IEA SHC Task 49
Solar Process Heat for Production and Advanced Applications

SolarPACES Annex IV

Potential studies on solar process heat worldwide

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1 IEA Solar Heating and Cooling Programme

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. Its mission is *"to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.*

The members of the IEA SHC collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 57 such projects have been initiated, 47 of which have been completed. Research topics include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat or Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45, 55)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42)

In addition to the project work, there are special activities:

- SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- Solar Heat Worldwide – annual statistics publication
- Memorandum of Understanding – working agreement with solar thermal trade organizations
- Workshops and seminars

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2 Introduction

Solar Heat for Industrial Processes (SHIP) is currently at the early stages of development. By the end of 2015, the worldwide SHIP-plant database of IEA Task 49 [1] listed around 160 operating systems with a total capacity of about 100 MW_{th} (140,600 m^2). Many of these systems are of experimental nature, and are relatively small scale. On the other side large plants with several thousand square-meters field size exist. This indicates that there is a great potential for market and technological developments expected, as for example 28 % of the overall energy demand in the EU27 countries originates in the industrial sector, majority of this is heat of below 250 °C.
The potentials of solar process heat worldwide have not been studied in detail. They depend on many parameters and conditions like climate, industrial and service sectors in different countries, energy prices, technological maturity, willingness for innovation, and financial conditions. According to the quite old study Ecoheatcool [2], around 30 % of the total industrial heat demand in Europe is required at temperatures below 100 °C and 57 % of this demand is required at temperatures below 400 °C. The main part of the heat demand below 100 °C could theoretically be met with solar thermal systems using current technologies, if suitable integration of the solar thermal system can be identified. With technological development, more and more medium temperature applications up to 400 °C will also become market feasible.
The POSHIP study of 2001 [3] showed that in several specific industry sectors, such as food, wine and beverages, transport equipment, machinery, textiles, pulp and paper, the share of heat demand at low and medium temperatures (below 250 °C) is around 60 %. Tapping into this potential would provide a significant solar contribution to industrial energy requirements.

The methodology which has been developed in order to realize thermal energy supply in industry with minimal greenhouse gas emissions is based on a three step approach:

- Technological Optimization of the processes (e.g. increased heat and mass transfer, lower the process temperature) and solar thermal system (e.g. operation of solar field, integration schemes, control, safety issues etc.)
- System Optimization (enhancing energy efficiency using e.g. Pinch Analysis for heat exchanger network for a total production site)
- Integration of renewable energy/solar thermal energy (based on exergetic considerations).

In the last two years the awareness for solar process heat in the industry increased and some new solar thermal systems were installed. This positive development should be supported now by further research and development in the key research questions of solar process heat.

As within the Task 49 the resources were not available to perform a worldwide potential study including all the different sectors, studying in more detail temperature levels, process heat demands and solar availability in combination with other restricting factors, we just describe in this document the general methodology and give a listing of available individual recent potential studies.

3 Methodologies for Potential Studies

Potential studies for the use of solar heat for industrial processes (SHIP) were carried out in the past for different countries or regions. A comprehensive study for Spain and Portugal identifies several sectors and processes to be suitable for the use of solar heat [3]. A similar study was performed for Austria [4]. Further potential studies for Victoria (Australia) [5], Italy [6], the Netherlands [7], Sweden [8], and Cyprus [9], partly support the identified sectors, but only identify a few additional ones. Aidonis et al. [10] performed a study for Greece, Wallonia (Belgium) and a few industrial sectors in Germany.
Prior potential studies in the field of solar heat for industrial processes differ significantly regarding their approach to select suitable industrial sectors and processes, and in their way to determine a quantitative potential. In some studies the potential is determined based on the energy and heat

demand of industrial sectors, one uses the available roof area and others calculate the potential on the basis of case studies of selected industrial companies. Generally, it can be distinguished between top-down and a bottom-up approaches.

At a top-down approach, data, e.g., distribution of heat demand or available roof area, for the whole industry is analyzed to select suitable sectors and to calculate a quantitative potential. This approach is followed in the comprehensive potential study for Austria in 2004 [4]. In a first step, the energy demand of the industry in Austria is analyzed and the low (<100 °C) and medium temperature (<250 °C) heat demand is calculated by adding the demand for space heating and steam generation for all industrial sectors. Hot water consumption is not mentioned, which only leads to a minor uncertainty because its share in industry is very low. At first, suitable sectors are selected to determine a theoretical potential. Therefore, sectors with a low heat demand or high waste heat potential are excluded. The sectors of Chemicals, Food and beverages, Rubber and plastics, Textiles and Prefabricated concrete components are selected. Further, the processes of washing, cleaning and surface treatment of metals are mentioned as suitable for the use of solar heat. The low and medium temperature heat demand of the mentioned sectors and processes is defined as the theoretical potential. This theoretical potential is divided in a short-term (<100 °C) and a mid-term (<250 °C) potential because at the time of the study collector technology for process heat generation at temperatures above 100 °C was neither technically mature nor available on the market. The technical potential was calculated by deducting the renewable share of 15 % of the heat supply and further 60 % due to possible efficiency measures and restrictions regarding economic feasibility. In addition, an average solar fraction of 40 % for process heat applications and 20 % for space heating is assumed by the authors. The figures for efficiency measures and solar fraction are not explained in detail.

At a bottom-up approach, selected industrial companies are analyzed and the results are used to determine suitable sectors, as well as a quantitative potential using statistics of the overall industrial heat demand or number and size of companies. This approach is followed in the potential study for Spain and Portugal [3]. The aim of this study was to determine the potential for solar heat at low (<60 °C) and medium (60 to 160 °C) temperatures. In a first step nearly 1700 enterprises were contacted by mail or called. In total 59 answers were received and finally case studies were performed in 34 industrial enterprises in Spain and Portugal. More than half of the enterprises belong to the sector Food and beverages and few case studies were done in Paper (4), Textiles (6), Leather (2), and one each in Cork and Automobile. The temperature distribution of the heat demand of each sector was determined on the basis of these case studies and the share of low and medium temperature heat demand of the whole sector was calculated. A theoretical potential is not clearly defined. The technical potential was determined by estimating the available roof area for each enterprise analyzed, which was the limiting figure in most cases, and assuming a maximum solar fraction of 60 %.

Comparing the two approaches, the advantage of a top-down approach is a coherent distribution of the industrial heat demand, which is the necessary basis to calculate a theoretical potential. This is, however, only true, if the used data can be verified. The calculation of the distribution of the industrial heat demand with a bottom-up approach incorporates, as the above mentioned example shows, a high uncertainty, unless a large number of companies are studied. In order to determine the temperature distribution and a theoretical potential, the top-down approach seems to be the better choice as the feedback to questionnaires is typically very low. Figures for restrictions as e.g. limited roof area, possible priory efficiency measures, as well as a solar fraction are necessary in order to calculate a technical potential. In case of a top-down approach one relies on assumptions for these figures, as the above example shows. Using a bottom-up approach the figures can be estimated with a much better certainty, again only if the number of enterprises studied is high enough. Nevertheless, the results of case studies have to be verified with literature. As the execution of a large number of case studies need high resources, this could be replaced by studying case studies and built examples from literature, possibly combined with a few additional case studies. The choice for one of the described approaches also depends on the availability of data regarding the overall industrial heat demand and its temperature distribution.

4 Available Potential Studies

4.1 General application potential of solar process heat

4.1.1 Procesol, 2002

The Procesol study by Aidonis et al. [10] provides a general guideline for design and maintenance of a solar process heat system. The different aspects limiting the application and influencing the design are mentioned.

4.1.2 Kalogirou, 2003

Kalogirou [9] describes in a Journal paper the potential of solar thermal collector systems for different plants in general terms. The temperature requirements of solar industrial process heat applications range from 60 °C to 260 °C. The characteristics of medium to medium-high temperature solar collectors are given and an overview of efficiency and cost of existing technologies is presented. Five collector types have been considered in the study varying from the simple stationary flat-plate to parabolic trough. Based on TRNSYS simulations, an estimation of the system efficiency of solar process heat plants operating in the Mediterranean climate are given for the different collector technologies. The annual energy gains of such systems are from 550 to 1100 kWh/(m^2a). The resulting energy costs obtained for solar heat in a location on Cyprus are from 0.015 to 0.028 C£/kWh depending on the collector type applied. The viabilities of the systems depend on their initial cost and the fuel price. These costs change continuously depending on international market trends and oil production rates. It is predicted that costs be reduced in the collector market, and fuel subsidies should be removed.

4.2 Potential in certain countries or regions

4.2.1 Portugal and Spain, 2001

Schweiger et al. [3] determined the potential for solar heat at low (< 60 °C) and medium (60 to 160 °C) temperatures for Spain and Portugal. 34 case studies in industrial enterprises were the basis on which the temperature distribution of heat demand was determined of which the share of low and medium temperature heat demand of the whole sector was calculated. More than half of the enterprises belonged to the sector Food and beverages and few case studies were performed in Paper (4), Textiles (6), Leather (2), and one each in Cork and Motor vehicles. The analysis of temperature levels showed that more than 60 % of the heat demand is needed below 160 °C except for Paper industry and that in some sectors almost the total heat demand is below 60 °C. The authors determined the technical potential by estimating the available roof area (which was the limiting figure in most cases) for each analyzed enterprise and assuming a maximum solar fraction of 60 %. Schweiger et al. determined the technical potential at 3.4 % of the industrial heat demand in Spain and 4.4 % in Portugal. They found Food and beverages to be the most promising sector for the use of solar heat. Chemicals, Paper, Motor vehicles, Tobacco, Leather, and Textiles are also mentioned as suitable for the application of solar heat.

4.2.2 Netherlands, 2001

Van de Pol et al. [7] identified promising sectors for the application of STS in the Netherlands. These are Food and beverages, Paper, Textiles, and Industrial laundries. The authors analyzed the energy demand and typical processes within the sectors to determine the share which could be supplied by solar heat. The focus was on hot water for processes below 60 °C whereas DHW and boiler make-up water were not considered. They calculated a potential (not clearly referred to as technical potential) of 3.2 % of the industrial heat demand. The use of waste heat is mentioned as a major barrier for the spread of solar heat for industrial processes. Additional barriers mentioned are the lack of sufficient and suitable roof area and competing technologies such as combined heat and power (CHP) and heat pumps.

4.2.3 Sweden, 2003

The investigation of Kovacs et al. [8] focuses on the options for industrial solar heating applications in Sweden. As waste heat recovery in many cases is competing with solar heat, this field is also given some attention. The authors look into different temperature requirements of processes in the different industry branches. They apply a factor found by the POSHIP project for Europe in order to estimate the potential in Sweden. The conclusions are that possible applications are numerous, mainly within food and mechanical industries, but that low prices of energy, unused waste heat potentials, and low awareness about the possibilities for solar heat make the situation tough. The estimated overall potential in Sweden is about 1.5 to 2 % of the industrial heat demand, which is about 1 to 2 TWh/year.

4.2.4 Austria, 2004

Müller et al. [4] calculated the low (<100 °C) and medium temperature (<250 °C) heat demand by adding the demand for space heating (not for DHW) and steam generation for all industrial sectors in Austria. The authors selected the following suitable sectors: Chemicals, Food and beverages, Rubber and plastics, Textiles and Prefabricated concrete components. They excluded the ones with a low heat demand or high waste heat recovery potential. The theoretical potential is defined as low and medium temperature heat demand of the mentioned sectors and heat demand of processes of washing, cleaning and surface treatment of metals across all sectors. Müller et al. calculated a technical potential of 3.9 %, by first deducting the existing renewable share of 15 % of the heat supply, and a further 60 % due to possible efficiency measures and restrictions regarding economic feasibility. In addition, they assumed an average solar fraction of 40 % for process heat applications (20 % for space heating).

4.2.5 Victoria-Australia, 2005

McLeod et al. [5] published a study on the potential of solar process heat for the Australian State of Victoria. They estimated the industrial and service sectors' heat demand to 53 % of the final energy consumption based on statistics about the shares of the different fuels. A technical potential for industry is not clearly declared. Within the study the following industrial sectors are mentioned as suitable for the application of solar thermal systems: Chemicals, Food and beverages, Machinery and equipment, Textiles, and Paper.

4.2.6 Greece, Wallonia and Germany, 2006

Vannoni et al. [11] describe the results of a potential study regarding solar heat for industrial processes in Greece, Wallonia (Belgium) and a few industrial sectors in Germany. For Greece, the authors identified a potential for hot water preparation in seven sectors (Chemicals, Food and beverages, Tobacco, Paper, Textiles, Leather and Transport equipment). For Germany, the potential was investigated for Food and beverages, Textiles and Paper. The authors only estimated a technical potential for Paper recycling and Bottle washing in breweries due to the lack of data for other sectors. They estimated a theoretical potential of 181 GWh/a for paper recycling and calculated a technical potential of 60 GWh/a by assuming a solar fraction of 30 %. They further assumed a specific solar system yield of 400 kWh/(m²a) and calculated a market volume of 150,000 m² collector area (aperture or gross area not specified) for paper recycling. The technical potential (167 GWh/a) and market volume (557,000 m²) for bottle washing in breweries was estimated identically, assuming a specific solar system yield of 300 kWh/(m²a). For Wallonia (Belgium), the study mentions following suitable sectors: Chemicals, Food and beverages, Paper, Textiles and Tobacco.

4.2.7 Europe, 2008

Vannoni et al. [6] investigated the potential of solar heat in industry for Italy by estimating the available roof and facade area. They estimated the available area by using employee-specific data on available areas and a reduction of 80 % for roofs and 93 % for facades due to availability. The authors calculated a technical potential of 3.7 % of the industrial heat demand for Italy. Using other literature and especially the Ecoheatcool study, describing from a top-down approach the industrial heat demand in temperature ranges within Europe (EU25). Vannoni et al. mention the following industrial sectors to be suitable for the application of solar process heat: Chemicals, Food and beverages, Motor vehicles, Textiles, Paper, Tobacco and Leather.

4.3 Recent country studies

4.3.1 Germany, 2011

An overview of the heat demand below 300 °C in Germany is presented, which is crucial to assess the potential not only of solar thermal but also of CHP and heat pumps in industry. The analysis of the temperature distribution of the industrial heat demand shows that the most important temperature ranges for the application of solar process heat in Germany are below 100 °C and between 100 and 200 °C. Further collector developments should focus on cost reduction for standard collectors used below 100 °C and development of cost effective process heat collectors up to 200 °C as well as demonstration projects in this temperature range. A theoretical potential of solar heat for industrial processes in Germany of 134 TWh per year, and a technical potential of 16 TWh per year were determined [12].

The most promising industrial sectors were identified and analyzed regarding suitable processes. Some of the selected sectors surely offer broad possibilities for the use of solar heat, whereas in others the restrictions of energy efficiency might reduce the theoretical potential substantially. The sectors of Chemicals and Food and beverages have the highest potential for the use of solar heat. In Chemicals, the possibilities for the use of waste heat has to be investigated in more detail, since a large amount of heat is consumed at temperatures above 500 °C. Considering its big share of the industrial heat demand at low temperatures, the results of the prior studies and the variety of suitable processes, the sector of Food and beverages has the highest short-term potential for the use of solar thermal energy in industry.

4.3.2 India, 2011

For the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) the company PWC performed a study on India [13]. Based on extensive secondary research from sources like the National Energy Conservations Awards reports by the Bureau of Energy Efficiency (BEE), the Annual Survey of Industries (ASI) database and the ‘Prowess database’, a list of various energy-intensive industrial sectors existing in India was prepared. This potentially exhaustive list covered all the sectors where energy-intensive industrial applications constitute a significant share of the overall production costs. All 37 identified industrial sectors were mapped against various energy-consuming processes/applications that form a part of their production cycle. This exercise helped to identify the different low- and high-grade heating/cooling applications, which could be potentially replaced with suitable solar technology applications. Out of the 37 sectors identified above, for the most important sectors their energy consumption, heating/cooling load as percentage, power generation, number and dispersion of units within a sector in India, and experience with solar technology were investigated. A number of 10 sectors were investigated in a prefeasibility study. The main objectives here were to:

- identify processes that can be complemented with solar energy in the industry,
- map the suitable solar technologies to the identified processes,
- estimate the conventional energy replacement potential for industrial process, and to
- arrive at the replication potential of utilizing solar applications in identified processes across industrial sectors

The sector-wise findings of the pre-feasibility study are given below:

Sector	Energy replacement potential (ktoe/annum)	Estimated monetary saving (Rs Million/annum)
Textile (Finishing)	383	7692
Pulp and Paper	45	1700
Pharmaceuticals	9	
Leather	17	1026
Food processing	80	1782
Dairy	27	916
Textile	19.6	740
Electroplating/Galvanizing	21	
Automobile	10.5	607
Agro malls	4.3	160

Table 1: Sector-wise findings of pre-feasibility study for India

Additionally, business models for financing were investigated.

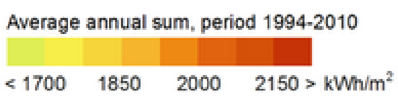
4.3.3 South Africa, 2011

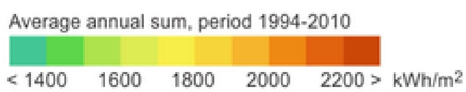
Brent and Pretorius investigated the potential using concentrating collectors in South Africa [17]. They discuss the trends and technologies in solar thermal concentrating collectors as well as CSP markets. A roadmap for the rollout of CSP in South Africa is presented, among else identifying the requirement in indigenous technology development.
A chapter deals with energy and electricity consumption in the industrial sector, showing that about 18 % is in mining and quarrying, 13 % in chemical and petrochemical, 24 % in non-ferrous metals, iron and steel industries. About 25 % are described as non-specific industry. Qualitatively, they analyse the possibilities for concentrator technology and propose absorption chilling in mines, as well as steam production in chemical and petrochemical factories. Also water desalination and waste-water treatment in mines are potentially interesting areas.

4.3.4 Tunisia, 2013

4.3.4.1 Context

The report “Estimation du potential d’applications solaires pour la satisfaction des besoins de process de l’industrie tunisienne” [14] was commissioned by UNEP (United Nations Environment Programme) to the Politecnico di Milano. Politecnico di Milano developed the methodology and subcontracted a Tunisian consultancy company to perform the study. ANME, the Tunisian agency for energy conservation, supported the realization of the work.





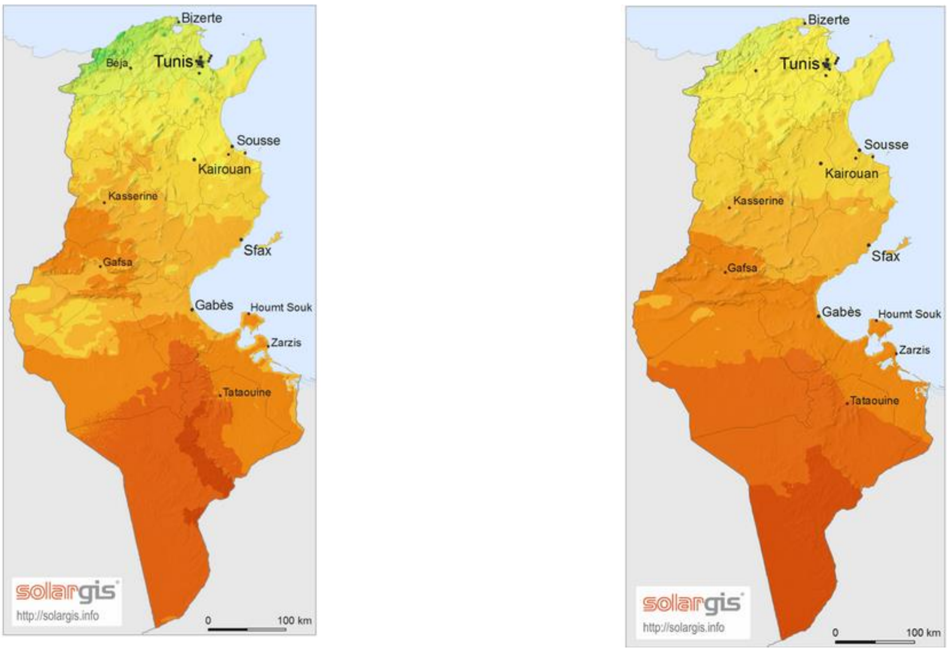


Figure 1: Global horizontal irradiation (left) and direct normal irradiation (right) in Tunisia

4.3.4.2 Method

The approach starts with macro variables; in this case the energy balance, which provides information on the amount of thermal energy to be targeted.

Then the analysis is refined in order to split the thermal energy consumed by industrial branch. The division is focused on branches actually having hot water and steam requirements, which would be suitable for solar applications.
The approach then suggests to audit 64 companies (56 answered actually), focusing on the maximum representation, based on the following parameters:

- Thermal energy consumed;
- Branches representativeness
- Regions representativeness; knowing that three major regions are suggested in relation to the solar radiation: The northern, central, and southern region.

Finally, the study presents 56 companies registered, which have been surveyed to determine their needs for hot water and steam, according to temperature levels (low: < 90 °C and average: < 250 °C). The results present advice in solar thermal technology choices depending on price criteria and temperature application.

4.3.4.3 Industrials sectors studied

- IMCCV: Construction materials industries, the thermal energy needs almost entirely go to hot air production.
- IME: Mechanical and Electrical Industries will also almost entirely go to uses other than the production of hot water and steam.
- IAA: Food industry
- ICH: Chemical industries
- ITHC: Textile, Clothing and Leather. These three sectors above use thermal energy almost exclusively for the production of hot water and steam.
- ID: Various industries are generally corresponding to hot air uses. The paper industry (using mainly steam) represents 30 % of the thermal energy consumption of ID.

Annual thermal energy consumed in Tunisian industries.	2010	
	toe	%
IMCCV	1 058 373	65,0
ITHC	67 958	4,2
IAA	112 999	6,9
ICH	166 136	10,2
IME	107 151	6,6
ID	114 985	7,1
Sum	1 627 602	100

Table 2: Balance of thermal energy industry in 2010 by branch (final toe)

The 56 companies surveyed have an energy consumption of around 195 ktoe, of which 85 % correspond to thermal uses (166 ktoe), and 15 % to electrical uses (29 ktoe).
Consumption of thermal energy confirms the dominance of petroleum products, which represent 55.8 % of total final energy consumed by these companies. Note the dominance of oil, which alone accounts for almost 55 % of the final energy balance, which is mainly due to the high consumption of this fuel by the Tunisian Company of Refining Industries (STIR) and the Tunisian Chemical Group (GCT), which is 76 ktoe for the two companies combined.
Concerning the consumption of natural gas, it is about 57 ktoe; or 29.4 % of final energy consumption balance of the companies surveyed.
In the end, the energy consumption corresponding to thermal uses is split between 34 % natural gas and 66 % oil products.

	toe	%
Electricity	28 868	14,8
Natural Gas	57 520	29,4
Petroleum products	109 240	55,8
Fuel Oil	107 419	54,9
Diesel Fuel	56	0,0
LPG	1 765	0,9
Sum	195 628	100

Table 3: Energy Balance of the audited Industrials (final toe)

4.3.4.4 Results

On the assumption that 1 m² installed flat plate collector would cost DT 700 (US$ 360 or € 320) and that 1 m² of parabolic trough or vacuum tubes would cost 1000 DT (US $ 516 or 459 €), one can obtain an estimate of the volume of business that could generate the solar thermal market in the industry.

The table hereafter summarizes these estimates, and shows a total market volume of approximately 347 MDT (US$ 179 million and € 159 million); of which 85 % would go to the parabolic trough market, and 10 % to the flat plate collectors. Vacuum tubes remain a niche technology, with only 5 % of the business volume of the market.

Total Industry	Flat plate Collectors		Parabolic trough collectors		Vacuum tubes		Total	Sector part of the market
	MDT	m²	MDT	m²	MDT	m²		
ITHC	8,4	12 000	56,0	56 000	0,0	0	64	19 %

IAA	17,5	25 000	94,0	94 000	11,0	11 000	123	35 %
ICH	6,3	9 000	49,0	49 000	4,0	4 000	59	17 %
ID	4,2	6 000	95,8	95 800	1,2	1 200	101	29 %
Total	36,4	52 000	295	294 800	16	16 200	347	100 %
Market share	10 %		85 %		5 %		100 %	

Table 4: Solar thermal market in the industry global turnover (potential in MDT and m²)

4.3.5 Chile, 2014

In the project APPSOL - Energia solar termica en industria [15], the company Aiguasol investigates the solar thermal process heat potential for mining and non-mining industries in Chile. The data bases for these two sectors are different. Heating and cooling in the industries is investigated. Applying selection criteria (only plants with more than 3 MW_{th}/a and temperature demand below 250 °C), 1611 plants were identified, whereas 2231 were excluded. The main branch was the food industry (alimentos), followed by paper and celluloses industry (papelera y celulosa) and wood (madera).About 89 % of the energy demand of 16.7 TWh/a is for heat and 11 % for cooling.

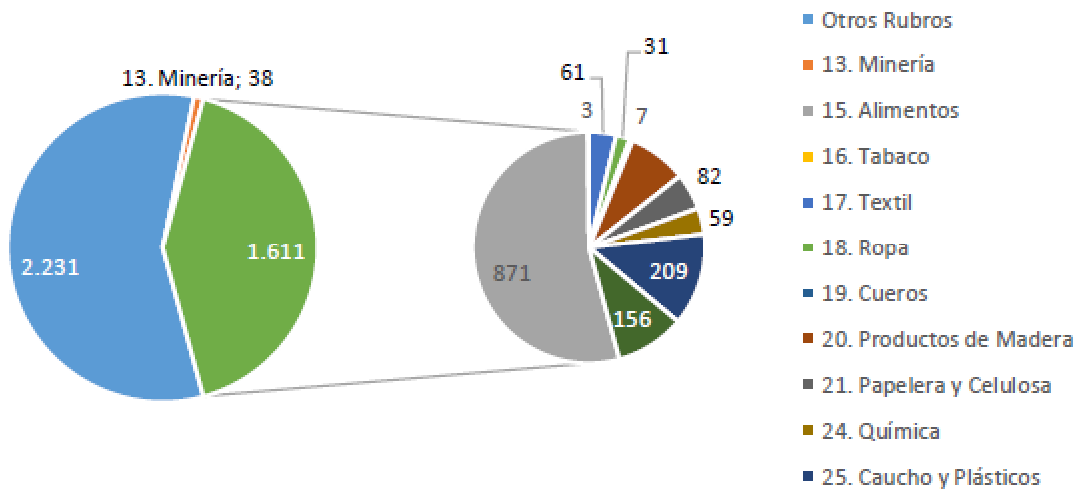


Figure 2: Selected 1611 companies grouped in industrial branches

Looking into the demand and the different solar radiation potential in the regions of Chile, the authors derive a theoretical solar thermal potential of about 7.2 TWh/a which can be covered by about 9 million m^2 solar collector area. The viable economical potential is mainly related to mining applications and is about 1.5 million m^2 in the mining sector and 0.4 million m^2 in other sectors.

4.3.6 Egypt, Pakistan, Morocco, 2015

Surface treatment, food, chemical, textile and leather are the five industry sectors with the greatest potential for utilising solar thermal systems in Pakistan. Solar heat below 100 °C can contribute 5.6 million MWh per year to these five industries if 7.1 million m^2 of collector area is installed in the country, although with long payback periods of between 10 and 20 years. These are some of the results of a market study [16], which looks at Solar Thermal Energy for Industrial / Commercial Use in Pakistan, Egypt and Morocco and was commissioned by the International Finance Cooperation (IFC). Two Austrian companies, CES clean energy solutions (CES) and S.O.L.I.D completed the study in March 2014.

“Egypt and Pakistan were chosen for the study because their population sizes and poverty levels made them focus countries for the IFC in the Middle East and North African region. Morocco was included because solar process heat technology could be relevant to a number of IFC investees in this nation," Alasdair Miller, an IFC Senior Clean Energy Specialist based in Cairo, Egypt, explains. "To identify the top five industries with the greatest potential, the authors used a method developed by CES, which allocates points across six categories relevant to estimating solar process heat potential," Robert Söll, project developer at S.O.L.I.D and one of the authors of the study, adds. The six categories are:

- Temperature level per industry
- Daily and seasonal variations
- Expected maximum share of solar energy below 100 °C
- GDP share
- Energy consumption per sector
- Investment potential

The potential for solar process heat in the three countries is enormous, adding up to 2.3 million m² of collector area in Morocco, 4.6 million m² in Egypt and 7.1 million m² in Pakistan (see the following table).

	Top five industries with greatest potential	Maximum solar contribution to low-temperature heat generation in the five industries [MWh]	Collector area potential to achieve maximum solar yield [m²]	Solar yield per m², averaged out across different applications and sites in a country [kWh]
Morocco	Surface treatment, food, chemical, textile and leather	1,714,650	2,300,000	746
Egypt	Tourism, chemical, food, textile and agriculture	4,571,139	4,600,000	994
Pakistan	Textile, surface treatment, food, chemical and leather	5,622,501	7,100,000	792

Table 5: Solar process heat potential in Morocco, Egypt and Pakistan under current market conditions, resulting in payback periods of up to 20 years

Results, however, differ significantly when looking at the investment potential under current market conditions, divided into payback periods of below and above 10 years. Because of the currently low energy prices in Egypt, the country has no short-term investment potential with payback periods of below 10 years. But in Morocco and Pakistan, payback periods of 10 years or less can be achieved in 26 % and 35 % of all cases, respectively.

	Investment potential payback period below 10 years [million USD]	Investment potential payback period between 10 and 20 years [million USD]	Share of short-term investment potential with payback below 10 years
Egypt	0	497.2	0 %

Morocco	570.5	1651.4	26 %
Pakistan	2383.9	4427.1	35 %

Table 6: Short-term investment potential for solar process heat potential in Morocco, Egypt and Pakistan with payback periods below 10 years

"The major limiting factors for the installation of solar thermal applications are the low prices of conventional energy sources, which are still heavily subsidised, a lack of human resources, and the lack of strong political will to implement reforms in the energy sector", the authors emphasise in their summary. Because of the long payback periods of more than 10 years, "the economics seem, in most cases, unlikely to lead to significant private sector interest in the short term", Miller concludes. Hence, the IFC has decided "not to progress any further" with a market development programme for solar process heat until energy subsidies are removed, for example, as has been announced in Egypt.

Given the removal of subsidies for conventional energy supplies, the authors of the study estimate the investment potential in Egypt with payback periods below 10 years at USD 3.587 million, and the investment potential with payback periods of more than 10 years at an additional USD 827 million.

More information:
www.solid.at
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4.4 Global Potential

4.4.1 IRENA, 2015

The International Renewable Energy Agency (IRENA) published a technology brief "Solar Heat for Industrial Processes" [18]. In a best-case scenario with considerable cost reductions for solar heat and without fossil fuel subsidies in industry, IRENA estimates a technical potential of 15 EJ or 850 GW_{th} by 2030 (out of then 160 EJ assumed annual process energy demand). This very high technical potential is to a large extent based on the necessity of new production capacity investments until 2030, mainly in the chemical sector. A share of 80 % of the capacity to be installed would be located in non-OECD countries.
The economically realizable potential is however expected to be significantly lower. Taking into account fossil fuel price development and technology learning curves for solar process heat, IRENA estimates that a share of 3.3 EJ (ca. 180 GW_{th}) could be realized by the year 2030.

4.4.2 Taibi et al., 2012

Taibi et al. [19] give an estimation of the global renewable potential in industry. The paper presents a top-down approach based on other literature studies. For solar thermal, they found a global potential of approximately 1,555 TWh (5.6 EJ) per year by 2050, which is about 2 % of the total final energy demand of the industry. This number may be a bit low considering that also regions with very good irradiation levels are included. Almost 50 % of the potential is seen in the low temperature food and beverages sector. Further promising sectors are machinery and equipment, mining and quarrying, textiles and leather, and transport equipment. The authors state that the potential has a roughly equal regional distribution between OECD countries, China and the rest of the world. Further, Taibi et al. found that solar process heat is close to economic feasibility in regions with good radiation but needs substantial cost reduction for Central Europe and other areas with lower solar resources.

4.4.3 UNIDO, 2011

The results of Taibi et al. [20] are used in the report “Renewable Energy in Industrial Applications” of the United Nations Industrial Development Organization (UNIDO). The authors additionally state that including heat from concentrating collectors for the chemical industry could increase the global potential of solar process heat to 8 EJ per year in 2050. It is estimated that the costs of solar process heat could drop by more than 60 %, mainly as a result of learning effects, from a range of USD 17 to USD 34 per gigajoule (GJ) in 2007 to USD 6 to USD 12 per GJ in 2050.

5 Conclusion

The present known worldwide installed area of 0.14 Mio m^2 of solar collectors in process heat applications is much smaller than the estimated potential. Several regional and country studies contribute to a better understanding of the large potential. In several studies the SHIP potential has been estimated based on restrictions like temperature range and available area. For Europe where mainly non-concentrating collectors had been investigated, the percentage of technical potential for solar process heat related to the total industrial heat demand is around 3-4% (see Figure 3).

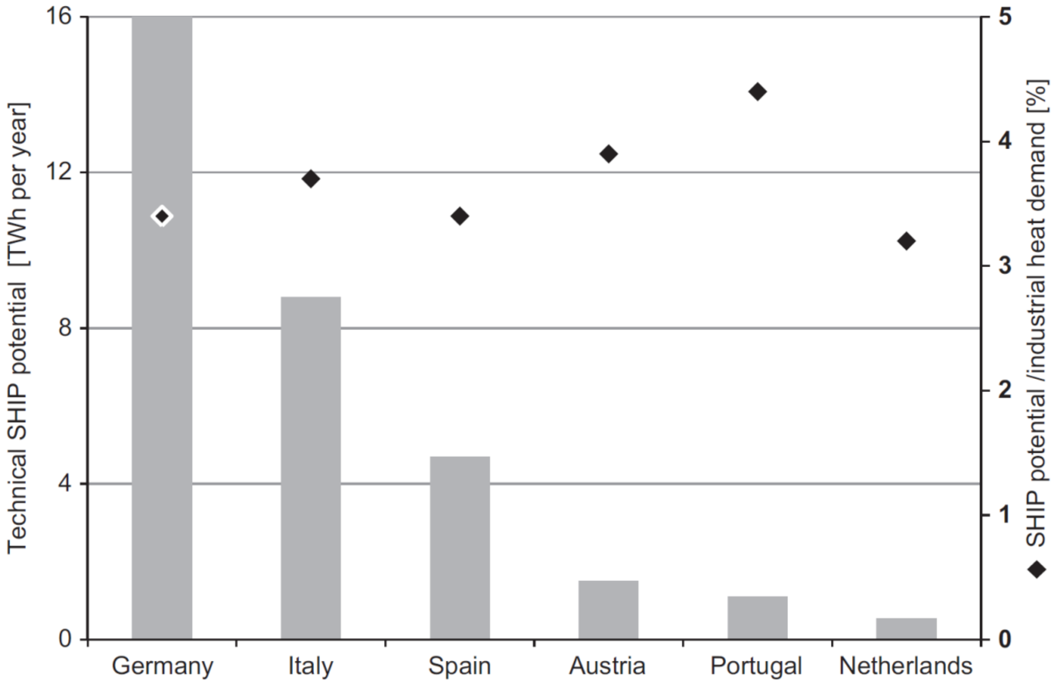

Figure 3: Technical potential for solar heat for industrial processes in European countries [21]

If one takes into account countries with a much higher solar radiation potential like Chile, India or South Africa, the percentage should be higher due to two reasons: Often in not so densely populated countries the limitation of space is less stringent than in the highly industrialized countries, on the other hand concentrating collectors also provide the possibility to cover even higher temperature heat demand up to 250 °C to 400 °C.

Also new collector developments like the vacuum flat plate collectors may help to extend the possibilities of solar process heat in countries with less direct irradiation. Therefore they should enlarge the technical potential to some extent.
The total global process heat demand was about 98 EJ in 2008 [19]. Considering the arguments mentioned above, about 4 % or 3.9 EJ global technical potential for solar process heat should be a conservative estimate. To very roughly calculate the order of magnitude of this, one could assume a mean useful annual solar irradiance (not specifying if global or beam) of 1200 kWh/(m^2a) and an annual solar thermal system efficiency of 40 %. This would result in a solar collector area of close to 2300 Mio. m^2. For the year 2050, Taibi et al. estimate a technical potential of 5.6 EJ,

corresponding to then about 3200 Mio. m^2.
This may be compared with individual country studies. 2.4 Mio. m^2 for Morocco, 4.6 Mio. m^2 for Egypt, 6 Mio. m^2 for Chile, 7.1 Mio. m^2 for Pakistan, 35 Mio. m^2 for Germany, and 155 Mio. m^2 for Europe complement and confirm this magnitude.

Of course the question of the economic potential is then connected to the market and cost development - on both sides, for conventional energy and for solar thermal systems.

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