Conference Proceedings

EuroSun 2014
Aix-les-Bains (France), 16 – 19 September 2014

Solar heat for agro-industrial processes: an analysis of its potential use in Southern Spain

Manuel Pérez-García[1*], Francisco J. Cabrera[1] and Ricardo Silva[1]

[1] CIESOL Solar Energy Research Centre. Joint Center University of Almeria-CIEMAT. Ctra. Sacramento, s/n, Almería E04120, Spain. Agro-food International Excellence Campus CeiA3.

[*] Corresponding author: M. Pérez-García. Tel.: +34 950015295. E-mail address: mperez@ual.es.

Abstract

This work presents an overview of the potential use of solar energy systems for agro-industrial processes in Southern Spain. Specific interest is given to Almería province, a location with high radiation levels where the existing production model, based on intensive agricultural exploitation, has resulted in the ongoing implantation of auxiliary industries, most of them with well identified thermal demands. Following the compilation of specific official socio-economic data sources, we identified and classified the industries and processes, including their corresponding temperatures and energy flow characterization. In addition to this, we present a preliminary estimation of the energy performance of different solar technologies for two selected case studies.

Keywords: process heat, solar energy, Andalusia, solar radiation.

1. Introduction

Industrial process heat is one of the more promising fields for using solar thermal technology, as has been comprehensively established by recent European reference reports and projects. Nonetheless, the number of installations presently in operation is still far from significant because of the inherent difficulties faced in developing a potential solar market; which unlike other solar technologies, such as photovoltaic, DWH or CSP, is extremely case dependent. Aspects ranging from the location constraints, the process temperature and the temporal production patterns make it more difficult to obtain uniform solutions in terms of the solar collector (both the size and technology), energy storage and systems operation. Specific analyses of demand are particularly valuable because they can provide further insight into potentiality studies not only for overall energy saving figures but also in terms of suitable systems configurations.

In general, transport and industry sectors are the main consumers of energy in the EU-27. In the case of process heat, the estimated percentages are 26%, 25%, and 33% for the EU-27, Spain and the Andalusian region (Southern Spain), respectively (Fig. 1).

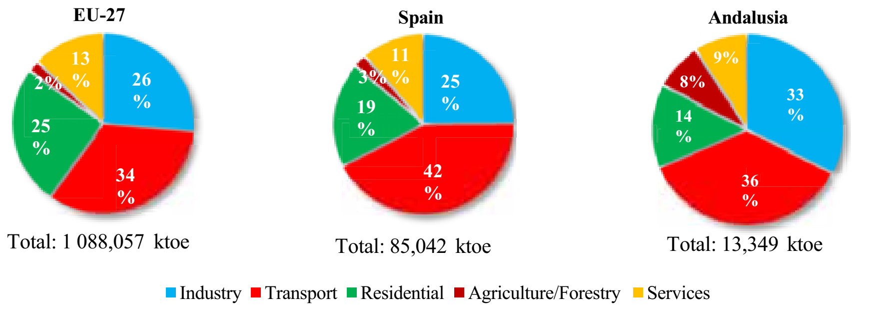


Fig. 1. Annual final energy consumption by sector in the EU-27, Spain and Andalusia (AAE, 2013; EC, 2013).

Many studies have assessed the potential for utilising solar heat in industrial processes (Kalogirou, 2003;

doi:10.18086/eurosun.2014.01.06 Available at http://proceedings.ises.org

Taibi, et al., 2012; Vannoni, et al., 2008). Thanks to these studies, the target sectors (chemistry, cement, metallurgy, ceramics, textiles, food, paper, glass, metal-mechanic, wood, rubber, extractives etc.) are well identified, as are the corresponding temperatures required for the processes' energy fluxes (Fig. 2). This temperature range is a key factor because it determines the most suitable solar collector technology. Accordingly, we can see that a significant percentage of the thermal demand is in the low temperature range (↓T_p), meaning flat-plate or evacuated collectors are suitable for use. Additionally, there is thermal demand in the 120< T_p ≤240ºC range; however, despite this also being process heat, consideration needs to be given as to the most appropriate solar concentrating technology, thus necessitating a wider approach to the systems configuration.
This present work particularizes the study of potential in the Andalusian agro-industrial sector (Southern Spain), and from there, to a more concrete approach that looks at Almería province. The characteristics of this case result in specific estimations aimed at evaluating the potential use of solar installations to drive such industries: high availability of solar radiation, the existence of modern and highly productive schemes based on intensive cropping technologies, the presence of additional thermal requirements related to auxiliary industries (packaging, plastic manufacturing, food preservation etc.) and, finally, the need to contribute to existing ecological approaches regarding plant cultivation and processing.

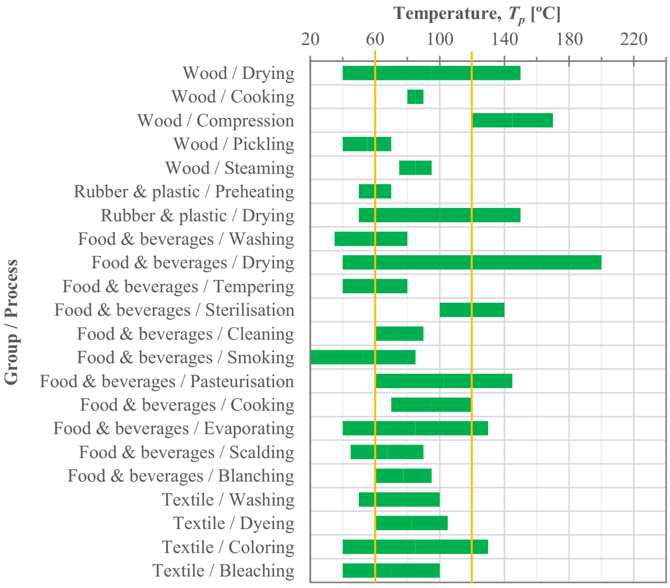


Fig. 2. Process temperature for heating applications in several industry groups (Aidonis, et al., 2002; Kalogirou, 2003; Lauterbach, et al., 2012; Monjo, 1988; Müller, et al., 2004; Schweiger, 2001).

2. Materials and methods

2.1. Thermal energy demand by industry

The starting point was a Spanish reference document charting the industrial application of solar energy for the period 2011-2020 (Schweiger, et al., 2011), which used the European Classification of Economic Activities (NACE) as the basis for identifying and classifying over 30 industrial sectors. This basic information was then particularized using both regional and national official references (AAE, 2013; GRIA, 2013; IECA, 2011; INE, 2011a; INE, 2011b) as well as consultations, visits and surveys of local industries and users. Based on this overall approach, certain representative case studies were selected according to the availability of data for dynamic analysis and for the sizing and selection elements.

For each process, we took into account the thermal energy demand for the process temperature, T_p, as well as the heat recovery and losses in the distribution system, obtaining the final thermal energy demand as net demand (the gross demand less recovery) plus losses. For industrial cooling processes, in accordance with the methodology of (Schweiger, Vannoni, Pinedo Pascua, Facci, Baehrens, Koch, Pérez and Mozetic, 2011), we considered that these would be covered by solar thermal energy using an activation temperature, T_p^*, and the characteristic coefficient of performance, *COP*, for the particular -sorption system used. Therefore, the cooling processes are classified according to their temperature as; cooling (5ºC<T_p, T_p^*=85, *COP*=0.7), refrigeration (-10<T_p<5ºC, T_p^*=95, *COP*=0.6), freezing (T_p<-10ºC, T_p^*=150, *COP*=0.5).

2.2. Solar thermal energy

The capacity of a solar collector for thermal generation is determined in steady state by its characteristic curve (ISO 9806, 2013):

$$\eta_{a|G_t} = \eta_o \frac{K_{\theta b}(\theta)G_{b,t}+K_{\theta d}G_{d,t}}{G_t} - a_1\frac{(T_{col}-T_a)}{G_t} - a_2\frac{(T_{col}-T_a)^2}{G_t} \quad \text{(eq. 1)}$$

where $\eta_{a|Gt}$ [-] is the performance relative to the aperture area and the global radiation in the tilted plane of the collector (G_t [W m^{-2}]); η_o [-] is the optical performance; a_1 [W m^{-2} ºC^{-1}] and a_2 [W m^{-2} ºC^{-2}] are the characteristic thermal loss parameters; T_a [ºC] is the ambient air temperature; T_{col} [ºC] is the average fluid temperature in the collector; and $K_{\theta b}$ [-] and $K_{\theta d}$ [-] are the incidence angle modifiers for the direct $G_{b,t}$ [W m^{-2}] and diffuse $G_{d,t}$ [W m^{-2}] solar irradiance hitting the collector plane.

The performance of various types of solar collectors has been analysed: Flat plate collectors (FPC), Evacuated tube collectors (ETC), Ultra-high vacuum (UHV), Linear Fresnel reflectors (LFR) and Parabolic-trough Collectors (PTC) Each has a characteristic performance depending on the average fluid temperature in the collector and the incident radiation and outdoor climate conditions (Fig. 3). We aimed to evaluate the thermal demand for process heat at various temperatures, T_p≤60ºC, 60<T_p≤120ºC, and 120<T_p≤240ºC and carry out the simulations at the highest interval temperatures. We analysed the solar contribution for the 8 Andalusian provinces; Almería (AL), Cádiz (CA), Córdoba (CO), Granada (GR), Huelva (HU), Jaén (JA), Málaga (MA) and Sevilla (SE), using typical meteorological climate data generated with Meteonorm v.7, thus obtaining the thermal energy production for each type of solar collector (Fig. 3) at each location from hourly TRNSYS v.17 simulations.

As an overall approach, the simulations were carried out assuming that all the solar thermal energy produced by the solar collectors was used in the processes - given that, at this first stage, thermal storage was a non-limiting factor, which could be sized and optimised once each installation's specific design was undertaken. Figure 3 summarizes the standard stationary performance of the solar collectors considered in this study. In spite of the specific primary limitations of the technologies according to these curves, which make FPC and ETC solar collectors barely suitable for high temperature collector fluids, and PTC and LFR solar collectors worse than the former for low temperature processes, the simulations for the different T_p ranges were performed hourly on all the collector types for comparative purposes.

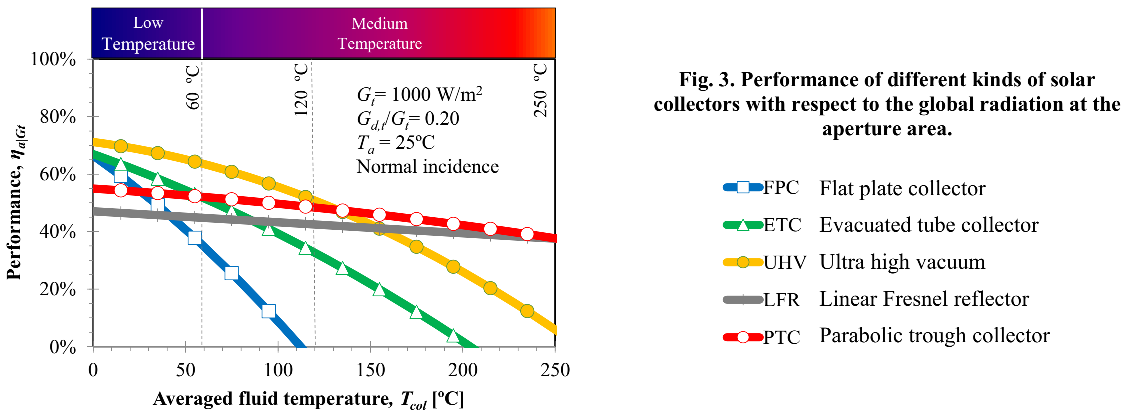


Fig. 3. Performance of different kinds of solar collectors with respect to the global radiation at the aperture area.

2.2. Solar fraction

Using simulations, the maximum annual thermal energy production Q [MWh yr^{-1}] was obtained for each type of solar collector, at each location, for each process temperature range (considering that T_{col}=T_p) per unit of aperture area A_a [m^2] (Fig. 10).

The annual solar fraction SF [%] (Fig. 11) on an aperture area, for each process temperature range, was obtained by dividing Q by the final thermal energy that the industry demanded (Net demand + Losses):

$$SF = \frac{Q}{Final\ thermal\ energy\ demand}100 \quad \text{(eq. 2)}$$

3. Results and discussion

In Andalusia, food product manufacturing (NACE Rev. 2= 10) is the industrial sector with, economically, the highest final energy consumption, making up 20% of the total - this represents 37% of this sector's national total. In the food industry, the subsector with the highest final energy consumption (Fig. 4) is fruit and vegetable processing (21%), followed by the vegetable and animal oils and fats subsectors (17%), bakery and farinaceous products (16%) and the processing and preserving of meat (16%). In economic terms, the main source of final energy consumption in the food industry is electricity – approximately 50% in all of the subsectors, followed by gas, and petroleum products (Fig. 4). These figures indicate that such industries possess great potential for using direct solar thermal energy, or conversion systems from solar energy into electricity (e.g. ORC, PV cells etc.).

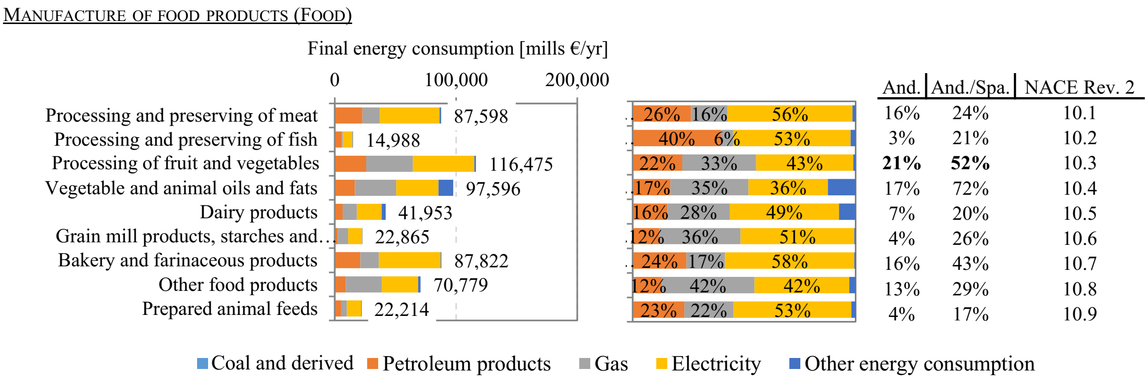


Fig. 4. Final energy consumption in economic terms per industrial subsector and the supply per sector for food production industries in Andalusia (IECA, 2011; INE, 2011a; INE, 2011b). [And, Andalusia; Spa, Spain]

With regard to agro-industries located in Almería province, the following subsectors have been identified following a specific survey:

- Food production (thermal soil disinfection, greenhouse climate control, water desalination).
- Greenhouse material manufacturing (plastic claddings, piping).
- Postharvest refrigeration and cooling (packhouses and logistic centres)
- Postharvest heating (preservation, cooking)
- Packaging manufacturing (paper, boxes, plastic envelopes for foods etc.).

After estimating the overall figures at a regional level, each basic industrial sector was characterized in terms of temperature and daily and seasonal operating patterns. Synthetic information was generated which was oriented to the dynamic analysis and sizing of solar installations for all of the industrial sectors. As an example, in this work two industrial subsectors are shown: (i) the processing and preserving of meat; as a transversal subsector, present in all of the provinces, and (ii) the processing and preserving of fruit and vegetables; as a local subsector of greater interest in the province of Almería.

3.1. Meat processing and preserving industries

These industries are dedicated to slaughter and meat preservation; the production and preserving of poultry and the manufacture of meat products.

Tab. 1. General industrial sector data for the meat processing and preserving industries in Andalusia.

10.1 (NACE rev 2) Processing and preserving of meat	**AL**	**CA**	**CO**	**GR**	**HU**	**JA**	**MA**	**SE**	**Andalusia**	**Industry pattern**
Industrial sites [nº] (and % AND/ESP)	55	85	57	63	35	40	133	157	625 (16%)	
Production [ud. t of meat in slaughterhouses]									823521	1281
Turnover [M€]	103	159	106	117	66	75	249	294	1171	2
Employees [nº]	1230	1898	1262	1397	790	892	2965	3500	13935	22
Fuel consumption [MWh]	68785	106108	70551	78092	44178	49866	165769	195633	778982	1247
Electricity consumption[MWh]	45331	69928	46495	51465	29114	32863	109246	128927	513367	822
Final energy consumption (heat generation) [MWh]	73318	113101	75200	83239	47090	53153	176694	208526	830319	1329
Electricity consumption (cold generation) [MWh]	9848	15191	10100	11180	6325	7139	23732	28008	111523	179
Available area [m²] (and % roof)	151819	234196	155716	172362	97508	110063	365878	431792	1719335 (76%)	2752 (76%)

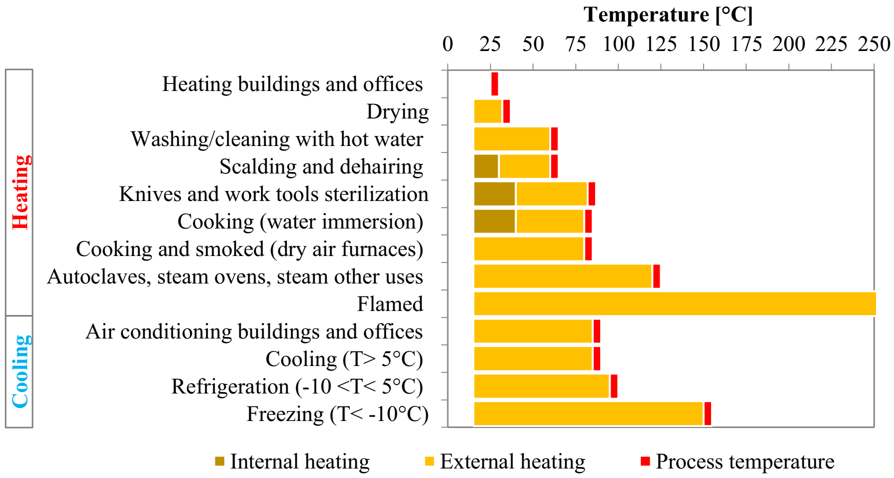


Fig. 5. Process temperature for heating and cooling activities in the meat processing and preserving industries.

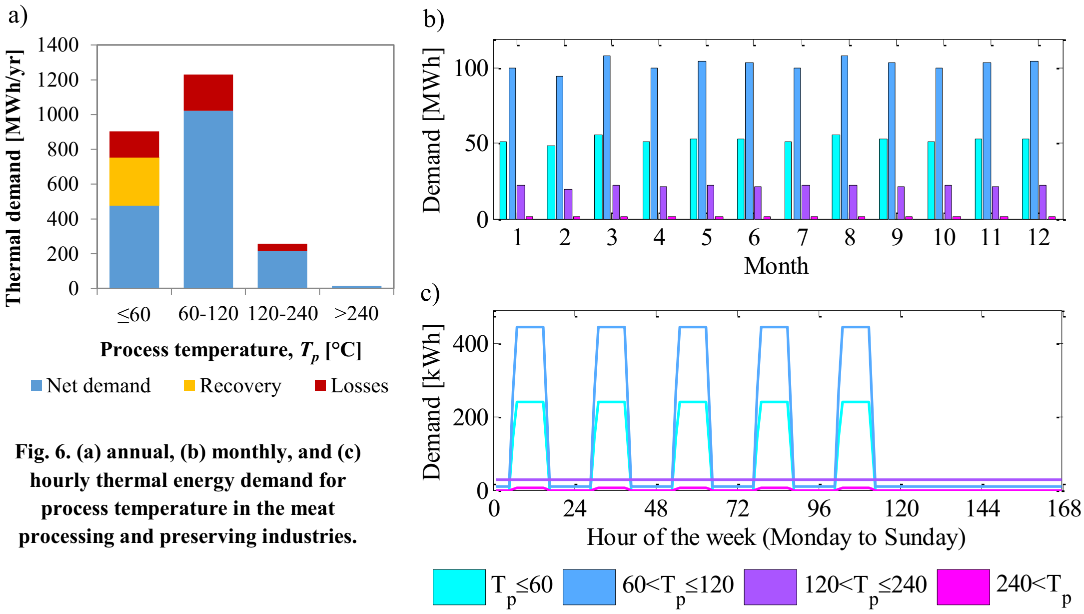


Fig. 6. (a) annual, (b) monthly, and (c) hourly thermal energy demand for process temperature in the meat processing and preserving industries.

3.2. Fruit and vegetable processing and preserving industries

These industries are dedicated to the preparation of frozen vegetables; the preparation and preservation of non-frozen vegetables; the preparation and storage of olives; the manufacture of canned fruit; producing grape juice; the manufacture of other fruit and vegetable juices and the processing and preserving of potatoes.

Tab. 2. General industrial sector data for the fruit and vegetable processing and preserving industries in Andalusia.

10.3 (NACE rev 2) Processing of fruit and vegetables	AL	CA	CO	GR	HU	JA	MA	SE	Andalusia	Industry pattern
Industrial sites [nº] (and % AND/ESP)	25	39	26	29	16	18	61	72	286 (24%)	
Production [ud t of finished product]									475642	2426
Turnover [M€]	103	159	106	117	66	75	249	294	1171	6
Employees [nº]	724	1116	742	821	465	525	1744	2058	8194	29
Fuel consumption [MWh]	78739	121463	80760	89394	50572	57083	189759	223944	891714	3116
Electricity consumption[MWh]	29180	45013	29929	33129	18741	21154	70323	82992	330462	1155
Final energy consumption (heat generation) [MWh]	80490	124164	82556	91381	51696	58352	193978	228924	911542	3185
Electricity consumption (cold generation) [MWh]	4775	7366	4898	5421	3067	3462	11508	13581	54077	189
Available area [m²] (and % roof)	36496	56299	37433	41434	23440	26458	87954	103799	413312 (74%)	1445 (74%)

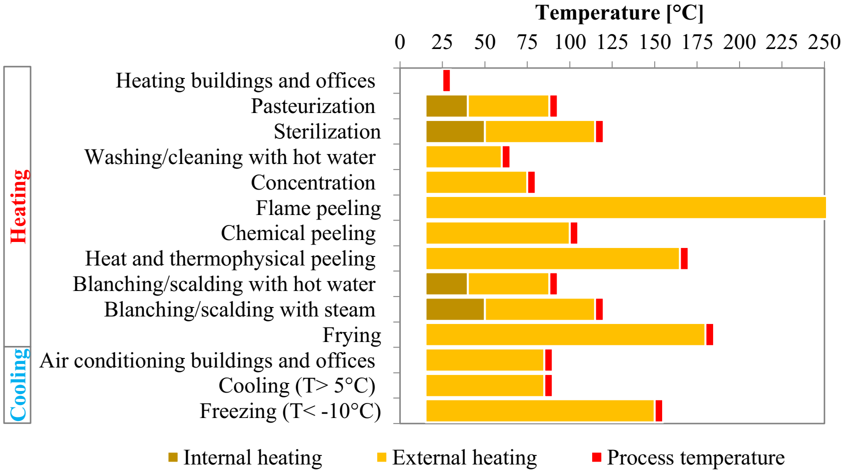


Fig. 7. Process temperature for heating and cooling activities in the fruit and vegetable processing and preserving industries.

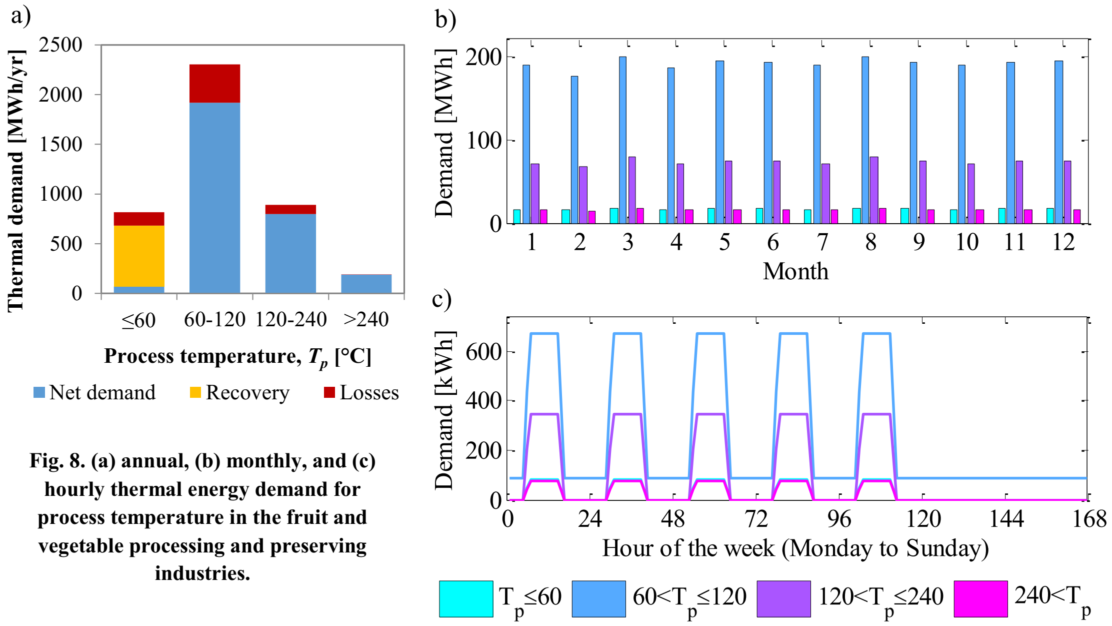


Fig. 8. (a) annual, (b) monthly, and (c) hourly thermal energy demand for process temperature in the fruit and vegetable processing and preserving industries.

3.3. Geographical information

To the above data we have added geographical information (Fig. 9) with the aim of integrating spatial solar radiation data sources.

a) b)

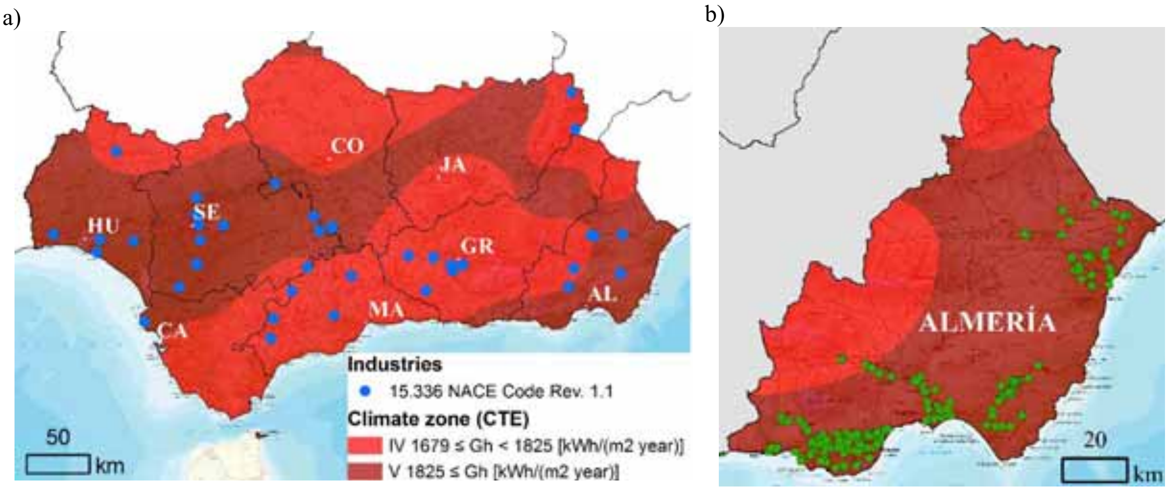


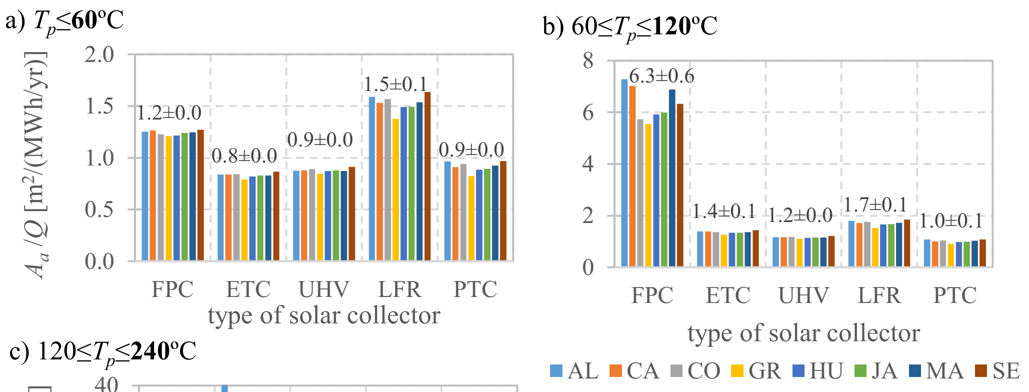
Fig. 9. Geographical distribution of (a) regional vegetable preserving industries (●) and (b) provincial vegetable packhouses and logistic centres (●) as well as climate zones.

3.4. Solar contribution

Figure 10 shows the aperture area required to generate 1 MWh yr^{-1} of thermal energy using different types of solar collectors, analysed from the different Andalusian provinces. The best performing solar collectors, for low temperatures (T_p≤60ºC) are ETC, UHV, and PTC (Fig. 10a); for medium temperatures (60<T_p≤120ºC), the PTC; and for higher temperatures (120<T_p≤240ºC), the PTC (Fig. 10b and c). PTC performance remained constant for all the temperature ranges since it was the best performing in all of them (Fig. 3).

Variability between Andalusian provinces is low, especially for lower temperature processes and for collectors with better performance; this is because the climatic conditions are similar.

The FPC collector cannot produce thermal energy at high temperatures due to it suffering the greatest heat losses.



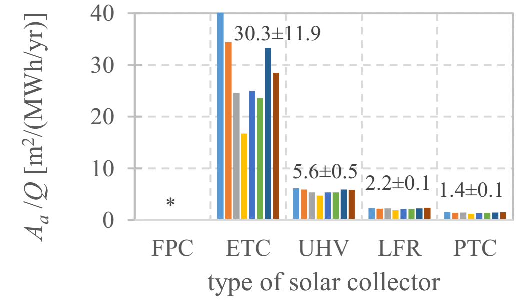


Fig. 10. Aperture area, A_a, by annual solar thermal energy production, Q, of different solar collector types, in the Andalusian provinces - for process temperatures, T_p, (a) 60ºC, (b) 120ºC, and (c) 240ºC. [*no solar thermal energy production].

For both types of industry analysed, the solar fraction, *SF*, (Fig. 11) is higher for the solar collectors with consistently better performance over all the aperture areas, obtaining high solar fractions even with a small solar field size at lower T_p (Fig. 11a.1 and b.1) – this is mainly due to lower thermal demand. For the same reason, the meat industry (Fig. 11a.) presents higher solar fractions for a given solar field size.

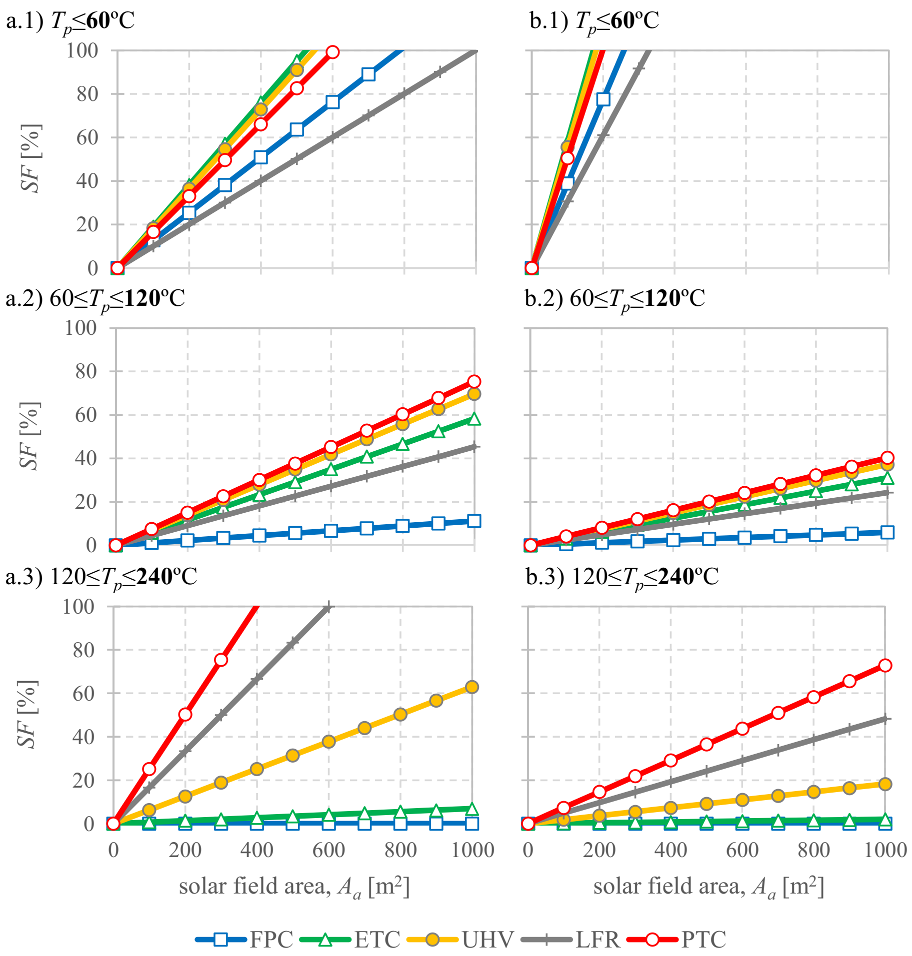


Fig. 11. Solar fraction, *SF*, for different aperture areas, A_a, of the solar collector types in (a.) the meat processing and preserving industries, and (b.) the fruit and vegetable processing and preserving industries - for process temperatures, T_p, of (.1) 60ºC, (.2) 120ºC, and (.3) 240ºC in Almería province (AL).

4. Conclusions

We have undertaken an analysis of potential solar energy use in Andalusia (Southern Spain). Geographical information was backed up with the spatial solar radiation resource. Tables and figures for thermal demand in the corresponding sectors were produced.

Industrial sectors, and particularly the agro- and food industries, possess great potential for solar thermal energy use.

The performance indicators for the main types of solar collectors elaborated in this work allow for a more considered selection of the most suitable technology, in energy terms, capable of meeting the corresponding heat demand for the sectors analysed.

5. Acknowledgements

This work has been supported by the *Consejería de Economía, Innovación, Ciencia y Empleo* of the *Junta de Andalucía* to whom we are grateful. We would also like to thank the FEDER funds, through Excellence Project P10-RNM-5927 “Simulation and Control of parabolic-trough solar thermal collector installations for process heat and cooling applications”.

6. References

AAE, info-Energy. (info-Energía), (2013). from http://www.agenciaandaluzadelaenergia.es/ciudadania/estadistica-info-energia.

Aidonis, A., Drosou, V., Mueller, T., Staudacher, L., Fernandez-Llebrez, F., Oikonomou, A., Spencer, S., 2002, PROCESOL II. Solar thermal plants in industrial processes: Design and Maintenance Guidelines., in, Pikermi, Greece.

EC, Eurostat. Energy statistics, (2013). from http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/introduction.

GRIA, Register of food industries of Andalusia. (Registro de Industrias Agroalimentarias de Andalucía), 2013 (2013). from http://www.juntadeandalucia.es/agriculturaypesca/gria/.

IECA, Directory of Companies and Establishments by Economic Activity in Andalusia. Year 2011. (In Spanish), (2011). from http://www.juntadeandalucia.es/institutodeestadisticaycartografia/iea/consultasActividad.jsp?CodOper=37&sub=42644.

INE, Industrial Companies Survey. Year 2011 (In Spanish), (2011a). from http://www.ine.es/jaxi/menu.do?type=pcaxis&path=/t05/p048/&file=inebase.

INE, Survey of energy consumption. Year 2011 (In Spanish), (2011b). from http://www.ine.es/jaxi/menu.do?type=pcaxis&path=%2Ft04%2Fp01&file=inebase&L=0.

ISO 9806, 2013, Solar energy - Solar thermal collectors - Test methods., in.

Kalogirou, S., 2003. The potential of solar industrial process heat applications. Applied Energy 76, 337-361.

Lauterbach, C., Schmitt, B., Jordan, U., Vajen, K., 2012. The potential of solar heat for industrial processes in Germany. Renewable and Sustainable Energy Reviews 16, 5121-5130.

Monjo, J., 1988. Aplicación de los colectores concentradores en la industria. Grupo Investigación Gas y Electricidad, S.A.,Palma de Mallorca. Era Solar Grupo Investigación Gas y Electricidad, S.A.,Palma de Mallorca. , 31-32.

Müller, T., Weiß, W., Schnitzer, H., Brunner, C., Begander, U., Themel, O., 2004, PROMISE. Produzieren mit Sonnenenergie: Potenzialstudie zur thermischen Solarenergienutzung in österreichischen Gewerbe und Industriebetrieben. Studie im Auftrag des Bundesministerium für Verkehr, Innovation und Technologie., in, Wien, Austria.

Schweiger, H., 2001, POSHIP. The Potential of Solar Heat for Industrial Processes. Final Report, in: Project No. NNE5-1999-0308, European Commission Directorate General Energy and Transport, pp. 174.

Schweiger, H., Vannoni, C., Pinedo Pascua, I., Facci, E., Baehrens, D., Koch, M., Pérez, D., Mozetic, L., 2011, Evaluación del potencial de la energía solar térmica en el sector industrial, in: Estudio Técnico PER 2011-2020, IDAE, Madrid, Spain.

Taibi, E., Gielen, D., Bazilian, M., 2012. The potential for renewable energy in industrial applications. Renewable and Sustainable Energy Reviews 16, 735-744.

Vannoni, C., Battisti, R., Drigo, S., 2008, Potential for Solar Heat in Industrial Processes, in: 33/IV, T. (Ed.), CIEMAT, Madrid.