentheses refer to the difference compared to base year 2025. Figures 2 to 4 in Chapter 5 present the minimum and maximum values following from the expert estimates. The Levelised Cost of Heat (LCoH) values refer to a discount rate of 4% (in [square brackets] the values using discount rates of 3% and 5%). Assumed lifetime is 25 years. All monetary data are in euros of the year 2024 (€$_{2024}$)

Metric	2025 (base year)	2030	2050
CAPEX [€/m²]	€416/m²	€389/m² (-6.5%)	€370/m² (-10.9%)
OPEX [€/m²/year]	€4.19/m²/year	€3.87/m²/year (-7.7%)	€3.80/m²/year (-9.3%)
LCoH [€/MWh]			
Northern Europe	€154 [€140 - €169]	€134 (-13%) [€122 - €147]	€119 (-22%) [€109 - €131]
Central Europe	€77 [€70 - €84]	€67 (-13%) [€61 - €74]	€60 (-22%) [€54 - €65]
Southern Europe	€51 [€47 - €56]	€45 (-13%) [€41 - €49]	€40 (-22%) [€36 - €44]
Yield increase (vs. 2025)	-	+7%	+15%

7 Outlook

The partners in IEA-SHC Task 68 are confident that the documented cost reduction is a reasonable estimate and may prove valuable in discussions on SDH with the target audience. Although, with only eight completed questionnaires, the sample of experts is not large, however, the cumulative knowledge of a wide range of experts has been widely integrated in the cost reduction measures listed in Annex A. In themselves the listing of cost reduction measures may already prove valuable. It may also be useful to repeat the survey to a wider group of experts.

Looking at the cost reduction estimation from a helicopter view one can see that both the estimated reductions in CAPEX and OPEX (each around 10% from 2025 to 2050), together with the expected yield increases (up to 15% from 2025 to 2050) result in considerable reductions in the calculated Levelised Cost of Heat (LCoH): just over 20% reduction at a discount rate of 4% and a lifetime assumption of 25 years. This means that with further deployment and research in solar thermal energy, experts estimate that the technology will autonomously become cheaper.

As a result of external events like rising energy prices, carbon pricing and increased awareness of the security of supply, solar thermal energy may become more and more competitive in the coming years. Still, supporting energy policy may temporarily be needed to overcome current barriers.

8 References

[1]
IEA SHC Task 55, Solar Heat for Cities
https://task55.iea-shc.org/Data/Sites/1/publications/Solar-Heat-for-Cities--The-Sustainable-Solution-for-District-Heating.pdf

[2]
IEA District Heating
https://www.iea.org/energy-system/buildings/district-heating

[3]
Technology Data for Generation of Electricity and District Heating, Danish Energy Agency, 2023,
https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-generation-electricity-and

[4]
Concentrating Solar Power, IRENA, 2012, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-CSP.pdf

[5]
Solar thermal power plants, DLR, 2021
https://www.solarpaces.org/wp-content/uploads/Study_Solar_thermal_power_plants_DLR_2021-05.pdf

[6]
Eurostat, HICP - all items excluding energy, food, alcohol and tobacco,
https://ec.europa.eu/eurostat/databrowser/view/teicp200/default/table?lang=en

[7]
Technological scope and potential cost reductions Early Phase Scale up, Ecorys, 2023, Menno van Benthem, Bram Boereboom, Yoeri Dijkhof, Rogier Eldering, Laura Heidecke
https://open.overheid.nl/documenten/ronl-7f47c24b05ff58a8c4fff5a8c68ac549b1a1fd1a/pdf

Annex A Cost Reduction Mechanisms

Phase Name	No.	Cost Reduction Mechanism (CRM)
Phase 1 (project Idea)	1.1	Ensure a good image and confidence at the client (among others clear communication may ensure the right choices from the start, resulting in lower project costs)
	1.2	Teambuilding: get client, landowner, operator and municipality together at the table and divide the work.
	1.3	Fast response to enquiry of a new project in order to quickly tell client about possibilities (present toolset for feasibility studies in report)
	1.4	Using a tender process as an incentive to reach low costs
	1.5	Realise that future developments in fossil fuel subsidies and true (environmental) pricing may shift the competitiveness of solar thermal district heating, resulting in more competition and lower costs.
Phase 2 (planning)	2.1	Standardisation: re-use project design
	2.2	Understanding demands and requirements of the customer
	2.3	Feasibility study: be fast and accurate, but still do not invest too much work
	2.4	Optimising layout for low energy losses, low material costs, high yield
	2.5	Financing: ensure beneficial financing
	2.6	Taking decisions on the plant construction and operation that are beneficial for the plant lifetime and durability: high quality components at reasonably low costs
	2.7	Find synergies with the rest of the system
	2.8	Make decisions in view of lifetime costs
	2.9	Anticipate to weather conditions and all other hazards during construction. Each delay in the process will result in additional costs
	2.10	Apply economy of scale (aim for large project size), resulting in lower project costs
Phase 3 (project preparation)	3.1	Clearly describe the work to be done (example: instruction film for contractors)
	3.2	Prepare logistics on site (where to store everything, which processes in which order, …)
	3.3	Local sourcing: reduce transportation costs and involve local suppliers (which also may be beneficial in operation phase)
	3.4	Learn from (ground-based) solar pv
	3.5	All machinery should be suited for the local (soil) conditions, else problems may occur (examples to be provided by partners)
	3.6	Save money by doing things right

	3.7	Contractual and policy design: de-risking may be more important than the costs of heat (guaranteed tariffs may be beneficial for client and end-user)
	3.8	Personal safety for all employees is important. Individual safety measures may seem cheaper (single safety rope for a person) but collective measures may be less limiting and obstructing (safety bars)
Phase 4 (construction)	4.1	Ensure that all materials meets standard, buy smart
	4.2	Standardisation, streamline processes
	4.3	Plan commissioning stages, ensuring that plant can be operated partly (concept of minimum viable product)
	4.4	Insurance: do not under-insurance nor over-insurance
	4.5	Prefabrication: modular, prefabricated components for reducing labour and construction time
	4.6	Simplify/optimise field hydraulics
	4.7	Commissioning while building: helps to discover problems sooner
	4.8	Quality check by third party (due diligence) to avoid extra costs because of errors
Phase 5 (operation over lifetime)	5.1	Monitoring: ensuring that plant runs fault-free
	5.2	Standardisation and automatization reduces costs of the operation
	5.3	Optimisation of running the plant
	5.4	Predictive control and plant optimization
	5.5	Load management: estimating heat demand and solar thermal supply
	5.6	Cheaper replacement parts (bigger contracts)
	5.7	Higher quality replacement parts (lower energy consumption, less pressure drop)
	5.8	Lifetime extension strategy
	5.9	Cheaper maintenance activities (cleaning collectors, services to pumps)
	5.10	Quicker maintenance allowing less heat missed during replacement of parts
	5.11	Low energy use for fluid pumping
	5.12	Opt for a long-term maintenance contract (all risk at maintenance provider)
Phase 6 (decommissioning)	6.1	Optimise plant for recycling
	6.2	Understand second-hand component and material market (although residual material value may be minimal)

	6.3	Ensure that a site is dedicated to solar thermal for 50 years, meaning that two generations of solar thermal plants may be built there