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AGR2017-2464

Solar Energy as an Alternative Tool in Agricultural Units in Costa Rica

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This paper should be cited as follows:

Obando-Ulloa, J. M., Rivero-Marcos, M., Sánchez-Ramírez, M. F., Martínez-Mora, E., Castro-Badilla, G., Araya-Rodríguez, F. and Guzmán-Hernández, T. J., (2018). **"Solar Energy as an Alternative Tool in Agricultural Units in Costa Rica",** Athens: ATINER'S Conference Paper Series, No: **AGR2017- 2464.**

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8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
URL Conference Papers Series: www.atiner.gr/papers.htm
Printed in Athens, Greece by the Athens Institute for Education and Research.
ISSN: 2241-2891
28/06/2018

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Abstract

Around the world, the agroindustrial sector is highly dependent on the fossil fuels for its production process. Therefore, there is an urgent need to find new alternatives of energy resources in order to replace this dependence and make the process more efficient, support the production process of small and medium-sized farmers with clean technologies and achieve the mitigation of the greenhouse gases to contribute to diminish the effect of the climate change from a local initiative. The aim of this research was to evaluate the implementation of a thermal hybrid forced system (LP gas solar hybrid system) in two agricultural production units for the milk pasteurization to process fresh cheese for the local market. The system was implemented in two milk factories in the Northern Huetar Region of Costa Rica. This area is characterized by its high cloudiness and high volume precipitation, aspects that have limited the use of this alternative technology through the years. The system replaced two wood boilers used to warm water for milk pasteurization to process cheese, sterilization of the milking equipment and other sanitization operations in the agricultural units. The system not only improved the process, but also removed the environmental contamination produced by the boilers and the greenhouse gases emitted to the atmosphere. In addition, the system was capable to supply more than 54% of the energy required by the process and reduced the electricity bill of these milk factories, while its economic analysis revealed that the initial investment can be recovered in around 3 years. In summary, the results show the efficiency of the implemented solar system that can be used as an alternative and clean energy resource for the production units in Costa Rica.

Keywords: Costa Rica, Milk factories, Production unit, Solar energy, Thermal hybrid forced system.

Acknowledgments: The authors are grateful with the Program of University Regionalization (PUR), through the Vice Presidency for Research and Extension of the Costa Rica Institute of Technology and the Ministry of Agriculture and Livestock (MAG) of the Northern Huetar Region for the financial assistance for the implementation of the systems at the dairy factories selected. JM Obando-Ulloa is indebted to the Grants Committee of the Costa Rica Institute of Technology and the Technical Secretariat of Incentives (Ministry of Science, Technology and Telecommunications, MICITT-Costa Rica) for the financial support to attend the 10th Annual International Symposium on Agriculture, organized by the Athens Institute for Education and Research (ATINER).

Introduction

Climate change is one of the current greatest challenges faced by humanity. 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 dairy and beef cattle is a major challenge in establishing production systems by reducing emissions of greenhouse gases (GHGs) that play an important role in the phenomenon of global warming (Estrada, 2001, Montenegro and Abarca, 2002).

The emissions of GHGs are measured by the carbon footprint (CFP) which includes the emissions of the whole service supply from the extraction of raw materials, their processing and even the use by consumers. The footprint is measured in CO_2 equivalent (CO_2e). These fumes can be direct or indirect and are quantified by international standards such as ISO 14064, PAS 2050, among others.

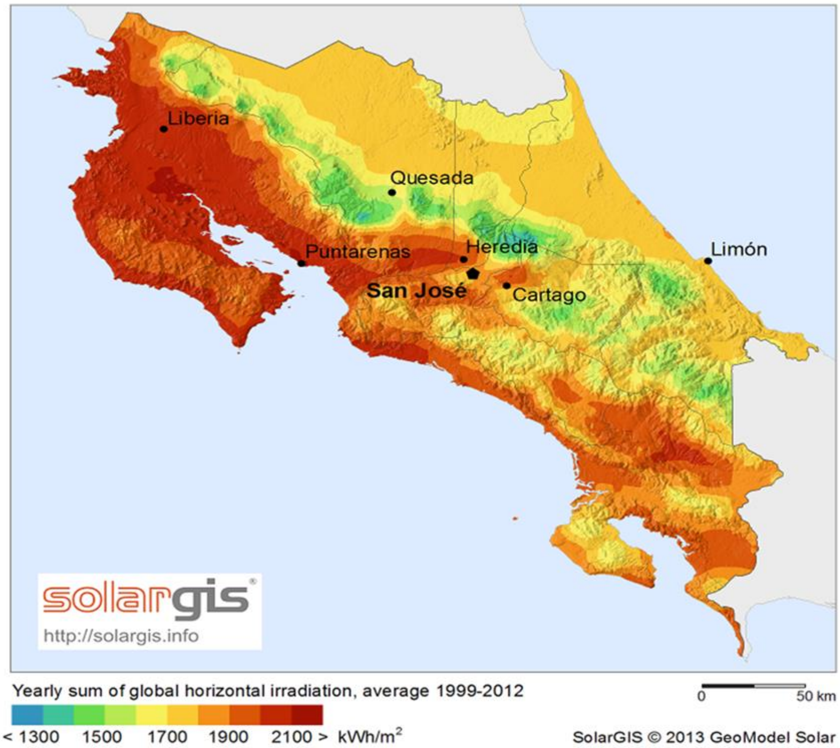
Studies in Costa Rica indicate that an average of 2.3 kg CO_2e / kg of fat and protein corrected for total milk production (FPCM) and 11.5 kg CO_2e / kg meat were emitted. To observe the differences between both systems, an investigation was conducted in 2011 to determine the CFP through the life cycle system for dairy farmers in Santa Cruz, Turrialba (Cartago, Costa Rica). The results showed that around 1.2 kg CO_2e / kg FPCM were given off. These emanations of CO_2e may vary according to climatic conditions, production systems and emission factors used in the construction of the carbon footprint (IMN, 2015; FAO, 2009; INTECO, 2006).

According to the Sixth National Energy Plan 2012-2030 of the Ministry of Environment, Energy and Telecommunications (MINAET), Costa Rica has a high potential rate in renewable natural resources, which can be used for energy purposes. However, this country bases its development on the use of fossil fuels. The average oil consumption growth in the last 20 years was increased by 4.7% annually, while the annual electricity consumption increased by 5.3% (MINAET, 2011).

Due to the great energy dependence on fossil fuels (diesel, fuel oil, liquid petroleum, gas), whose consumption produces high levels of carbon dioxide emissions CO_2 (Hassanien et al., 2016), it is necessary to promote policies for the rational use and energy efficiency and find new production system alternatives using renewable energy sources.

According to MINAET (2011), Costa Rica has a theoretical solar potential around 10,000 MW (Figure 1). However, this country just uses 0.14 MW. Based on this situation and according to the policies of MINAET for the energy sector that stablishes the promotion of energy saving programs in the macro consumers, the Research Group on Solar Thermal Systems for Agriculture has been focused on the implementation of solar thermal technologies for heating water for the pasteurization process as well as the use of photovoltaic systems to generate the required power in dairy production units in the Huetar Northern Region of Costa Rica.

Figure 1. *Global Horizontal Irradiation Registered in Costa Rica during 1999 and 2012*



Source: Solar Gis (http//:solargis.info).

Around 55% of the milk producers (850 producers) affiliated to the main Costa Rican cooperative enterprise "Dos Pinos R.L.", with a total production higher than 50% of domestic production (0.6 million kg milk) is concentrated in the Northern Huetar Region, mainly in San Carlos County (Alajuela, Costa Rica), according to Paniagua et al. (2005) and Lorente (2010). These producers systematically use hot water (warmed by electric heaters with heat exchangers, kerosene, bunker and gas) in their units to clean and sterilize the milking system and the milk factory facilities, which have not only a strong impact on the operational costs but also on the environment.

Therefore, the Research Group on Solar Thermal Systems for Agriculture has studied alternatives and energy efficiency strategies, opportunities and potential present in the area to recommend to these producers an alternative energetic tool. On this concern, solar photovoltaic, solar thermal electricity and solar heating and cooling can be combined to address these needs in part, including those of agriculture, craft industry, cooking and desalination. Indeed, solar process heat is currently untapped, but offers a significant potential in many industrial sectors.

One of the areas where solar energy can be extensively used is water warming. Hot water is required for bathing, drinking and washing purposes in houses, industries and commercial organizations. During a 20-year period, one solar water heater can avoid over 50 tons of CO_2 emissions. Depending on climate and requirement, a properly designed, installed, and maintained solar water heater can meet from half to nearly all the hot water demand. It can operate in any climate; performance varies depending, in part, on how much solar energy is available at the site, but also on how cold is the water coming into the system (Shukla et al., 2009).

Technology that uses solar energy is the most environmentally friendly, available and used in other sectors and countries. In addition, these systems are reliable and robust for the assimilation by producers. The initial investment cost is affordable, while the recovery time and return on investment are attractive. The validation of this technology is definitely needed for its implementation in the dairy factories of Costa Rica.

On this concern, the aim of this work was to design, implement and evaluate a thermal hybrid forced system for water warming in two dairy factories located in the Northern Huetar Region of Costa Rica.

Methodology

Location of the Dairy Factories where the Systems were Implemented

The systems were implemented in two different factories: LLAFRAK and San Bosco Dairy Products. These factories are located in Juanilama and San Bosco (Santa Rosa, Pocosol, Alajuela), respectively. These factories were chosen because they are located on an agricultural and cattle area where the employment sources are limited. According to the Social County Development Index (MIDEPLAN, 2013), San Rosa (Pocosol) is placed on the 440th (of 477 counties) nationwide position. Based on these issues, farmers have searched economical alternatives to face these limited conditions.

LLAFRAK and San Bosco Dairy Factories have 18 and 24 affiliated producers, respectively. These producers depended on a wooden boiler to warm water for the pasteurization of milk (Figure 2). However, it was an inefficient process which could not assess the safety of the process and affected consumer health and environment.

Figure 2. *Wood Boilers Used in LLAFRAK* (A) *and San Bosco* (B) *Dairy Factories to Warm Water for Milk Pasteurization and Sanitization Operations*

Source: www.solarhuetarnorte.org.

Solar Thermal Systems Implemented at the Dairy Factories

The solar thermal systems designed and built by the Research Group on Solar Thermal Systems for Agriculture have been described previously (Guzmán-Hernández et al., 2017; Guzmán-Hernández et al., 2016a; b). In general, the group has designed two thermosiphon systems, which have been implemented for research and teaching purposes at the milk factories of the Technology Institute of Costa Rica (ITCR) and of the Technical, Agricultural and Industrial School (ETAI) in Santa Clara, San Carlos, Alajuela. In addition, a photovoltaic system was also implemented at the milk factory of the ITCR for the production of AC energy. However, the group decided to install a thermal hybrid (solar- gas) forced system at LLAFRAK and San Bosco Dairy Factories.

Recorded Data

Temperature

The systems implemented in LLAFRAK and San Bosco were capable to record the data related to the temperature of water that enters and leaves from the system. This data allowed the estimation of the energy produced by the system, energetic saving, production cost decreasing, carbon footprint and investment recovery.

Energy Produced by the Thermal Hybrid Forced System

The energy produced by the thermal hybrid forced system is based on the temperature change in the material and it is equal to the product of heat capacitance and temperature change. This system uses the heat capacity and the change in temperature of the fluid (water) during its pass through the system. The amount of heat or energy depends on the specific heat of the medium, the temperature change, and the amount of the storage water (Equation 1).

$$Q = m \cdot \mathrm{Cp} \cdot (\mathrm{T_f} - \mathrm{T_i}) = m \cdot \mathrm{Cp} \cdot \Delta\mathrm{T} \quad \text{(Equation 1)}$$

where Q is the heat stored, m is the mass, Cp is the specific heat and ΔT is the temperature difference between initial (i) and final (f) water temperature (Guzmán-Hernández et al., 2017; Shukla et al., 2009).

Energetic Saving

The energetic saving was estimated based on the temperature reached by water after passing through the thermal system (T_f) and the temperature required (T_r) for the cleaning and sanitizing operations at the dairy factory (Equation 2). In this case, the temperature required in the dairy factories was set at 70 °C.

$$\text{Energetic saving} = \mathrm{T_f} / \mathrm{T_r} \times 100 \quad \text{(Equation 2)}$$

Economic Saving

The economic saving was determined by the change on the costs structure of the dairy factories due to the implementation of the hybrid forced system and the costs associated to the operation of the wooden boiler.

Carbon Footprint Reduction

The reduction of the carbon footprint was determined by comparing the carbon dioxide (CO_2) released to the atmosphere by the wood boiler and the hybrid forced system implemented at the dairy factories. In addition, the data provided by the International Energy Agency (IEA, 2010) was used to determine the contribution of CO_2 to the atmosphere, according to the energy source (Table 1).

Table 1. *Carbon Dioxide (CO_2) Release to the Atmosphere according to the Energy Source*

Energy Source	Carbon dioxide release (kg)
LP Gas	0.23400
Firewood	1.70000
1 kWh (electricity)	0.00557

Source: International Energy Agency (IEA, 2010).

Investment Recovery

The recovery time of the initial investment (I_i) was estimated by taking into account the economical saving of the evaluated year (S_y) (Equation 4).

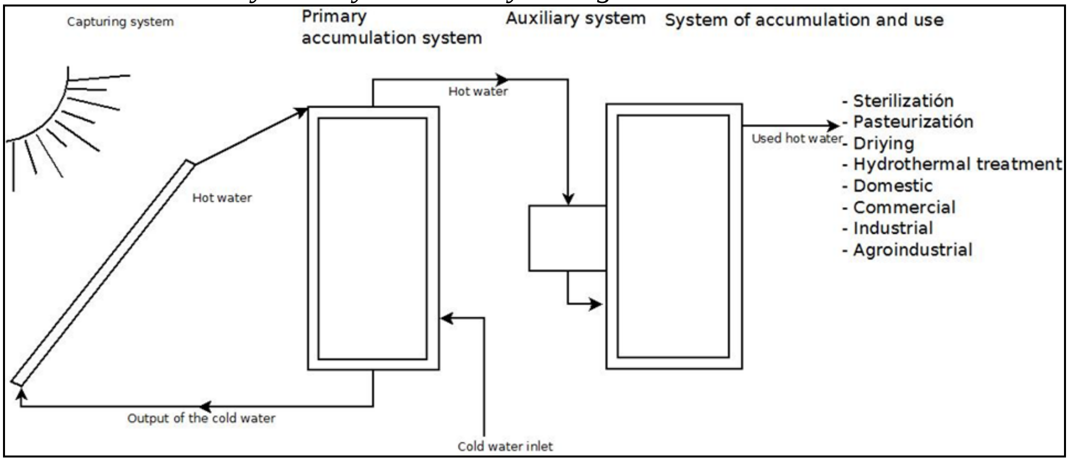
$$\text{Investment recovery} = I_i / S_y \quad \text{(Equation 4)}$$

Results

Solar Hybrid Forced Systems Implemented at the Dairy Factories

Thermosiphon (or thermosyphon) is a method of passive heat exchange, based on natural convection, which circulates a fluid without a mechanical pump. This method is used for circulation of liquids and volatile gases in heating and cooling applications such as heat pumps, water heaters, boilers and furnaces. On the other hand, a thermosiphon heat system is defined as the movement of a fluid (water) by two factors: gravity and heating by sunlight. As the sun shines on the collector, the water inside the collector flow-tubes is heated. As it heats, this water expands slightly and becomes lighter than the cold water in the solar storage tank mounted above the collector. Gravity then pulls heavier, cold water down from the tank and into the collector inlet. The cold water pushes the heated water through the collector outlet and into the top of the tank, thus heating the water in the tank. When water is heated, it expands and then its density decreases, so the water entering the system is denser, which allow water be stored in a reservoir. This occurs within the solar collector as part of convective heat exchange (Figure 3). As it was mentioned above, this system was implemented at the milk factories of the Technology Institute of Costa Rica (ITCR) and of the Technical, Agricultural and Industrial School (ETAI) in Santa Clara, San Carlos, Alajuela.

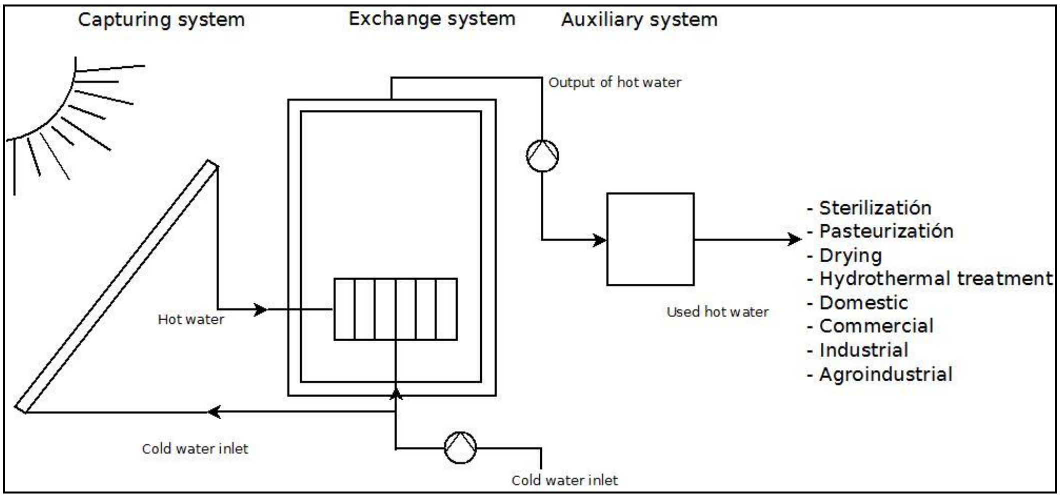
Figure 3. *Basic-hybrid Thermosiphon System with Electrical Resistance. The Cold Water Inlet is Brought Forth from an Elevated Tank, Above the System and Water Movement Occurs by Gravity and Density Change*



Source: www.solarhuetarnorte.org.

Based on the basic- hybrid thermosiphon system, the research group designed and implemented a hybrid forced system at LLAFRAK and San Bosco dairy factories because it is more efficient than the basic-hybrid thermosiphon system and a mechanical force was also required to pump water into the system due to the water source was located away from the area where the systems were placed. Even though both systems have the same elements, they are arranged differently. The forced system has little additional equipment, such as sensors, a solar battery, a hydraulic group with movement pumps, a control system and an expansion vessel (Figure 4).

Figure 4. *Thermal Hybrid Force System with Gas 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*



Source: www.solarhuetarnorte.org.

The hybrid forced system implemented at the dairy factories is composed by solar thermal panels to warm water. These panels are connected to a 302 L tank, which is couple to a gas auxiliary system. The tanks have three internal devices to connect thermocouples to register the data related to the captured energy and the hot water used on the dairy factory activities (Figure 5).

Figure 5. *Thermal Hybrid Forced System Implemented at LLAFRAK and San Bosco Dairy Factories* (A) *Solar Panels* (B) *Auxiliary System* (C) *Reservoir for Hot Water* (D) *Solar Cooking Pot for the Pasteurization of Milk*

Source: www.solarhuetarnorte.org

Temperature

According to the record of water temperature at the entrance of the hybrid forced system, water reached a temperature around 27.9 °C (data not shown), while after passing through the thermal system, the water temperature was generally increased by approx. 55% (Table 2). In fact, the highest temperatures were reached in April 2016 and 2017 (65.21 and 63.21 °C, respectively). On the other hand, the lowest temperature was registered in January 2017. This low temperature is due to the transition from the wet season to the dry season in Costa

Rica, which the days are characterized as rainy and cold, contrary to the transition from the dry to the wet season that has place in the middle of April.

Table 2. *Output Water Temperature (T_f), Temperature Required (T_r) and Daily Energy Produced by the Thermal Hybrid Forced System Implemented at LLAFRAK and San Bosco Dairy Factories*

Month	Year	Water temperature (°C)		Energy produced (KWh)
		T_f	T_r	
February	2016	57.5	70.0	4.3
March	2016	59.5	70.0	3.6
April	2016	65.2	70.0	1.6
May	2016	57.6	70.0	4.2
June	2016	54.3	70.0	5.4
July	2016	54.9	70.0	5.2
August	2016	56.9	70.0	4.5
September	2016	56.2	70.0	4.7
October	2016	40.3	70.0	10.1
November	2016	38.1	70.0	10.9
December	2016	36.8	70.0	11.3
January	2017	35.7	70.0	11.7
February	2017	39.6	70.0	10.4
March	2017	41.8	70.0	9.6
April	2017	63.2	70.0	2.3
Mean		**50.5**	**70.0**	**6.7**
SD		**10.4**	**0.0**	**3.6**

These results allowed corroborate the solar potential shown by the different areas in Costa Rica, even though they are known as locations with a rainy weather. In this case, Santa Rosa (Pocosol) and in general the Northern Huetar Region are considered as a low solar productive area due to their cloudy and rainy weather conditions. Indeed, the Institute of Electricity of Costa Rica stated in the 1970´s that it was not possible to produce solar energy in this area because of its lower irradiation level.

Energy Saving

As it has been previously stated, the system was able to increase water temperature by 55%. This fact means that the system was capable to produce around 54% of the daily energy required (232.4 KWh) for the operation of the dairy factories, which represented an energy saving around 72%. This result also assess the efficiency of the thermal solar systems as a tool for the production chain in the Northern Huetar Region of Costa Rica, which has a free and clean energy source potential that can be used all year round to warm water for the economic activities performed in this area (Table 3).

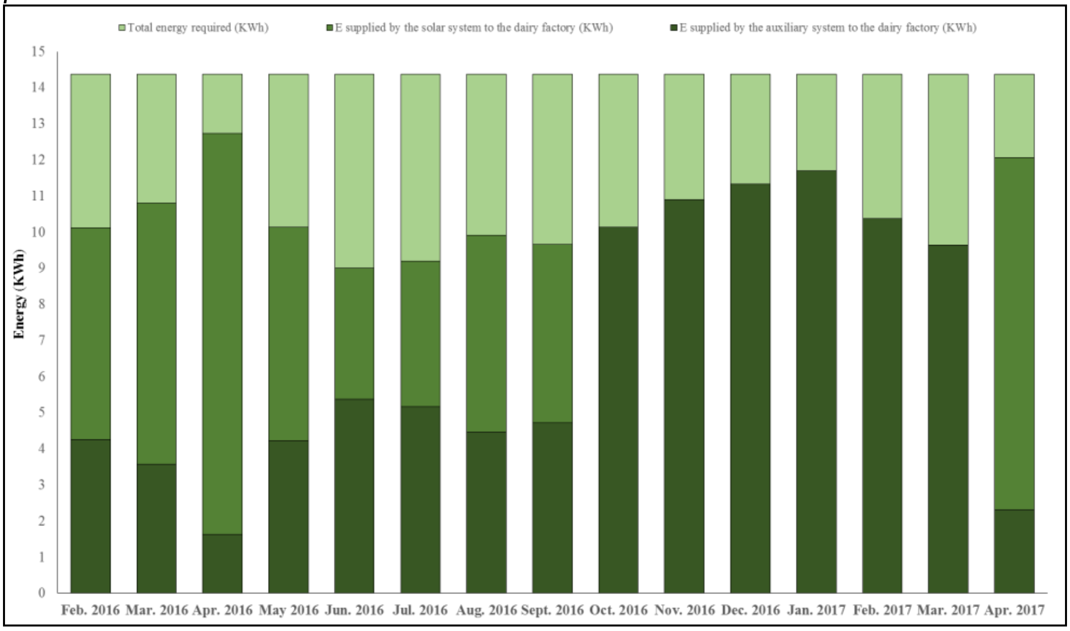
Table 3. *Total Energy Required, Energy Supplied by Both the Thermal Hybrid Forced System and Auxiliary Systems for the Operation of the Dairy Factories and the Energy Saving Reached*

Month	**Year**	**Energy (KWh)**			
		Total required	**Supplied by the thermal system**	**Supplied by the auxiliary system**	**Saving (%)**
February	2016	414.1	291.4	122.7	82.2
March	2016	442.6	332.6	110.0	85.1
April	2016	428.3	379.6	48.8	93.2
May	2016	442.6	312.3	130.4	82.3
June	2016	428.3	268.2	160.2	77.5
July	2016	442.6	283.3	159.3	78.4
August	2016	442.6	305.2	137.5	81.3
September	2016	428.3	287.7	140.7	80.3
October	2016	442.6	130.4	312.2	57.6
November	2016	428.3	103.4	324.9	54.4
December	2016	442.6	93.8	348.8	52.6
January	2017	442.6	82.2	360.4	51.0
February	2017	399.8	111.3	288.5	56.6
March	2017	442.6	145.6	297.0	59.7
April	2017	428.3	359.3	69.1	90.3
Mean		**433.1**	**232.4**	**200.7**	**72.2**
SD		**12.9**	**107.2**	**107.9**	**14.9**

Efficiency of the Thermal Hybrid Forced System

The efficiency of the thermal hybrid forced system was low from October 2016 to March 2017 (Figure 5), where the daily trend varied from 2.67 to 4.73 KWh due to the saturation of the solar panels by temperature (Ortiz-García, 2013). The irradiation captured by panels made them increase their temperature, which also reduced their performance. So, it is recommended to install a cooling system or set the panels in a well-ventilated place to avoid this handicap (Hancco-Apaza et al., no date).

Figure 5. *Efficiency of the Thermal Hybrid Forced System Implemented in the Dairy Factories in Santa Rosa Pocosol (Alajuela, Costa Rica) on Water Warming for Pasteurization and Sanitization Process*



Economic Saving

The structure of the production costs of the dairy factories is composed by 63% of raw material (milk, inputs, packaging products), 1% of factory load (machinery maintenance, gas, etc.) and 35% of workforce (salaries and social security charges).

According to the structure costs associated to water warming by wood burning, it was mainly composed by wood, which had a monthly cost around US$87 and a part time worker in charge of the operation of the boiler (monthly salary US$265). However, this structure changed with the implementation of the thermal hybrid forced system due to the only cost associated to the operation of the system is represented by the PL gas for the auxiliary system (US$104 per month).

Therefore, the dairy factories registered a US$247 saving per month with the implementation of the thermal hybrid forced system (Table 4).

Table 4. *Economic Saving Registered by the Dairy Factories with the Implementation of the Thermal Hybrid Forced System*

Item	Operation cost (US$)		Saving (US$)
	Wooden boiler	Thermosiphon system	
Wood	87	0	
PL Gas	0	104	
Workforce	265	0	
Total	352	104	247

Carbon Footprint Reduction

The dairy factories previously used 2,267.96 kg of firewood [mainly melina wood (*Gmelina arborea*)] as fuel to warm water, which corresponds to 96 felling trees, in plantations not older than 3 years old. So, the wooden boiler generated a total of 3,855.5 kg CO_2 per month. On the other hand, the thermal hybrid forced system emits approx. 46.3 kg CO_2 per month from the auxiliary LP gas equipment, which is activated when water temperature is lower than the demanded (70ºC).

Therefore, the replacement of the old wood-burning system by the current thermal hybrid forced system has allowed reduce the CO_2 amount emitted every month to the atmosphere by 98.8% (Table 5).

Table 5. *Comparison of the CO_2 Emitted to the Atmosphere by the Wooden Boiler and the Thermosiphon System*

Energy source	CO_2 emitted to the atmosphere (Kg/month)	
	Wooden boiler	Thermosiphon system
LP Gas	0.0	46.3
Firewood	3,855.5	0.0
Total	3,855.5	46.3

Investment Recovery

Both dairy factories invested around US$8000 in the implementation of the thermal hybrid forced systems. The implementation of these systems registered a monthly saving around US$247. According to Equation 4, the dairy factories could recover their initial investment in approx. 3 years.

Discussion

In the present work, the thermal hybrid forced systems achieved a monthly energy production around 232.4 kWh and a total volume around 2,788.8 kWh. This energy volume is able to cover 54% of the energy required for the operation of the dairy factories, which includes water warming for equipment washing and sanitization. However, with the implementation of the thermal hybrid forced systems, approx. 72% of the energy required for water warming is covered. In addition, by storing this water in a sealed tank, hot water can be always provided for the cleaning and sanitization of the dairy factory, even when there are interruptions with the auxiliary system to assure food safety.

In any case, it can be stated that the amount of energy produced mainly depends on the intensity of incident solar radiation, regardless of the temperature and precipitation level of the zone, which are constant and abundant throughout the year in the Northern Huetar Region. This fact is especially noticeable in the thermal systems, whose energy production varies linearly with the light that impinges on the solar panels. In addition, this is the reason why it is always necessary to place the panels in the position and angle that maximizes the incident light (Benítez-Salazar et al., 2013).

As it is well known, 7% of the energy produced in Costa Rica is generated with a thermal source, while 93% of the energy generated in the country comes from non-fossil sources (ICE, 2010). This makes the amount of CO_2 that is avoided to emit to the atmosphere with solar systems as not significant as it can be in other countries that are more dependent on the fossil fuels. However, even if hydroelectric plants do not pollute in terms of GHG emissions, it does not mean that they do not have an environmental impact on the regions where they are built. River diversions and direct impact on the microclimate and fish fauna, deforestation and expropriation of lands by flood are some of its negative consequences. It makes it possible to verify that solar energy stands out as a viable and feasible technology in various domestic, industrial and technological applications (Iglesias-Ferrer and Morales-Salas, 2013).

According to the economic saving shown by the thermal hybrid forced systems, the recovery of the initial investment is currently given in 3 years, with a 25 year useful life of the panels (González, 2009). However, according to the forward estimate made by the Industry Chamber of Costa Rica, the electricity bill was increased by 14.3%, and it is expected this trend to continue. In Costa Rica, continuous energy is mostly hydroelectric, and it is in dry times that the use of thermal generation with imported fuels has been gradually used (DSE, 2012). This variability in rainfall regimes has increased over the last 10 years, prolonging the dry period, which will be a cause of the progressive increase of electricity due to lack of rain in the future (Alvarado et al., 2012).

It should be noted that, in the amount calculated, the environmental cost of the implementation of thermal solar systems is not taken into account, which would significantly increase the saving of the electricity bill. And it is that, at the moment, the companies do not contemplate in their accounting the generated environmental costs. The new environmental regulations and pressure from non-governmental organizations and international credit agencies have changed this attitude and have led companies to pay increasing attention to these costs.

Over time, society will adopt renewable energies, since fossil fuel reserves are limited and they are only generated over the course of geological times. Therefore, the question is not whether society will adopt renewable energies, but when it will. Lifetimes of fossil fuels could be extended by new extraction technologies, but the need to minimize the adverse effects of climate change is a more immediate problem than the depletion of fossil fuels (Timmons et al., 2014).

Conclusions

It has been demonstrated that it is possible to generate solar energy independently of the weather conditions of the Northern Huetar Region of Costa Rica. The results obtained through the solar thermal systems implemented in the dairy factories selected can prove the benefits of this technology on the agriculture exploitations of Costa Rica due to they can be used successfully in agricultural production processes, sterilization of automated milking and pasteurization of milk. In addition, it can be seen that these systems are an efficient source to reduce operational costs as well as carbon footprint. However, it is required to continue with data registration and designing other solar systems, for further use in other agricultural activities such as the drying of seeds, fruits, vegetables and medicinal plants.

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