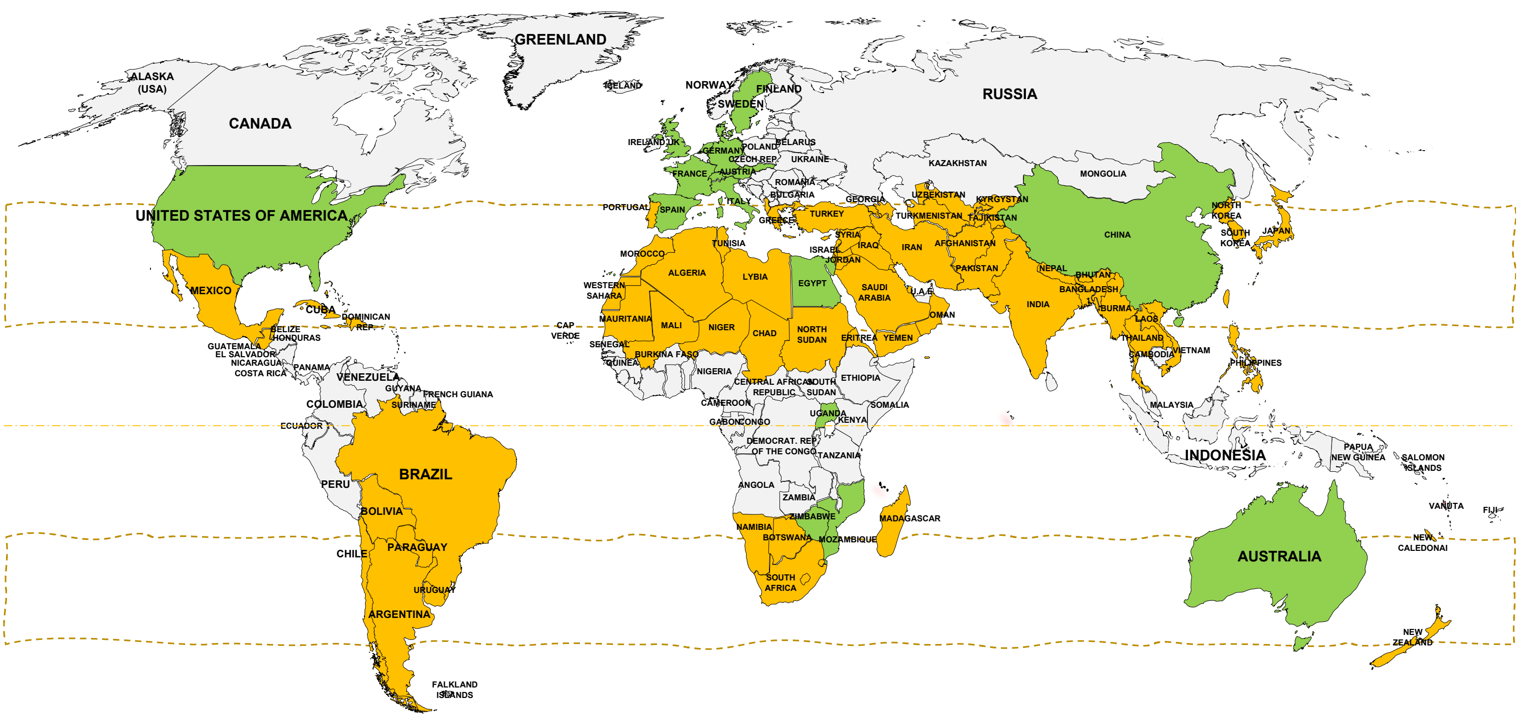
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Technical and Economic Database for Assessment of Solar Cooling



IEA SHC TASK 65 | SOLAR COOLING FOR THE SUNBELT REGIONS

Technology Collaboration Programme
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SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Technical and Economic Database for Assessment of Solar Cooling

This is a report from SHC Task 65: Solar Cooling for the Sunbelt Regions and work performed in Subtask C: Assessment and Tools

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Date 4 July 2024

Report D-C2, DOI: 10.18777/ieashc-task65-2024-0009

Cover photo credit: World map with Sunbelt regions (marked yellow) and the 18 countries of the participating Task 65 experts (marked green), source: Neyer Brainworks & JER

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 *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)
- Solar Cooling (Tasks 25, 38, 48, 53, 65)
- 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)
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- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46, 71)
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In addition to our Task work, other activities of the IEA SHC include our:

- SHC Solar Academy
- *Solar Heat Worldwide*, annual statistics report
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Contents

1 Executive Summary

The goal of the IEA SHC Task 65 “Solar Cooling for the Sunbelt regions” is to focus on innovations for affordable, safe, and reliable Solar Cooling systems for the Sunbelt regions worldwide. Countries located between the 20th and 40th degree latitudes in the Northern and Southern Hemispheres, placed in the Sunbelt, face increasing cooling needs on the one hand and higher solar irradiation on the other a compelling solution.

Assessing solar cooling options requires thorough technical, economic, and financial evaluations at each project stage, utilizing tools that provide key performance indicators (KPIs) considering economic, social, and environmental factors. This assessment is particularly challenging in Sunbelt countries due to varying local conditions, necessitating a comprehensive database for accurate KPIs and a Life Cycle Cost (LCC) analysis to address crucial financial and operational questions. Additionally, reviewing and adapting existing tools, along with sensitivity analyses on critical parameters, is essential for understanding future prospects of solar cooling technologies.

Activity C2 aims to create a comprehensive database of technical and economic data for solar cooling components and Sunbelt countries, supporting extensive assessments and providing insights into future scenarios. This database will establish a solid framework for sensitivity analyses and future scenario planning for solar cooling concepts.

The IEA SHC Task 53 databases form the basis for the economic analysis of solar cooling systems (total system, ST- or PV-based, including all already installed main components). An internal expert survey of Task 65 has shown that the average investment costs per kW cold for different system sizes are:

- 2,100 €/kW for small ST-based or 1,500 €/kW for small PV-based systems (<10 kW),
- 1,600 €/kW for medium ST-based systems or 1,200 €/kW for medium PV-based systems (10-50 kW),
- 1,200 €/kW for large ST-based systems (50-100 kW) and
- 1,000 €/kW for ST-based systems over 500 kW.

These costs are critical for techno-economic analysis and future scenario planning. Economic parameters influencing key performance indicators (KPIs) include economic base data, consumption-based costs, operational costs, and capital costs. The Climate Profiling Tool helps assess local weather conditions for solar cooling potential. Life-Cycle Cost-Benefit Analyses (LCCBA) are used to develop business models and financing solutions, emphasizing dynamic cash flow models. Learning curve models show cost reductions through experience, though their application is limited by data availability for complex solar cooling systems. A detailed economic and financial LCCBA model focuses on dynamic cash flow and KPIs such as internal rate of return (IRR), net present value (NPV), and levelized cost of energy (LCoE). Sensitivity and risk analyses help optimize project outcomes and support financial due diligence. The concept of 'Multiple Benefits of Energy Efficiency' is applied to solar cooling projects to capture additional benefits and drivers.

Future energy prices will be influenced by various factors such as energy supply and demand, technological advances, political and regulatory frameworks, geopolitical developments, and economic trends. Companies can prepare for these uncertainties through methods like sensitivity analysis, scenario analysis, hedging, flexibility in planning, and considering long-term trends and inflation in their profitability calculations.

2 Scope of Activity C2

Activity C2 is focusing on the elaboration of a database and collection of technical (e.g. standard reference systems, etc.) and economic data (energy prices for electricity, natural gas, etc.) for different components (Investment, maintenance, lifetime, etc.) and for the different Sunbelt countries (based on subtask B demo cases) is the bases for the following extensive assessment of the solar cooling concepts.

The data base should also give indications on future scenarios for technical and economic boundaries (e.g. efficiency of conventional chillers, energy prices) to provide the base and a solid framework for the sensitivity analyses and future scenarios.

3 Methodology

The concurrent technical, economic and financial assessment of solar cooling options is of high importance in each stage of the life cycle of a project, starting with a comparison of different technology options and pre-design, detailed planning, optimizing of operation but also for policy design with proven concepts. In all life cycle phases, it is crucial to have corresponding tools that deliver the necessary information and key performance indicators for the various stakeholders. The Key Performance Indicators (KPIs) need to take into consideration economic, financial, social, and environmental issues as well as other 'Multiple co-benefits'. Tools and their specific outputs permit to provide guidance on optimized system design and implementation and show the level of quality of both the most critical components and systems.

Assessing solar cooling along the Sunbelt countries is further challenging due to different local conditions such as energy prices, the investment cost of components, energy conversion factors, greenhouse gas (GHG) emission factors, conventional technical reference systems. A comprehensive database of these technical and economic parameters is crucial to deliver prompt and accurate KPIs. However, besides detailed local results, a set of generalized KPIs should be provided under standardized technical and economic boundaries to allow comparison, general conclusions, and trend analysis across different solar cooling concepts (e.g. PV vs. ST, SE vs DE, etc.).

A thorough technic-economic-financial analysis based on a Life Cycle Cost (LCC) assessment allows answering questions like: (i) Which technical solutions to implement (e.g. higher CAPEX investment in exchange for lower OPEX)? (ii) Influence on cash flows? (iii) Calculation of bids to clients (iv) Effects of equity and debt financing shares? (v) Needs for subsidies/grants? (vi) Which are parameters to monitor? Target-performance comparison? (vii) project reporting and decision making (e.g. to management boards, project stakeholders) (viii) financial engineering for reporting, negotiations & due diligence with Financiers (FI) (ix) subsidy or funding demand calculations (amount and timing) for policymakers … and many more (Bleyl et al., 2019).

Several tools, models, and methods are available, which need to be screened, evaluated, and adapted for solar cooling in Sunbelt countries. A great number of these tools and methods are well known or even developed by previous IEA Task participants. However, taking the targeted countries and the number of new interested participants an iteration for reviewing should be set before getting into the act of adaptation.

Finally, when all questions can be answered satisfactorily with the corresponding tools and KPIs there is a need to show the future perspective of solar cooling. Thus, sensitivity analysis on most critical parameters is of great interest. It is to analyse the potential of future developments of conventional technology, energy prices, and optimization potentials of components/systems of solar cooling. These parameters are e.g. investment costs (solar/conventional), electricity price (energy/capacity), electrical efficiency (solar/conventional), etc.

4 Database

The databases previously used in IEA SHC Task 48/53 form the basis for the elaboration. In addition, a survey was conducted among the task experts during the third expert meeting and data was collected if any analysis of systems was performed (see Activity C4 report).

Main result as from system point of view is the summary of specific investment costs for different sizes per kW cold. The variation of prices is clearly visible and obvious due to variation of system layouts, applications etc. However, the estimated average ST cooling system costs for small scale (<10kW) system are around 2.100 €/kW, medium scale (10-50 kW) around 1.600 €/kW, large scale (50-100kW) around 1.200 €/kW and for larger system (>500kW) around 1.000 €/kW. The result is shown in Figure 1 below.

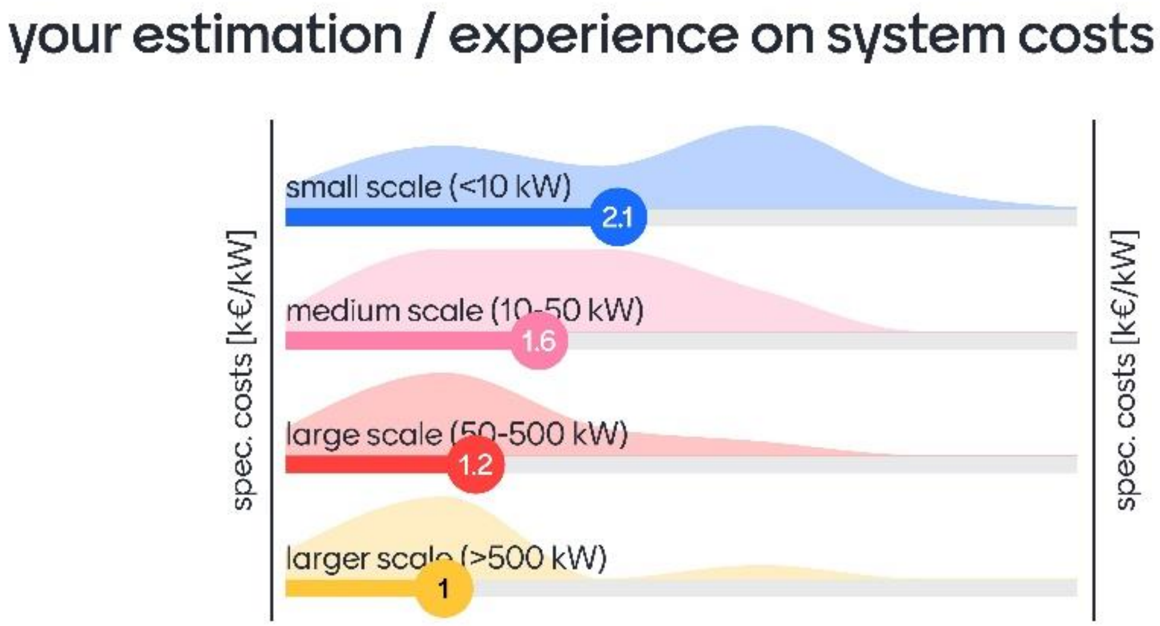

Figure 1: Estimated system costs for small (<10 kW), medium (10–50 kW), large (50–100 kW) and larger (>500 kW) ST cooling systems; elaborated during a Task 65 expert meeting

The estimated average PV cooling system costs for small scale (<10kW) system are around 1,500 €/kW and medium scale system (10-50 kW) around 1,200 €/kW, based on the Task 65 evaluation of average prices for split units (Der Standard, 2023) and costs for installed PV systems (Daniel et al., 2023).

For the techno-economic analysis (see Activity C3 report) the system costs are either result of simplified cost estimations of components (task tool) or are directly input data (e.g. LCCBA tool). However, the investment costs have been the main influencing parameter in economics, thus this value needs to be elaborated with care and should be taken into consideration in any future scenario (sensitivity analyses, etc.).

4.1 Economic Database for Task 65

Parameters that influence the economic KPIs are mainly categorized in

- Economic base data (period, interest rates, etc.)
- Consumption based costs (energy, water, etc.)
- Operational based costs (maintenance, repair, etc.)
- Capital based cost (first investment, residual values, etc.)

All parameters for the economic analyses are defined and collected in the different tools (cp. Activity C3). The formats and details needed vary accordingly.

- Annual vs. monthly
- Constant vs. dynamic

Some, if not most, of these parameters are challenging due to current development and events triggered by force majeure and details could be discussed extensively. However, the aim of these calculations and definitions is to generate reasonable cut-off values. The results present best known averages and will differ from project specific values.

Examples how the values are defined on annual base can be seen in the following two Tables 1 and 2.

Table 1: Examples for needed economic boundary conditions based on annual values

ECONOMICS		TASK 65 Standard
period under consideration	a	25
credit period	a	10
inflation rate	%	3.0
market discount rate	%	3.0
credit interest rate	%	3.0
inflation rate for energy prices electri	%	3.0
inflation rate for energy prices gas	%	3.0
equity ratio	%	0.0
public fundings rate	%	0.0
consumption based prices		**TASK 65 Standard**
electricity consumption	€/kWh	0.1
electricity peak power	€/kW/year	80
gas consumption	€/kWh	0.05
gas annual fix	€/year	70
water consumption	€/m3	2.5

Table 2: Examples of capital (investment, life time) and operational (maintenance & service) based values for main components of a solar heating and cooling system

	TASK 65 Standard			
	Investment depending on SIZE!		lifetime a	Maintanance & Service (% of invest) %
Solar Collector (Evacuated Tube)	100 m²	399.5 €/m²	18	1.5
Auxilieries (pumps, pipes,..)	100 m²	223.0 €/m²	20	2.5
Natural Gas	100 kW	15.8 €/kW	15	3.5
Heatpump (reversible)	50 kW	388.7 €/kW	18	2.5
air cooled VCC	40 kW	415.4 €/kW	15	3.5
Absorption chiller - SE	35 kW	787.1 €/kW	18	3
Cooling Tower (wet)	80 kW	3345.4 €/kW	20	3.5
hot storage	5 m³	1593.0 €/m³	20	2
cold storage	2 m³	1429.1 €/m³	20	2

The following tables summarize the economic inputs values used in the IEA Task tool, all values can be changed during the entire calculation of a specific project. However, if systems should be compared in general only a set of common agreed average values brings comparability.

4.1.1 Economics

The basic economic parameters mainly influence the discounting and annualizing of all cost categories.

Table 3: Economic input values

Economics	Unit	Abbr.	T65 - Standard
Period under consideration	a	N	25
Credit period	a	NL	10
Inflation rate	%	i	2
Market discount rate	%	d	2
Credit interest rate	%	m	3
Inflation rate for energy prices electricity	%	iee	3
Inflation rate for energy prices	%	ieg	3
Fraction of initial investment without financing	%	fL	0
Public funding's rate	%	p	0

4.1.2 Consumption Based Prices for Electricity, Energy Carrier and Water

Table 4: Consumption based input values

Electricity	Unit	Abbr.	T65- Standard
Electricity consumption	€/kWh	$C_{el.c}$	0.10
Electricity peak power	€/(kW.a)	C_{Pel}	80.0
Feed-in tariff for CHP (only 15 years)	€/kWh	C_{CHP}	0.03
Tariff duration for CHP	a	C_{CHP_a}	15.0
Feed-in tariff for PV (only 13 years)	€/kWh	C_{PV}	0.03
Tariff duration for PV	a	C_{PV_a}	13.0
Feed-in without subsidies	€/kWh	$C_{feed\text{-}in\ w/o\ sub}$	0.03
Energy carrier			
Natural gas consumption	€/kWh	$C_{gas.c}$	0.05
Natural gas annual fix	€/a	$C_{gas.a}$	70.0
Biogas consumption	€/kWh	$C_{biogas.c}$	0.07
Biogas annual fix	€/a	$C_{biogas.a}$	170.93
Pellets consumption	€/kWh	$C_{pellets.c}$	0.05
Pellets annual	€/a	$C_{pellets.a}$	40.0
Oil consumption	€/kWh	$C_{oil.c}$	0.06
Oil annual	€/a	$C_{oil.a}$	167.0
District heating consumption	€/kWh	$C_{DH.c}$	0.07
District heating annual	€/a	$C_{DH.a}$	0.00
District cooling consumption	€/kWh	$C_{DC.c}$	0.10
District cooling annual	€/a	$C_{DC.a}$	0.00
Feed-in tariff for district heating	€/kWh	C_{fiT_DH}	0.04
Feed-in tariff for district cooling	€/kWh	C_{fiT_DC}	0.06
Water consumption			
Water consumption	€/m^3	$C_{WA.c}$	2.50

4.1.3 Investment-material & Installation

The following equations are used to calculate the economy of scale for the different components. Exemplarily, first equation shows the determination of the economy of scale for a flat plate collector and second equation is used for the determination referring to heat rejection.

$$C_{xx} = \mathrm{d} + c * \mathrm{CAP}^{e_{FPC}}$$

$$C_{xx} = c * \mathrm{CAP} + e_{HR}$$

Each category considers the primary and secondary device. The abbreviations are listed in the following Table 5.

Table 5: Abbreviations investment costs

Abbr.	Description	Unit
d	Minimal price per component	€/unit
c	Cost for first unit and capacity	€/unit.capacity, e.g. €/m²
e	Decreasing coefficient	-
CAP	Capacity	e.g. m², kW, etc.
	lifetime	a
$\%_{main.comp}$	Maintenance per component	-

Table 6: Example input values for cost calculation

Collectors	CAP	Abbr.	d	c	e	lifetime	$\%_{main.comp}$
Flat plate collector (FPC)	A_{SC}	C_{sol/m^2}	210	400	-0.50	20	0.02
Evacuated tube (ETC)	A_{SC}		230	740	-0.32	18	0.02
Solar auxiliaries FPC	A_{SC}	C_{sol_aux/m^2}	-	815	-0.36	20	0.03
Solar auxiliaries ETC	A_{SC}		-	5500	-0.70	20	0.03
PV panel	A_{PV}	$C_{sol/kWp}$	-	1830	-0.07	20	0.02
Auxiliary heating systems							
Natural gas boiler	P_H	$C_{aux.H/kW}$	-	600	-0.29	15	0.04
Condensing boiler			-	357.93	-0.39	20	0.03
Oil Boiler			-	4287.5	-0.98	12	0.12
Electric heater			-	154.8	-0.67	20	0.03
Pellets			-	2231.0	-0.49	15	0.03
Heat pump			-	380.11	-0.18	18	0.03
Reversible HP			-	2173.3	-0.44	18	0.03
Absorption heat pump			-	3700.0	-0.45	18	0.03
Adsorption heat pump			-	3700.0	-0.45	18	0.03
CHP			-	15648.0	-0.54	15	0.08
District heating			-	297.79	-0.16	30	0.03
Solar cold production							
Absorption chiller SE	P_C	$C_{aux.C/kW}$	-	3700	-0.45	18	0.03
Absorption chiller DE			-	4300	-0.46	18	0.03
Adsorption Chiller			-	3700	-0.45	18	0.03
District Cooling			-	297.79	-0.16	30	0.03
Heat rejection							
Cooling tower – wet	P_{CT}	C_{CT}	-	21.19	1649.4	15	0.04
Cooling tower – dry			-	46.76	2628.6	20	0.02
Cooling tower – hybrid			-	593.53	593.53	15	0.03
Hot/Cold tank							
Hot tank	$V_{HS/CS}$	C_{store/m^3}	-	2500.0	-0.28	20	0.02
Cold tank			-	2135.0	-0.30	20	0.02
Battery	BS	$C_{store/kW}$	-	393.26	-0.29	10	0.02

Vapor compression chillers							
Water cooled VCC < 250 kW	P_C	$C_{aux.C/kW}$	-	3096.0	-0.51	15	0.04
Water cooled VCC > 250 kW			-	6543.5	-0.534	15	0.04
Air cooled VCC < 250 kW			-	1258	-0.30	15	0.04
Air cooled VCC > 250 kW			-	1530.9	-0.258	15	0.04

4.1.4 Other costs

Table 7: Example input values other costs

		Abbr.	**SHC**	**REF**
Auxiliaries heating	% of boiler		0.50	0.50
Auxiliaries cooling	% of chiller		0.50	0.50
Control, electricity and monitoring	% of Material	$\%_{cem}$	0.10	0.07
	Sum equals the total material costs			
Design, planning and commissioning	% of total Material	$\%_{dpc}$	0.20	0.15
General costs associated to works	% of total Material	$\%_{work}$	0.30	0.30
Indirect costs and industrial benefits	% of total Material	$\%_{ben}$	0.05	0.05

4.2 Technical & Environmental Database for Task 65

In the technical data base efficiencies, environmental conversation factors, etc. are collected. The main components listed are:

- Solar sources:
  - Flat plate collector
  - Evacuated tube collector
  - Photovoltaic
- Heat sources:
  - Natural gas
  - Combined heat and power
  - Heat pump and reversible heat pump
  - Absorption heat pump and reversible absorption heat pump
  - District heating
  - Natural gas boiler
  - Condensing natural gas boiler
  - Electrical heater
  - Oil boiler
  - Pellet boiler
- Cold source:
  - Air- or water-cooled vapor compression chiller
  - Single effect absorption chiller
  - Double effect absorption chiller
  - Adsorption chiller
  - District cooling
- Heat rejection:
  - Wet cooling tower
  - Dry cooling tower
  - Hybrid cooling tower
- Storage:
  - Hot water storage
  - Cold water storage
  - Battery storage

These components can be used as reference system or as part of the solar heating and cooling system. An example of annual vs. monthly efficiency and conversions factors can be seen in the Table 8 below.

Table 8: Technical and environmental conversation factors for natural gas and electricity on annual and if available (here Austria) as monthly value

		TASK 65 Standard			AUSTRIA		
	unit	efficiency of the boiler [-]	(non renewable) primary energy factor kWhuse/kWhPE	CO2 factors kgCO2/kWhPE	efficiency of the boiler [-]	(non renewable) primary energy factor kWhuse/kWhPE	CO2 factors kgCO2/kWhPE
natural gas	year	0.9	0.9	0.26	0.88	0.86	0.24
	january	0.93					
	feburary	0.92					
	march	0.9					
	april	0.89					
	may	0.82					
	june	0.81					
	july	0.81					
	august	0.81					
	september	0.82					
	oktober	0.91					
	november	0.92					
	december	0.93					
Electricity	year	n.a	0.4	0.55	n.a	0.55	0.55
	jannuary	n.a			n.a	0.53	0.18
	feburary	n.a			n.a	0.54	0.16
	march	n.a			n.a	0.58	0.12
	april	n.a			n.a	0.61	0.09
	may	n.a			n.a	0.63	0.06
	june	n.a			n.a	0.64	0.05
	july	n.a			n.a	0.64	0.05
	august	n.a			n.a	0.64	0.05
	september	n.a			n.a	0.61	0.09
	oktober	n.a			n.a	0.57	0.15
	november	n.a			n.a	0.56	0.15
	december	n.a			n.a	0.54	0.16

The first subsection cooling includes (seasonal) energy efficiency ratio (SEER/EER) for the reference vapor compression chiller (VCC). The EERs are depending on the nominal capacity and its underlying standard compressor technology (e.g. on/off screw for small scale, controlled turbo for large scale, etc.). The capacity is subdivided in two groups: 5 to 250 kW and 250 to 1,000 kW. The values are provided for air and water cooled VCCs. In the group5 to 250 kW the EER_{ref} and the $ESEER_{ref}$ for district cooling are defined with 2.8 and 6.0 for capacities exceeding 250 kW respectively (Figure 2).

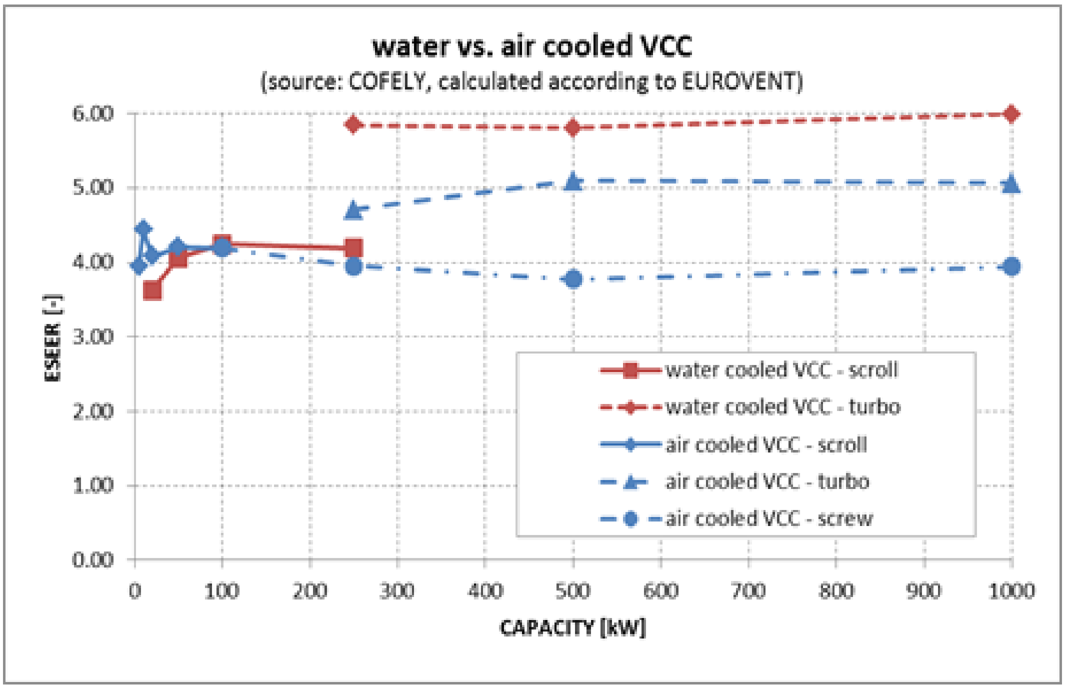

Figure 2: Reference efficiency for air/water cooled vapour compression chillers

More details are defined in the respective Tool documentations.

4.3 Learning Curve Models for Cost Development

Learning curve models are used to estimate how costs decrease as a result of cumulative experience gained over time. These models are based on the premise that as more units of a product are produced or more services are delivered, the cost per unit decreases due to factors such as improved efficiency, economies of scale, process optimization, and learning effects (Castrejon-Campos et al., 2022).

The two common types of learning curve models are:

- Cumulative Average Model: In this model, it is assumed that the average time or cost per unit decreases by a constant percentage each time cumulative production doubles.
- Time-Based Learning Model (also known as Experience Curve Model): This model assumes that the time or cost per unit decreases by a constant percentage each time the cumulative production doubles.

The amount of data needed for learning curve models depends on the complexity of the process, the variability in the data, and the desired level of accuracy. In general, more data points allow for a more accurate estimation of the learning curve effect. However, a rough rule of thumb is that at least 10 data points are needed to start fitting a learning curve model, and more data points can improve the accuracy of the model.

It's important to note that learning curve models are best applied in situations where there is a significant learning effect present, such as in manufacturing industries or service delivery where repetition and experience play a role in cost reduction. Additionally, the assumptions underlying learning curve models should be carefully considered to ensure that they are appropriate for the specific context in which they are being applied.

When using learning curve models, it's also essential to regularly validate the model against actual data and adjust it as needed to account for any unforeseen factors that may affect cost development.

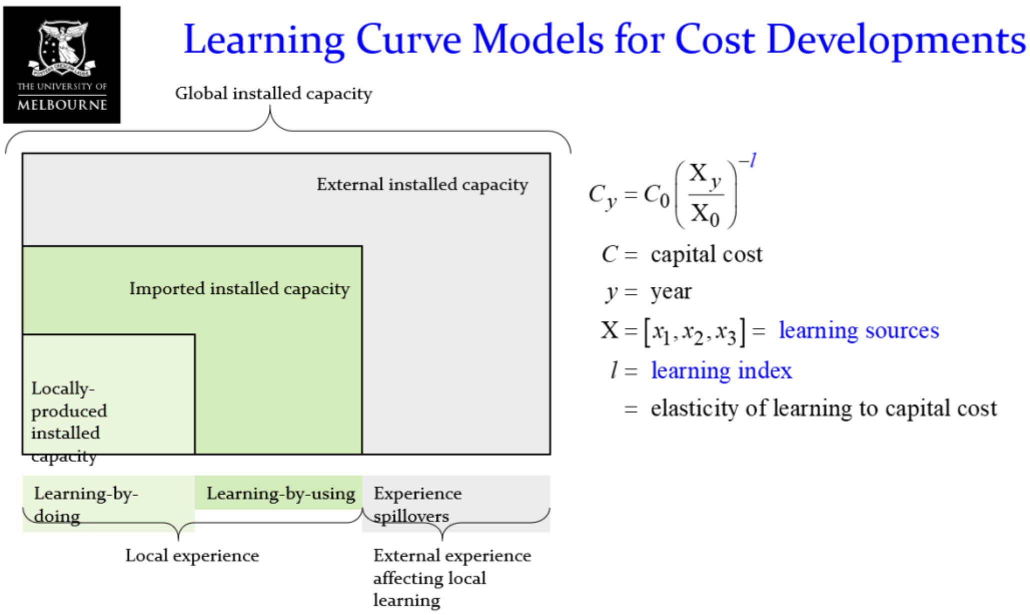

Figure 3: Modelling future system costs for solar cooling

The learning curve model could be applied to a certain typology of solar heating and cooling system. E.g. PV driven split units, the less complex, the better comparable and precise the prediction and results. However due to complexity, especially in thermal driven systems, not sufficient data could be collected in Task 65. Only few systems were analyzed with different applications and layouts. The knowledge on how to collect and how to calculate is evident through this activity. However, the application of the model including results presentation is not possible. If sufficient data is available the model could be applied in a follow up task/activity or in specific system configuration through manufacturer.

4.4 Climate Profiling Tool

This free tool for assessing local climate and weather conditions (https://profiler.purix.com/Chart) for adoption of solar cooling technology is provided by Purix. Powered by weather data from the most recent calendar years, the tool makes a comprehensive amount of valuable data available at a fingertip, collected from thousands of weather stations across the globe.

Guidance of tool usage:

- Select a location of interest from the interactive map, or from the dropdown menu of countries and available weather stations.
- Based on your prior knowledge or behavior of a specific building the location selected, select the desired threshold outdoor temperature at which cooling is required.
- Based on your selections, the Profiling Tool visualizes the number of hours per months, which requires cooling of the building, sorted by cooling during night hours, hours during the day with or without solar radiation.
- The Profiling Tool also features an illustration of the outdoor temperature and relative humidity distribution curve at the selected location for the latest calendar year (descended order).
- As a courtesy to visitors, the complete climate profile data is available for download, enabling access to historical weather data for more detailed building energy performance evaluations.

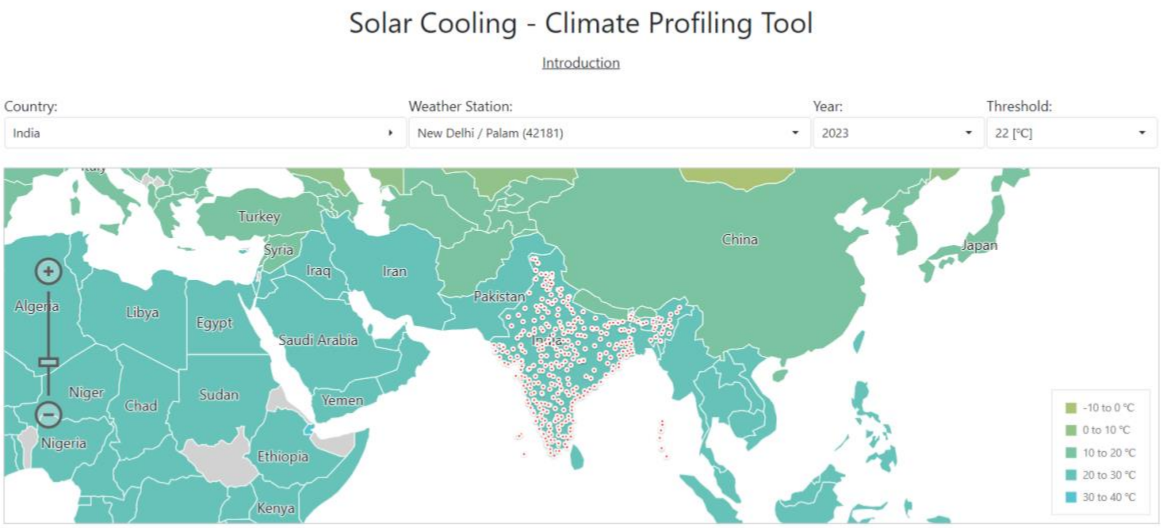

Figure 4: Climate Profiling Tool: selection of location

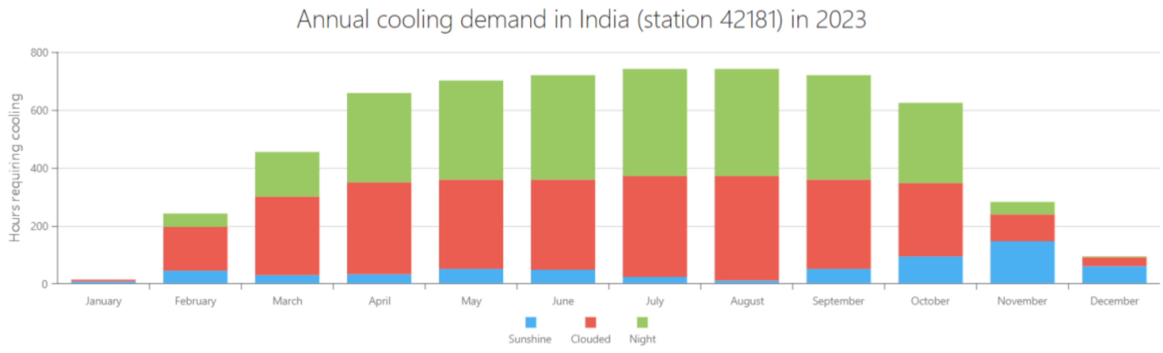

Figure 5: Climate Profiling Tool: monthly cooling hours according to the set threshold (22°C) value for the selected location (New Delhi / Palam)

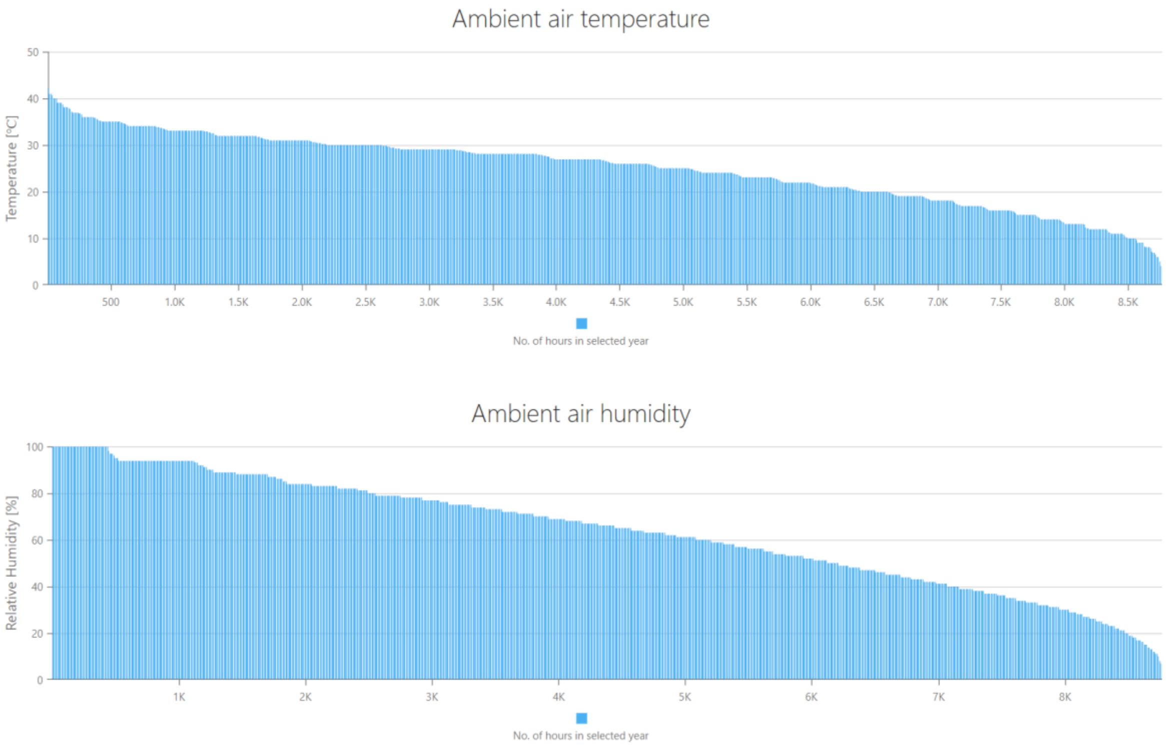

Figure 6: Climate Profiling Tool: sorted ambient air temperature and humidity for the selected location

4.5 Investment Calculations Based on Life-Cycle-Cost-Benefit Analyses (LCCBA)

Solar cooling solutions typically require high upfront capital expenditures. They may also be perceived as risky by potential clients due to their complexity or unfamiliarity with solar cooling technologies. These and other non-technical barriers underscore the importance of developing client- and service-oriented solar cooling solutions for greater market penetration – in particular in the Sunbelt regions.

The development and implementation of business cases (BC) and models (BM) and financing solutions for solar cooling solutions requires sufficiently detailed economic and financial modeling tools and capacities. Basically, assessments need to be based on dynamic cash flow models. Profit and loss accounting or 'engineering economics'-type assessments (such as economic comparison of investment alternatives based on VDI 2067 or Ö-Norm 7140 or the like) are not suitable or sufficient to satisfy 'financial engineering' or due diligence process or requirements.

In order to justify higher up-front investments, a thorough understanding of the economic and financial implications of SBC project cash flows (CF) are needed as a basis for further discussion and strategy development with relevant stakeholders. Likewise, it is important to communicate and present investment opportunities in a business language that potential investors are familiar with. Technical performance parameters of energy efficiency (EE) measures, or static economic analysis, are less meaningful and unlikely to attract interest and understanding from financial decision makers. Therefore, this requires a dynamic CF modeling, and economic and financial key performance indicators (KPI) including sensitivity and risk analysis. The goal of the first part of the paper is to shed light on these questions (Bleyl et al., 2019).

In conclusion, investment calculations based on a Life-Cycle Cost-Benefit Analyses (LCCBA) are needed to support BM development and financing solutions (see D2 report 'Business Models and Financing Options for Solar Cooling')**.**

Model description: The economic and financial Life Cycle Cost Benefit Analysis (LCCBA) is built on a dynamic cash flow model of the solar cooling business case, with a focus on the perspectives of potential investors and financing institutions. For this purpose, the projected income and expense CFs are modeled over an entire project cycle of 25 years, with the degree of detail of a pre-feasibility study. Economic KPIs are the internal rate of return (IRR), the net present value (NPV) and a dynamic amortization period, separately for the project (P-CF) and the equity cash flow (E-CF). Furthermore, the 'Levelized Cost of Energy' (LCoE) (IEA/NEA 2015) concept is applied to calculate levelized cost of energy savings as a simple comparison Indicator to different energy supply and savings variants. On the financing side, the influence of typical debt ratios of 70% on the remaining equity CF, as well as liquidity, is examined using the financial KPIs 'Cash Flow Available for Debt Service' (CFADS) and the 'Loan Life Coverage Ratio' (LLCR).

The analysis also includes a multi-parameter sensitivity analysis of the IRR and NPV with respect to deviations of relevant input parameters, e.g. CAPEX, OPEX, price development of the energy cost baseline, and project duration, and to determine threshold values for BM contributions. Throughout the paper, all monetary figures exclude value added tax (VAT), and tax effects are not considered.

Overview of input data needed for LCCBA:

All project types:

- **Project story outline** *(if possible a picture to illustrate the project)*
- **Project schedule**: Start, project duration, construction time *(until supply begins)*
- **Life cycle cost** of measures: CAPEX, variable and fix OPEX
- **Financing**: Interest rates; equity & debt shares; subsidies

For Energy Efficiency / Savings projects:

- **Baseline data**: energy & prices *(in MWh & price/MWh, maintenance cost ...)*
- **EE-measures and related savings** *(in % of baseline or in MWh)*

For Renewable / Supply projects:

- **Cooling supply**: energy & prices *(in MWh & price/MWh, e.g. feed-in tarif)*
- **Technical performance data** of equipment *(kW, annual full load operating hours), COP ...)*
- **Energy purchase cost**: Electricity, fuels, biomass *(in price/MWh, price/kW ...)*

<u>Sample Outcomes of the LCCBA:</u>

Table 9: LCCBA Summary and KPIs addationl cas hybrid vs. VCC system (Source: Energetic Solutions)

		project cash-flow	equity cash-flow
project duration	years	15	
total investment	USD	49,702	
invested equity	USD	-	14,911
invested debt capital	USD	-	34,792
interest rate for discounting	%	7.9% (WACC)	10% (equity interest rate)
net present value	USD	17,325	13,180
internal rate of return (IRR)	%	13.0%	18.5%
payback period (dynamic)	years	6.9	7.1
Loan Life Cover Ratio	-	1.9	-

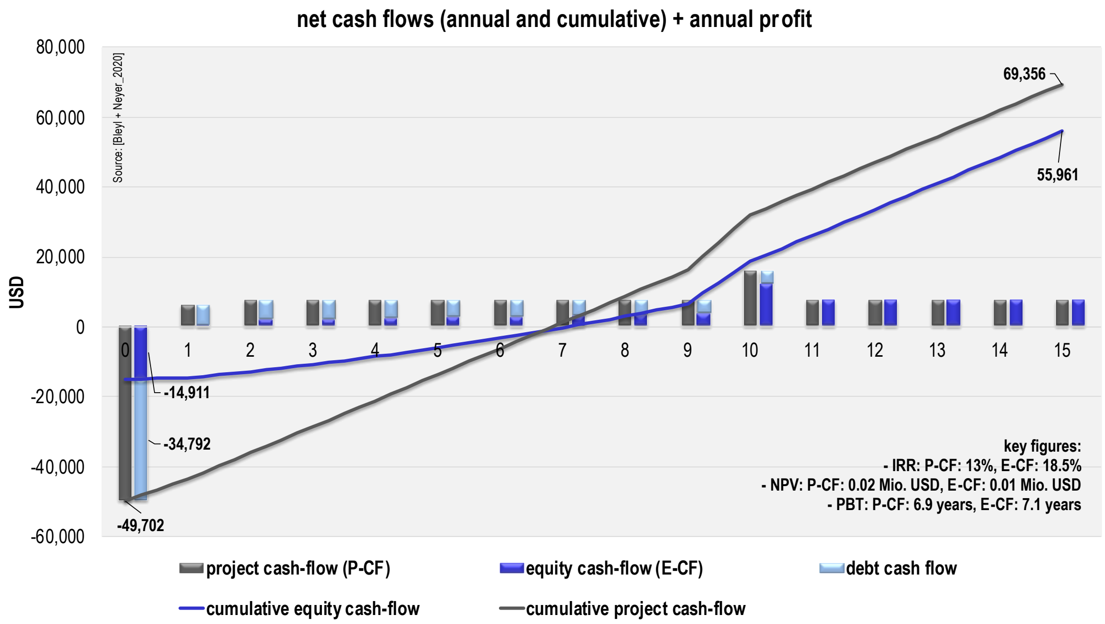

Figure 7: LCCBA project-, equity- and debt cash flows (Source: Energetic Solutions)

Table 10: LCCBA cash flow table (Source: Energetic Solutions)

Cash flow and liquidity prognosis	unit	cumulative	average (mean)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
investment																			
equity capital	USD	14,911	-	14,911	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
investment costs	USD	49,702	-	49,702	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
subsidies/construction cost grants	USD	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
loan disbursement	USD	34,792	-	34,792	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
interest + principal payment (debt capital)	**USD**	**48,186**	**3,195**	**0**	**5,915**	**5,671**	**5,427**	**5,184**	**4,940**	**4,697**	**4,453**	**4,210**	**3,966**	**3,723**	**0**	**0**	**0**	**0**	**0**
loan repayment	USD	34,792	2,307	0	3,479	3,479	3,479	3,479	3,479	3,479	3,479	3,479	3,479	3,479	0	0	0	0	0
interest on debt capital	USD	13,395	888	0	2,435	2,192	1,948	1,705	1,461	1,218	974	731	487	244	0	0	0	0	0
sum of sales revenues from regular operation	**USD**	**127,567**	**8,457**	**0**	**7,167**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**	**8,600**
Electricity cost savings	USD	127,567	8,457	0	7,167	8,600	8,600	8,600	8,600	8,600	8,600	8,600	8,600	8,600	8,600	8,600	8,600	8,600	8,600
Others	USD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
sum of costs from regular operation	**USD**	**8,509**	**564**	**0**	**946**	**1,135**	**1,135**	**1,135**	**1,135**	**1,135**	**1,135**	**1,135**	**1,135**	**-7,198**	**1,135**	**1,135**	**1,135**	**1,135**	**1,135**
budget for operation and maintenance	USD	16,842	1,117	0	946	1,135	1,135	1,135	1,135	1,135	1,135	1,135	1,135	1,135	1,135	1,135	1,135	1,135	1,135
budget for replacement cost	USD	-8,333	-552	0	0	0	0	0	0	0	0	0	0	-8,333	0	0	0	0	0
project cash-flow (P-CF)	**USD**	**69,356**	**4,598**	**-49,702**	**6,220**	**7,465**	**7,465**	**7,465**	**7,465**	**7,465**	**7,465**	**7,465**	**7,465**	**15,798**	**7,465**	**7,465**	**7,465**	**7,465**	**7,465**
equity cash-flow (E-CF)	**USD**	**55,961**	**3,710**	**-14,911**	**306**	**1,794**	**2,037**	**2,281**	**2,524**	**2,768**	**3,011**	**3,255**	**3,498**	**12,075**	**7,465**	**7,465**	**7,465**	**7,465**	**7,465**
Cash Flow Available for Debt Service	USD	119,058	7,893	0	6,220	7,465	7,465	7,465	7,465	7,465	7,465	7,465	7,465	15,798	7,465	7,465	7,465	7,465	7,465
Debt Service Coverage Ratio	-	-	-	**0.0**	**1.1**	**1.3**	**1.4**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**4.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

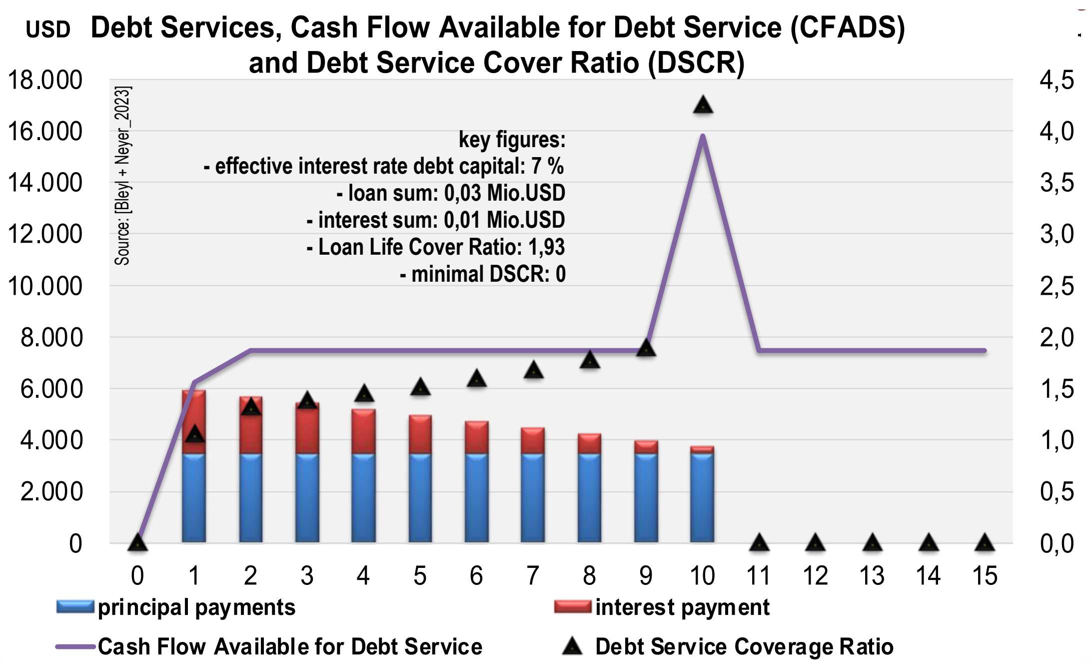

Figure 8: LCCBA financing incl. debt service, CFADS & DSCR (Source: Energetic Solutions)

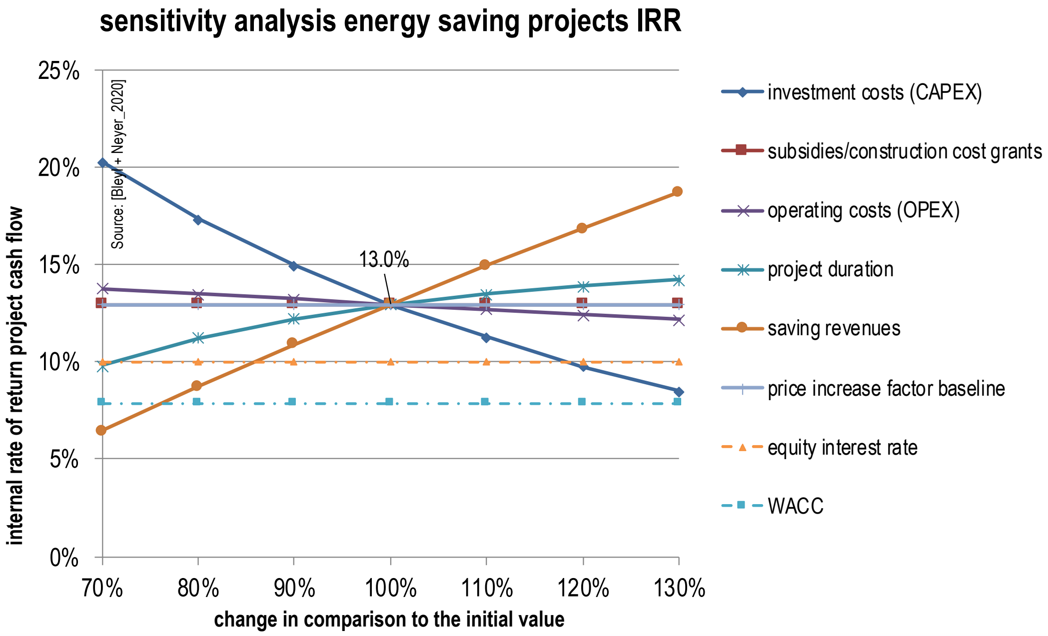

Figure 9: LCCBA sensitivity analyses: project IIR = f(input data ±30%) (Sources: Energetic Solutions)

Through these results the following high-level overview of possible applications and tasks in the realm of solar cooling systems that dynamic LCCBA models can support:

1. Develop a tailored **solar cooling strategy** focusing on economic, financial, and environmental targets and measures specific to a company or country.
    a. Conduct **pre-feasibility and feasibility assessments for projects**:
    b. Evaluate **economic viability** using key performance indicators (KPIs) such as IRR, NPV, and dynamic payback period.
    c. Assess **financial viability** using KPIs like CFADS and DSCR, and implement financial engineering strategies for feasible financing and optimization.
    d. Calculate the **generation cost** of solar cooling facilities and determine Levelized Cost of Cooling (LCoC) or savings (LCoS) in EUR/MWh produced or saved.
    e. Evaluate different variants, scenarios, and sensitivities to optimize project outcomes.
2. Develop **business models and value propositions for Energy Service Companies** (ESCOs) and perform cost and price calculations for service offerings.
3. Provide support for **financial due diligence processes** during project evaluation.
4. Perform **risk assessments** including scenario analysis, 'What-if' scenarios, and quantification of risks.
5. Offer **management and planning support** for solar cooling projects or programs.
6. Assist in **contract negotiations** with clients and suppliers, including calculation of negotiation targets and scope.
7. Prepare **project documentation** for decision-makers, financial institutions, and other stakeholders to demonstrate project bankability and achievements.
8. Conduct **policy assessments** related to solar cooling initiatives and projects.

Given the long payback time of most Solar cooling cases, the economic rationale often cannot be justified by CF from future energy cost savings alone, nor could these CFs convince potential investors. By applying the concept of the 'Multiple Benefits of Energy Efficiency' (IEA 2019) to Solar Cooling projects or programs, we are attempting to capture additional benefits, revenues, and drivers on the microeconomic level.

5 Future Scenarios

Current price fluctuations in energy prices can be taken into account in profitability calculations in various ways. Here are some methods that can help:

- Sensitivity analysis: Perform a sensitivity analysis to see how changes in energy prices affect the economics of your project. Vary energy prices up and down by certain percentages and analyse the impact on profitability.
- Scenario analysis: Create different scenarios with different energy price developments (e.g. baseline scenario, optimistic scenario, pessimistic scenario) and analyse the financial impact of each scenario. This helps to understand the range of possible outcomes.
- Hedging: In some cases, companies can reduce energy price volatility by entering into contracts to hedge energy prices. This can help to limit price fluctuations and improve planning certainty.
- Flexibility and adaptation: Build flexibility into your planning to respond to changing energy prices. This may mean using contract clauses that allow for price adjustments or considering the possibility of switching to alternative energy sources.
- Consideration of inflation and long-term trends: When forecasting energy prices for profitability calculations, it is important to consider long-term trends and the rate of inflation. This can help to make more realistic assumptions about future prices.

By factoring price fluctuations in energy prices into profitability calculations, companies can be better prepared for risks and make informed decisions to maximize the profitability of their projects. Future energy prices are difficult to predict and depend on a variety of factors, including geopolitical developments, technological advancements, market conditions, policy decisions, and global economic trends. Here are some scenarios that are often considered:

1. Reference Scenario (Business-as-Usual)
   - Description: This scenario assumes that current trends continue without significant changes in policy or technological frameworks.
   - Expectations: Moderate increases in energy prices due to rising demand and limited fossil fuel resources.

2. Technology Scenario
   - Description: Rapid advancement in renewable energy and storage technologies.
   - Expectations: Lower energy prices due to decreasing costs for solar and wind energy as well as improvements in energy storage and efficiency.

3. Policy Scenario
   - Description: Strict political measures to reduce CO_2 emissions, such as carbon taxes or subsidies for renewable energy.
   - Expectations: Fluctuating prices. Fossil fuels may become more expensive, while renewable energy becomes cheaper.

4. Crisis Scenario
   - Description: Geopolitical tensions, natural disasters, or unexpected market disruptions.
   - Expectations: Strong price fluctuations and potentially high prices for fossil fuels due to supply shortages.

5. Sustainability Scenario
   - Description: Global shift towards sustainable practices and green energy.
   - Expectations: Long-term stability and potentially lower prices due to a diversified energy supply and sustainable practices.
   - Factors Influencing Future Energy Prices:
   - Supply and Demand: Changes in global energy demand and the supply of fossil fuels and renewable energy.
   - Technological Advances: Innovations in energy generation, storage, and efficiency.
   - Political and Regulatory Frameworks: Laws and regulations affecting energy consumption and production.
   - Geopolitical Developments: Tensions or cooperation between countries that are major energy producers or consumers.
   - Economic Trends: Global and regional economic developments that influence energy consumption and production costs.

Summary

Future energy prices will be determined by a complex interplay of factors, and different scenarios offer various perspectives on possible developments. A comprehensive analysis should consider all these aspects to make informed predictions.

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