Renewable energy sources for industrial consumers - a past to present analysis of technical and financial efficiency

A Delcea\(^1\,^2\) and I Bitir-Istrate\(^1\)

\(^1\) University “Politehnica” of Bucharest, Faculty of Power Engineering, Energy Generation and Use Department, 313 Spl. Independenței, Bucharest, Romania

\(^2\) Corresponding author: aida.delcea@gmail.com

Abstract. Renewable energy sources represent one of the solutions to mitigate the impact energy production, transportation and use have on climate change. Solar heat for industrial processes is an emerging solution that has yet to reach its true potential. When an industrial consumer is considering installing an energy source on site, a technical and financial analysis is performed to find the optimal solution. However, the analysis is characterized by a certain degree of uncertainty due to the assumptions made, that influence the final decision. Hence, the profitability of renewable energy-based solutions can either be overvalued or undervalued when compared to a fossil fuel-based solution. In this paper, the solar heat potential for the industry in Romania is calculated. Then, a past to present analysis is performed in order to assess the real benefits an industrial energy consumer would have gained had he considered a few years back to cover a fraction of its heat consumption with a solar heat source, by using the real historic data regarding the energy market evolution. The results show that subsidies are necessary in order to make solar heating profitable and more appealing for industrial applications in the market conditions from Romania.

1. Introduction
Heating and cooling represent half of the energy demand in the European Union (EU) and most of it is presently covered with energy produced from fossil fuels. The impact that energy consumption has on the environment determines the scientific and policy making communities to find clean, environmentally-friendly alternatives to traditional heat and cold sources. \([1]\), \([2]\)

Solar heating and cooling are already mature technologies and numerous projects are being implemented and are working all around the globe. The solar heating and cooling market in the EU28 (including Switzerland) has evolved slowly but steadily in the last decade, growing from around 23 GW installed capacity in glazed collectors (flat plate and vacuum tube) in 2009 to 36.1 GW installed capacity in 2018. The corresponding collector area is 51.5 km\(^2\) and the estimated thermal energy generation from these sources is about 25.6 TWh. The top countries by installed capacity in solar heating and cooling are Germany, Greece, Italy, Austria and Spain (with over 2 GW in each country), while the highest installed capacity per capita can be found in Cyprus, with 0.6 kW per person. Higher market growth in recent years can be seen in Poland and Denmark, primarily due to governmental support programs. \([3]\)

However, solar heat still accounts for only 0.22% of the total final energy consumption in the EU28 and less than 0.004% in Romania and most solar thermal systems are used primarily for hot water production and space heating, mostly in residential and tertiary sectors. \([4]\), \([5]\), \([6]\).
The industrial sector is a good candidate for solar thermal implementation, due to the almost constant load over the year in most cases, especially when compared with uses like space heating. In Romania industry accounted for 28% (6.4 Mtoe) of the final energy consumption of 23 Mtoe in 2017 (see figure 1), considering the energy uses only. This share is between the one for the European Union (25% of 1061.2 Mtoe) and the one for the World (32% of 8838.5 Mtoe).

Out of the 6.4 Mtoe – 74.9 TWh final energy for industry in Romania, 66.97% (4.3 Mtoe – 50.1 TWh) was consumed in four industries: 21.17% in the iron and steel industry (1.36 Mtoe – 15.9 TWh), 20.84% in the chemical and petrochemical industry (1.34 Mtoe – 15.6 TWh), 15.86% in the non-metallic minerals industry (1.02 Mtoe – 11.9 TWh) and 9.09% in the food, beverages and tobacco industry.

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**Figure 1.** Share of final energy consumption (energy use) by sector for Romania (inner doughnut), EU 28 (middle doughnut) and for the World (outer doughnut) in 2017. Data sources: [4], [7].

**Figure 2.** Final energy consumption in industry (energy use) by fuel type for Romania (inner doughnut) and EU28 (outer doughnut) in 2017. Data source: [4].

**Figure 3.** Final energy consumption in industry (energy use) by subsector for Romania and EU28 in 2017. Data source: [4].
(0.59 Mtoe – 6.8 TWh). On a European level, these industries accounted for 55.65% (145.0 Mtoe - 1686 TWh) of the final energy consumption in industry (see figure 3). [4]

The industrial energy demand is mainly covered with natural gas and electricity, both in Romania and in the European Union (see figure 2). Their share in Romania is 36% (2.2 Mtoe – 25.9 TWh) and 30% (1.9 Mtoe – 21.7 TWh) respectively. The rest is covered with energy from solid fossil fuels, oil and petroleum products, heat, and renewables. The latter has a share of only 6% (0.4 Mtoe - 4.4 TWh) of the total final energy consumption in industry. For the EU28, electricity is the main resource, with a share of 35% (89.9 Mtoe – 1045 TWh), while natural gas accounts for 32% (83.2 Mtoe - 967.3 TWh) of the final energy demand in industry. The data for renewables and waste is higher than in Romania, with a share of 11% (27.3 Mtoe – 317.2 TWh). [4]

Regarding the end uses, most energy demand in industry represents heating and cooling demand, both on EU28 and Romania with a share of 73.92% and 77.30% respectively. Cooling accounts for just 4.15% and 2.40% respectively, so most of it is destined for heating purposes. Out of this, space heating has a share of 14.95% and 19.23% respectively, while high temperature processes have the highest share. However, low and medium temperature heating processes (<200°) and space heating, which have a high potential of integrating solar thermal technologies, have a cumulated share of 45.91% and 37.58% respectively (see figure 4).

The first purpose of this paper is to calculate the technical potential of solar heating in industry in Romania, in order to emphasize the importance this sector could play in the future development of solar energy. Tough there are similar studies for different countries in the world, no other similar study for Romania was identified by the authors. Secondly, a past to present analysis for a hypothetical solar heat application in industry will be performed, using real market data from Romania, in order to determine the technical and financial efficiency of such solution.

2. Solar heat potential in industry

2.1. Solar heat technologies

There is a large variety of technologies available that convert solar energy into useful energy. Classified by the form of the output energy, solar panels can be [2]:

- photovoltaic cells – produce electricity only.
- solar thermal collectors – produce thermal energy only.
hybrid collectors – produce both electricity and thermal energy.

Electrical energy can also be produced from high temperature solar thermal collectors, but through a series of intermediate thermodynamic transformations and not directly from solar radiation.

Solar thermal collectors convert the solar irradiation that hits its surface (absorber) into thermal energy by heating a heat transport fluid. The main criterion which can be used to classify them are the working temperature, concentrating ratio, the orientation and design. The main types of solar thermal collectors are [2], [6], [8]:

- Flat Plate Collectors (FPC) – low temperature.
- Evacuated Tube Collectors (ETC) – low and medium temperature.
- Compound Parabolic Collectors (CPC) – low and medium temperature.
- Parabolic Trough Collectors (PTC) – low and medium temperature.
- Cylindrical Trough Collectors (CTC) – low and medium temperature.
- Linear Fresnel Refractor (LFR) – low and medium temperature.
- Parabolic Dish Reflector (PDR) – medium and high temperature.
- Heliostat Field Reflector (HFR) – medium and high temperature.

Low temperature is considered below 100°C, medium temperature between 100°C-300°C and high temperature over 300°C. A detailed picture of the indicative temperature range for each type of solar collector is presented in figure 5. FPC and ETC are the most common technology for low temperature applications and are characterized by a unitary concentration ratio and flat absorbers. Concentration ratios over 1 can be achieved with CPC (1-5), LFR, PTC, CTC (10-50) and PDR, HFR (100-1000/1500). CPC, LFR, PTC and CTC have tubular absorber types, while PDR and HFR have point absorber types. Usually, tracking systems are used for higher temperatures collectors (single axis for medium temperature applications and two-axes for high temperature applications). Due to their high temperature potential, PDF and HFR are usually employed for power generation rather than heat production. [6], [9]

2.2. Potential industrial sectors and processes

Aside from space heating, there are many industrial processes that are suitable for solar thermal technologies. Although there are existing solar technologies suitable for high temperature industrial processes, they are mostly employed for power generation, hence this paper will mostly focus on low and medium industrial processes.

Make-up water heating, preheating and washing are the most common potential processes among all subsectors. The most promising sectors for solar heat implementation are food, beverages and tobacco (mainly dairy, tinned food, meat and beverages), chemical (including plastics and rubber), paper, pulp and printing, and textiles and leather. Figure 6 illustrates the temperature ranges for some industrial processes that require heat at low and medium temperature (<200°C). [5], [9], [10], [11]

A key challenge for the implementation of solar systems in industry is choosing the optimal solar thermal collector and method of integration into the existing industrial process. The solar technologies
for industrial processes are similar to those used in the residential applications (hot water production and space heating). The main differences consist in [9]:
- higher requirements of heating and cooling in industrial processes.
- higher temperature levels for industrial processes.
- industrial processes are often continuous.
Due to the wide range of potential industrial processes, each application will have different technical and economical efficiencies. Also, solar thermal energy cannot cover all the heat demand of most industrial processes, due to its intermittent nature. Hence, back-up solutions that use other fuels and appropriate control systems must be considered. The aspects that influence the feasibility of each solution are mainly [2], [9]:
- the type of process.
- the available area for the collectors.
- the characteristics of the heat demand.
- the process heat demand at various temperatures.
- the availability of thermal heat storage
- the availability of heat recovery units.
- the trends regarding energy costs.
- the capital and operational costs.

The most basic configurations of solar thermal integration in industrial processes include the solar collectors, the heat transfer fluid, pipes, pumps and heat exchangers, but also thermal storage and back-up heat source as optional components. [12] Such a configuration is illustrated in figure 7.

2.3. Potential industrial sectors and processes
In this subsection, the technical solar heat potential of the industrial sector in Romania is determined. The reference data used for calculations is the final energy consumption for energy use in industry available on Eurostat, in [4], for the year 2017.

Firstly, the heating and cooling demand by sector and end-use was determined. The share of energy for heating and cooling assumed in this study is the one determined in reference [1] for Romania in 2012. Also, the temperature distribution level of heating and cooling demand for industrial processes is assumed to be equal to the ones determined in reference [1] for the European Union, as detailed data for Romania was not available. The authors appreciate this assumption does not introduce high errors, as heating and cooling processes are similar across countries given the same industry. Results are presented in Table 1.

Secondly, the theoretical potential of solar heat for industrial processes was determined. This was done by adding the heat demand for space heating and low and medium process heating (under 200°C). The Iron and Steel, Non-ferrous metals and Non-metallic minerals sectors were excluded from the calculation, because of the high share of high temperature processes, which lead to a high potential for waste heat recovery that can cover the low and medium temperature demands, as explained in reference [5]. Also, a temperature of under 200°C was considered suitable for the most common solar collectors, the FPC and the ETC. This leads to a theoretical potential of 20.5 TWh, 27.37% of the final energy consumption in Romania in 2017 for industry or 7.89% of the final energy consumption in Romania in 2017.

The difference between the theoretical and technical solar heat potential are given by the following restrictions [5]:

Figure 7. Basic configuration industrial process solar heating. Sources: [2], [12].
A solar fraction of 30% will be used to account for the fourth restriction. By applying these figures to cover the total heat demand.

In [5] it is assumed that only 40% of the theoretical potential can be used due to the first 3 restrictions. The difference between the production and demand.

- the necessary space for solar collectors installation may be insufficient on-site.
- the difference between the production and demand.

In [5] it is assumed that only 40% of the theoretical potential can be used due to the first 3 restrictions. A solar fraction of 30% will be used to account for the fourth restriction. By applying these figures to the theoretical potential, the technical solar heat potential of the industrial sector in Romania resulted is 2.46 TWh, 3.28% of the final energy consumption in Romania in 2017 for industry or 0.95% of the final energy consumption in Romania in 2017. For comparison, Table 2 presents the technical potential technical solar heat potential of the industrial sector available from other studies for Germany, Italy, Austria, Spain, Portugal, Netherlands, China and for the World. The comparison will not be 100%

### Table 1. Calculated industrial heat demand with detailed temperature distribution for each industrial sector in Romania, in TWh.

| Sector                           | Space cooling | Process cooling | Space heating | Process heating | non-H/C |
|----------------------------------|---------------|-----------------|---------------|-----------------|---------|
|                                  | <30°C | -30+0°C | 0+15°C | <100°C | 100+200°C | 200+500°C | >500°C |       |
| Iron and Steel                  | 0.007 | 0.000 | 0.000 | 0.000 | 0.206 | 0.274 | 0.047 | 0.362 | 10.814 | 4.143 |
| Chemical and Petrochemical      | 0.033 | 0.622 | 0.187 | 0.167 | 0.844 | 2.373 | 1.267 | 0.255 | 7.791  | 2.067 |
| Non-ferrous metals              | 0.006 | 0.000 | 0.000 | 0.000 | 0.151 | 0.116 | 0.130 | 0.416 | 0.825  | 1.021 |
| Non-metallic minerals           | 0.028 | 0.000 | 0.000 | 0.042 | 0.581 | 0.196 | 0.956 | 1.319 | 6.659  | 1.714 |
| Paper, Pulp and Printing        | 0.004 | 0.000 | 0.000 | 0.006 | 0.106 | 0.116 | 0.855 | 0.045 | 0.014  | 2.092 |
| Food, Tobacco                   | 0.079 | 0.000 | 0.289 | 0.742 | 1.762 | 1.298 | 1.401 | 0.360 | 0.218  | 0.859 |
| Machinery and transport         | 0.108 | 0.000 | 0.000 | 0.009 | 2.368 | 0.226 | 0.653 | 0.218 | 0.000  | 0.658 |
| Other Industry                  | 0.116 | 0.000 | 0.002 | 0.083 | 2.483 | 0.670 | 4.066 | 1.432 | 0.000  | 5.914 |
| Total                           | 0.381 | 0.622 | 0.478 | 1.049 | 8.501 | 5.269 | 9.376 | 4.407 | 26.321 | 18.468 |

- heat recovery measures should be applied on-site prior to choosing a renewable energy resource to cover the total heat demand.
- even some low and medium temperature processes require heat supplied by electricity due to operational requirements.

### Table 2. Technical solar heat potential of the industrial sector in various countries. Sources: [6], [9], [11].

| Country   | Potential |
|-----------|-----------|
|           | TWh       | %         |
| Romania   | 2.46      | 3.28%     |
| Germany   | 16        | 3.40%     |
| Italy     | 8.9       | 3.70%     |
| Austria   | 1.5       | 3.90%     |
| Spain     | 1.4       | 3.40%     |
| Portugal  | 4.7       | 4.40%     |
| Netherlands | 0.6      | 3.20%     |
| China*    | 345.4     | 5.54%     |
| Global**  | 4166.7    | 10.00%    |
accurate as the temperature levels, industrial subsectors and temperature requirements vary across these studies. Also, the percentual value for China was determined as a share of the final energy demand only for the industries considered and the percentual value for the World was determined as a share of the final energy demand predicted for 2030. Nevertheless, a general idea can be made.

3. Case study
In this section we analyzed a hypothetical case study for the implementation of a solar heat system for industrial process heating (SHIPH). The technical and financial aspects considered for this analysis are presented in the following paragraphs.

The proposed solar system has a collector surface area of 100 m$^2$. The conversion factor for glazed collectors in domestic hot water applications is usually 0.44 [13], so we chose a slightly higher conversion factor of 0.5 to quantify the benefits of the continuity in demand of industrial processes. The annual global irradiation on horizontal (GHI) for this study was determined as the average of the GHI for the 10 most populated cities in Romania. For this purpose, the Global Solar Atlas online tool from [14] was used and a value of 1335 kWh/m$^2$/year was obtained. The estimated annual production of solar thermal energy was calculated with the following equation [13]:

$$E_{\text{solar}} = f_{\text{solar}} H_0 A_a$$  \hspace{1cm} (1)

where $f_{\text{solar}}$ is the conversion factor, $H_0$ is the GHI for the considered location and $A_a$ is the collectors’ aperture area. The resulted annual solar thermal yield is thus 66.8 MWh/year.

As for the financial input data, the price of the solar collectors was considered 500 EUR/m$^2$. This assumption was based on data presented in [6] and [15]. We assumed that the installations costs are 20% of the collectors’ costs, similar to reference [16]. The operational costs were estimated at about 1% of the investment costs per year, based on reference [15].

The financial analysis was performed for multiple scenarios. The first criterion for setting up the scenarios was the type of energy replaced by the solar energy. We performed the calculations for both natural gas and electricity, as they account for most of the final energy consumption in industry in Romania. The second criterion was the percentage of subsidies. Calculations were performed for percentages ranging from 0% to 90% of total investment costs. Also, as the price of both natural gas and electricity are different for industrial consumers with different energy demands, the financial analysis was performed for consumers in different consumption bands, ranging from IB to IF for electricity (20 MWh÷150000 MWh) and I2 to I6 for natural gas (>1000 GJ). The IA and I1 bands were not included because they are not suitable for the size of the collectors.

Figure 8. NPV and IRR evolution with subsidies quantum for natural gas replacement scenarios.
The hypothetical project was implemented in less than one year, in 2009, with commissioning taking place in early 2010. The lifetime expectancy considered for the solar collector is 20 years. For the first ten years of analysis, historical data of natural gas and electricity prices from Eurostat was used, VAT and other recoverable taxes excluded [17], [18]. For the 2020-2029 period, the considered increase of the prices was the same as the one recorded in the 2010-2019 period, for each consumption band. The discount rate used in the analysis is 5.5%. The reference moment for discounting was 2009.

The Net Present Value (NPV) and the Internal Rate of Return (IRR) were calculated using the predefined functions available in Microsoft Excel. The results were plotted and are illustrated in figure 8 for natural gas and in figure 9 for electricity.

For this case-study, in the current market conditions of Romania, SHIPH as an alternative to a natural gas-based source is not financially efficient without subsidies. Only for subsidies of over 60%, the NPV starts to become positive for I2 type consumers, while more than 70% subsidies are needed for NPV to become positive for I6 type consumers. Even if larger-scale projects are taken into consideration, that could potentially reduce the investment costs in collector down to 250 EUR/m², the project would still not be profitable.

However, SHIPH as an alternative to an electricity-based heat source is financially efficient without subsidies for the IB, IC and ID type consumers. For subsidies of over 10% of total investment costs, the NPV starts to become positive for even for IF type consumers. An alternative to subsidies in this case would be considering installing larger-scale SHIPH projects, that could cut down investment costs in collectors down to 250 EUR/m². However, a detailed analysis would be needed in this case because the increase in the installed capacity can lead to a decrease in the conversion factor.

4. Conclusions
This paper focused on solar heat production potential for the industry in Romania.

In the first part of the work, the technical solar heat potential of the industrial sector in Romania was determined to be around 2.46 TWh or 3.28% of total industrial demand, which shows a great potential that could be exploited.

The second part of the paper consisted in a past-to present technical and financial analysis of a hypothetical study-case that used real historical market data available. We showed that in the present market conditions in Romania, solar heat as an alternative to natural gas is not feasible. As an alternative to electricity, solar heat is at the limit of feasibility and not appealing, especially for industrial consumers with high energy consumptions.

Figure 9. NPV and IRR evolution with subsidies quantum for electricity replacement scenarios.
All things considered, financial support schemes are necessary for SHIPH to further develop. Although there was a support scheme for solar heat adopted in the past at a national level, called "Casa verde clasic", it was addressed only for tertiary (mostly public institutions) and residential sectors. As solar energy is an abundant, carbon-free resource and there is a great technical potential in industry to switch from natural-gas and/or electricity consumption to solar heat consumption, policy makers should seriously consider including the industrial sector in solar energy support schemes.

Further research might focus on practical applications for industries where a high potential for SHIPH has been identified and on solar heat for industrial process cooling.

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