Solar Energy Opportunity Map for the Spanish Microbrewery Industry

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Abstract

Microbreweries are less energy-efficient and pay higher energy price than larger breweries. In addition, although in Spain the electricity price is up to 5 times higher than the natural gas, full-electric microbreweries have been identified. The integration of solar thermal systems is seldomly economically attractive since the production profile is commonly performed by batches during non-consecutive days. In this study, the Levelized Cost of Heat and Cold is calculated for a microbrewery located in the south of Spain, as a reference case. To achieve this, the heat and cold demand, the electricity consumption, and the price of the components and electricity are considered. Employing TRNSYS the heat and cold is calculated. Furthermore, it is proposed to install a PV system of 10 kW_p to reduce the LCOHC. The results are then obtained for the 52 Capitals of the Provinces of Spain. For the reference case the LCOHC varies between 0.28 and 0.323 €/kWh. When the PV system is considered in the calculation, the LCOHC is reduced to the range of 0.249 - 0.305 €/kWh. Moreover, the Discounted Payback Period is between 9.8 and 19.5 years. Additionally, a production profile that quintuples the actual beer production is proposed with a larger PV system. In this case the LCOH can be reduced to the range of 0.17 to 0.21 €/kWh. Therefore, the main contribution of this study is to show that regardless the location in Spain, the integration of a PV system in a full-electric microbrewery would always present economic benefits compared to the base case without self-generation.

Keywords: LCOHC, photovoltaic, industrial heat and cold, TRNSYS.

1. Introduction

In December 2019, the European Commission announced the European Green Deal project, aiming to make the European Union climate-neutral by 2050. Moreover, the industrial sector has a leading role to play in the transformation towards a carbon-neutral economy. Currently, it accounts for 20% of the EU's of greenhouse gas emission (European Commission, 2019). According to the energy consumption of a company, it can be classified as energy-intensive or non-energy intensive. Therefore, this designation works as a starting point to identify energy efficiency potential of a company. Although the EU designates the food and beverage manufacturing as non-energy intensive, it is classified as an energy-intensive industry by U.S. Energy Information Administration (U.S. EIA, 2019). Besides, producing beer is a highly energy-intensive process accounting for up to 8% - 9% of total production costs (Sturm *et al.*, 2013; Kubule *et al.*, 2016).

Numerous studies of solar energy for the brewing are focused on medium and large size breweries. (Schmitt et al., 2012; Lauterbach et al,. 2014,Eiholzer et al., 2017). Small and medium sized enterprises (SMEs) are diverse and commonly require actions targeting specific needs. The case of small and microbreweries is an example of this. Regarding energy consumption, three main characteristics are worth to mention:

- Small breweries cannot purchase large centralized efficient boilers and chillers that run continuously.
- Heat recovery strategies are challenging to apply, as the beer production is a batch process often performed on different days. Hence, additional costs for energy storage are involved.
- Since they are small energy consumers, their energy contracts are usually as regulated users, increasing the energy price compared with larger industries that negotiate more competitive prices.

Additionally, the number of microbreweries has steadily raised globally in the past two decades and the trend is that the market will continue to expand (Garavaglia and Swinnen, 2017). For instance, in Europe the number of microbreweries increased from 3,020 in 2011 to 8,203 in 2019. Particularly in Spain, a traditionally wine producing country, the number of registered microbreweries has increased from 70 in 2011 to 379 in 2019 (The

doi:10.18086/swc.2021.29.07 Available at http://proceedings.ises.org

Brewers of Europe, 2021). When all Spanish microbreweries are counted, not only those in the official national registry, but the number of microbreweries also reaches 998 (for 2018).

The brewing process requires heat, cold and mechanical power. Commonly, heat is provided with fossil fuel, e.g. natural gas, whilst the latter two with electricity. However, certain microbreweries are operating completely on electricity since it is easier to comply with industrial safety regulation.

A previous feasibility study in Chile was performed by the authors based on a microbrewery that employs liquefied petroleum gas (LPG) for heat and electricity to supply cold by employing a compression chiller. One conclusion was that for a solar thermal system the discounted payback period can as low as 3.83 years, saving 40% of the annual thermal energy demand. Moreover, for a PV system that covers 82% of the annual electricity consumption, a DPP of 5.2 years can be achieved in provinces with high solar irradiation and high electricity price from the grid (Pino et al., 2020). On the other hand, a microbrewery located in Seville (Spain) can reduce its natural gas consumption and the corresponding CO_2 emissions by integrating a solar thermal system (flat-plate collectors). Nevertheless, the DPP is over 29 years due to the low natural gas price in Spain (Pino et al., 2019).

Furthermore, one of the few energy-related studies for microbreweries is based on a case study in South Africa. It presents an optimal solution, obtained by simulation results, to reduce the energy cost by implementing a grid-connected tracking PV system and a battery storage to the microbrewery (subjected to demand response). A payback period for the complete PV system of 13.8 years is reached.

In Spain both electricity and natural gas prices are regulated for small consumers. Since electricity price is between 0.126 and 0.199 €/kWh (3.0A tariff), whilst natural gas is 0.0414 €/kWh (TUR 2 tariff), both including specific taxes and distribution fees but not VAT, full-electric breweries have higher saving potential by including solar energy. Among the 100 breweries with larger PV systems reported globally in 2019, 74 are located in the U.S., 11 in Australia, and only 7 in Europe (van der Linden and Wolf, 2019).

This study presents an opportunity map for photovoltaic solar energy integration in Spanish microbreweries based on the Levelized Cost of Heat and Cold (LCOHC). The load profile is based on an actual Spanish microbrewery. Through simulations performed in TRNSYS the annual heat and cold demand are estimated for different location (Klein *et al.*, 2011). In addition, the investment cost and electricity tariff allow to calculate the LCOHC. Therefore, the main contribution of this study is to present economic feasible alternatives to conventional energy use in microbreweries, which commonly are not considered in the potential for solar energy analyses due to their small size and their challenging batch process.

2. Methodology

In order to calculate the Levelized Cost of Heat and Cold (LCOHC) it is vital to know the heat and cold demand. In addition, to calculate the demand for different location a simulation model that considers the local ambient conditions must be created. For that purpose, the methodology employed in this study is:

- Definition of the load profile and temperatures of the process.
- Adjustment of empirical models for the components that supply heat and cold.
- Simulation in TRNSYS of the components that represent the brewery's energy load and calculation of heat and cold demand, and electricity consumption.
- Calculation of the LCOHC for the different scenarios proposed, varying PV installed capacity and location.
- Creation of maps employing Geographical Information System (GIS).

2.1. Load profile:

Since the brewing process is performed in batches, especially in micro and small breweries, there is no common load profile that represents them all. In addition, the energy consumption is frequently required for short periods of time, causing high peaks of energy demand. To reduce this impact, thermal storages (hot and cold) are usually installed. Moreover, microbreweries commonly lack a centralized monitoring and control system. Therefore, to define the load profile for this study, a description of the process by the master brewer helped in establishing the temperatures and duration of the different stages. In addition, the electric bills were reviewed.

There are three main components to supply the heat and cold demands:

- HVAC system for heating and cooling of the conditioning room. It is an air-air reversible air conditioner and heat pump. It works under an on-off scheme. The set temperature is 20°C.
- Water chiller to provide water (15% glycol) at -2 °C, which is stored in a 1.2 m^3 cold storage tank.
- Electric heat resistors. There are 2 heat resistors of 10 kW that supplies heat to two kettles.

Non-invasive sensors were installed to obtain detailed data of the energy consumption and the temperature that define the process for 8 months, covering both winter and summer months. The temperature sensors were placed inside the conditioning room and at the water and air inlets and outlets of the chiller. In addition, energy monitoring clamps were installed in the HVAC system for a short period (2 weeks), then they were installed at the chiller and at the central board that control the heat resistors.

2.2. Modeling the components:

First, to model the HVAC system performance, the heat and cold demand of the conditioning room were estimated. The conditioning room is inside the brewery's facilities, specifically in a warehouse which indoor temperature is not controlled. The warehouse partially absorbs the impact of the environment condition over the conditioning room, i.e. solar irradiation and ambient temperature. Therefore, the thermal losses of the conditioning room were calculated in steady state at each time step. In addition, the interior temperature of the warehouse was estimated by a sinusoidal equation (eq. 1) that varies throughout the year and between day and night.

$$T_{indoor} = T_{avg} + (T_{max} - T_{min}) \cdot \sin\left(\frac{t}{8760} \cdot 360 - 100\right) + sin\left(\frac{t}{24} \cdot 360 - 180\right) \qquad \text{(eq. 1)}$$

Where T_{indoor} is the dry-bulb temperature of the interior of the warehouse and T_{avg}, T_{max} and T_{min} are the annual mean, maximum and minimum dry-bulb temperatures of the location, respectively.

The U-value for the walls of the conditioning room is 1 W/m^2K and for the floor it is 2 1 W/m^2K. There are also infiltrations of 1/h and 4 hours per day it increases to 2/h, considering activities performed in the conditioning room.

The set point conditions of the conditioning room are 20 °C and 50% RH. And it is assumed that the HVAC system is capable to maintain it, therefore the heat and cold demand are calculated. Consequently, the electricity consumption is calculated employing the COP (winter) and EER (summer). These performance parameters are calculated for each time interval employing the empiric model developed by Cherem-Pereira and Mendes (2012) to estimate a correction factor Z (eq. 2). The nominal nameplate values of the equipment are: Heating capacity of 3.5 kW, $COP_{nominal}$ =3, and cooling capacity of 3.2 kW, and $EER_{nominal}$ =2.8.

$$Correction\ factor\ Z = \frac{Z_{real\ condition}}{Z_{nominal\ condition}} \qquad \text{(eq. 2)}$$

The correlation coefficients employed are the one presented by Meissner et al. (2014):

$$Z_{EER} = 1.3884740 + 0.076999 \cdot T_{wb,i} - 0.00093 \cdot {T_{wb,i}}^2 - 0.05425 \cdot T_{db,o} + 0.0002746 \cdot {T_{db,o}}^2 + 0.0001448 \cdot T_{wb,i} \cdot T_{db,o} \qquad \text{(eq. 3)}$$

$$Z_{COP} = 1.3884740 + 0.076999 \cdot T_{wb,o} - 0.00093 \cdot {T_{wb,o}}^2 - 0.05425 \cdot T_{db,i} + 0.0002746 \cdot {T_{db,i}}^2 + 0.0001448 \cdot T_{wb,o} \cdot T_{db,i} \qquad \text{(eq. 4)}$$

Where, $T_{wb,i}$, $T_{wb,o}$, $T_{db,i}$, $T_{db,o}$ are the wet bulb and dry bulb temperatures of the inside of the conditioning room (where the evaporator is) and the outdoor (where the condenser is) in °C, respectively.

To model the air-water chiller performance, the simplified Gordon-NG model is employed. It is recommended by the ASHRAE, due to its simplicity of resolution to estimate the coefficients. It allows to calculate the inverse value of the COP (eq. 5). (Lee et al., 2012).

$$\frac{1}{COP} = -1 + \frac{T_{ci}}{T_{wo}} + \frac{1}{\dot{Q}_e}\left(-\beta_1 + \beta_2\, T_{ci} - \beta_3\, \frac{T_{ci}}{T_{wo}}\right) \qquad \text{(eq. 5)}$$

This model has been chosen based on the information available from measurements, its ease of use and its adequate adjustment for machines that work with a fixed speed compressor.

In order to obtain the regression coefficients (βs) a dataset of 3654 observations was used. Each observation corresponds to measurement in a 1-minute interval. The R value of the regression exceeds 0.999. The regression coefficients obtained are: $\beta_1 = 0.03055$, $\beta_2 = 11.54$, and $\beta_3 = 698.98$. Therefore, the regression model presented in eq. 6.

$$\frac{1}{COP} = -1 + \frac{T_{ci}}{T_{wo}} + \frac{1}{\dot{Q}_e}\left(-0.03055 + 11.54\,T_{ci} - 698.98\,\frac{T_{ci}}{T_{wo}}\right) \quad \text{(eq. 6)}$$

Where, T_{wi} is the cold-water inlet temperature, T_{wo} is the cold-water outlet temperature, both in Kelvin, and heat $\dot{Q}_e$ is the heat removed from the water stream in kW.

Finally, for the heat resistors a COP = 1 is employed. Hence, all the heat supplied is equivalent to the electricity consumption.

2.3. Simulation model

A simulation model developed in TRNSYS 17 is utilized to calculate the total annual thermal demand. The meteorological information is obtained from Meteonorm in TMY format (Meteotest, 2018).

The heating and cooling loads for the conditioning room are calculated according with the thermal losses to the environment and infiltration mentioned above.

In order to calculate the heating load, an input file with hourly values of water volume employed for the different set temperatures is provided. For instance, the process demands water at 70 °C, 95 °C, and 100 °C during the boiling process. For the latter, there is also considered heat for evaporation (10% of the fluid mass). The sensible heat to reach the set temperatures considers the initial temperature of the water from the mains (location dependent), except for the boiling process where it starts at 70 °C.

The cooling load that the water chilled needs to supply is composed by 5 variables. Two variables are part of the process (a) when the hot wort is cooled from 100 °C to 20 °C (to start the fermentation) and (b) when it is cooled again to 2 °C (for maturation). These values are read from the input file as volume of fluid that needs to be cooled. In addition, the thermal losses to the environment (at T_{indoor} of the warehouse) are considered: (c) for the fermenters in fermentation stage, (d) for the fermenters in maturation stage, and (e) for the cold thermal storage. The U-value for the fermenters is 0.35 W/m^2K and for the cold storage 0.28 W/m^2K.

When all the heat and cold demands are calculated for one time-step, the electricity demand is also calculated employing the instant performance indicators for the different components (COPs and EER). The time-step of the simulation is 15 minutes.

Finally, in the same TRNSYS model the PV system is modelled. The PV generation is calculated employing Type 94a (rated efficiency = 16.3%, Vmp = 37.4 Vdc, Imp = 8.6 Adc), whereas the inverter is modeled utilizing the Sandia Performance Model for grid-connected PV Inverters (King *et al.*, 2007).

For each time-step, the electricity demand and the PV generation are compared to calculate if electricity is obtained from or injected into the grid. In addition, the values are separated in three periods for each day in order to represent the time-of-use (ToU) tariffs that regulate small and medium enterprises subject to the tariff 3.0A in Spain.

2.4. Levelized Cost of Heat and Cold (LCOHC) and Discounted Payback Period (DPP):

The Levelized Cost of Energy is a well-established metric to compare specific cost per unit of energy during the entire lifespan of the project. It gained recognition in the power generation industry as it was employed to compare different technologies, e.g. a coal power plant versus wind power.

When considering solar integration in an industrial process (or for residential use), it is not so clear to define what the initial investment, O&M cost, and supplied energy should be. Therefore, a system boundary should be established. For instance, it is important to define if the LCOE will consider only the solar part or also the auxiliary or existing components, a problem that power stations do not have since they are entirely built to supply electricity.

Within the results of IEA SHC Task 54 a guideline to calculate the Levelized Cost of Heat for solar thermal systems was published (Louvet *et al.*, 2017). The authors propose two levels for performing the calculation. The first one only considers the investment, O&M costs, and energy supplied by the solar system. The second one considers all the equipment employed to supply heat. Thus, the energy supplied is the total load. Consequently, the investment of the conventional system, e.g. a gas boiler, its O&M cost are also included in the analysis together with the solar system itself. The eq. 7 presents the formula to calculate the LCOH defined in the Task 54, where I_0 and S_0 are investment and subsidies, T is the period of analysis, C_t are the O&M costs for the period *t*, TR is the corporate tax rate, Dep_t is the depreciation for the period *t*, RV is the residual value after the period of analysis, *r* is the discount rate, and E_t is the heat supplied during the period which usually is an annual figure.

$$\mathrm{LCOH} = \frac{I_0 - S_0 + \sum_{t=1}^{T} \frac{C_t \cdot (1-TR) - DEP_t \cdot TR}{(1+r)^t} - \frac{RV}{(1+r)^T}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \qquad \text{(eq. 7)}$$

To calculate the LCOHC (including cold) the LCOH definition was used, however neglecting some terms regarding corporate accounting (like depreciation, RV and TR) since commonly microbreweries finances are similar to residential or SME instead of large corporations. In addition, as in Spain there are no current subsidies at a national level, they are not considered (some Autonomous Communities have some subsidies available, however they are not permanent and certain conditions apply).

The formula employed to calculate the Levelized Cost of Heat and Cold (LCOHC) is presented in eq. 8. In this study, a period of analysis of 25 years and a 5% discount rate are utilized. No VAT is considered in the costs.

$$\mathrm{LCOHC} = \frac{I_0 + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \qquad \text{(eq. 8)}$$

On the other hand, the Discounted Payback Period (DPP) is the amount of time that it takes (in years) for the initial cost of a project to equal to the discounted value of expected cash flows. It is employed to estimate the profitability of a project, considering the time-value of money. If the resulting DPP is lower that the lifetime of the project it is profitable. The initial cash flow would be negative due to the investment, but the cash flows of the next periods (years) will be positive. Therefore, the DPP will occur when the negative cumulative discounted cash flows become positive. The DPP can be calculated as in eq. 9.

$$\mathrm{DPP} = \text{Year before DPP occurs} + \frac{\textit{Cumulative Discounted Cash Flow in year before recovery}}{\textit{Discounted Cash Flow in year after recovery}} \qquad \text{(eq. 9)}$$

2.5. Cost structure

For the LCOHC calculation there are two costs that should be included: the initial investment and the annual O&M cost. The initial investment values considered for this study are presented in Tab. 1 (including installation). These values were obtained from local quotations to suppliers (March 2021, in Andalusia, Spain). The price for the PV system is estimated as for a residential system due to its size from Jäger-Waldau (2019). Moreover, the expected lifetime and annual cost of maintenance as a percentage of the investment are also presented (VDI-Gesellschaft Bauen und Gebäudetechnik, 2012).

Tab. 1. Investment and maintenance cost for the microbrewery's equipment.

Component	Investment incl. installation, [€]	Lifetime, [years]	Maintenance as % of Io
Resistors – 2 x 10 kW	2500	5	0.0%
Chiller – 7.5 kW	5000	15	3.5%
Chilled water tank - 1.2 m^3	2160	15	1.5%
HVAC – 3.5 kW	1100	10	3.5%
PV (Jäger-Waldau, 2019)	1100 [€/kWp]	25	2.0%

The operational costs consider mainly the "fuel" employed to supply the heat and cold, in this case, electricity. In Spain, the regulated users observe a fix term and a variable term in their electricity receipt. The fixed term is composed of the contracted power that, if it is exceeded during the month, a penalization fee is charged. The variable term depends on the energy consumed during the month. In addition, the tariff for SME (named 3.0A) considers 3 periods during the day: peak (P1), shoulder (P2), and valley (P3). Therefore, the contracted power cost is the sum of the three periods, and the energy costs are also divided according to the time if use. Tab. 2 present the values employed for this study, obtained from an actual electricity receipt of the studied microbrewery for March 2021. The fixed term is for the total year in euros per kilowatt. Additionally, there is a specific tax to electricity of 5.11% that affects the entire bill and VAT of 21%, which in this study is not considered for the LCOHC calculation. Moreover, a 3% electricity price annual increment is considered. Finally, since 2019 there is the opportunity for user with self-generation to inject the surplus generation to the grid and receive economic benefit for it, which is considered as a "negative cost" for this study. This compensation for selling electricity is expressed as a percentage of the purchased electricity price. This percentage is not fixed, instead each distribution company offers a regulated percentage for the user. The value presented in Tab. 2 is obtained from a formal quotation of March 2021. It is desirable that this percentage increases to encourage the distributed generation.

Tab. 2. Electricity price for a regulated user in Spain (Tariff 3.0A), employed in the study.

Electricity, ToU tariffs		
Contracted power: 25 kW		
P1 (peak)	42	€/(kW-yr)
P2 (shoulder)	26	€/(kW-yr)
P3 (valley)	18	€/(kW-yr)
Energy price P1	0.19	€/kWh
Energy price P2	0.17	€/kWh
Energy price P3	0.12	€/kWh
Specific Tax	5.11%	
VAT*	21%	
Estimated annual increment of price	3%	%/yr
Net-billing compensation ratio	23%	

Note: *VAT is not included for the LCOHC calculation

Consequently, the O&M cost for the LCOHC calculation has the form of eq. 10. The replacement cost of equipment only applies if one of the components has reached its lifetime in the period *t*.

$$C_t = \quad Replacement\ Cost\ of\ equipment_t + Maintenance\ Cost_t + (1+0.03)^{t-1} \cdot 0.0511 \cdot [\text{Contracted power } \cdot (\text{P1} + \text{P2} + \text{P3}) + \sum_{i=1}^{3}((enegy\ consumed_i - 0.23 \cdot\ enegy\ injected_i) \cdot energy\ price_i)] \qquad \text{(eq. 10)}$$

In this study, the DPP is only calculated for the PV system. Hence, the annual cash flows correspond to the energy that is saved of being consumed from the grid and the earnings from the injected electricity to the grid.

Finally, when the energy demand is obtained from the simulation, the costs are calculated and the LCOHC and DPP are obtained. When this process is performed in several locations, the results are location-dependent and they can be included in maps created employing QGIS software (QGIS Development Team, 2021).

3. Results and Discussion

The first result obtained from the simulation correspond to the energy demand for the actual location of the microbrewery. Since the TMY data does not represent and actual year, it is not possible to compare the results with actual measurement. Nevertheless, the results were compared for two weeks of data, one in winter and one in summer, where there were production days and the ambient temperatures matches the ones of the measurements, obtaining satisfactory agreement.

In addition, the LCOHC of the reference case for all the locations was calculated. It means, the LCOHC of the current solution to supply heat and cold (no PV) for the current production profile, which is one batch per week (650 l), performed on Thursdays. It was calculated for the 52 different climates of the Provinces of Spain. The results are presented in Fig. 1. It can be observed that the range of the LCOHC varies from 28 - 32 cent€/kWh. Certain warmer and colder regions present the higher values due to the lower efficiency of the chiller and HVAC system with extreme temperatures. Moreover, the temperature of the water from the mains impacts the heat demand. In addition, these values consider the electricity price depending on the time of the day where the energy is consumed, which happen to be more expensive during the working hours.

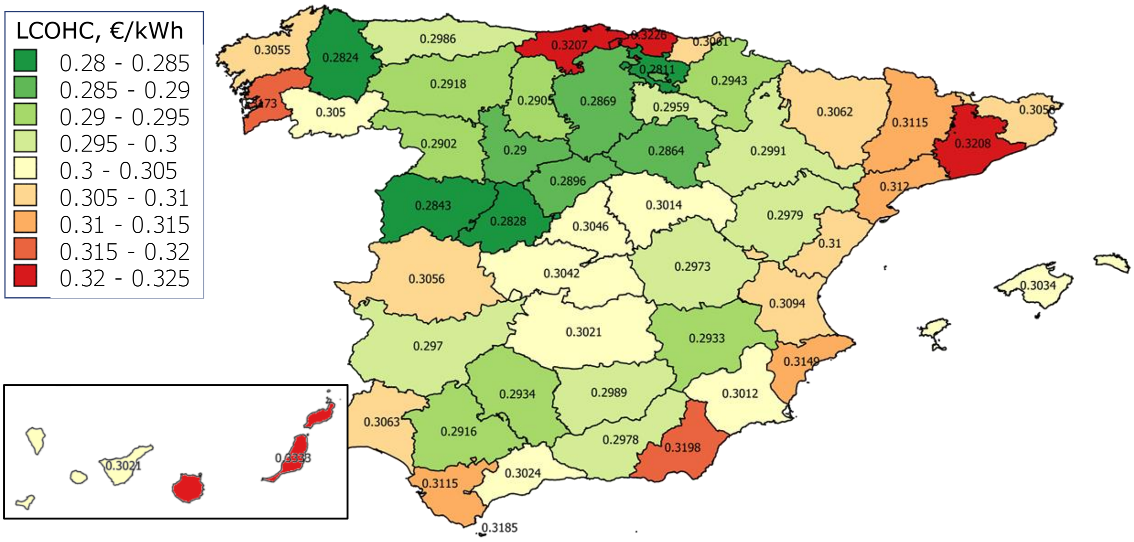

Fig. 1. LCOHC for the reference case not including PV in the different climates of the Capital of Provinces of Spain.

In order to select a size in PV system to be installed, a parametric analysis was performed for the actual location of the microbrewery (Jerez de la Frontera, Andalusia). The location has a latitude of 36°, Global Horizontal Irradiation (GHI) equal to 1903 kWh/m^2-yr, and average dry-bulb ambient temperature $T_{a,avg}$ = 17.6 °C. Fig. 2 present a contour diagram where x-axis represents the slope of the PV modules and the y-axis the installed capacity (from 1 to 30 kW$_p$). The color scale indicates in blue the lower values of LCOHC and the yellow color the higher. For the current location, it is observed that for a certain installed capacity, the lowest values are reached for a slope same as the latitude of the location (this is a climate with very hot summers). In addition, an optimum is not achieved. Hence, when the PV system is larger, lower values of LCOHC are achieved within the range of installed capacities analyzed. Nevertheless, there are other constraints that limit the total installed capacity:

- Roof available area. In this case it has not been considered.
- Distribution company limit: the maximum installed capacity should be lower than the contracted power, being 25 kW in this case.
- The payback period should be lower than the time of analysis, i.e., 25 years. In some regions with lower irradiation the PV system of 20 kW$_p$ was nor recovered.

Consequently, for the analysis of all the Provinces of Spain a 10kW$_p$ system with a slope same as the latitude is simulated.

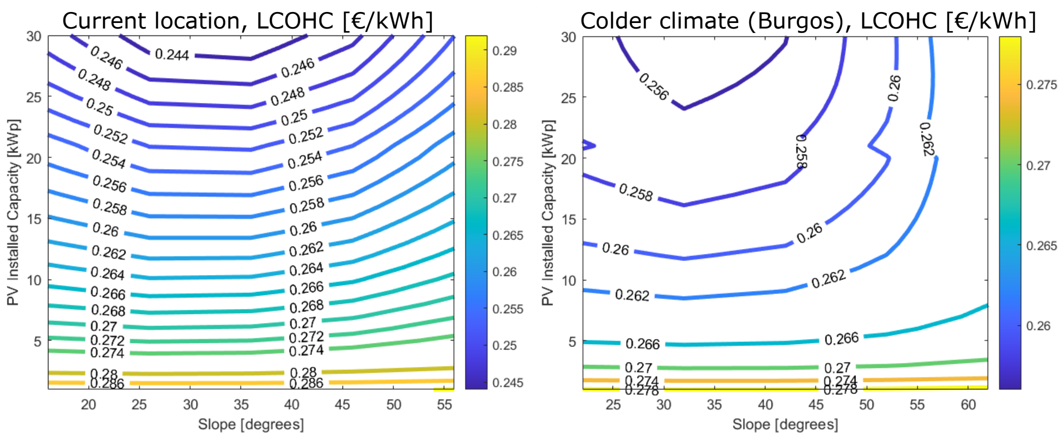

Fig. 2: Contour diagram for the LCOHC parametric analysis regarding slope and installed capacity of the PV system for Jerez de la Frontera (left) and Burgos (right).

In addition, it can be observed in Fig. 3 (right) the heat demand for the heat resistors and the cold demand for the chiller depending on the mean ambient temperature. Both curves show a linear behavior when increasing the ambient temperature. However, the cold demand of the chiller is more dependent since the slope of the curve is higher than for the heat resistors (in absolute value).

When COP of the components and the PV generation are considered to calculate the electricity purchased from and injected into the grid, it can be observed in Fig. 4 that electricity from the grid tend to decrease with the ambient temperature. However, there is no clear trend in the scatter plot for the electricity injected into the grid (left). On the other hand, when it is compared with the annual GHI (right), a clear trend of the electricity injected into the grid is observed (increasing with the GHI), nevertheless, there is no clear trend for the electricity purchased from the grid depending on the GHI.

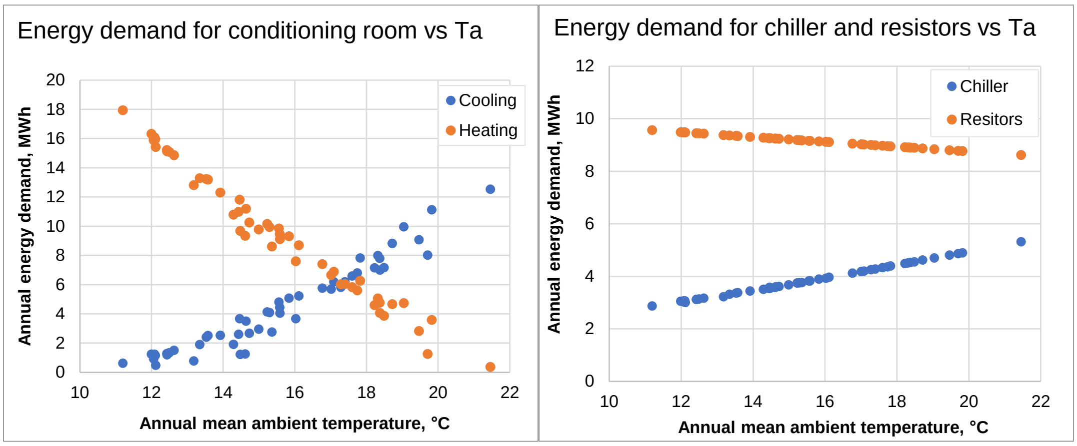

Fig. 3. Heat and cold demand supplied by the HVAC system depending on the annual mean ambient temperature of the 52 Provinces of Spain (left). Heat demand for the electric heaters (resistors) and cold demand of the water chiller depending on the annual mean ambient temperature of the 52 Provinces of Spain (right).

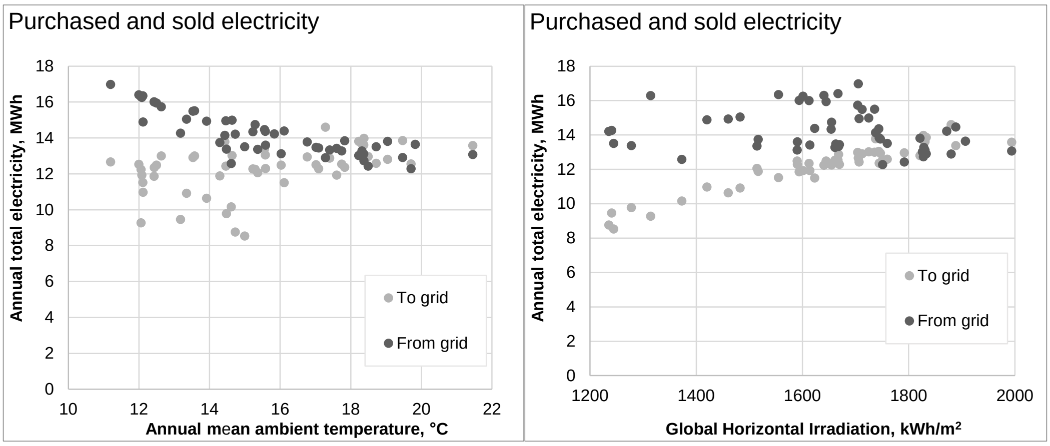

Fig. 4. Total electricity injected to the grid and bought from the grid when a 10 kWp PV system is installed, depending on the annual mean ambient temperature (left) and depending on the annual global horizontal irradiation (right) of the 52 Provinces of Spain.

Moreover, when the costs and cash flows are considered to calculate the LCOHC (Fig. 5), no clear trends are observed depending on the ambient temperature. For the scatter plot of LCOHC depending on the GHI, a slight negative slope can be noted, nevertheless, not completely clear. It can be inferred that higher PV generation (with higher GHI) reduces LCOHC, however, due to "hotter" climates the performance in cooling mode of the HVAC system and the chiller are reduced, hence more electricity for cooling is consumed.

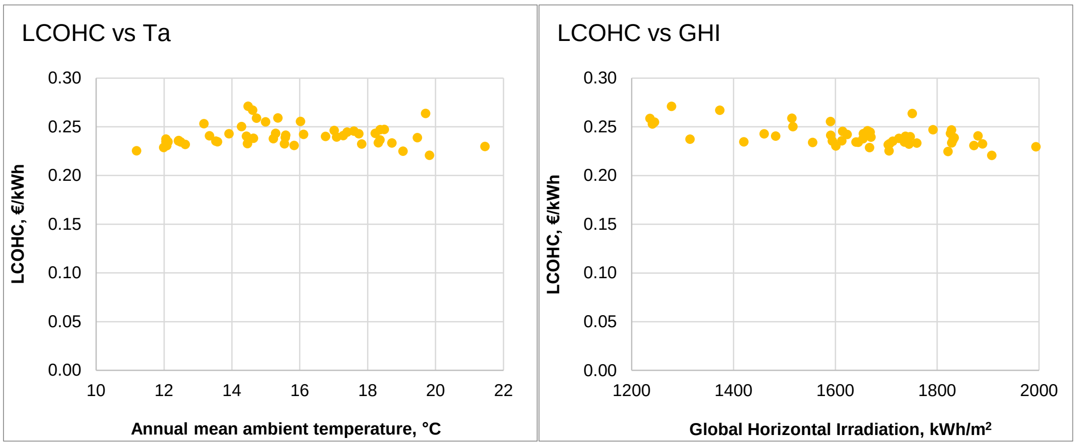

Fig. 5. LCOHC when a 10 kWp PV system is installed, depending on the annual mean ambient temperature (left) and depending on the annual global horizontal irradiation (right) of the 52 Provinces of Spain.

The map of LCOHC for Spain considering a 10 kWp PV system is presented in Fig. 6. Furthermore, a map presenting the DPP of the same system is shown in Fig. 7. On the LCOHC map it can be observed that the values are in the range of 24.9 cent€/kWh in Sevilla to 30.5 cent€/kWh in Cantabria. The behavior is mostly even in the inner regions, with the higher values in the Mediterranean coast, the Gran Canaria Island, and in the north of the peninsula, where less solar irradiation is available. The case of La Palma de Gran Canaria is odd, since the nearby Tenerife island, with similar climate, has noticeably lower LCOHC. This might be related to the specific weather file considered for the location. Nonetheless, the main observation is that for all the locations the LCOHC with the PV system is lower than the reference system (Fig. 1).

On the other hand, when the DPP map is observed (Fig. 7) it can be inferred that regions with lower irradiation have a longer payback period (mainly in the north). The DPP ranges from 9.8 years in Seville to 19.8 years in Cantabria. Since this value is highly dependent on the cash flows, the period could be noticeable reduced if the net-billing ratio is increased (currently 23%), and therefore the earning from selling electricity to the grid increases.

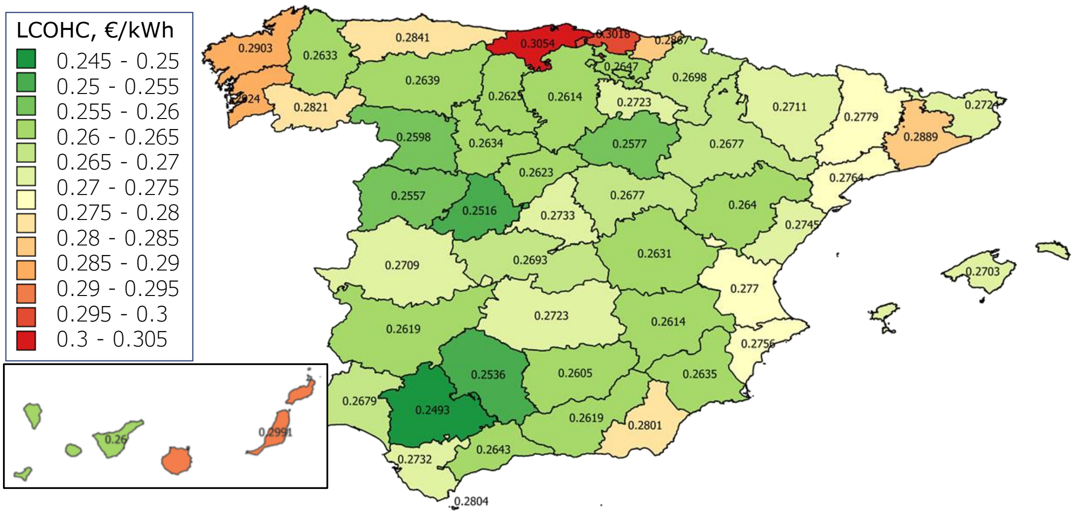

Fig. 6. LCOHC for the different Provinces of Spain considering the actual production profile and a 10 kWp PV system installed at a slope same as the latitude of each location.

Although 10 years (best case for DPP) are less than half of the expected lifetime of the PV system, when discussed with the microbrewery owners it was a too-long payback period for taking a decision in this regard. Commonly, microbreweries are in a market expansion stage in the first years, therefore other investments have financial priority. Hence, subsidies and/or flexible financial mechanisms for clean energy integration could be offered to foster the solar integration in the industries.

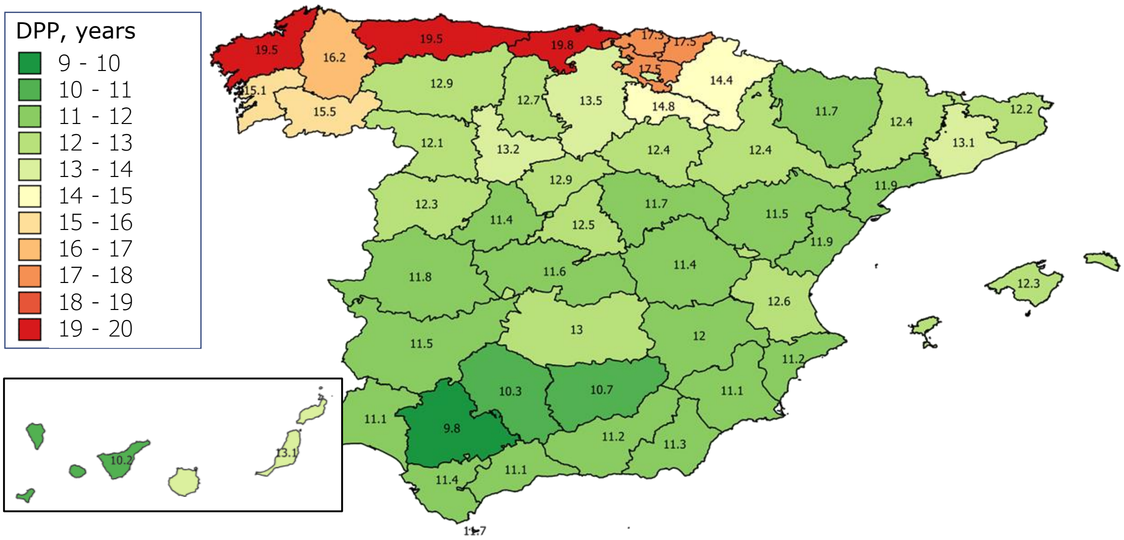

Fig. 7. Discounted Payback of a 10 kWp PV system installed at a slope same as the latitude Period for the different Provinces of Spain considering the actual production profile.

Finally, a case where the beer production is increased by 5 times has been analyzed, brewing from Monday to Friday instead of only on Thursdays. In this case some modifications of the components were considered:

- The capacity of the chiller and the volume of the cold storage were increased 3 times. Since the cold demand for one batch is the same, it was not necessary to increase them by 5 times. Nevertheless, it was increased by 3 times because in this case the fermentation process and maturation process require 5 times more energy since there are 5 fermenters for each stage instead of 1 (calculated for the hotter weather: Sevilla). The investment (and replacement cost) was also increased by 3 times, which affects the maintenance cost too.
- The HVAC system capacity was increased by 3 times. Although the volume of the conditioning room was increased five-fold, the area of the walls does not increase in the same proportion, hence the thermal losses to the environment do not increase 5 times. Similarly, the investment on the HVAC system was considered 3 times higher than the reference case.
- The PV system installed capacity in this case was increased up to 20 kW_p.
- The heat resistors were maintained the same since they are capable to produce 650 l of beer per batch.

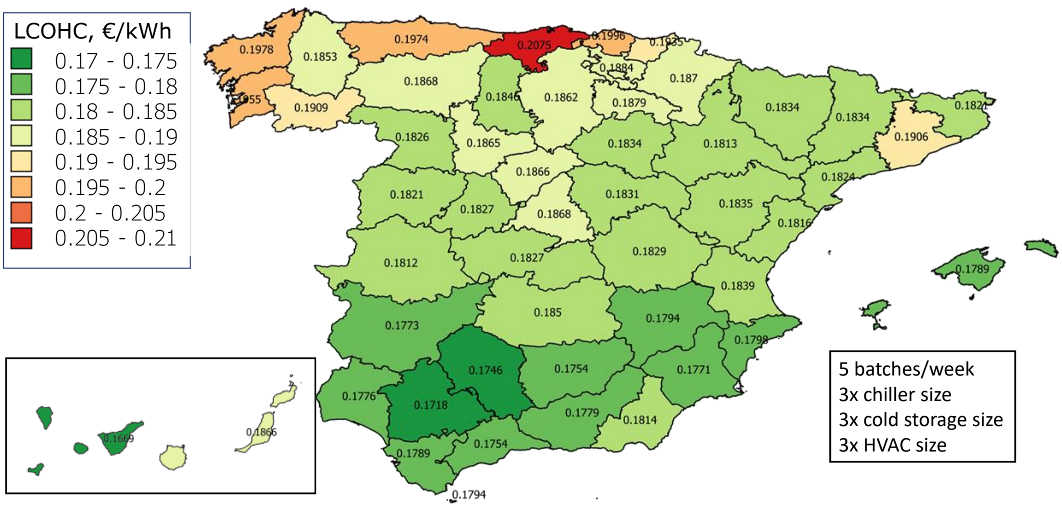

Fig. 8. LCOHC for an intensive production profile (5 times per week, Monday to Friday).

The results for this “intensive” production profile are presented in Fig. 8. It can be observed that the LCOHC is lower than the reference case and the regular production profile with 10 kW_p of PV. The range of the LCOCH is between 17.2 cent€/kWh in Sevilla to 20.8 cent€/kWh in Cantabria. These results are mainly due to a higher utilization of the components (chiller, HVAC, and resistances); hence, they are better amortized. In addition, to self-consume a higher share of the PV generation leads to higher economic benefits due to saving energy than selling it to the grid. The DPP for this case is in the range of 5.9 years in Seville and in Santa Cruz de Tenerife and 15.4 years in La Coruña.

Regardless of the "intensive" production profile presenting the lowest LCOHC, it represents a fictitious scenario that should be used as a benchmark for reference only. The labor would be highly increased, therefore, from the operation point of view it would be better to increase the size of the kettles and fermenters than the number of batches.

4. Conclusions

Although the brewing process requires heat at low temperature (<120 °C), there are few projects where solar thermal systems are integrated in the process. Therefore, the integration of a photovoltaic system to supply the heat and cold demand on breweries can lead to economic benefits. In this regard, for full-electric microbreweries the installation and operation of the PV system is simpler than solar thermal and supplies energy for cold and mechanical power. For the brewery of the case of study under the Spanish electric tariffs and solar resource, the PV system presented better results, i.e. lower Levelized Cost of Heat and Cold, for all the locations analyzed.

For this type of industry, where there are long periods where the product should be maintained under certain temperature condition, the heat and cold requirements are highly dependent on ambient temperature. However, the LCOHC has not a direct correlation with the ambient temperature since there are other effects affecting that impact the LCOHC. For instance, both the heat and cold demands tend to compensate the overall energy demand for hot and cold climates, commonly the locations with hot climates also have high solar irradiation levels, and the time-of-use tariffs also alter the energy cost depending on the time of day where the energy is consumed.

In addition, it is recognized that the Levelized Cost of Energy is highly dependent on the assumptions. For the LCOHC there is a similar conclusion, especially for the initial investment, energy price and energy price projections. Therefore, this study included the investment of all the components that supply heat and cold to be as thorough as possible.

Although, the net-billing ratio (23%) and the annual electricity price increment (3%/yr) are conservative, the LCOHC is lower than the reference case for all the locations analyzed (10 kW_p PV system). The LCOHC range for the reference case is between 0.28 and 0.323 €/kWh, whilst in the case including the PV system, it is between 0.249 and 0.305 €/kWh). The Discounted Payback Period of the PV system itself ranges from 9.8 to 19.8 years.

Nevertheless, the scenario where the production is increased by 5 times the components are larger, hence representing a higher investment, lower LCOHC values are achieved due to better amortization of the investment. The values of LCOHC in the intensive production scenario with a 20 kW_p PV system installed ranges from 0.17 to 0.21 €/kWh, whereas the DPP ranges from 5.9 to 15.4 years.

This study contributes to create knowledge regarding energy-related analyses for microbreweries. Commonly in Spain, the microbreweries do not know their energy consumption and perceive renewable energy as an expensive technology. The present results aim to encourage brewers to evaluate non-conventional energy sources, taking advantage of the current low price of PV, high available solar irradiation, and high electric prices from the grid.

Finally, to increase the renewable energy penetration in small industries, subsidies and flexible loans should be offered. Although in the scenario with no subsidies the PV system presents economic benefits, the brewery owners recognize that the payback period is too long and there are other investments that they would prioritize.

The future work that succeeds this study should include other solar technologies, e.g. solar thermal with and without concentration and hybrid PV-T modules, and a different load profiles, since brewing once a week is economically challenging to high-investment solutions as solar.

5. Acknowledgments

Alan Pino acknowledges the financial support from ANID PFCHA/DOCTORADO BECAS CHILE/2017.

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