Implementation of solar thermal and photovoltaic energy for the production process of corn tortillas

Implementación de energía solar térmica y fotovoltaica para el proceso de producción de tortillas de maíz

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This paper offers a method of implementing solar thermal and photovoltaic energy to reduce the consumption of gas and electricity from the network that a common business dedicated to the production of tortillas, thereby it is intended to contribute to the vector aimed at the implementation of clean energy, and also serve as a guide for these facilities become common not only in the field of tortilla if not in other small and medium enterprises. One of the key aspects of this research is to understand the import culture of the corn tortilla as a staple food in Mexican society as well as the process and cost of manufacture and thus be able to design alternatives to reduce costs through the implementation of new technologies. The implementation of a hybrid solar thermal - photovoltaic system is undoubtedly an excellent proposal for cost reduction in the production process of corn tortillas, it is also a responsible proposal that helps to reduce greenhouse gas emissions.

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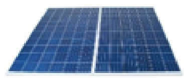
Abstract

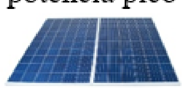
A methodology was developed for the implementation of solar thermal and photovoltaic energy in an establishment dedicated to the production of tortillas with an electrical consumption between 491 kWh and 572 kWh per year, with a consumption of 2,235 liters of LP gas weekly. The available solar resource was determined at an angle of 22 ° using the Liu & Jordan method, and the F-Chart method was also used for thermal sizing. For photovoltaic sizing, the critical month was selected, and the peak power that the photovoltaic system must have to generate the energy consumed by the electrical loads was also determined. It was calculated that 511.4 kg of LP gas and 2,984.76 kWh of electrical energy will be saved per year.

Implementation of solar thermal and photovoltaic energy for the production process of corn tortillas		
Objectives	**Metodología**	**Contribución**
Conduct energy consumption studies in a tortilla factory  Sizing the solar termal and thermal installation for a tortilla factory	Thermal sizing, Liu & Jordan method and F-Chart  Photovoltaic sizing, based on peak power 	Efficiency and sustainability in traditional food production  Decrease in LP gas and electricity consumption

Photothermal, Photovoltaic, Implementation

Resumen

Se desarrolló una metodología para la implementación de la energía solar térmica y fotovoltaica en un establecimiento dedicado a la producción de tortillas con un consumo eléctrico entre los 491 kWh y los 572 kWh bimestrales, con un consumo de 2,235 litros de gas LP semanalmente. Se determinó el recurso solar disponible a un ángulo de 22° utilizando el método de Liu & Jordan, así también para el dimensionamiento térmico se utilizó el método F-Chart. Para el dimensionamiento fotovoltaico se seleccionó el mes mes crítico, también se determinó la potencia pico que el sistema fotovoltaico debe tener para generar la energía consumida por las cargas eléctricas. Se calculó que al año se ahorrarán 511.4 kg de gas LP y 2,984.76 kWh de energía eléctrica.

Implementación de energía solar térmica y fotovoltaica para el proceso de producción de tortillas de maíz		
Objetivos	**Objetivos**	**Contribución**
Realizar los estudios de consumo energético en una tortillería  Dimensionar la instalación solar térmica y térmica para una tortillería	Dimensionamiento térmico, Método Liu & Jordan y F-Chart  Dimensionamiento fotovoltaico, con base a la potencia pico 	Eficiencia y sostenibilidad en la producción de alimentos tradicionales  Disminución del consumo de gas LP y electricidad

Fototérmico, Fotovoltaico, Implementación

Introduction

The corn tortilla represents a fundamental basis in the diet of Mexicans and South Americans, and being such a versatile element in the kitchen, it has been marketed in North America under the concept of fast food 'Tex-Mex food' and in Europe in the eighties, to later become popular around the world. However, it is in Mexico where we could say that this industry is fully developed, both in the production of corn tortillas and in the elaboration of nixtamal. 'The term nixtamal comes from the Nahuatl: nixté (ashes) and tomalli (cooked dough), as in ancient times the ashes of the cooker were used as a source of alkalis to achieve the cooking in an alkaline medium, necessary to give the desired texture to the dough and allow the starch to mix with the protein or gluten'.

The industry dedicated to the production of corn tortillas is large abroad, but even more so in our country, it is so important in the diet that it is included in the food basket where it is estimated that around 217.9 grams of tortillas are consumed per person per day, generating a monthly expenditure of approximately $147.04 mxn, representing 11% of the total estimated at $1,344.94 mxn per person. Taking this into account, we can say that the energy demand for its production is very important. For this reason, studies have been carried out to evaluate various alternatives not only to supply, but also to reduce this energy demand. Some studies are aimed at optimising the processes that are carried out either by making modifications to the mills, the maintenance that is given to them or the type of raw material that is used, testing different quantities of maize, maize flour, water and/or lime, and others are aimed at obtaining energy by other means to reduce costs caused by the same energy demand; examples of this are the attempts to implement clean energy in the production process or reusing heat that is normally wasted during the process (CONEVAL, 2021) (Juárez Hernández & Sheinbaum Pardo, 2019).

Box 1

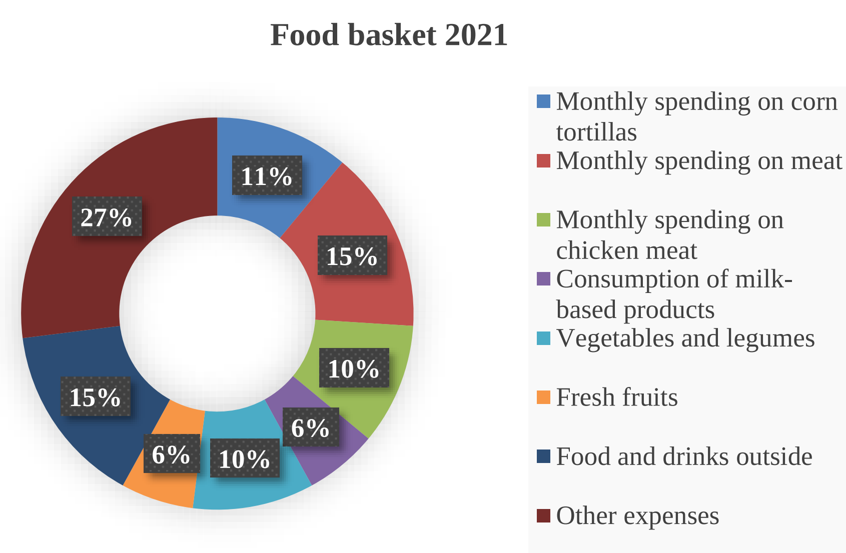


Figure 1

Percentage of expenditure on food basket 2021

Source: Own elaboration with information from CONEVAL

Solar thermal heaters are an option to inject thermal energy into the process without generating an expense in the production, this type of technology has already been implemented in the mills with satisfactory results. It is worth mentioning that the objective of these heaters is not to replace the burning of natural gas to satisfy the thermal demand of the process, but to implement them as a source of energy for pre-heating the water used to cook the corn. We could say that, with the exception of some rural mills in the country, absolutely all the mills work with electric motors in the process during the cooking of the corn to obtain the nixtamal, but in the same way we can say that the great majority of tortilla factories in the country use them during the cooking of the dough, where attempts have been made to increase their efficiency and that of the mechanical components present in the machines used.

On the other hand, we have the need to satisfy the electrical energy demanded by the electric motors, and it is here where photovoltaic solar energy and photovoltaic cells could have a significant impact on the nixtamalisation and production of tortillas, because apart from being a clean and inexhaustible energy, their main advantage is that, like solar thermal collectors, they do not generate a constant expense in production.

However, despite the fact that a large number of projects have been carried out implementing all the aforementioned alternatives, the truth is that within the tortilla production sector the implementation of these technologies is still seen as an option with many unknowns, as a result of the lack of knowledge of the high profitability that these technologies provide to the tortilla production process, Not to mention that the results of projects carried out have not been properly disseminated, which is why this project aims to evaluate the energy demand of a common tortilla factory in the city of Ciudad del Carmen, Campeche, and make an estimate of the economic profitability that a project using these energy technologies could present compared to the current market.

Methodology

The activities in the tortilla factory under study begin at 05:00 hrs, the first grinding of nixtamal is carried out and then the tortilla machine is turned on and tortilla production begins. Tortilla production takes place on two occasions during the day, the first starts at 05:00 hrs and ends at approximately 08:30 hrs in the morning, the second starts at approximately 11:00 hrs and ends at 13:00 hrs of the day.

The maize is cooked the day before, so that in the morning the maize is ready to be ground, during the first grinding the volume of maize is around 80 kilograms and during the second grinding around another 120 kilograms. The nixtamal is mixed with nixtamalised maize flour in a ratio of 1 kilogram of nixtamal to 3 kilograms of nixtamalised maize flour, so that around 600 kilograms of nixtamalised maize flour are used daily. The mixer is in charge of this process and does it intermittently with loads of 40 to 50 kilograms, which are stirred for around 5 minutes. Once the nixtamal has been mixed with the nixtamalised corn flour, the result is the dough used to make tortillas, which is delivered to the tortilla hopper in 50-kilogram portions. The tortilla machine works constantly during most of the production hours. During the afternoon from 14:00 to 15:00 hours, the maize to be used the following day is cooked; this quantity varies on some days between 200 and 250 kilograms. The maize is cooked in water at a ratio of 1 litre per kilogram of maize for approximately 5 minutes until it reaches 70° and is left to stand for the rest of the day and night until the early hours of the morning, when it is used for the first milling of the day.

Water consumption

The water used in maize cooking is 1 litre per kilogram of maize used, using about 200 litres of water per cooking per day, and for each kilogram of nixtamalised maize flour, about 1.4 litres of water are used, using about 840 litres of water per day. So the total water demand for the production of corn tortillas is the sum of the water used in these two processes, so that about 1040 litres of water are used per day.

Electricity consumption

The tortilla factory has 4 electric motors to perform different functions within the tortilla production process:

Milling: The motor used for milling the corn grain is the one with the largest capacity, it has a power of 5 horsepower and operates at 220 Volts with a consumption at full load of 12 amperes. This mill takes about 1 minute to grind 2 kilograms of maize, so that throughout the day it keeps operating for approximately 2 hours net throughout the day, on average, the mill consumes about 5.2 kWh per day.

Mixer: The motor used by the mixer has a power of 2 horsepower and operates at 110 Volts with a full load consumption of 3.5 amperes, the mixer takes on average 5 minutes to do its job, mixing around 50 kilograms per load, in total around 33 loads are mixed per day. The daily usage time is about 3 hours net over the course of the day and on average, the mixer consumes about 1.1 kWh per day.

Tortilla machine: The motor used in the tortilla machine is a 1 horsepower motor which operates at 110 Volts with a full load consumption of 5 amps. The tortilla machine is kept in operation for approximately 2 hours in the morning and 1.5 hours in the afternoon working for 3.5 net hours per day, so on average the tortilla machine consumes about 1.9 kWh per day.

Agitator: The last motor is the agitator, not all threshing machines have this last process, the purpose of the agitator is to arrange the tortillas and arrange them once they come out of the burner, the motor used is 1/4 horsepower, it operates at 110V with a consumption of 2 Amperes. This motor runs for the same amount of time that the tortilla shaker is in operation, approximately 3.5 hours a day. On average the shaker consumes about 0.8 kWh per day.

At the end of the day the electric motors used in the tortilla production consume a total of 9 kWh per day, 270 kWh per month, giving a total of 540 kWh per two-month billing period.

The service number of the premises was requested from the Federal Electricity Commission (CFE) in order to compare the billed consumption with the consumption measured in Figure 2, which shows that the consumption ranges between 491 kWh and 572 kWh billed throughout the year. This means that the energy demanded by the electric motors actually amounts to around 540 kWh.

Box 2

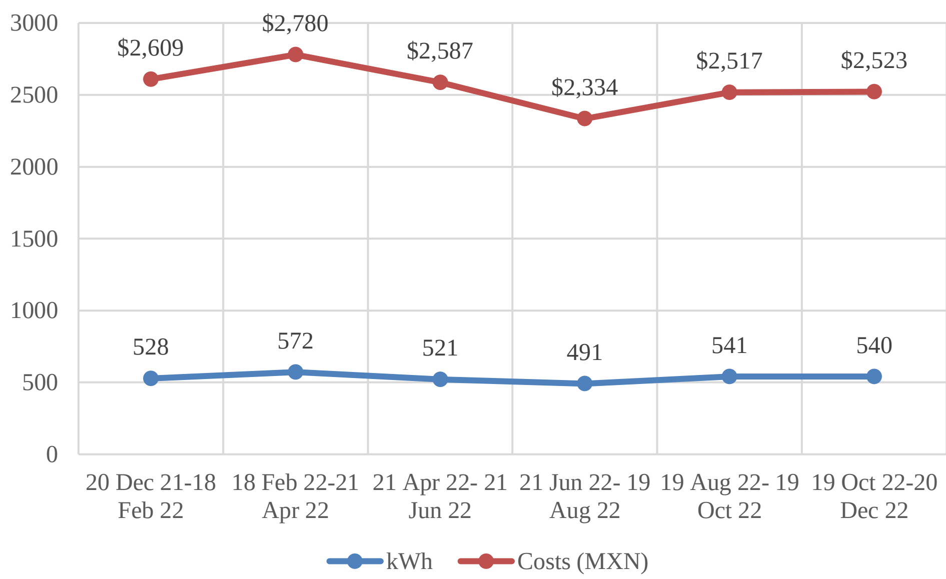


Figure 2

Graph of energy consumption and costs per period

Source: Own elaboration with CFE receipts

The same graph shows the economic amounts for energy consumption determined by the CFE, where the highest amount coincides with the highest consumption recorded, so that the amount for electricity consumption is around $2,500 pesos per billing period. It is important to mention that the tariff applied is Low Voltage Small Demand.

Calorific consumption

The amount of heat energy used can be estimated by the equation [1].

$$\boldsymbol{Q = m * C_P * \Delta T} \qquad [1]$$

Where:

Q: Heat energy (J)
m: Mass of material (kg)
C_P: Specific heat (J/kg * K)
ΔT: Temperature change experienced by the material (K)

The amount of energy demanded must be calculated according to the quantities of ingredients used, cooking requires a total of 200 litres of water per cooking, 200 kg of corn is cooked daily and 2 kg of lime is added. Nixtamal cooking at the Insurgentes tortillería consists of injecting heat into the mixture for 5 to 10 minutes to reach a temperature of 70°C and then leaving it to rest for the rest of the day.

Liu & Jordan method

The Liu & Jordan method (Duffie & Beckman, 2013) allows the calculation of incident solar radiation on an inclined plane, providing an approximation using few variables for estimation and maintaining a margin of error compared to field measurements. This method is useful for finding the optimal angle of inclination for solar collectors, as it is possible to obtain approximate values of collection depending on the angles of incidence and inclination; in this project, latitude was used as the angle of inclination for the solar collectors and the generation potential at this angle is estimated using the following equation [2].

$$H_{t,i} = H_t\left(1 - \frac{H_d}{H_t}\right)R_b + H_d\left(\frac{1+\cos\beta}{2}\right) + H_t\rho_g\left(\frac{1-\cos\beta}{2}\right) \quad [2]$$

Where:

$H_{t,i}$: Total insolation incident on a sloping surface ($kW * h/m^2$)
H_t: Total global desolation of the site ($kW * h/m^2$)
H_d: Horizontal diffuse insolation ($kW * h/m^2$)
R_b: Ratio of direct insolation to total insolation
β: Solar collector inclination
ρ_g: Terrain reflectance

The *f* -Chart Method

The *f* -Chart curves method is commonly used for the sizing of solar thermal installations, it allows the calculation of the contribution that a solar thermal collection system would have to the total heat demand of a process, as well as its average performance over a long period of time. This method is efficient for calculations and estimations over long periods of time, i.e. it should not be used for short term (daily-weekly) estimations. It is important to mention that this method is only applicable in heating systems where the minimum temperature for the energy supply is approximately 20 °C. Monthly meteorological data on solar radiation, water temperature and ambient temperature are used for its development (De la cruz Figueroa, et al., 2021). The method for liquid systems is performed using the equation [3].

$$f = 1.029\,X - 0.065\,Y - 0.245\,X^2 - 0.0018\,Y^2 + 0.0215\,X^3 \quad [3]$$

Its application consists of identifying the dimensionless variables of the heating system and performing operational simulations to determine the correlations between the variables and the performance of the system for a given period of time. The resulting correlations determine the variable *f* (fraction of the monthly load supplied by solar energy as a function of the dimensionless parameters). The method comprises 2 dimensionless parameters "X" and "Y", where the former represents the ratio between the absorbed solar radiation and the demanded heat load and the latter is a ratio between the collector losses and the heat loads. (Duffie & Beckman, 2013)

Photovoltaic sizing

The sizing of the PV system is done based on the peak power that the PV system must have to generate the energy consumed by the ECL electrical loads, which is calculated according to the equation [4].

$$P_P(AFV) = \frac{E_{CL}}{H_P * \eta_{ET} * R_T} \quad [4]$$

Where:

E_{CL}: Energy consumed by electrical loads (kWh).
H_P: Local solar resource (h).
η_{ET}: Overall total system electrical efficiency.
R_T: Thermal efficiency of the module (Typically taken as 85% for systems without batteries).

The overall total electrical efficiency of the system ‘’ is determined by multiplying the efficiency of the lines or losses set in the wiring ‘’, efficiency of the charge controller ‘’, efficiency of the electrochemical storage system ‘’, efficiency of the inverter ‘’ and the efficiency of any other electronic devices that use and handle or drive the generated power. The commonly used default values are: , , y . It is important to mention that the peak power of an existing PV array can be calculated based on the total number of PV modules and the peak power of the PV module in question, as shown in equation 3.26 (Sánchez Juárez, Martínez Escobar, Santos Magdaleno, Ortega Cruz, & Sánchez Pérez, 2017).

$$\boldsymbol{P_P(AFV) = N_T * P_P(MFV)} \quad [5]$$

Where:

N_T: Total number of photovoltaic modules which results from the multiplication of the number of modules connected in series. “N_S” by the number of modules connected in parallel “N_P”.

Results

The calculated thermal demand was 3,586.05 kWh, energy required to raise the temperature of the water from room temperature to the reference temperature (70 °C). Table 1 shows that the amount of energy demanded is similar throughout the year, with a slight increase between the months of November and March.

Box 3

Table 1

Month	Thermal demand ΔT (°C)	N (day/month)	DQ (MJ)	DQ(kWh)
January	45.3	31	1175.68	326.58
February	44.7	28	1047.84	291.07
March	43.7	31	1134.15	315.04
April	42.1	30	1057.38	293.72
May	40.9	31	1061.49	294.86
June	40.4	30	1014.69	281.86
July	40.7	31	1056.3	293.42
August	40.5	31	1051.1	291.97
September	40.4	30	1014.69	281.86
October	41.1	31	1066.68	296.3
November	43	30	1079.99	300

Source: own elaboration.

The tortilla factory uses three-phase electric motors operating at 220 VAC, and that the local electrical distribution network (RELD) provides electrical energy at a voltage of 220 VAC, three-phase at 60 Hz, we can deduce that the system requires a two-phase 220VAC, 60 Hz DC/AC inverter to be able to feed our installation and interconnect with the RELD. The first step is to calculate the electrical demand of the system, this with 4 motors in the production process; table 2 shows the daily electrical consumption of each one of them.

Box 4

Table 2

Daily electricity consumption

Loads	Volts	Amper	Power (kW)	Time of use (h)	Consumption (kWh)
Mill	220	12	2.64	2	5.28
Mixer	110	3.5	0.39	3	1.17
Tortilla machine	110	5	0.55	3.5	1.93
Agitator	110	2	0.22	3.5	0.77
Total	220	22.5	3.8	12	9.15

Source: own elaboration

Once the thermal demands were calculated with equation 1, the calculation of the incident solar radiation at the angle of the latitude of the place was carried out, and the Liu & Jordan Method was also applied, where own meteorological data was used, as well as the real data of commercial flat plate solar collectors, the model chosen was the AXOL 240 LITRES MS 2.5 BLUE of the commercial brand Modulo Solar. Finally, it was possible to compare the results obtained between the monthly heat demand, the thermal energy of the proposed collectors and the consumption of LP gas, as shown in figure 3. In this figure it can be seen that for the latitude of the place under study in the months of November, December and January are the months with the lowest contribution of thermal energy with the proposed system.

Box 5

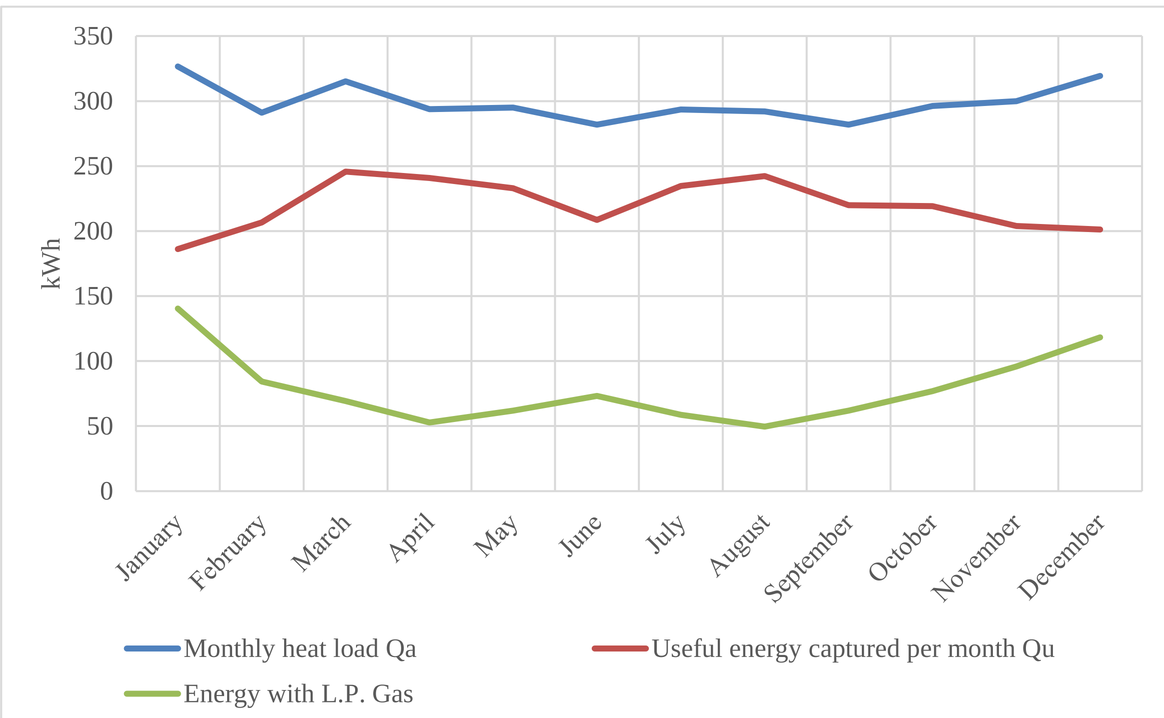


Figure 3
Comparison of thermal energy

Source: Own elaboration

Based on the estimates of the available area for the installation of the equipment, it was determined that high efficiency photovoltaic modules were needed, and that they should be panels with a monocrystalline structure. The solar photovoltaic module selected was the LR5-72HTH 585~600 M model from LONGi. Once the calculations had been made, comparisons were obtained between the electrical energy demanded and the electrical energy coming from the proposed system, as shown in figure 3. It should be noted that in the months of July and August the photovoltaic electrical energy is exceeded, so the system interconnected to the grid will supply this surplus to the national electrical grid.

Box 6

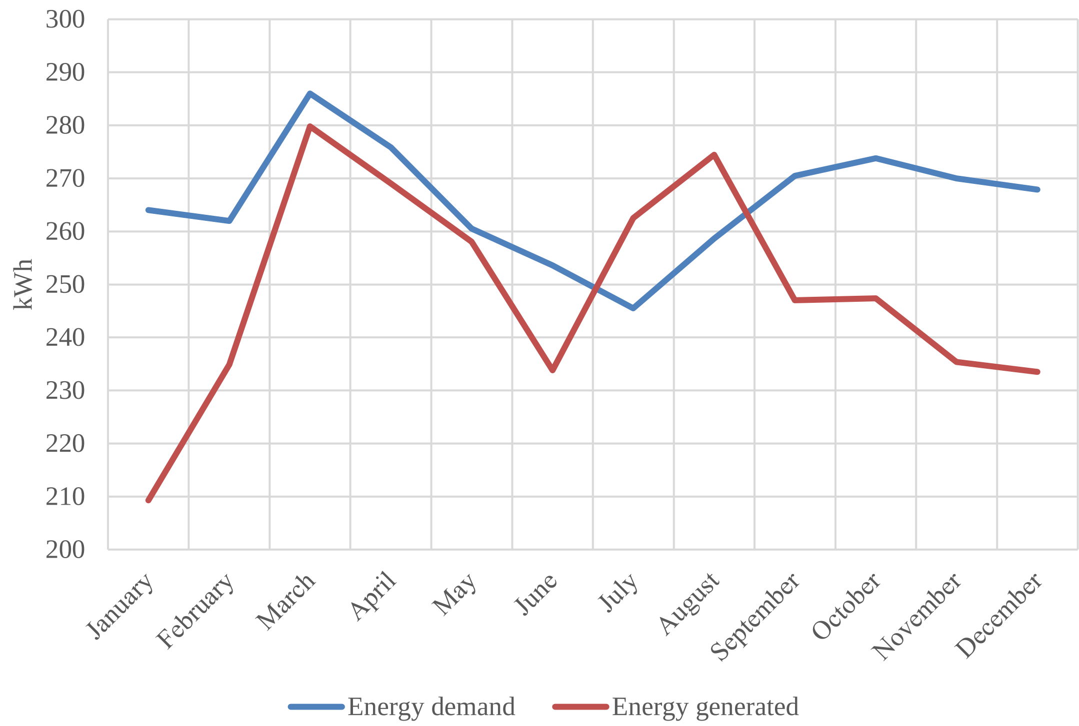


Figure 3
Comparison of electricity

Source: Own elaboration

In the case of the results with respect to the payback time of the investment, calculations were made and it was determined that the present project would recover the investment in 5.04 years. In a study from Spain and Ecuador, a minimum payback time of 8.75 years was estimated for photothermal installations, noting that only the photothermal installation without photovoltaic was considered, although it is not a comparison of similar projects, it gives us an overview of the results obtained in the present study.

Conclusions

The system will have an annual solar fraction of 0.7368, in other words, the solar thermal system will provide 73.68% of the thermal energy demanded. In the case of the solar photovoltaic system, throughout the year, the installation will produce 94% of the electrical energy demanded, so it is concluded that the use of solar thermal and photovoltaic energy is profitable for businesses similar to the one in the study, and if extrapolated to the whole country, it would contribute to the medium-term goals set for the use of clean technologies, improving efficiency and sustainability in traditional food production, concluding that the use of these mature technologies would economically benefit Small and Medium Enterprises in Mexico, as well as their consequent support to the environment by decreasing the consumption of LP gas and electricity.

Statements

Conflict of interest

The authors declare that they have no conflicts of interest. They have no financial interests or personal relationships that could have influenced this book.

Authors' contribution

Rayón-Alcudia, Cesar: contributed to the calculations for the entire project.
Meza-Cruz, Onésimo: Contributed to the project idea, and advised on the photothermal part.
Mandujano-Ramírez, Humberto J: Advised on the photovoltaic part.

Availability of data and materials

Data are available on request at: omeza@pampano.unacar.mx

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Abbreviations

$\boldsymbol{AFV}$	Photovoltaic Array
MFV	Photovoltaic Module

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