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Development of an evaluation methodology for the potential of solar-thermal energy use in the food industry

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Abstract

The research project 'Solar Heat in the Liquid Food Industry' (part of the FORETA Research Network [1]) focused on the development and optimisation of low-temperature heating systems for the liquid food industry. Its main objectives are in energy efficiency, waste heat recovery and the feasibility of a solar-thermal process heating system. Based on the particular simulation results the overall solar-thermal potentials for German breweries and dairies were determined. In this connection a literature review indicated that most of the potential studies on solar-thermal energy use in the industry or related to specific industrial sectors are based on the total use of low-temperature heat. In opposition to these results, the available and mainly limited roof area was found to be a more important aspect for the solar-thermal potential. Hence, the development of a methodology for a site-specific analysis was necessary. The interconnection of only a few defined evaluation criteria resulted in a more realistic estimation of the potential for a solar-thermal heat supply.

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1. Background and introduction

Heat energy is one of the most important production factors in the industry. In connection with increasing energy costs advanced and efficient energy supply systems are required. Additionally, a sustainable production attracts more and more the consumer's attention. Hence, the reduction and replacement of fossil fuels are major objectives for industrial production. Besides new high efficient energy converting systems or waste heat recovery solar-thermal process heating systems are a very promising renewable technology for fuel replacement. It is possible to cover the

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low-temperature heat demand up to 100 °C – including space heating and energy for hot service water – with sophisticated, market available conventional solar-thermal systems.

With regard to Germany's total amount of industrial heat energy the fraction of low-temperature energy suitable for solar-thermal applications is 21 % [2] or 153 TWh a^{-1} (2011) [3]. As the industry consists of various branches the heat energy demand differs between them. It is obvious that there are also sub-sectors with mainly heat energy demands above 100 °C, for example the metal production and processing or the production of glass and ceramics. However, there remain many sub-sectors with large low-temperature energy demand.

2. Energy in the liquid food industry

The research project 'Solar Heat in the Liquid Food Industry' aimed at the development of heat energy supply systems for low-temperature energy demand focussing on solar-thermal energy. A comprehensive review identified the food industry and especially its sub-sectors breweries and dairies as very promising for solar-thermal applications. With efficient production technology more than 90 % of the required thermal energy demand in both sub-sectors is below 100 °C [4]. As Table 1 illustrates, only a few processes, e. g. wort boiling (beer production) or high temperature heat treatment of milk like sterilisation (for shelf life extension) need temperatures above 100 °C and are not suitable for solar-thermal energy supply. However, low-temperature processes like pre-heating, thermisation or cleaning applications dominate the processing of milk and the production of beer.

Table 1. Exemplary Process Temperatures in Breweries and Dairies.

	Sub-Sector	Process	Max. Operating Temperature [°C]
Processes < 100 °C	Dairy	Homogenization	75
	Dairy	Flash pasteurizing	72
	Brewery	Mashing in (Pre-Heating of Brewing Water)	65
	Brewery / Dairy	Bottle Cleaning	85
	Brewery / Dairy	CIP	90
Processes > 100 °C	Dairy	Sterilization	120
	Brewery	Wort boiling (evaporation of water)	~ 100

Additionally, the seasonal beer production and milk processing follows the solar radiation in Europe. However, there are also some important challenges associated with the use of solar-thermal energy. An example is the batch production at breweries and dairies requiring heat energy networks with integrated storage tanks to separate energy use and the availability of solar-thermal energy. This solar-thermal energy depends also on available areas for the collectors. Therefore, the necessary collector area to cover the remaining low-temperature energy demand after optimising the conventional heat energy supply system, realising energy efficiency and waste heat recovery measures had to be determined. In contrast to the expectation the limiting factor for solar-thermal systems was not the low-temperature energy demand as mainly represented in other potential studies but the available collector mounting area.

3. Previous potential studies

A solar-thermal potential analysis of the research project 'Solar Heat in the Liquid Food Industry' is input information for a potential study of the sub-sectors brewery and dairy in Germany. Moreover, a comprehensive review on existing potential studies provides the background and an overview of data collection, methodologies and with this the defined potentials.

Several studies on the potential of solar-thermal energy use in the industry are available [4,5,6]. The analysis done are for different regions and focus either on Europe or on country specific conditions. The studies are mainly very general and do often not distinguish between the different industry sectors or analyse just a specific group of industries [4]. Hence, it is complicated to compare the results of the studies. A transferability of the methodologies to specific sub-sectors is only limited given. The solar-thermal potential is directly and solely linked to the thermal energy demand. The potential is estimated for different supply temperatures also reflecting the applicable system (collector) technology and a general factor of reduction considering future energy efficiency. Other aspects like waste heat recovery or solar fraction are subordinated. On the one hand this approach provides – for each study with its specific analysed conditions – a limited but sufficient solar-thermal potential estimation. On the other hand, many important aspects are not taken into account. One of these aspects is the available roof area for collector mounting. Altogether this leads to inaccurate potential estimations and also to a wide range of determined potentials. Hence, the potentials within the studies vary from 0.3 … 4.5 % with regard to the thermal energy demands of the respectively analysed industry. For a more accurate estimation of the actual solar-thermal potential within a specific branch the development of a transferable evaluation methodology is necessary.

4. Approach and objectives of the methodology

The two project partners, a medium-sized brewery and a large-sized dairy, are basis for an exemplary potential analysis of solar-thermal energy use within the research project. The analysis mismatched the on-site examination of heat energy demand and available roof area. Table 2 shows the necessary collector area for the brewery to cover the state-of-the-art low-temperature energy demand is 4,800 m² in contrast to 3,500 m² of technically feasible collector area. More significant is the situation at the dairy were the necessary collector area is twice the technical feasible one.

Table 2. Comparison of low-temperature energy demand and collector area.

	Low-Temperature Energy Demand *(Solar-thermal energy potential)*	Necessary Collector Area*	Technical Feasible Collector Area
	[MWh]	[m²]	[m²]
Brewery	1,440	4,800	3,500
Dairy	3,440	11,200	5,400

* Solar-thermal System performance rating 300 kWh m^{-2} a^{-1}

The roof area for collector mounting was identified as the most critical factor for the solar-thermal potential and it is necessary to analyse this area more detailed. Not only the total roof area has to be considered in this connection, but also aspects as constructions (e.g. cooling towers) or light domes on it, as well as shading. A matrix that enables a quick and clear aerial view based analysis as well as a methodology for an estimation of the solar-thermal energy potential had to be developed.

5. Methodological definition of sub-sector specific solar-thermal potential

5.1. Methodology

As Fig 1 illustrates, the methodology is separated into five parts. A database generated by collection, analysis and evaluation of general statistical data available from statistical offices and sub-sector associations is the first step to be taken. For example the number and size of companies, the thermal energy demand or the volume of production are relevant information. Specific key figures are also available from a large number of sub-sectors associations or from literature and necessary for the potential determination. Otherwise these figures must be defined on basis of the collected statistical data.

These data allow to select a sufficient number of representative companies for the definition of a sub-sector average with its thermal energy demand, the number of employees or the volume of production.

The focus of the methodology is on the analysis of the roof area with the evaluation matrix and its defined criteria described in detail in Chapter 5.2.

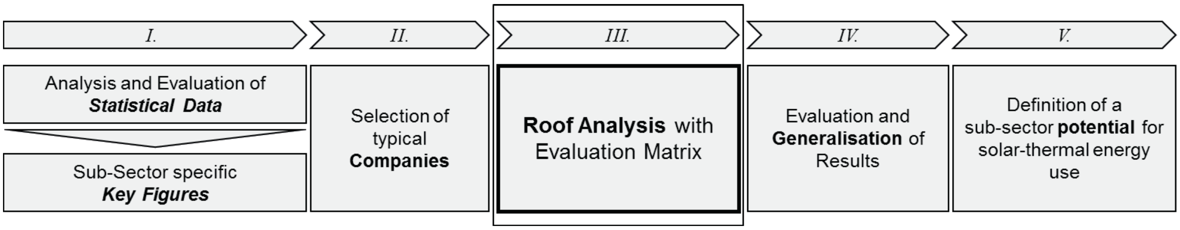

Fig. 1. Structure of Evaluation Methodology.

The final two steps aim to define a general sub-sector potential for solar-thermal applications. The results of the evaluation matrix are summarised to a sub-sector average and provide universally valid factors for a high quality prediction of the solar-thermal potential for the analysed sub-sector.

5.2. Evaluation matrix

An easy to handle evaluation matrix is the key issue of the methodology. Only four steps are necessary for preparation and accomplishment:

(1) Input Data is the building area (including production and administration) as well as a high quality aerial view of the company's site. Base area of buildings can be defined manually with construction plans or with any *GIS–software* (geographic information system). In this connection also the building orientation has to be obtained to predict the annually available solar radiation.

(2) The evaluation of the roof design distinguishes between flat roofs and saddleback roofs. For each roof design and its orientation, a *Collector Area Factor* for the maximum collector area concerning to the building's base area is defined. Figure 2 and Table 3 show exemplary factors. The result is the maximum collector area and the relation between the building's base area and collector area represented by the *Roof Area Factor B* (equation (1)).

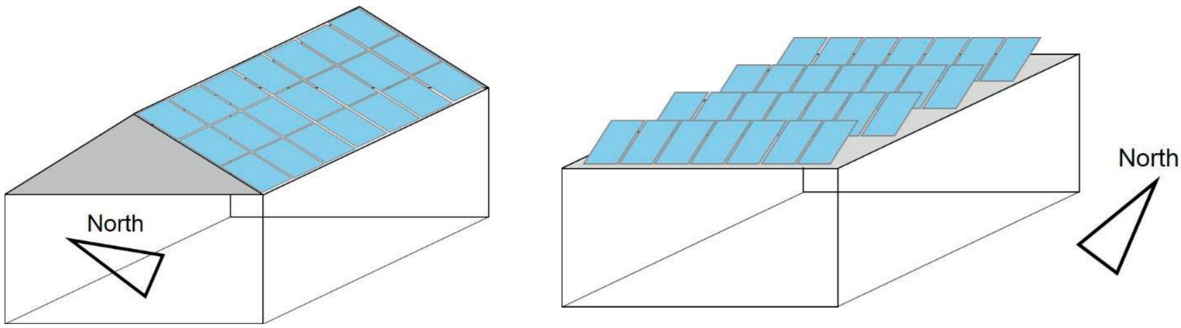

Fig. 2. Collector mounting Saddleback Roof (left picture); Flat Roof (right picture).

Table 3. Exemplary factors of roof evaluation.

	Direction	Collector Area Factor (CAF)	Comment
Flat Roof (Figure 2)	South	0.5	Full area useable
Saddleback Roof (Figure 2)	East to West*	0.55	Only one side usable
Saddleback Roof	North to South*	1.1	Both side usable
* with regard to the roof ridge			

$$B = RoofArea_1 \times CAF + RoofArea_2 \times CAF + RoofArea_n \times CAF \quad (1)$$

(3) The third step is a detailed analysis of the companies' roof structure by four criteria with defined evaluation factors (Table 4) and consider the following aspects:

- *Effectively available roof area* → areas with light domes, cooling towers, ventilation devices or any other structures are subtracted from the total roof area
- *Shading* → areas shaded by trees, chimneys, storage tanks
- *Continuous areas* → the possibility of large collector areas are analysed (not interrupted or separated by different building heights)
- *Number of buildings* → a large number of buildings results in numerous small collector arrays

Table 4. Evaluation criteria of roof structure.

Criteria		Evaluation Range (step rate)	Comment
C	Effectively available roof area	1 … 0 (0.1)	1 = full available
D	Shading	5 … 1 (1)	5 = no shading
E	Continuous area	5 … 1 (1)	5 = single huge area
F	Number of buildings	5 … 1 (1)	5 = single large building

The result of this step is a *Roof Structure Factor I* in the range from 0.01 to 1.0. Equation (2) shows the interaction of the four criteria. Multiplication of the *Roof Structure Factor I* with the *Roof Area Factor B* provides the company specific *Usage Factor II* (equation (3)) for the actually available collector area.

$$I = C \times \frac{(D + E + F)}{15} \quad (2)$$

$$II = B \times I \quad (3)$$

(4) The last step is the multiplication of the total base area of the buildings with the *Usage Factor II* resulting in a realistic estimation of the maximum collector area.

6. Exemplary application

With the brewery company *Allgäuer Brauhaus AG* the application of the methodology exemplary is illustrated. The *Allgäuer Brauhaus AG* is a medium-sized brewery with an annual rate of production of 200,000 hl_{Beer}. Figure 3 shows an aerial view as well as a layout plan (true to scale) of the production site.

According to the layout plan of the brewery's production site the base area of the building is about 13,300 m². As Figure 3 illustrates, nearly the complete roof area has a flat roof design apart from the small building at the lower right corner with a saddleback roof design. Therefore, the *Roof Area Factor B* is defined with 0.5.

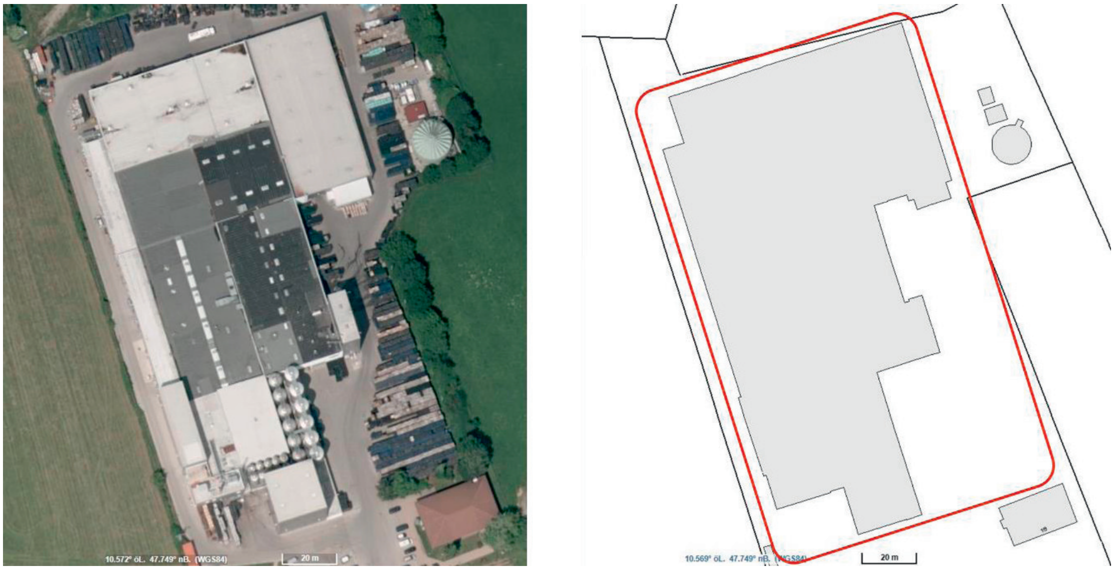

Fig. 3. Aerial view (left picture); Ground Plan (right picture) *Allgäuer Brauhaus AG* [7].

The other evaluation criteria (C to F) can be defined with the specifications given in Table 4. The roof of the production site provides mainly good conditions. The *Shading Criteria D* for example is defined with a specific evaluation of 5 because all building part are at the same level and no shading can be identified.

Table 5. Evaluation of the roof of *Allgäuer Brauhaus AG*.

Criteria		Specific Evaluation	Comment
C	Effectively available roof area	0.8	just a few light domes
D	Shading	5	nearly all building parts at the same level
E	Continuous area	4	large area useable (only interrupted by the light domes)
F	Number of buildings	4	one large building complex

With the results of the specific brewery evaluation (Table 5) and the definition of the *Roof Area Factor B*, the *Roof Structure Factor I* (Equation (4)) as well as the *Usage Factor II* (Equation (5)) can be determined.

$$I = 0.8 \times \frac{(5+4+4)}{15} = 0.693 \tag{4}$$

$$II = 0.5 \times 0.693 = 0.347 \tag{5}$$

The technically applicable collector area based on the evaluation is 4,600 m² for the Allgäuer Brauhaus AG. Important in this connection is the fact, that the evaluation as shown, does not allow any evaluation of the static conditions of the buildings. Hence, the collector area as defined is a maximum area and might be reduced by static restrictions.

7. Solar-thermal potentials at breweries and dairies

The collected statistical data as well as the specific key figures are basis for the determination of the overall solar-thermal potential for the German breweries and daires. Table 6 exemplarily shows the essential statistical data and key figures for the two sub-sectors.

Table 6. Statistical Data and Key Figures 2011 [8,9,10,11,12,13].

		Breweries	Dairies
Number of Companies	[-]	1,341	166
Volume of Production	[hl_{Beer} a^{-1}]	91,566,480	---
Volume of Processing	[t_{Milk} a^{-1}]	---	29,765,000
Thermal Energy demand	[GWh a^{-1}]	2,761.5	6,036.9
Specific energy demand	[kWh hl_{Beer}^{-1}]	30.2	---
Specific energy demand	[kWh kg_{Milk}^{-1}]	---	202.8

A large number of small companies with minor contribution to production and processing as well as small fractions of energy demand are part of the sub-sectors. Relevant are breweries with a rate of production > 10,000 hl_{Beer} a^{-1}. These 340 companies produce 98.5 % of the German beer. With regard to the rate of milk processing about 100 dairies > 50,000 t_{Milk} a^{-1} are of importance. These companies process about 96 % of the milk in Germany. For a representative and detailed evaluation a sufficient number of 100 breweries and 50 dairies has been selected. The results of the evaluation are shown in Table 7.

Table 7. Results of the analysis with the evaluation matrix.

		Breweries	Dairies
Specific building area	[m² hl_{Beer}^{-1}] / [m² t_{Milk}^{-1}]	0.0856	0.1122
Specific roof area	[m² hl_{Beer}^{-1}] / [m² t_{Milk}^{-1}]	0,0793	0.1053
Roof Area Factor B	[-]	0.649	0.609
Roof Usage Factor II	[-]	0.361	0.353

With the rate of beer production and the rate of milk processing (Table 6) as well as the *Roof Usage Factor II* (Table 7) the maximum collector area can be defined to 2.83 Billion m² for the brewery sub-sector and 1.8 Billon m² for the dairy sub-sector. The thermal energy available from this collector area can be determined with a specific energy output defined for solar-thermal systems. With regard to reviewed systems in operation as well as simulation results gained in the project “Solar Heat in the Liquid Food Industry” an annual system energy output of 300 kWh m^{-2} is achievable. As Table 8 illustrates this is a solar-energy supply of 849 GWh a^{-1} for breweries or 30.7 % of the thermal energy demand and 353.8 GWh a^{-1} for dairies or 6.4 % of the thermal energy demand.

Table 8. Solar-thermal potentials for German Breweries and Dairies.

		Breweries	Dairies
Thermal energy	[GWh a^{-1}]	2,762	6,037
Collector area	[m²]	2,830,000	1,180,000
Solar-thermal energy	[GWh a^{-1}]	849	353.8
Solar-thermal potential*	[%]	30.7	6.4

* with regard to total thermal energy demand

An exemplary comparison with the method of a more general potential study [4] shows completely different results in contrast to the potentials defined with Table 8. Basis for the potential there is an analysis of the thermal energy demand of nine industries selected with the requirement of favourable solar-thermal conditions. Therefore the possible solar-thermal energy supply for breweries is 331 GWh a^{-1} and for dairies 724 GWh a^{-1}. This is less than half for the breweries and twice as much for the dairies and illustrates the missing accuracy with the application of general potentials on basis of the thermal energy demand to specific sub-sectors.

8. Conclusion and further steps

The solar-thermal potentials (Table 8) strongly differ between breweries and dairies by factor five. On the one side, the dairy sub-sector is dominated by companies with very large rates of milk processing and respectively large energy demands. This leads into high specific rates of processing according to the base of production area and collector mounting area. On the other side, the brewery sub-sector consist of a large number of small- and medium-sized companies. This means a more favorable spread of the energy demand compared to the base area of production sites and results in a higher solar-thermal potential.

The exemplary definition of the solar-thermal potentials with the developed methodology illustrates the varying results just for breweries and dairies. With a view to other sub-sector specific conditions the potential may also differ in a wide range. First analysis results of the malt industry and the meat industry confirm this expectation. Furthermore, comparing these results with the results of other potential studies shows again the limited transferability for general potentials on specific sub-sectors. Hence, for the determination of a more convincing and detailed potentials it is necessary to analyse the respectively sub-sector on its own.

The methodology developed will be improved and its application. Therefore some more sub-sectors shall be analysed. It is planned to implement the methodology in an automated application, for example a Spreadsheet-Tool.

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