

Review and resource assessment, solar energy in different region in Ecuador

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Abstract. Environmental pollution caused by the generation of electricity through fossil fuels leads several countries to adopt strategies for the exploitation of renewable energy sources. In this work, the current energy situation of Ecuador and the incorporation of photovoltaic generators in the national system is reviewed. The document is completed with the evaluation of the energy potential for an average load in the four regions of Ecuador. The selection of the locations of the system under study is chosen through the solar atlas and the meteorological data for a year. The technical dimensioning and economic analysis is achieved through the Homer software. The results show that the insular region reaches the lowest value of leveled cost of energy (COE) \$0.529, an autonomy of 22.7 hours and unmet electric load 0.06% per year.

1 Introduction

During the global financial crisis, the substitution of fossil fuels by renewable energy for the production of electricity was promoted [1]. Nowadays, the increase in energy consumption, climate change, emissions derived from fossil fuels and energy independence contribute to the introduction of renewable energies [2]. The use of renewable energy sources has been the policy of several countries in the world to achieve sustainable development [3].

The solar energy is a mature technology and proven in several applications, the energy potential is analyzed by means of climatic and geographical factors for use in urban areas [4]. Latin America is one of the most dynamic markets in terms of renewable energy, the International Renewable Energy Agency (IRENA) indicates that between 2010 and 2015 more than 80,000 million dollars were destined in non-conventional renewable energies, not including large hydroelectric power plants. Brazil, Chile, Mexico, Peru and others are taking advantage of their renewable resources in order to increase their energy and economic efficiency [5]. Ecuador presents the Electrification Master Plan 2013-2022, aligned with the Constitution of the country and the objectives of the National Plan for Good Living, which constitutes a planning tool determining the investments to guarantee the normal supply of electricity, increase of the reliability and security of the electrical system through the development of projects for the generation and expansion of the Ecuadorian electricity sector [6]. In reference [7], the researchers use spatial tools such as Geographic Information Systems (GIS) with the objective of identifying the potential of energy sources in Ecuador for the possible location of solar and

wind generators. The results share the areas with greater potential for the implementation of these technologies, the information is classified in spatial layers according to the technology of the renewable resource and location.

Capturing the greatest amount of solar radiation is a complex work due to the constant change in meteorological variables. Several investigations have proposed methodologies to solve the problem, in the reference [8], the authors calculated for a year the azimuth and altitude angles solar. With the information obtained, the sun was tracked on both axes by means of a programmable logic control (PLC), the results showed that with the implemented system of two axes, more energy is collected compared to a fixed system (42.6%). In [9] several configurations of hybrid systems, control strategies and the techno-economic study are analyzed. The authors compare the results using the Homer software and the PSO algorithm. The results show that the feasible solution is based on the COE, renewable fraction, maximum renewable penetration, level cost.

This work studies in section I the number of photovoltaic projects in Ecuador and the sites with the highest radiation in each of the regions of Ecuador, in section II a photovoltaic system is simulated for an average load for the selected places in the section previous, in section III the results obtained are analyzed having as a comparison parameter the cost of energy. Finally, the conclusions are exposed.

2. Background

The multi-year energy balance published by the ARCONEL (Electricity Regulation and Control Agency) shows that Ecuador generated and imported 15,749.65 GWh in 2007, while for 2016 it increased 67.7% to

23,254.62 GWh. The consumption of energy for public service reported in December 2017 is 20,204.22 GWh, which corresponds to 88.66%, the remaining percentage is lost in the distribution system. Table 1 shows the nominal power of the generators installed in Ecuador.

Table 1. Nominal Power in Electric Generation

	Generator	MW	%
Renewable Energy	Hydraulics	4,515.96	56.19%
	Wind	21.15	0.26%
	Photovoltaic	26.48	0.33%
	Biomass	144.3	1.80%
	Biogas	7.26	0.09%
Total renewable energy		4,715.15	58.67%
Non - Renewable	Thermal	1,937.48	24.11%
	Thermal turbogas	921.85	11.47%
	Thermal turbovapor	461.87	5.75%
Total non-renewable energy		3,321.19	41.33%
Total nominal power		8,036.34	100%

Solar energy had no participation in the Ecuadorian market until 2015 with 0.01 MW. In 2011, the extinct Conelec (National Electricity Council) issues the regulation 004/11 called “Treatment for Energy produced with Non-Conventional Renewable Energy Resources” with the objective of establishing the requirements, prices, their period of validity, and of dispatch for the electric power delivered to the National Interconnected System and systems isolated by the generators that use non-conventional renewable sources, up to an installed capacity of 50 MW [10]. The renewable energies included in the regulation are: biomass, wind, photovoltaic, biogas, geothermal and hydroelectric power plants. With which encourages private investment in renewable energy.

The price to be paid in photovoltaic power plants for the energy measured at the point of common coupling (PCC) is 40.03 cUSD/kWh in the continental territory and 44.03 cUSD / kWh in the insular territory of Galapagos, while for wind power plants is 9.13 cUSD/kWh and 10.04 cUSD/kWh respectively. The utilities that subscribed to this contract until December 31, 2015 have a validity of 15 years from the subscription of the qualifying title. Also, they have preferential dispatch in a mandatory manner so that they deliver to the interconnected national system up to the limit of 6% of the installed capacity.

The technical parameters regarding the quality of the electrical energy produced by the photovoltaic systems will be the same established for the conventional generators monitored by the CENACE (National Electricity Operator).

The preferential price attracted the generation companies, where 17 projects were submitted for 284 MW filling the Conelec incentive quota, the expected investment was USD 700 million up to 2015 [11], however the expectations were not met reaching the 26.47 MW of installed power in 2017, distributed in 29 solar plants. Table 2 shows the photovoltaic power plants installed in provinces of Ecuador with their respective power.

Table 2. Nominal power of solar plants

Provinces	Number of plants		Nominal Power (MW)	
	2007	2016	2007	2016
Cotopaxi	0	2	0	2
El Oro	0	6	0	5.99
Galápagos	1	7	0.02	1.64
Guayas	0	4	0	3.98
Imbabura	0	0	0	4
Loja	0	6	0	5.99
Manabí	0	2	0	1.50
Morona Santiago	0	1	0	0.37
Pichincha	0	1	0	1
Total	1	29	0.02	26.47

2.1 Solar radiation in Ecuador

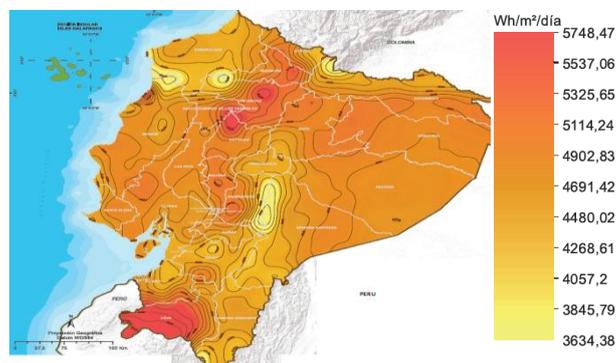


Figure 1. Average global radiation

Solar radiation is radiant energy emitted by the sun, particularly electromagnetic energy, the wavelength and frequency of electromagnetic waves are important to determine their energy. Figure 1 shows the average global radiation map obtained by the solar energy incident on a surface per unit area. For the study of a locality it is necessary to compare the information with meteorological databases (software) and to take field data through meteorological stations. Due to its location and because it is a country with very varied topographic characteristics, Ecuador has a high potential for renewable energy applications. The maximum value of radiation in Ecuador is 5,748 Wh/m²/day, the minimum value is 3,634 Wh/m²/day while the average value is 4,574 Wh/m²/day. The solar atlas was presented by the CONELEC and prepared by the Corporation for Energy Research (CIE) with the aim of promoting the use of solar energy. For the development of the solar atlas the

information provided by the National Renewable Energy Laboratory (NREL) of the United States was used, the data have been compared with information from weather stations with an error among the data of 10% [12].

Ecuador has 4 regions (coast, sierra, east and insular region), in each of the regions the highest radiation points are chosen according to figure 1, for the coastal region the province of Manabí is chosen, the coordinates are 0°7.6'S , 80°18.4'W the average annual solar radiation is 4.79 kWh/m²/day. For the sierra region, the province of Loja is chosen with the following coordinates 4°19.8'S, 80°12.7'W the average annual solar radiation is 5.6 kWh/m²/day. For the Ecuadorian east, the place of greatest radiation is in the province of Sucumbios with the coordinates 0° 27.3'S, 75° 44.9'W with an average annual solar radiation of 4.35 kWh/m²/day. Finally, the last location is for the island region on San Cristobal Island, the coordinates are 0° 53.0'S, 89°35.8'W and the average annual solar radiation is 6.1 kWh/m²/day [13].

3 Proposed Systems

For the simulation of the load, the average per capita consumption 1,143 kWh/inhab was used [14], for a family consisting of 5 members reaching a consumption of 476 kWh/month, the residential load characteristic curve is shown in the figure 2 [15].

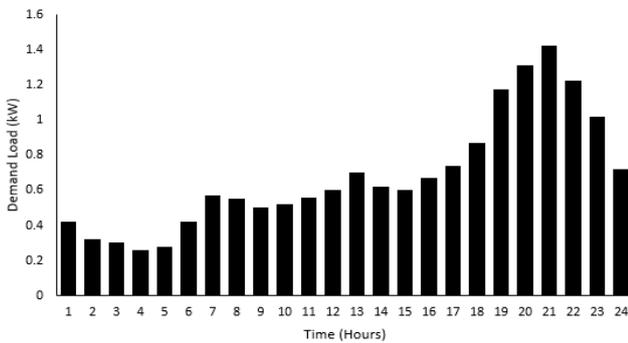


Figure 2. Average global radiation

The load is characterized by a maximum consumption of 1.4 kW, average of 0.66 kW and a minimum consumption of 0.25 kW. The photovoltaic system to be simulated is isolated, as a storage system has a battery bank.

3.1 Photovoltaic Subsystem

A photovoltaic generator consists of several photovoltaic cells connected in series and parallel. The prediction of solar radiation is essential to obtain the generation of the photovoltaic system and know the feasibility of the proposed system. The output power of the photovoltaic generator depends on the solar irradiation, the ambient temperature and is calculated using equation 1.

$$P_{PV} = f_{PV} * Y_{PV} * \frac{I_T}{I_S} \quad (1)$$

Where Y_{PV} is the rated capacity of the PV array (kW), I_T is the total incident radiation on the panel surface (kWh/m²), I_S is 1000 W / m², f_{PV} is the reduction factor that refer to the PV array power output to account for reduced output in operating conditions. The module used for the simulation is of commercial manufacture, flat plate type of 145W, the temperature coefficient is -0.460, operating temperature is 45 °C and efficiency of 14.4%.

3.2 Battery Bank

The storage system is composed of a battery bank. When the production of the photovoltaic panels is greater than the load, the excess energy is stored in the batteries, the storage system is in charge state, the energy stored in a time t can be calculated by equation 2, while the discharge process is calculated by equation 3 [16].

$$E_{Batt}(t) = E_{Batt}(t-1) \times (1 - \sigma) + \left[E_{pv}(t) \times \eta_{Inv} - \frac{E_{Load}(t)}{\eta_{Inv}} \right] \times \frac{\eta_{bb}}{\eta_{Inv}} \quad (2)$$

When the energy generated by the photovoltaic system is less than the demand or at night, the battery bank delivers the stored energy to satisfy the load, the process is called discharge and is calculated using equation 3.

$$E_{Batt}(t) = E_{Batt}(t-1) \times (1 - \sigma) - \left[\frac{E_{Load}(t)}{\eta_{Inv}} - E_{Gen}(t) \right] \quad (3)$$

Where $E_{Batt}(t)$, $E_{Batt}(t-1)$ are the energy storage in the battery (Wh) in a hour (t); σ is hourly self-discharge rate; E_{pv} is the energy generated by the photovoltaic panel; $E_{Load}(t)$ is the hourly energy required by the load; η_{bb} and η_{Inv} are the battery efficiency and efficiency of the inverter [17].

3.3 Inverter

The system under study contains elements in DC, the balance between the flow of energy between the elements of AC and DC is made by an electronic inverter. The inverter used in this work has a capacity of 2 kW, a life time of 15 years and an efficiency of 95%.

4 Results and discussion

The different configurations are simulated and evaluated using the Homer software, the program evaluates hundreds and even thousands of viable configurations to find the optimal sizing of the hybrid system proposed depending on how the problem is configured, the

simulation is performed for one year in steps of time from one hour to one minute.

Taken as reference the data of the solar atlas of Ecuador, the place has been chosen with the highest radiation for each of the regions. The coordinates of the site for the coastal region is $0^{\circ} 7.1'N$, $80^{\circ} 2.3' W$ located in the province of Manabí. In the sierra region, the province of Loja has the highest radiation values in the region, the coordinates of the site are $4^{\circ}19.6'S$, $80^{\circ}17.9'W$. The province of Orellana in the Oriente region is chosen for the document, the coordinates of the site is $0^{\circ} 27.3'S$, $75^{\circ}44.9'W$ while in the insular region the San Cristobal Island has one of the highest values of radiation with $6.1 \text{ kWh/ m}^2/\text{day}$, the coordinates of the site is $0^{\circ} 53.0'S$, $89^{\circ} 35.8'W$. The proposed system is observed in figure.3.

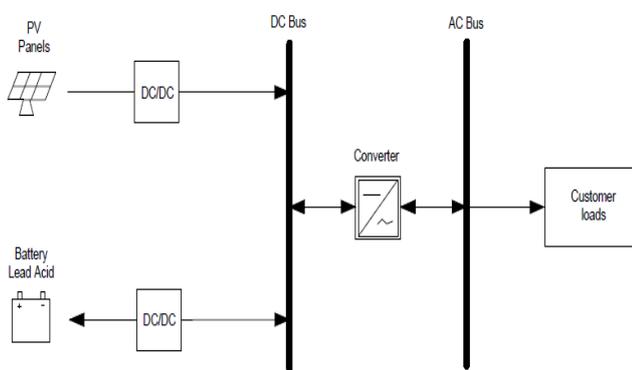


Figure 3. System under study

The results of the simulations are shown in table 3. In the eastern region it has the largest photovoltaic system with 22 kW, 30 batteries of 1 kWh. The cost of energy is $\$0.659/\text{kWh}$ and the total net present cost is $\$49,330$ which makes it the most expensive system of the evaluated despite the size of the photovoltaic system has unmet electric load of 0.10% (0.608 kWh / yr). Where, the unmet electric load is that load the power system is unable to serve, the battery autonomy is 27.2 h, the expected life is 6.3 yr and the storage wear cost $0.419\$/\text{kWh}$.

The simulated system for the coastal region achieves the following results: a photovoltaic system of 20 kW, 30 batteries of 1 kWh, the cost of energy is of $\$0.632/\text{kWh}$ and the net present cost is $\$ 47,322$.

Table 3. Simulation results of photovoltaic systems

Región	PV (kW)	Battery (kWh)	Converter (kW)	COE (\$)	NPC (\$)	PV Production (kWh)	Battery Autonomy (hr)	Unmet Electric Load (%)
Oriente	22	30	2	\$0.659	\$49,330	28,060	27.2	0.10
Costa	20	30	2	\$0.632	\$47,322	28,314	27.2	0.07
Sierra	14	28	2	\$0.571	\$42,748	23,161	25.4	0.09
Galápagos	12	25	2	\$0.529	\$39,588	21,709	22.7	0.06

The unmet electric load is 0.07 % (4.53 kWh/yr), the battery autonomy is 27.2 hr, the expected life is 6.3 yr and the storage wear cost $0.419 \text{ \$ / kWh}$. The results of the battery are the same as those of the previous system when having the same number of batteries.

The simulated system for the Sierra region is a 14 kW photovoltaic system, 28 batteries of 1kWh, the cost of energy is $\$ 0.571/\text{kWh}$, the total cost present is $\$42,748$, the unmet electric load is 0.09% (5.69 kWh/yr), the expected life of battery is 5.86 yr and the storage wear cost $0.419 \text{ \$ / kWh}$, the battery autonomy is 25.4 hr which is lower than the previous systems evaluated.

The system evaluated with the best result is the one located in the insular region with a 12 kW photovoltaic generator, 25 batteries of 1 kWh, the cost of energy is 0.529, the net present cost is $\$39,588$, the unmet electric load is 0.06% (4.02 kWh/yr), the expected life of battery is 5.26 yr and the storage wear cost $0.419 \text{ \$/kWh}$, the battery autonomy is 22.7 hr. The proposed system for the insular region has better economic results, but also less benefits from the bank of batteries because it has fewer units.

Figure 4 shows the total electrical load served for the proposed system in each of the regions, which is the total amount of energy that was used to satisfy the main and deferrable loads during the year. The Costa region has a total power in a year of 5,790.9 kW, in the Insular region it is 5,791.4 kW, in the Oriente region it is 5789.3 kW, while the sierra region is 5,789.7 kW.

The excess electricity in the simulated system for the Galapagos region is $14,774 \text{ kW / year}$ which is 68.1%.

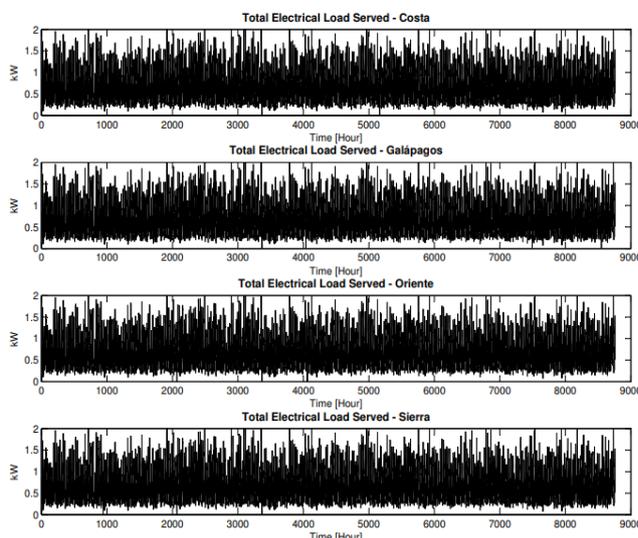


Figure 4. Total electric load for the 4 regions

5 Conclusions

The present work shows the high solar radiation that is in the regions of Ecuador, the highest value of global solar radiation was found in the Galapagos Islands, the annual average value is 6.1 kWh/m²/ day. As a result of the new policies implemented in the electrification master plan, the status changed from the 0.02 MW installed in 2007 of solar plants to 26.47 MW, which contributed 0.33% to the generation of renewable origin in 2016, which represents the 58.67% at the country level. It is still a small percentage, but there have been samples of the implementation of solar generators. The work is completed with the economic technical evaluation for a simulated average load in each of the regions of the country, the results show that in the Galapagos region the lowest COE \$ 0.529 and TNPC \$39.588 are achieved, where the main generators are of non-renewable origin. This work intends to give an approach to entrepreneurs and the government for the implementation of this type of technology.

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