Geothermal and Solar Energy Applied to Air Conditioning and Electricity Generation for Homes: Case study Baños in Cuenca-Ecuador

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Abstract– This article presents a hybrid system composed of a photovoltaic system and use of heat emanating from volcanic sinkholes, the case of Baños in Cuenca-Ecuador is analyzed. The purpose of the study is to satisfy the simultaneous demand for electricity and thermal load to the surrounding area where there are human settlements to improve the comfort of the houses taking advantage of the special conditions of the place, this study is analyzed without connection to the public electricity network.

Keywords— Geothermal energy, renewable energy, volcanic heat, heat demand, solar panel.

I. INTRODUCTION

The heat produced by the core and mantle of the planet has energy that can manifest itself in the form of volcanoes, hot springs and geysers. Since very remote times, humanity has used it in ceremonial, mythological events and currently in tourist and recreational processes.

Geothermal energy, product of the geological processes of the planet, is an inexhaustible source and can be used all year round. The geological processes in the Andean region, the proximity to the subduction zone and closeness to the Circum-Pacific Belt, give rise to volcanic activity in Ecuador, consequently large sources of water are produced with temperatures above 200 °C, sufficient for reuse. in processes linked to human activity and its immediate needs, a change in the energy matrix of each country also contributes.

Geothermal sources and their use could be a very viable alternative with cheaper investments. Shepherd et al. [1] indicates the possibility of having an alternative supply system such as medium and low enthalpy geothermal energy for the generation of electrical energy and other additional elements, now becoming a space of great interest for municipalities.

This technology has been developing worldwide for several decades. According to Gudmundsson et al. [2] states district heating is the world's largest direct geothermal energy use sector, especially when developed alongside district cooling.

The first global studies were carried out, as stated by Gudmundsson et al. [2] at the end of 1984, the installed thermal power of all direct use projects in the world was approximately 7072 MW and the associated flow rate 57,803 kg/cm2.

The potential presented by the system can save the amount of oil in 2.8 million per year. Conventional uses of geothermal fluid were established in communities that used the hot springs primarily for bathing.

The different processes used as indicated by Pastor et al. [1] in direct geothermal applications use heat exchangers to keep the geothermal fluid separate from the working fluid that transmits the heat from the geothermal fluids to the application.

There are other applications such as the paper industry, wood, food packaging, washing machines, refrigeration, etc. therefore, and as indicated by Budiardo et al. [3] The continuous increase in energy consumption has caused the indiscriminate production of greenhouse gases, becoming a great challenge for humanity.

As a possible solution there are new alternative sources for energy supply, but nevertheless these new technologies require a revolutionary change in the processes used by society and that are very necessary to improve the local economy.

Among the possibilities is the concept of "cascade use", for electricity generation applying geothermal processes, including direct uses, as indicated by Pastor et al. [1] where the geothermal fluid gives up its heat as the process advances and undergoes a progressive decrease in temperature. Due to this, the resource suffers a decrease in its energy quality completely.

This concept can be defined as the use of geothermal energy at different thermal levels in sequential processes. Within the state of the art for geothermal energy in the form of a waterfall, a search was made in contemporary and current scientific articles. Taking as reference the following characteristic elements of the geothermal resource, energy levels, technologies used, products generated, degree of use of the resource, technology costs and investment costs of the project.

Cascade case studies for geothermal energy were identified on the African continent. Manifest Mburu et al. [4] the evaluation of the technical feasibility was carried out, to drill a new well for the project as an additional energy supplement. The temperature of the geothermal resource at the head of the wells is 89.6 0C and the applications have temperatures above 50 °C as a limit. The cost of implementing this project has been estimated at USD 40,000.

In the Barrier community (Samburu District) the concept of Geothermal Village is proposed, with the purpose of implementing electrical and thermal energy for human settlements. Cascading application is intended, as indicated by Varet et al. [5] includes electricity production through ORC plants, heat production for food drying, sanitary applications, ecotourism, pumping water for livestock and crops.

Additionally Vared et al. [5] indicates that the resource would have 120 °C with wells drilled to a depth of 500 m and a flow of 55.6 l/s with the capacity to produce between 1 and 2 MW of electricity.

The American continent is highly enriched with this natural phenomenon. Arrubarrena et al. [6] highlights the case of Mexico, which has the installed capacity for the direct use of geothermal heat, currently reaching 164.6 MWt, which shows the potential and uses that can be given to this natural resource. Additionally, the potential of RG in the country is very high since there are wells with temperatures above 200 0C and even in Chihuahua, medium enthalpy processes were used for a 300 kW Ormat Binary cycle. It was reported that the geothermal well used supplies a basic flow of 35 ton/h and a temperature of 98 °C at a depth of 300 m.

Ratlamwala et al. [7] highlights that in Canada, researchers from Ontario analyzed an integrated system for electricity generation, heating and hot water. The system consists of a quadruple effect refrigeration system and a multi-stage binary start with isobutane as working fluid, which together provide the final products.

In the United States, GR technology has developed more rapidly, as noted by Culver et al. [8] , the scheme proposes to use the effluent of the binary cycle plant with a temperature of 96.1 °C, reducing it to approximately 24 °C, using a flow of 3.5 l/s.

There are other processes linked to the geothermal system, as indicated by Gordon et al. [9], the facility consists of a power plant in conjunction with a plant for dehydration of onion and garlic. The plant came into operation in 1988, it consists of four 1.2 MWe units, to jointly produce 3.6 MWe. of net horsepower at a design temperature of 141 °C (285 0F).

In other regions according to Lund et al. [10], in which the cascade system is used is: Klamath Falls Oregon, in the region there are 6 geothermal wells with temperatures from 27 °C to 93 °C and depths around 90 m. Its use v towards agriculture and aquaculture and the main well for heating greenhouses.

The internal heat of the earth, that is, geothermal energy can have applications depending on the available temperature. Thanks to new technologies it could be used as an alternative for local energy generation [11]–[13], with the aim of providing the Ecuadorian population with more viable mechanisms to clean the environment using inexhaustible and clean energy.

In Cotton City New Mexico, Kutscher et al. [14] indicates that in this area it is considered to install a Kalina cycle plant with a net power of 1 MWe, using an ammonia-water mixture as working fluid, well depth 120 m. temperature between 115 °C to 120 °C and a flow of 63 L/s.

In 2003 for Erickson et al. [15], in Alaska, the available GRs are hot springs and geothermal wells with a temperature of 74 °C (165 °F) and a depth of 300 m. resources used to maintain the ice museum. Absorption refrigeration machines fed with geothermal resources were used.

In China, as Feng et al. [16], the cascade use of geothermal water applied to: radiant heating heat pumps for heating, plate heat exchanger is analyzed. Various techniques are applied to maximize the use of geothermal energy and decrease the depletion of geothermal reservoirs.

According to Jiajia et al. [17], the ground heat exchanger takes the underground soil as a heat source or sink to supply cooling or heating. It has been widely used in building heating and cooling systems due to its high efficiency and environmental friendliness. It states that terrestrial heat exchangers are classified into water-based and air-based heat exchangers according to the heat transfer medium. They can be used passively or actively. Associated research and projects are introduced and discussed for each approach.

For Farayi et al. [18], a multi-generation system that includes an absorption chiller, an organic flash cycle, a concentrated photovoltaic module, a reverse osmosis unit, and thermoelectric modules are integrated to produce cooling, heating, electrical power, and fresh water. It becomes important to take into account other processes necessary to carry out this research work. We must take into account and as Lorente et al. [19] and according to different estimates, this internal heat of the earth is flowing towards the surface, at a rate of 4.2 x 10 13 J/s. Most of this heat flux comes from the mantle, representing around 82% of it. Another 16% comes directly from the core and the remaining 2% is emitted by the Earth's crust. This 2% represents 8 x 10 12 J/s.

The results according to Cúnsulo et al. [20] are related to the identification of optimal gradients and depths for the use of the resource as a Passive Geothermal Cooling System, in order to provide hydrothermal comfort conditions in arid urban areas during the summer.

Due to the aforementioned, it determines a great potential of the resource to be used, allowing to produce a great source of geothermal origin. As indicated by Ioan et al. [21], the soil simulation is summarized in the currently available thermal response test models for vertical soil heat exchangers. Including the heat transfer processes outside and inside the wells.

II. METHODOLOGY

In the present investigation, a model is proposed for the use of thermal energy for the use of hot spots in the vicinity of the Volcano located in the Baños de Cuenca-Ecuador Parish. This volcano is not active but it allows to take advantage of the heat that it emanates and combine the energy potential with an isolated photovoltaic system and in these conditions have electricity and heat for heating environments. Next, in Fig 1, the scheme of the system under study is presented.

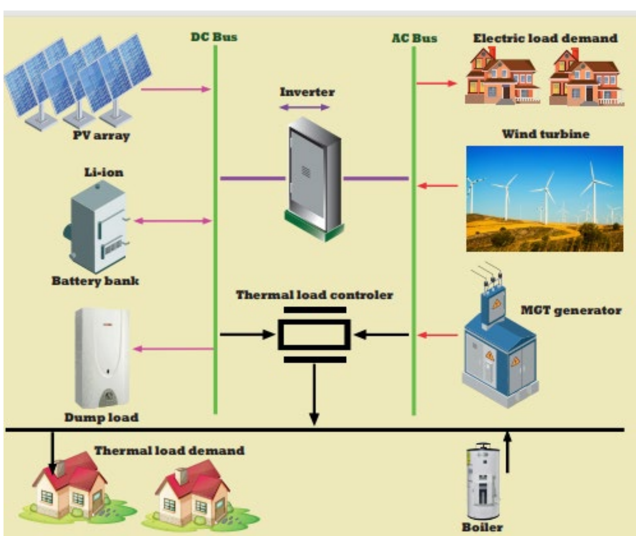


Fig 1. Proposed scheme to supply electrical and thermal energy to the surrounding sector.

III. LOCATION OF RESEARCH

Baños was established at the beginning of the 17th century, when the Spanish exploited the gold and silver mines in the area. It has an area of 327.3 km² and the altitude varies from 2,050 to 4,200 meters above sea level. Historical records indicate that in 1693 the city diversified. Baños as a populated place dates back to pre-colonial and even pre-Inca times, since the presence of natural resources such as hot springs, gold veins, plus its geographical location between the plain occupied by the City of Cuenca and the grasslands of the upper basin of the Yanuncay River.
According to history, reference is made to the fact that the Inca Túpac Yupanqui, father of the Cuencan Huayna Capac, Emperor of the Incas, knew it for its hot springs. Outbreaks of hot waters that emerge due to the action of an inactive volcano at a temperature of about 75 degrees Celsius, make it a highly visited tourist site.

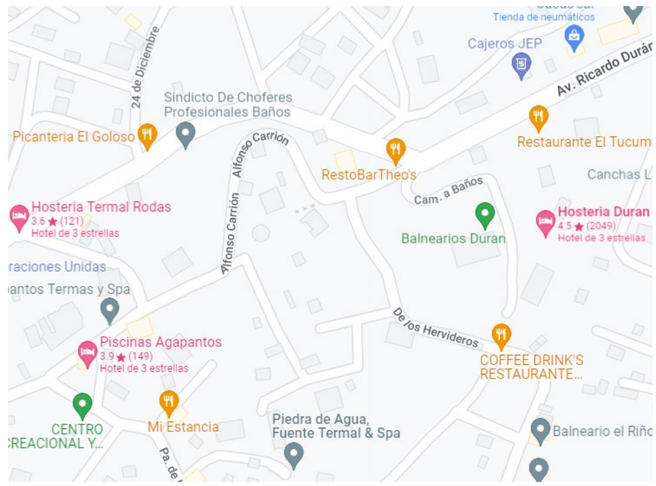


Fig 2. Location of Baños in Cuenca-Ecuador

To obtain the air conditioning system for single-family homes, the following stages are proposed:

a) Respective bibliographic review, in order to identify the information that will serve as the basis for the implementation and improvement of air conditioning systems with the use of geothermal energy.

b) An energy system is designed that includes the use of geothermal heat combined with photovoltaic solar panels.

c) Carry out simulations for different conditions.

d) Obtain results in terms of electrical power for your application.
e) Analyze the proposal and its operation, through the implementation of the system.

In this study, the Homer Pro tool was used for the simulation and optimization of different system hardware components to meet the demand for electrical and thermal load. Input parameters include weather conditions as shown in Fig 3.

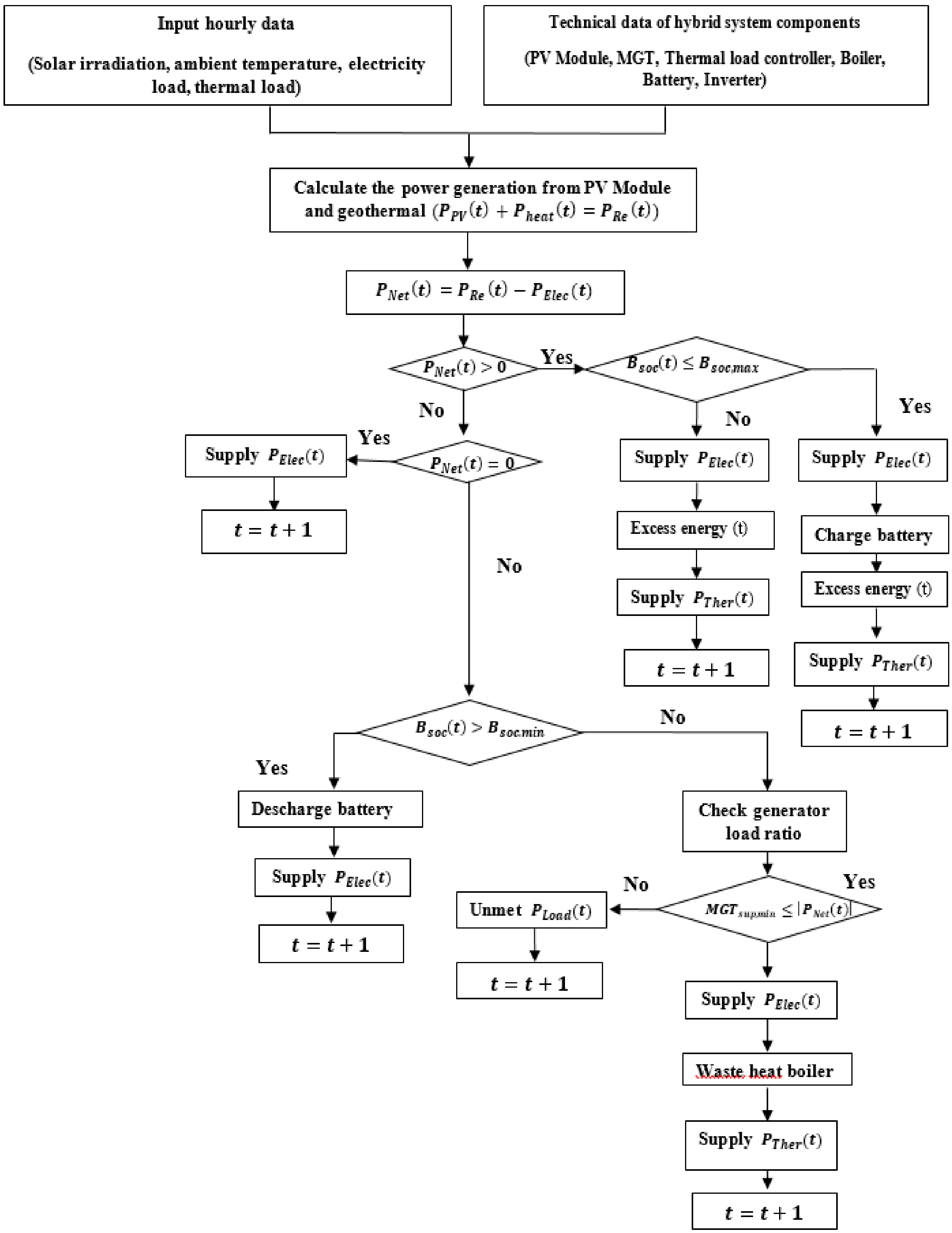


Fig 3. Strategy for cyclic load and satisfy the demand for thermal and electrical loads.

IV MATHEMATICAL MODELING.

The mathematical relationships that govern the studied system are presented in this section. The power supplied by the photovoltaic systems and output volcanic geothermal heat are presented in hourly temporal resolution, determined based on their potential.

A. Modeling of the photovoltaic system

The output power of the solar PV system was determined from Equation (1), where: D_{PV} is the module power reduction factor (86%). P_{rated} is the nominal power of the PV (200 W), S_{ref} is the incident solar irradiation at STC (1000 W/m^2), S(t) is the incident solar irradiation at the PV, αP is the temperature coefficient of the power (-0.38%k^(-1)) T_{cell} (t) is the PV cell temperature, and T_{ref} is the reference cell temperature in STC (25°C).

$$P_{PV}(t) = P_{rated} D_{PV} \left(\frac{S(t)}{S_{ref}}\right) [1 + \propto_p (T_{tell}(t) - T_{ref}] \qquad (1)$$

The cell temperature of the photovoltaic module was found from equation (2). $T_a(t)$ is the room temperature, $T_{cell,NOCT}$ and $T_{a,NOCT}$ is the nominal operating cell temperature (NOCT) and the NOCT at room temperature, respectively. In addition, the S_{NOCT} is the solar irradiance incident to the NOCT (800 W/m^2), η_{PV} is the panel efficiency (20.05%), rα is the solar transmittance-absorbency of the PV module, the HOMER platform assumes 0.8.

$$T_{cell} = T_a + S(t) \left(\frac{T_{cell,NOCT} - T_{a,NOCT}}{S_{NOCT}}\right) \left(t - \frac{\eta_{PV}}{r\alpha}\right) \qquad (2)$$

B. Heat pump modeling

A numerical model was developed to simulate the performance of the heat pump [22]. Assumptions, initial conditions, and thermodynamic properties of fluids were mentioned in the literature review. The total heat transfer in the heat exchangers is calculated using the Number of transfer units (NTU) method [23]–[25], and the heat transfer coefficient in the single-phase and two-phase state of the evaporator and condenser.

The mass flow of the refrigerant can be obtained as determined by the authors according to references [26]–[30] and is evaluated by (3):

$$\dot{m}_{ref} = n_v \, x \, \rho_1 \, x \, v_G \, x \, \omega \qquad (3)$$

$$n_v = 0.9322 - 0.0636 \left(\frac{\rho_2}{\rho_1}\right) + 0.0017 \left(\frac{\rho_2}{\rho_1}\right)^2 \qquad (4)$$

Hence, ω is not constant and is a function of time and the heating and cooling load demand of the sector under study. The compressor process is considered to be isentropic. In this way, the power can be obtained as specified in the references [31]–[33] as:

$$\dot{W}_{comp} = \frac{\dot{m}\_ref(h_{2,isen} - h_1)}{\eta_{total}} \qquad (5)$$

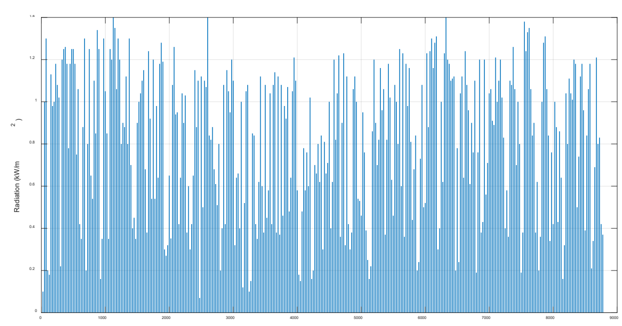
$$\eta_{total} = \eta_{is} \eta_{mech} \eta_{elec} \qquad (6)$$

$$\eta_{is} = 0.834 - 0.0555 \left(\frac{\rho_2}{\rho_1}\right) \qquad (7)$$

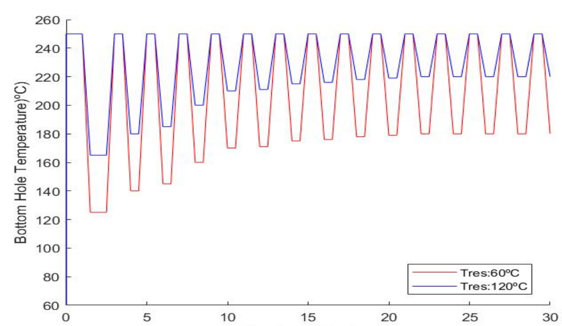
V. SIMULATIONS

A. Input Data.

Below are the input data of the designed system, consisting of solar radiation (Fig 4a) and wellbore temperature cycles. The wellbore temperature cycles for a baseline case are shown in Fig. 4b, except an initial reservoir temperature of 60 C is used instead of 120 C. The two temperatures are in the analysis range at the locality and Based on these temperatures, the future heating/cooling system necessary to supply the residences in conjunction with the photovoltaic production system is designed.



(a)



(b)

Fig 4. (a) Solar radiation. (b) wellbore temperature cycles.

VI. RESULTS

The results at the outlet and the refrigerant mass flow rate were obtained using known input parameters, such as the geometry of the heat exchangers, the inlet temperature and the desired heating demand. The calculation requires an initial estimate of the saturated temperature at the evaporator and condenser level and the iteration cycles continue. Finally, when the results are almost equal to the initial assumptions, it means that the results converge.

Fig 5 presents the scenarios of the annual exergy evaluation, with the help of photovoltaic systems and another without a solar component. The red bars in Fig. 5 present the normal GSHP system without the PV system and the blue bars are the hybrid GSHP system integrated with PV systems. In case 1, the PV area is smaller than cases 2, 3 and 4. Therefore, the results are only for the evaluation of different cases. The results obtained represent that the maximum and minimum irreversibility occur in the hybrid system with the photovoltaic arrays (fourth scenario). The exergy destruction in the first scenario is 85.12% higher than in the seventh scenario.

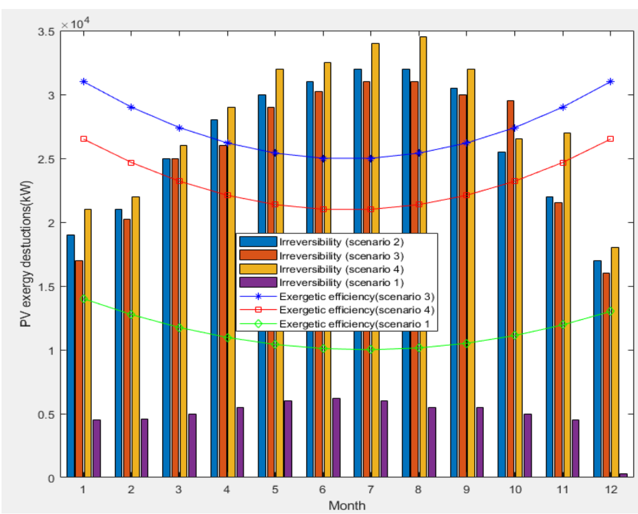


Fig 5. Comparison of monthly solar photovoltaic exergy in different scenarios

VII. CONCLUSIONS

In Baños of Cuenca-Ecuador, the use of geothermal heat from the sinks at the different prospecting points can be very useful. In reality, depending on this single source can lead to errors if you plan to generate electricity, however, by forming a hybrid system with solar panels, the use of electricity for homes near the inactive volcano where there are concentrated human settlements becomes attractive. Heat can be of great benefit for heating environments and with heat pumps the system can be made effective by reverting the system from heat to cold and therefore have heating and cooling circuits.

Ecuador is in a permanent search for options that allow it to transform its energy matrix with a high participation of renewable energies. It will be possible when initiatives of this nature that come from the private and public sectors are planned and put into practice for the greater benefit of the communities and citizens in general.

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