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# Branch-Specific Application Potential for Solar Process Heating and Cooling in the Spanish Industry until 2020

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In the present paper the application potential of solar thermal energy in the Spanish industry until the year 2020 is analysed. The industrial heat demand at low and medium temperature (up to a temperature of 250 ºC) represents 40,9 % of the total industrial heat demand. The equivalent fraction in the 32 branches analysed is 80,2 %. The theoretical techno-economic application potential is 68,2 GW (97,4 millonss of m2). The potential for implementation until 2020 in the favourable scenario is 10,1 GW and 1,7 GW in the business-as-usual case. 75 % of the application potential is located in industrial branches and climatic zones, where the available roof and ground surface is a limiting factor. Therefore, industrial roof and ground areas should be considered as a scarce resource, which should be optimised with regard to a maximum generation of solar energy. Solar thermal systems are competing mainly with photovoltaics (PV) for the available roof areas, and with CHP as an alternative means of covering low and medium temperature heat demand. A comparative analysis of these technologies with respect to economics and primary energy saving potential is included. Compared to CHP, solar thermal allows for higher primary energy savings with the trade-off of a poorer economic performance. Costs per saved primary energy of industrial solar thermal plants can be 2 to 4 times lower than the equivalent costs of PV systems.

## 1. Methodological approach

The methodological approach used in this study is the result of a long experience of the company energyXperts.NET in the analysis of solar thermal systems for industrial processes, which started in a systematic and structured way with the project POSHIP (Schweiger et al. 2001) and which has been continued in the following years both in the framework of the international expert group of the Task 33/IV “Solar heat for industrial processes” within the Progras SolarPACES and Solar Heating and Cooling of the International Energy Agency, and by the participation in different projects and activities in the industrial sector. The methodology applied is a synthesis of the methods applied in different potential studies at European and international level (for a comparative analysis see Vannoni et al. (2008)), and of the own experience.

Starting from statistical data of the national statistics bureau (INE) on energy consumption in industrial branches (data for the year 2007) a detailed analysis of the processes in each of the branches has been carried out, with the objective of breaking down the energy consumption in each branch by levels of temperature and by processes. Parallel, a study on the available roof and ground areas suitable for solar thermal systems has been carried out. Based on this information on energy consumption, processes used and available surface for each of the branches a “*representative company*” has been defined. The application potential of solar thermal energy has been determined for this representative company, and then extrapolated to the entire branch, taking into account established techno-economic criteria.

32 branches and sub-branches of the food, textile, wood, pulp- and paper, chemical, plastics processing, machinery and equipment and diverse manufacturing industries have been studied in detail, classified by NACE code. Those sectors represent 47,7 % of the total heat consumption and 93,6 % of the heat consumption at low and medium temperature (up to 250 ºC) and 89,5 % of the application potential for solar

thermal. The potential for the rest of industrial sectors (with heat demands predominantly at high temperature and, therefore, less suitable for solar thermal application) has been estimated and added to the potential of the 32 branches / sub-branches analysed in detail, in order to determine the application potential in the entire Spanish industry.

## 2. Detailed analysis of one sector

### 2.1 Analysis of the heat and cooling demand of the branch

First of all, for each industrial branch a literature review has been carried out in order to identify the processes consuming heat and cooling, to determine the temperature levels required in each of the processes, and to determine the quantitative distribution of the industries' total energy consumption over the different processes.

For the definition of temperature levels the generic process model of the EINSTEIN thermal energy audit methodology has been used (Schweiger et al. 2012). Following this model, the thermal energy demand of a process is composed by three parts:

- *maintenance*: the energy demand required in order to maintain the process equipment at a given temperature. This energy contribution is required at a temperature level equal or higher than the process temperature.
- *circulation*: heating of material flows entering the process from an initial temperature up to the process temperature.
- *start-up*: initial heating of an equipment (e.g. a water bath) after a break of operation, until the process temperature is reached.

*Both* in the case of circulation and in the case of start-up a significant part of energy supply can take place at temperatures well below the process temperature. Therefore, not only the process temperature itself has to be known, but also the initial or entrance temperature of media before heating up, and the outlet temperature of outgoing media.

In industrial heat supply systems the temperature of the heat supply to some process generally is different of the process temperature (e.g. very often hot water baths for processes well below 100 °C often are heated up with steam at temperatures around 170 – 180 °C). In order to couple a solar thermal system to the conventional heat supply, generally it is recommended to modify the existing heat supply system. Therefore, for the potential analysis not the temperature level of the current supply system (often too high) should be taken as a reference, but the minimum required supply temperature has to be determined.

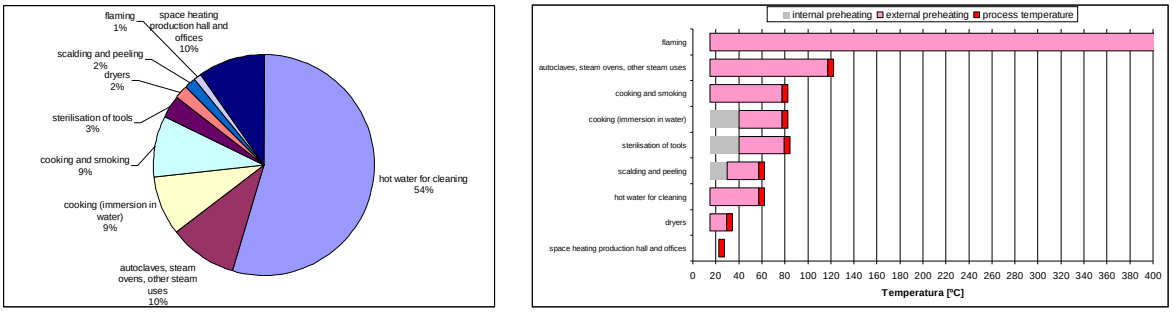



*Figure 1: Distribution of the process heat demand (left) and temperature levels (right). Example: sector 15.1: meat processing industry.*

### 2.2 Representative company for the branch

Based on the branch's total energy consumption, the distribution of the total demand by processes and the temperature levels associated with each of the processes, a reference model company has been defined for each branch. This reference company has been modeled using the software EINSTEIN

### 2.3 Heat recovery potential

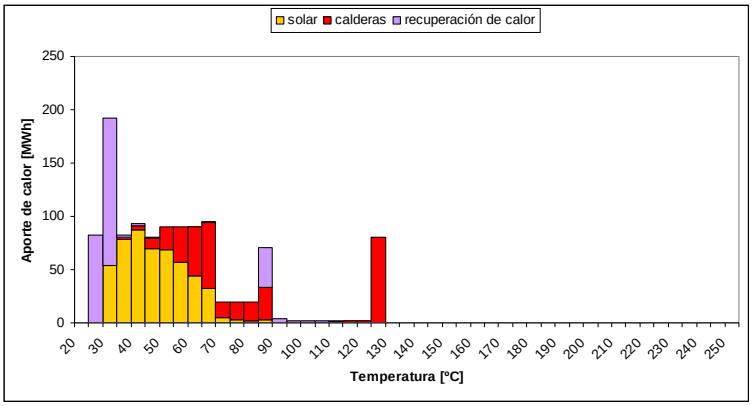
The degree of implementation of heat recovery determines strongly both the quantity and the quality (temperature level) of the energy demand. Therefore, as a base for determining the solar application potential,

both the (average) current level of heat recovery has to be considered, and the future – not yet exploited – heat recovery potential. A detailed analysis of the heat recovery potential requires quite a deep analysis exceeding the frame of the current study. Therefore, an estimative calculation based on simplifying assumptions has been carried out using the EINSTEIN software (estimate mode for heat recovery calculations).

### 2.4 Potential for solar process heat

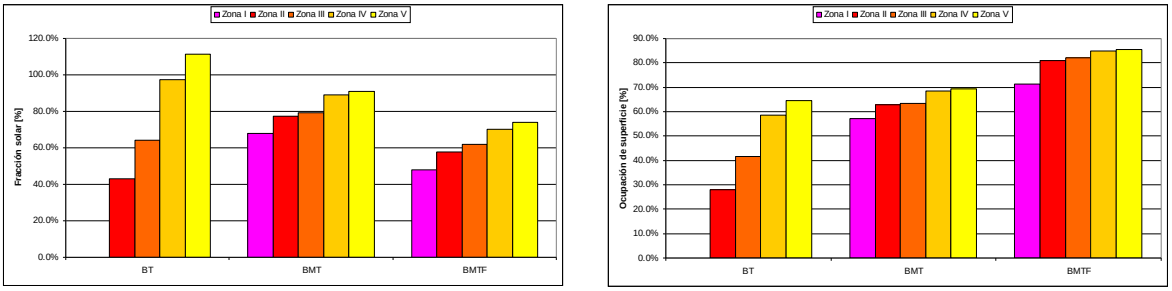
For each branch's representative company dynamic system simulations have been carried out with the software EINSTEIN for each climatic zone, after previous calibration and validation with TRNSYS. In total 1440 simulations have been carried out for 32 industrial branches, 5 climatic zones, 3 combinations of solar collector technology / demand profile (BT, BMT or BMTF) and 3 sizes of available roof and ground area (0,5x, 1x and 2,5x the available area of the representative reference company). Figure 2 shows a typical result of such simulations. Average rates of solar fraction and roof surface occupation are obtained as weighted mean of the 3 company roof sizes (0,5x, 1x and 2,5x; Figure 3).

*Figure 2: Contribution of heat recovery (violet) and solar process heat (yellow) and conventional system (red)*




*to the total heat demand by temperatures. Sector 15.1: meat processing industry. Example of simulation results for flat plate collectors, zone IV.*

*Figure 3: Average solar fraction (left) and average occupation of available surface area (right) by climatic zone*




*(from I: northern Spain to V: southern Spain) and by reference demand (BT: only low temperature demands up to 60 °C; BMT: low and medium temperature demand up to 160 °C; BMTF: like BMT, but additionally including solar cooling). Sector 15.1: meat processing industry.*

## 3. Results: Application Potential for Solar Process Heat and Cooling in the Spanish Industry

Table 1 shows the detailed results of the solar application potential obtained for each of the 32 branches studied. The distribution of the total solar potentia over the branches is shown in Figure 4.

*Table 1: Potential for industrial solar thermal installations by scenarios F (favourable) and D (business as usual).*

| Industrial branch | Potential scenario F (favourable) | | | |
|---|---|---|---|---|
| | Installed power | Aperture area | Useful heat generation | Solar fraction (ref.: BMT) |
| | [MW] | [1000 m2] | [MWh] | % |
| 15.1 : Production, processing and preserving of meat and meat products | 1 024 | 1 463 | 950 433 | 18,37% |
| 15.2 : Processing and preserving of fish and fish products | 201 | 287 | 156 963 | 12,65% |
| 15.3 : Processing and preserving of fruit and vegetables | 209 | 299 | 244 100 | 6,40% |
| 15.4 : Vegetable and animal oils and fats | 141 | 201 | 182 735 | 5,83% |
| 15.5 : Dairy products | 546 | 781 | 520 974 | 13,47% |
| 15.6 : Grain mill products, starches and starch products | 158 | 225 | 185 338 | 8,56% |
| 15.7 : Prepared animal feeds | 232 | 332 | 212 260 | 7,85% |
| 15.81, 15.82 : Bread; pastry goods and cakes, rusks and biscuits | 373 | 534 | 283 693 | 9,35% |
| 15.83, 15.84: Sugar, cocoa; chocolate and sugar confectionery | 162 | 232 | 164 253 | 7,56% |
| 15.85, 15.86,15.87, 15.88, 15.89 : Other food products | 227 | 325 | 201 468 | 8,43% |
| 15.9 : Manufacture of beverages | 693 | 990 | 592 426 | 19,14% |
| 17.3 : Finishing of textiles | 106 | 152 | 114 570 | 4,40% |
| 20 : Manufacture of wood and of products of wood and cork | 705 | 1 007 | 545 414 | 16,33% |
| 21.1 : Manufacture of pulp, paper and paperboard | 151 | 216 | 206 951 | 1,42% |
| 21.2 : Manufacture of articles of paper and paperboard | 188 | 268 | 157 762 | 4,56% |
| 24.11 : Manufacture of industrial gases | 25 | 36 | 33 807 | 4,50% |
| 24.12 : Manufacture of dyes and pigments | 5 | 7 | 6 142 | 0,61% |
| 24.13 : Manufacture of other inorganic basic chemicals | 177 | 253 | 170 926 | 3,96% |
| 24.14 : Manufacture of other organic basic chemicals | 8 | 12 | 8 501 | 4,86% |
| 24.15 : Manufacture of fertilizers and nitrogen compounds | 141 | 202 | 166 101 | 1,43% |
| 24.16 : Manufacture of plastics in primary forms | 43 | 61 | 51 738 | 1,28% |
| 24.17 : Manufacture of synthetic rubber in primary forms | 26 | 38 | 35 620 | 1,99% |
| 24.3 : Manufacture of paints, varnishes and similar coatings, printing ink and mastics | 184 | 263 | 155 875 | 4,75% |
| 24.4 : Manufacture of pharmaceuticals, medicinal chemicals and botanical products | 276 | 395 | 280 359 | 12,50% |
| 24.5 : Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations | 173 | 247 | 133 053 | 11,20% |
| 24.6 : Manufacture of other chemical products | 197 | 281 | 171 647 | 5,03% |
| 24.7 : Manufacture of man-made fibres | 11 | 15 | 8 814 | 0,50% |
| 25 : Manufacture of rubber and plastic products | 863 | 1 232 | 696 048 | 11,48% |
| 28.5 : Treatment and coating of metals; general mechanical engineering | 354 | 506 | 268 208 | 15,77% |
| 29 : Manufacture of machinery and equipment n.e.c. | 286 | 409 | 214 154 | 11,08% |
| 30, 31, 32, 33, 36, 37 : Office machinery and computers, electrical machinery and apparatus, radio, television and communication equipment and apparatus, medical, precision and optical instruments, watches and clocks, furniture, recycling | 555 | 793 | 415 158 | 14,17% |
| 34, 35 : Manufacture of motor vehicles, trailers and semi-trailers, other transport equipment | 618 | 882 | 460 430 | 8,33% |
| **TOTAL BRANCHES STUDIED** | **9 060** | **12 943** | **7 995 922** | **7,24%** |
| Other branches | 1 068 | 1 526 | 943 910 | 12,51% |
| **TOTAL INDUSTRY** | **10 128** | **14 469** | **8 939 832** | **7,57%** |

The industrial heat demand at low and medium temperature (up to a temperature of 250 ºC) represents 40,9 % of the total industrial heat demand. The equivalent fraction in the 32 branches analysed is 80,2 % (for a comparison see the results obtained in other similar studies in Table 2).

The theoretical techno-economic application potential is 68,2 GW (97,4 millonss of m2). From this total potential 14,7 GW are for low temperature applications, 36,8 GW for medium temperature applications, and additional 16,6 GW for medium temperature applications including solar cooling.

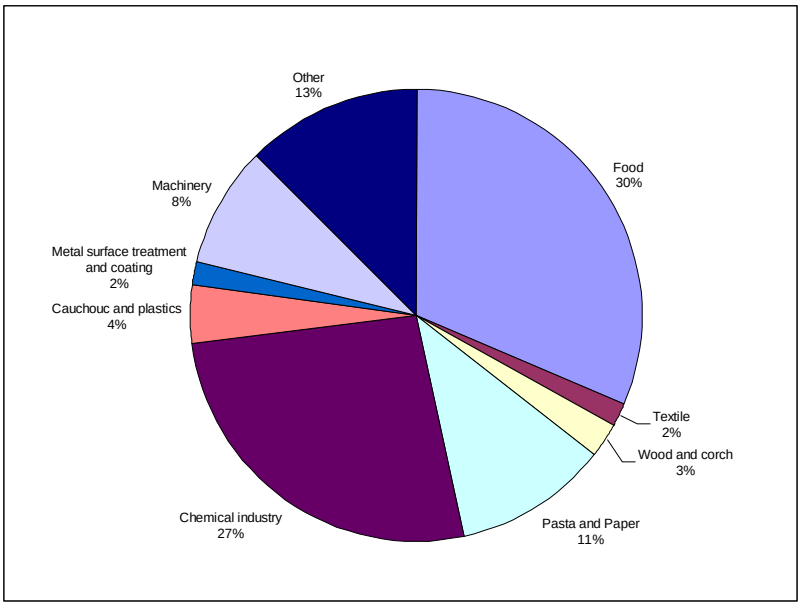



*Figure 4: Distribution of the solar process heat potential by branch (scenario F: favourable)*

*Table 2. Distribution of the industrial heat demand by temperature levels. Comparison of the present results with those of previous studies.*

| Source: | Present study | POSHIP (Schweiger et al. 2001) | ECOHEATCOOL (xxx) | Weiss and Biermayr (xxx) |
|---|---|---|---|---|
| Low temperature (< 60°C) | 8,0 % | | | |
| Medium temperature (< 120°C) | 21,9 % | | 30 % (< 100 ºC) | 14 % (< 100 ºC) |
| Medium temperature (< 160°C) | | 23 % | | |
| Medium temperature (< 250°C) | 40,9 % | | 57 % (< 400 ºC) | 30 % (< 200 ºC) |

The implementaion potential (depending on the estimated degree of implementation) in the favourable scenario F is 10,1 GW, of which 2,9 GW are at low temperature (< 60 ºC) and 7,2 GW at medium temperature (from 60 ºC to 250 ºC) including cooling. The average solar fraction is 7,5 % of the heat demand at low and medium temperature (5,4 % if the cooling demand is included into the reference base), and reaches almost 20 % in the beverages and meat processing industries. The implementaion potential reduces to 1,7 GW in the business-as-usual scenario (D).

An important part of the solar process heat potential is concentrated in the food industry (almost 40 % of the total). Other sectors with a high potential are the manufacturing industry (including automobile industry, NACE codes 29 – 37, with 14,4 %), the chemical industry with 12,5 %, the industry of cauchouc and plastics process ing with 8,5 % and the wood and cork processing industry with 7 % of the total.

The minimum values of useful heat generation, required in order to fulfil the economic feasibility criteria as defined in the favourable scenario (substitution of natural gas, pay-back of 10 years, funding of 200 €/m2 for flat plate collectors and 300 €/m2 for medium temperature collectors) are 952 kWh/kW (666 kWh/m2) for low and 742 kWh/kW (519 kWh/ m2) for medium temperature, which corresponds to 71 % or 63 % respectively of the generation of the reference system in optimum conditions (continuous demand, no storage) in climatic zone IV (the climatic zone where the major part of the Spanish industry is located in). As an alternative to

subsidies by installes surface or nominal power, a similar level of economic performance could be obtained applying a feed-in tariff for heat of 3 c€ por kWh of generated heat (low temperature) and of 5 c.€/kWh (medium tempearature).

The application potential is concentrated in the provinces with major presence of the industrial sector and which dispose of a medium or high level of solar radiation: in first place Madrid, Barcelona and Valencia (provinces with a potential higher than 4 GW) and in second place (from 2 to 4 GW each) Alicante, Murcia, Sevilla and Málaga. In these 7 provinces 44 % of the total national application potential is concentrated. t

75 % of the application potential (in terms of generated useful heat) is located in industrial branches and climatic zones where the available roof or ground surface is a limiting factor (potential constrained by available surface: 25 % or intermediate cases – constraints by both surface and demand: 50 %). In order to obtain the total techno-economic potential a degree of occupation of the available surface of 56 % (for the studies branches) and of 36 % for the total industry would be required. From this fact it can be deduced that the available surface (industrial roofs and near ground surfaces) have to be considered as a scarce resource, whose utilisation for the purpose of energy conversion should be optimised.

Solar thermal energy is competing mainly with fotovoltaics (for the available space: roofs), and with cogeneration, for the heat demand at low and medium temperature. As a result of a comparative study of those technologies (see Schweiger et al. 2011 for details) the following can be highlighted:
From the point of view of energy performance, solar thermal systems generate a primary energy (PE) saving of 1,29 kWh_PE per kWh_t delivered, which is approximately the double saving of an efficient cogeneration plant. Therefore, from the energy and environmental point of view, solar thermal systems should be preferred to cogeneration plants based on fossil fuels. From the economic point of view, it can be stated that the additional cost per unit of primary energy saved by solar thermal systems is between 2,2 and 3,9 times lower than that of fotovoltaics. In other words: by solar thermal systems the same amount of primary energy can be obtained with half or a quarter of public resources destinated to feed-in tariffs or other types of incentives. The primary energy saving per unit of roof or ground surface is between 2,4 and 3,1 times higher in solar thermal systems compared to fotovoltaics.
Therefore, in order to optimise the use of roof and ground surfaces as a scarce resource, it is highly recommended to provide the appropriate measures and incentives, so that solar thermal systems become the technology of first choice occupying these surfaces, whenever a use of the generated heat is possible.

## 4. Conclusions

The EINSTEIN software has been shown to be a very useful tool for carrying out detailed analysis of branch specific application potentials of solar thermal energy. As could be expected from previous studies, there is a very high and unexploited application potential for solar process heat generation in the industrial sector at low and medium temperature. Appropriate measures and incentives should be provided, so that solar thermal systems become the technology of first choice occupying these surfaces, whenever a use of the generated heat is possible.

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