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Abstract

Nowadays the implementation of clean energy as an alternative to the adaptability to climate change, and to mitigate the greenhouse effect of the planet is more important than before. This work has managed to design, build, install and start generating data showing the potential for energy generation from the use of solar energy in agricultural activities in the northern region of Costa Rica (San Carlos). This has been achieved through the use of solar thermal energy systems in thermosiphonic forced wells, generating power through photovoltaic systems. The selected production units include two dairy and two cheese manufacturing plants in the northern region of Costa Rica, known as the “Huetar Norte”. The use of these systems allows us to achieve self-consumption in electricity of 30-50 percent of the production unit. In the case of the production of energy to heat water with a solar system it gives us between 20 and 37 C^0, per day. With these temperatures over 50 percent of the energy required to raise the water temperature to 70 C^0 is supplied by the system for washing and sterilizing milking equipment and other necessities. Furthermore wireless data transmission equipment has been installed to record the use of the thermal energy of the tanks as well as the production of electricity. The results of the correlation between solar energy production potential, electric costs, and the generation of hot water for the months of May to November and regulate mathematical models are shown to both systems. This brings us closer to the use of sustainable production in Costa Rica, as well as a significant reduction in the carbon footprint in animal production methods in the country.

Keywords: Dairy and cheese processing, Farms, Solar energy, Thermal and photovoltaic systems.

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Introduction

At present one of the greatest challenges facing humanity is climate change; the continued deterioration of the environment is threatening access to non-renewable resources and the welfare of future generations. In the agricultural sector it is well known that the production of cattle, both dairy and beef, is a major challenge in establishing production systems by reducing emissions of greenhouse gases that play an important role in the phenomenon of global warming (Estrada 2001; Montenegro and Abarca, 2002; Conde and Saldana, 2007; Alonso et al., 2012).

Studies in Costa Rica indicate that on average 2.3 kg CO2e / Kg FPCM (fat and protein corrected for total milk production) and 11.5 kg CO2e / kg of meat were emitted. To observe the differences between systems in 2011, an investigation was conducted on carbon footprint through the life cycle system for dairy farmers in Santa Cruz de Turrialba. The results show that on average 1.2 kg CO2e / kg FPCM are given off. These emanations of CO_2 equivalent may vary according to climatic conditions, production systems and emission factors used in the construction of the carbon footprint (INTECO, 2006; IMN, 2015; FAO, 2009-2015).

This means that the product carbon footprint (PCF) is the product of a calculation of greenhouse gas emissions (GHGs) of the service supply chain as a whole instrument viewed from the extraction of raw materials, production processes and even consumer usage. The footprint is measured in CO_2 equivalent and these fumes can be direct or indirect, and be quantifiable by international standards such as ISO 14064, PAS 2050 among others.

According to the Sixth National Energy Plan 2012-2030 of the Environment, Energy and Telecommunications Ministry, Costa Rica is a country with high potential in renewable natural resources that could be used for energy purposes. However, our country bases its development on the use of petroleum products. The average oil consumption growth in the last 20 years was 4.7% annually and electricity by 5.3% per annum, Ministry of Energy and Telecommunications Environment (MINAET, 2011).

Each energy source has different potential emissions of CO_2, so the composition of the matrix of energy supply and technology and consumer equipment (vehicles, industrial and agricultural equipment, etc.) determines the level of emissions from the energy system of the country. Given the great energy dependence on fossil fuels, whose consumption produces high levels of emissions, it is necessary to promote measures for rational use and energy efficiency. By doing so we can say that the international trend of energy use, according to the International Renewable Energy Agency (IRENA, 2013), cited by MINAET (2011), poses a greater share of renewable sources in the global energy matrix, such as geothermal, solar, wind and biomass; and a decrease in the use of non-renewable like coal, oil and gas. Based on these approaches, the need to opt for production systems using renewable energy sources is clear.

Costa Rica, as it appears in the VI National Energy Plan 2012-2030 (MINAET, 2011) presents a theoretical potential in the case of a solar fountain of 10,000 MW, of which the degree of utilization is at least 0.14 MW. Given this situation and framed in the line of action of the strategy 2.2 MINAET 2011 for the Energy sector: "To promote energy saving programs in the macro-consumers", this paper intends to apply in dairy production systems and dairy use solar energy for both heating water, pasteurization, as well as the use of photovoltaic power generating equipment within the system.

According to the Agrifood National Institute of Technology (INTA, 2011) "Mitigate is to think how the production of beef and milk should improve energy efficiency to reduce GHG emissions per unit of product." That being so, it is imperative to apply technologies that minimize the impact generated by the production process of the sector. Livestock is responsible for 18% of the global emissions of greenhouse gases (GHG) according to the report presented by FAO 2009 on the environmental impact of this activity (Matthews, 2006; Abarca, 1997).

In the canton of San Carlos there are 55% of the members of the Cooperative Milk Producers, "Dos Pinos RL", with a total of 850 producers and a production of more than 50% of domestic production 0.6 million kg milk (Paniagua et al., 2005; Lorente, 2010).

Based on the above proposal, the research team has studied alternatives and energy efficiency strategies, opportunities and potential present in the area and decided to opt for the technology to capture solar as a viable and effective alternative for generating and use of electric and heat energy from renewable sources.

The sun's energy can be used in the country with advantages in applications on both a large and small scale. In the case of the North, there are many producers of milk and dairy products in small and medium enterprises. They are using systematically hot water in their units, heated by electric heaters with heat exchangers, kerosene, bunker and gas.

This work focused on capturing solar energy to make these systems production more environmentally friendly.

The technologies using solar energy are available and in use in other sectors and countries, and are reliable and robust for the assimilation by the producers; the investment cost is affordable and recovery times and return on investment are attractive. The validation of this technology in the region is definitely needed and should be placed in the innovation process by milk and dairy producers in the North.

The objectives of the work have been to design, implement and evaluate three solar thermal system catchments (thermosyphon and forced) and photovoltaics for water heating and electricity production in milk and dairy production of the Huetar Norte region of Costa Rica and to transfer the results through a training program for both producers and students alike on the use of solar thermal and photovoltaic systems on agricultural systems, such as a local pilot program.

Materials and Methods

The location of milk and dairy producers, are presented in Table 1.

Such dairy producers are associated with the Milk Producers Cooperative "Dos Pinos" and independent producers, whose spending on hot water is between 160 and 215 l / day at a temperature of 70 ^{o}C.

Table 1. *Units of Dairy Production and Dairy Processing Selected for the Huetar Norte Region*

Dairy / Dairy Producers	Location	Equipment installed
1.-Technological Institute of Costa Rica, San Carlos Regional Headquarters (RERI-SSC) Zona Norte, Florence	Zona Norte, Florence	thermosyphon solar thermal and photovoltaic hybrid system
2.-Agricultural and Industrial Technical School (IFS)	Zona Norte, Santa Clara	thermosyphon solar thermal and hybrid system
3.-Dairy Producers Juanilama LLAFRAK of San Rosa de Pocosol	Zona Norte Santa Rosa de Pocosol	Solar thermal forced and hybrid

The work was carried out between February and December 2015, recording the data from a computer system from solar systems acquisition management / energy production / consumption thermosiphonic, forced, and photovoltaic systems, from May to December. The productive characteristics of each unit can be seen in Table 2.

Table 2. *Production and Economic Dairies and Dairy Producers in which the Work was Done in the Huetar Norte Region*

Dairy producer	Área	Kg milk daily	Volume of hot water use	volume heated water annual	Annual water bill	Electric bill / invoice annually in dolars
ITCR-SSC	24 ha	500 kg	160 l / día	58.40 m^3	$ 486.50 USD	$ 3 333.30 USD
ETAI	35 ha	650 kg	120 l / día	43.80 m^3	$ 365.00 USD	$ 3 556.00 USD
Lácteos LLAFRAK	30	650 kg	215 l /día	78.47 m^3	$ 653.95 USD	$ 3 111.10 USD

Area Kg milk daily annual water electric bill / invoice annually in dollars.

Research Description

In this research, three solar systems, two thermosiphonic, one forced and one photovoltaic were designed and built, and analyzed, design and implementation of infrastructure computerized, data collection, management/ energy production/consumption systems were conducted by thermocouples and Loguer data.

Once the systems were assembled we proceeded to data collection by monitoring variables such as lighting, clouds, daylight hours, direct and diffuse solar radiation, the mass of heated water, (water temperature at the inlet and outlet of the system), and energy production and its net balance.

The modules installed with thermal, counted with the following specifications: Flat solar collectors for water heating. An accumulator tank 302.40 l of water, with coupled auxiliary electrical system. This tank was allowed three interiors for connecting thermocouples. These thermocouples were connected to a computer that recorded data capture energy and water use through a meter, an escape valve and a valve connecting the solar system with an electric auxiliary system. A pipe system connecting the equipment for sterilization and a mounting base (López 2006 and Khan 2010).

Facilities number of adjustments according to the unit that consume hot water. Elevated tank, in case necessary. Thermometers.

The photovoltaic system had the following specifications: photovoltaic solar panels connected to the network intended for consumption. A charge controller, investor, and several connection facilities plus base floor mounting.

It also featured additional equipment for the proper establishment and implementation of research and measurement of energy parameters: A measurement module for digital meteorological data for the Regional Headquarters, San Carlos. A CPU, such as database server computer, data backup unit, monitors, keyboards and cables.

Measurement modules meteorological data by zone in coordination with the National Meteorological Institute (INM).

Finally, the data that allowed us to use medium and high mathematical models of simple and multiple linear regression correlations, meteorological data radiation, direct lighting, diffuse sunlight, temperatures with energy capture in the system, and use were generated under constant weather conditions in the North Huetar region of Costa Rica.

Definition of Variables to Assess

The variables analyzed were as follows: Determination of the real potential of capture and generation of heat and electricity from solar energy in which the variables listed in Table 3 were evaluated.

Table 3. *Description of Variables to be Evaluated for the Determination of Energy Efficiency and Reduced Production Costs through the Application of Solar Energy in Agricultural Economic Activities as an Alternative to Climate Change in the North Huetar Region*

Type	Variable	Method of production	Method of production	Frequency Evaluation Period
1. -Using systems	1.1. Average temperature of cold water inlet	computerized sensors	Daily, monthly Annual	Feb-Dec 2015
	1.2. Outlet temperature collectors			
	1.3. Inlet temperature collecting tank			
	1.4. Operating temperature.			
2.-Economic valuation	1.5. Water use in dairy	Mechanical measurement clock		
	1.6. Masa cold / hot water	Mechanical measurement clock		
	1.6.1 produced kWh / consumed	Using digital sensors		
	1.7. economic differential	handpicking		

According to the variables listed in Table 3 differential (savings) electricity system based on the use of solar systems, and the energy balance of the systems were estimated.

Energy efficiency and decreased production costs were determined. In addition, calculating the decreased carbon footprint, by the product of the value of annual kWh saved and the average value was evaluated CO_2 Kg.

Heat (Q) produced by the system was calculated by the equation:

$$Q = Cp \cdot y \cdot V \cdot DT$$

whereby Q corresponds to the energy required for the temperature change is given in (kJ), Cp is the specific heat of water (in this case a value of 4.18 kJ / kg · K was used), and corresponds to the liquid density (1000 kg / m3), V the volume of liquid in m3 (corresponding to the storage capacity of the system, which ranges from 150 to 200 L) and T is the temperature variation (T in Kelvin), calculated by the difference between the temperature reached by the water in the system (Tf) and T input or environment (Ti). The results of this calculation were expressed in the corresponding SI units through the respective conversions.

In case we could not count on the value of Tf reached by the water in the system, its estimation through Q values produced by the system, recorded daily on the website was calculated https://enlighten.enphaseenergy.com (Enphase Energy Inc., Petaluna CA, USA).

Finally mathematical regression models and correlation, as well as general usage graphs of temperatures in the three systems are shown.

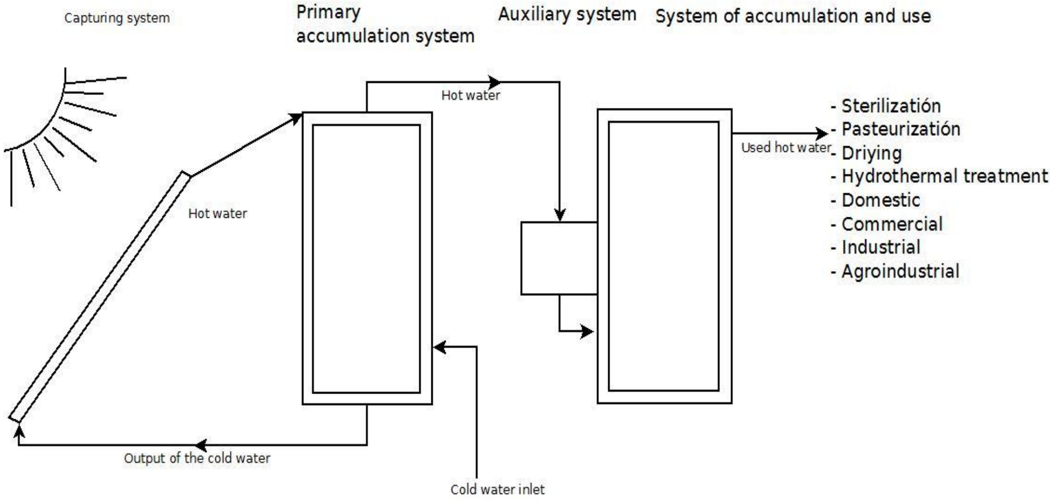
Results and Discussion

Three systems were designed and adapted namely two thermal thermosiphonic, one photovoltaic and the other forced.

Thermosiphon Thermal System

The thermosiphon heat system is defined as the movement of a fluid (water) that moves by two factors, by gravity and by heating this fluid by sunlight. When water is heated this expands and then decreases in density, so that water entering the system is denser and the latter, unit gravity and decreasing density, make up the hot water stored in a reservoir. This occurs within the solar collector as part of a convective heat exchange, as shown in Figure 1.

Figure 1. *Basic-hybrid System Thermosiphon with Electrical Resistance. The Cold Water Inlet is Brought Forth from an Elevated Tank, above the System and Water Movement Occurs by Gravity and Density Change*



Forced Solar System

Like the thermosiphon system, forced solar heat has the same elements, only arranged differently and additional equipment. This system is composed of sensors, a solar battery, a hydraulic group with movement pumps, a control system and an expansion vessel as shown in the technical scheme 2 and 3. The schemes are similar to those reported by Energy Savings at Home, (Res & Rue Disemination, 2005; Quiros, 2011).

Figure 2. *Forced Gas System with Auxiliary System. The Cold Water Inlet is Brought Forth from a Deposit that may be Elevated or not, and Movement, and the Use of Water Occurs through One or Two Pumps according to Application Circumstances*

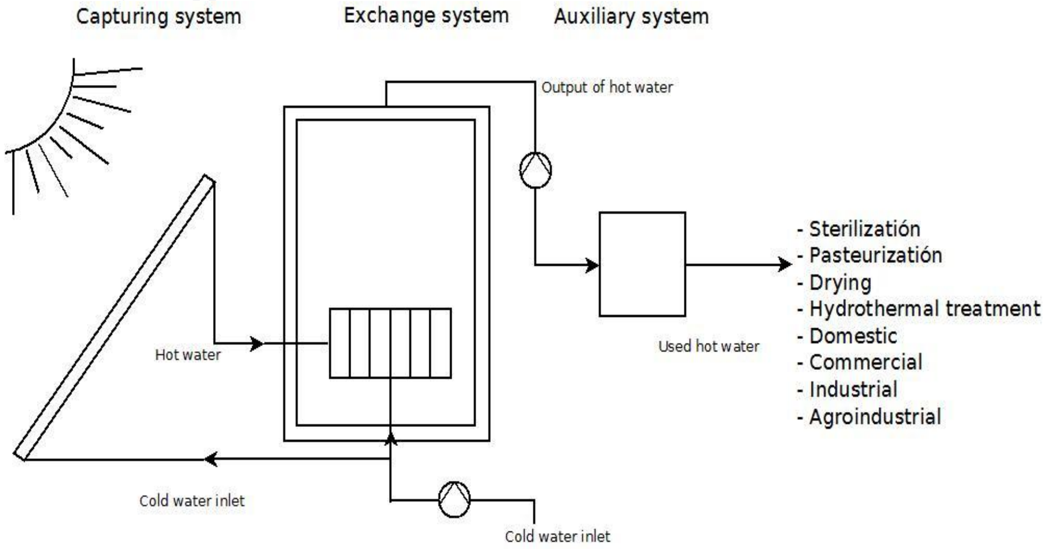
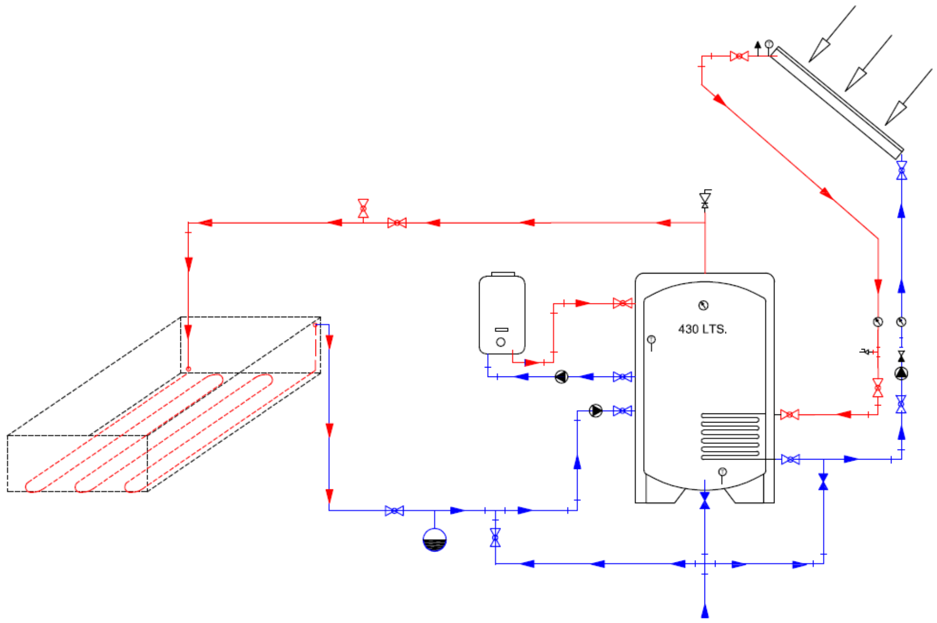


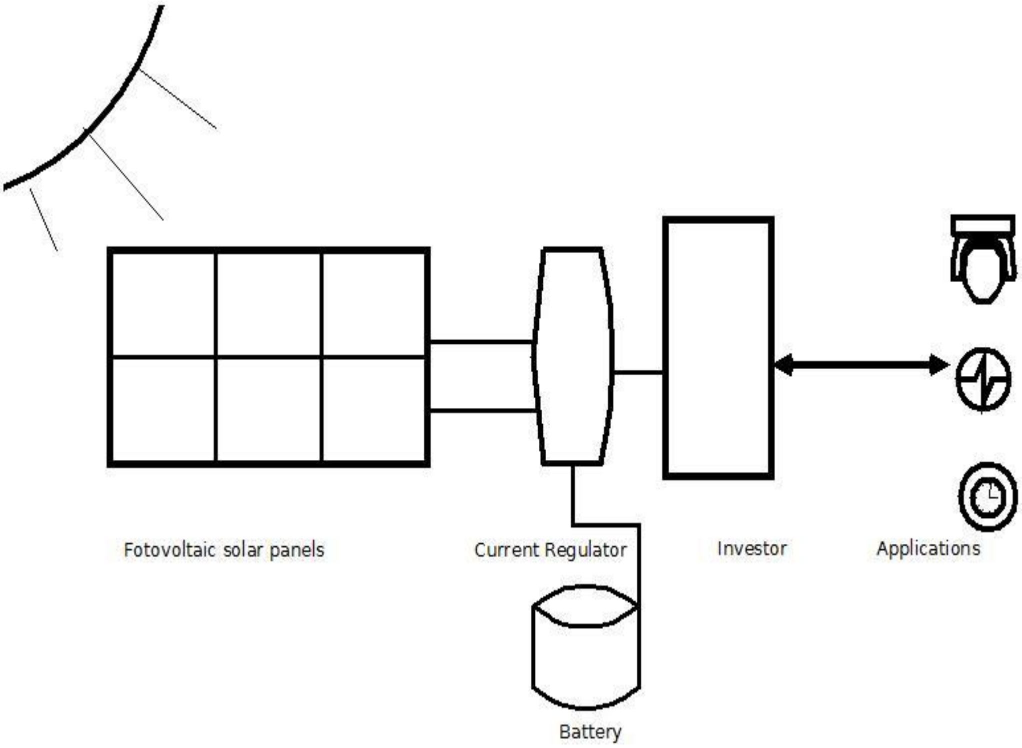
Figure 3. *A System of Solar Energy Hybrid Type with Forced Gas, Installed in the Processing Plant of the Association of Dairy Producers Association Juanilama LLAFRAK in Santa Rosa de Pocosol*



Uptake Photovoltaic System

Photovoltaic solar energy is generated from the use of special solar panels that produce electricity from direct and diffuse solar radiation, using a semiconductor called a photovoltaic cell. The energy produced can be used in many applications in economic activity in general, in isolated places, and to power equipment, among others, Figure 4.

Figure 4. *Schematic Diagram of a Solar Photovoltaic System*



In the area where the dairy of the Regional Office of the Costa Rica Institute of Technology (ROCRI) of the School of Agronomy, and part of the Program of Agricultural Production (PAP), lies, average temperatures of above 25 °C, were recorded from May to December 2015. In the thermal system installed on these dairy temperatures were above 50 °C, except for July, which was approximately 42 °C. Data collected during the months from May to December 2015 are shown in Table 4.

Table 4. *Average Temperature of Inlet and Outlet Water in the Heating System, and Final Temperature Reached at the Dairy Regional Headquarters (DRH) in the Period May-November 2015*

Month	Water inlet temperature (°C)	Water outlet temperature (°C)	Δ Temperature	Demanded temperature (° C)
May	27.54	52.49	24.95	70.00
June	27.34	50.81	23.47	70.00
July	25.97	41.86	15.89	70.00
August	26.09	71.71	45.62	70.00
September	27.39	71.08	43.69	70.00
October	26.27	68.70	42.43	70.00
November	25.99	69.65	43.66	70.00
December	26.65	56.34	29.69	70.00

Source: Own Calculation.

In this thermosiphon thermal system, hybrid solar energy production of approximately 542.3 kWh was produced whose maximum yield was 74 kWh / day, this was obtained during the month of August 2015 while in December solar energy production was only 42.3 kWh / day (Table 5). Because of this, the system was only able to meet the energy demand required for different dairy operations of the Regional Office of DRH in the months of August, September and November, while in July it was only able to supply 39% of the energy required (Figure 5). Overall, this energy production was reduced between 40 and 50% of the energy consumed in this unit, considering an average requirement of 128.17 kWh.

The energy produced is translated into a total of 1,007.9 kg CO_2 captured, which in turn amounts to a total of 26 trees and a total savings of $ 434.24 USD in electricity bills at this dairy farm (Table 6).

More importantly, this system supplies hot water, with temperatures of 70^0 C, for the processes of washing and sterilization equipment, dairy and laboratories to the School of Agronomy of biocontrol and Quality Meats in parallel form.

The results coincide with those quoted by other authors such as (Eubank and Davis, 1993; Montenegro and Abarca, 2002; Matthews, 2006; 2010; Papendieck, 2010; Lorente, 2010).

Table 5. *Average Monthly Solar Power and Energy Produced by the Thermal System Supplied for the Operation of the Dairy Regional Headquarters RERI in kWh Depending on the Temperatures Achieved*

Month	Average energy production by the thermic system en kWh	Energy supplied by the system (%)
May	69.2	59
June	68.9	49
July	67.4	39
August	74.0	104
September	73.6	102
October	73.3	97
November	73.6	99
December	42.3	68

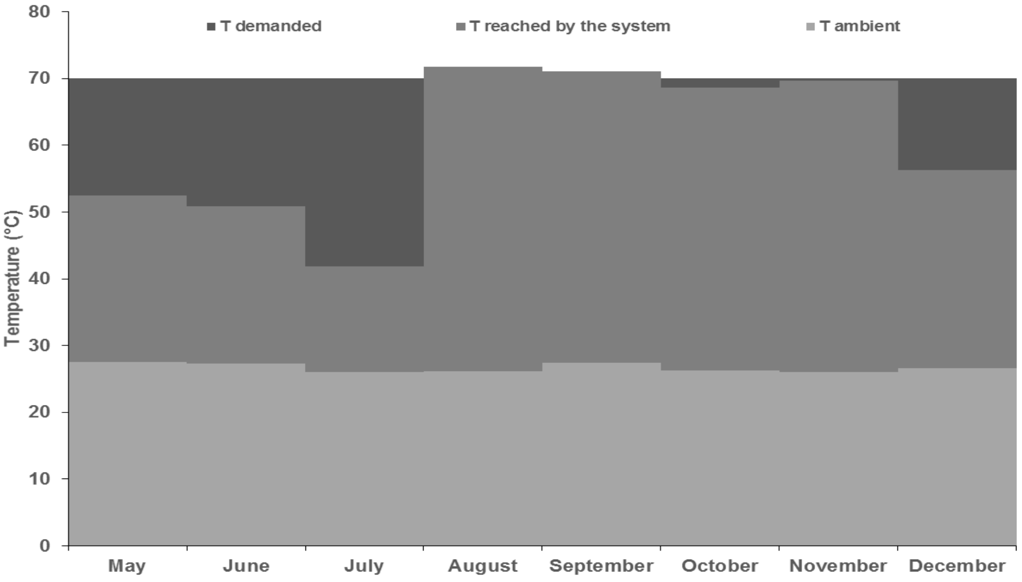
Source: Own Calculation.

Table 6. *Energy Balance of Thermal and Photovoltaic Systems Installed in the Dairy Regional Headquarters DRH*

Month	Total energy produced by both systems thermal and photovoltaic kWh	Economic value of the energy produced (¢) *	Carbon captured (Kg CO$_2$)	Equivalent trees (u)
May	233	$ 53.30	123,60	3
June	215	$ 50.60	111,80	3
July	241	$ 57.10	127,20	4
August	273	$ 62.20	139,00	3
September	263	$ 60.60	120,00	3
October	245	$ 57.90	120,00	3
November	274	$ 61.16	120,00	3
December	270	$ 61.00	146,3	4
Total	2014,00	$ 464.60	1007,90	26

* *Source:* Own Calculation. Data obtained according to the current rate by Cooperative Rural Electrification. San Carlos R.L. (COOPELESCA R.L.).

Figure 5. *Monthly Average Room Temperatures Reached by the System and Sought for the Operation of the Dairy Regional Headquarters RERI*

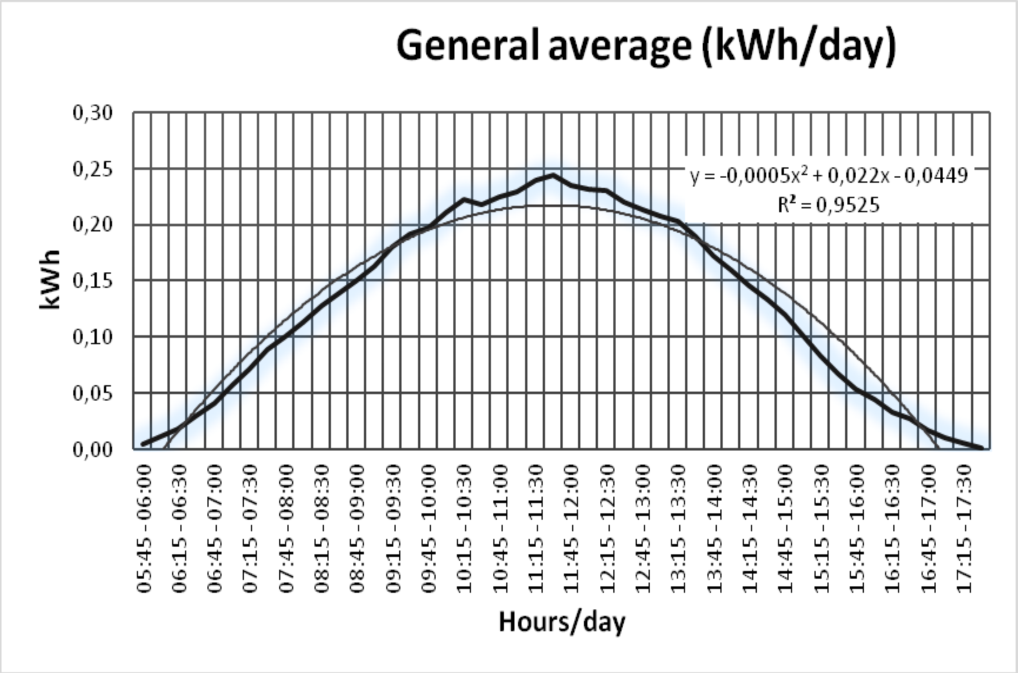


Source: Own Calculation.

Photovoltaic System

The average energy per hour during the day from 6.00 am to 6.00 pm, produced by the photovoltaic system during the months of May to December, can be seen in Figure 6, where the best fit curve offers a coefficient determination of 95 percent, with multiple polynomial regression model, where the energy gain is shown throughout the day.

Figure 6. *Average Generation during the Day Photovoltaic Panels Evaluated at Dairy DRH San Carlos Headquarters from May to December 2015*

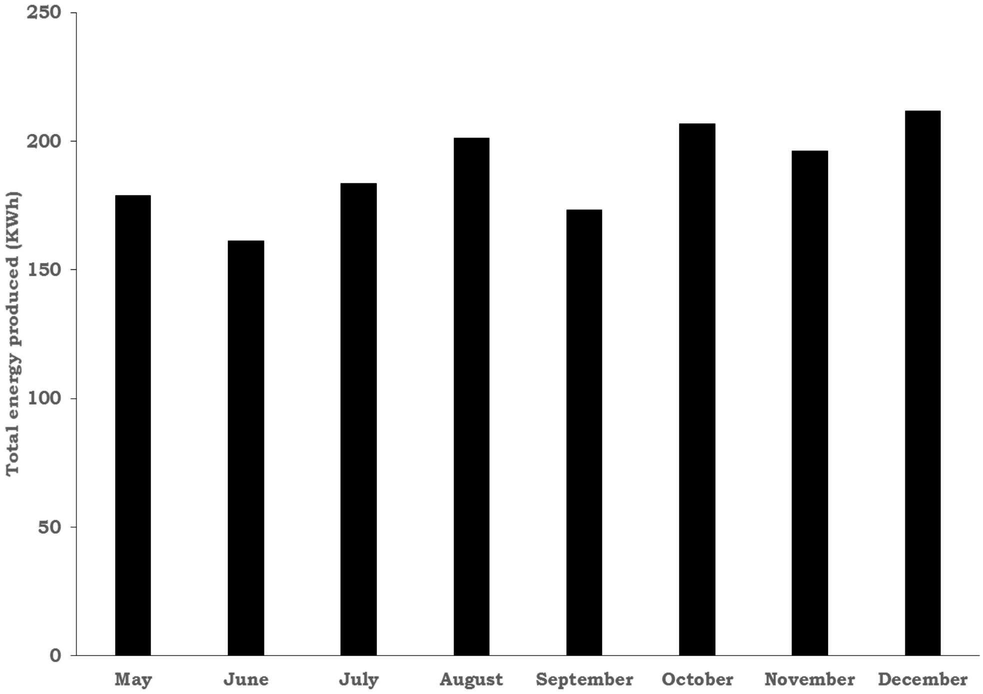


Source: Own Calculation.

Similarly, the average energy per day during each month evaluated, the system can be seen in Figure 7 and Table 7 in the summary.

System	Variable	Average	Min	Max
Fotovoltaico	kWh/dia	6.12	1.24	11.10

Figure 7. *Generation Average per Day and Month of the Photovoltaic System*



Source: Own Calculation.

Conclusions

Solar thermal and photovoltaic systems uptake can be used successfully in agricultural production processes, sterilization of automated milking and pasteurization of milk.

According to the results obtained at the Dairy Regional Headquarters DRH, it can be seen that the systems solar energy capture are an efficient source to reduce operational costs for electricity in a cattle farm, as well as carbon footprint.

Solar technology contributes to the reduction of greenhouse gases, reducing the carbon footprint of agricultural unit related to dairy farming.

Recommendations

We need to continue with data registration and designing other solar systems, for further use in agricultural systems in other activities such as the drying of seeds, fruits, vegetables and medicinal plants.

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