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Design, implementation and evaluation of the energy performance of a photovoltaic solar system in Cota, Colombia

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Abstract

In recent years the growth of photovoltaic technology (FV) worldwide has allowed reducing the emission of the greenhouse gases. This article presents a design, implementation and energy evaluation of 1 kW autonomous photovoltaic system installed in Bioparque La Reserva de Cota, Cundinamarca Colombia. The FV System generates 3,36 kWh/month, with represents an economic saving of (122.31 USD/year) and a CO_2 reduction about 0.028 Tn/year, this value is equivalent to 2.9893 gallons of ACPM or 3.6523 gallons of gasoline. The results show that production costs and greenhouses gases emissions decrease, which means a contribution to mitigate the climatic change.

Keywords: *climatic change, photovoltaic panel, renewable energy, solar energy, solar panel*

1. Introduction

The need about increase the use of renewable and clean energies in worldwide is well known [1]. Due to they generate less environmental impact, they are regulated by inexhaustible nature cycles [2].This makes photovoltaic energy be one of the alternatives with the highest growing and demand in the latest years [3], since it allows to rural and urban population have electricity access and a viable and sustainable energetic infrastructure [4]; because energy is not longer a luxury but a necessary product for modern life. The world economic growth along with growing population, mainly in developing countries; requires more energy to raise the expected global energy demand by approximately 25% by 2040 [5].

Energy can be classified into two main categories according to areas of utilization such as renewable and non-renewable energy resources. Renewable energy is an energy resource that is replaced rapidly by a natural process, or it is an energy source that is naturally replenished. Wind turbines, fuel cells, solar cells, nuclear energy, and hydroelectric energy are examples of renewable energy resources. Non-renewable energy sources or natural resources are those sources that drain fossil reserves deposited over centuries [5]. The world population expects a growth of 7.5 billion people in 2017 to 8.2 billion in 2030, due to it, energy demand is expected to increase with an accelerated speed during this period, this population growth brings pollution and is suggested that policymakers must encourage the use of technologies which reduce the pollutant emission, helping to decrease climate change irreversible effects [6].

There is an urgent need for implementing an use of sustainable energy and invest in energetic efficiency, since is the most cost effective and rational way to reduce the carbon dioxide (CO_2) emissions. This has carried out the governments to launch initiatives and pass specific legislation to achieve this aim [7]. So, photovoltaic solar energy is one of the renewable energies with the fastest growing in the world, but there is still remains a lot to advance its technology. One of the subjects to which it is subjected to discussion is the efficiency of solar photovoltaic panels seeking to optimize the capacity of solar radiation capture [8].

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There is a dominant model for energy production, planned from hydroelectricity macro projects from large dams and nuclear power plants that generate thousands of megawatts to satisfy the electricity need of populated centers away from its production areas. By the same way, gasoline and diesel production is processed in refineries located in distant territories and countries [9]. The above promotes the development of non-conventional renewable energies when using renewable energy sources. It is necessary to take into account the power of the renewable energy flow, which makes it necessary to evaluate the reliability of the Power Supplies based on them [10].

Taking advantage of the constant solar energy in Colombia, the implementation of an efficient and viable photovoltaic system is an option to reduce the carbon dioxide emissions into the atmosphere, especially when our country looks for strengthen the commitment of productive activities with the sustainability and climatic change mitigation with the vision about consolidating an economy that is sustainable, productive, innovative and competitive; that harmonizes the economic production with the preservation and efficient use of resources [11].

Colombia is no stranger to the problem associated with the increase in greenhouses gases emissions; it is among the first 40 countries that emit the most in worldwide, with 0,42% of global emissions in 2012 [12].

Despite the strategic advantage of its geographical position over the Ecuador, the solar resource has been little explored for the generation of electricity supply and service networks. As a country, the resource about electric generation relies in the hydroelectrics, with a 64% share in 2010, and a 31% in combustion of fossil material. Only 6 MW are attributed to the photovoltaic sources, around 78,000 solar panels are used, mostly in island and rural areas [2]. Colombia, being a tropical country presents potential risk associated with the climatic change, especially in aspects related with the water availability, the vulnerability of ecosystems in front of probably escenarios of extreme climatic variation has been indicated, making emphasis in the probably sustancial changes in the water ofert and availability [13].

Thanks to the geographical and climatic conditions in Colombia, is justified the implementation of a photovoltaic system with self-sufficiency, more if is taken into account that the Cota rural area has constantly of water and electricity reasoning. What causes that the electricity is expensive and on occasions blinking. By the other side, Cota has solar radiation of 3,0 kWh/m2dá, the outputs of renewable energy resources, especially photovoltaics and wind power generations, depend on natural conditions. For example, solar irradiance, the amount of clouds and the speed of wind have much influence on the fluctuation of renewable energy outputs [14].

An important aspect related to the DG market of distributed generation and existence regulations could be improved to reduce or exempt the taxes on the photovoltaic DG equipment, as well as give government incentives; allow consumers to enjoy greater benefits allowing the energy surplus will be sold to the distributor or in the free market; exempt taxes to nonprofit institutions; and include in the housing programs the requirement about energetic efficiency and DG in the projects [15].

1.1. Environmental advantages of the photovoltaic solar system

Taken into account the realities and the overview in global climatic change question, the efforts that can be made are important. A potential solution to this problem is the implementation of renewable energies with clean generation, where the technology that comprehends solar energy is considered more friendly because the raw material is sunlight that is transformed into electric energy [16]. Therefore, this research implements a renewable, efficient and viable energy system through a photovoltaic solar system, this experience will allow generated good environmental and sustainable development practices, with the intention of increasing the environmental awareness in the visitors of the Bioparque La Reserva de Cota.

The photovoltaic system does not generate a negative impact on the flora and fauna, neither originates toxic wastes, during the installed and running process there are not substances that can go outside and pollute the aquifer systems. With regard to the noise, the system does not generate noise pollutions, does not exist noises produced by a solar plant. Neither atmospheric pollution is generated, the solar plant does not emit any pollutant gas.

2. Materials and Methods

2.1. Study area

The study area is located in Bioparque La Reserva Cota, Cundinamarca (Colombia) (Fig. 1). Has an approximated extension of 19 ha part of which are used for the representation of five ecosystems in some regions of Colombia: tropical dry forest, high Andean forest, low Andean forest and piedmont, savanna wetlands and tropical rainforest [17]. Is located in the western side of the Cota- Chía Serrania, 2 km from the municipal seat, between 2,688 and 2,713 masl and geographic is located in the 04°48'36.9"N, 74°06'57.9"W coordinates [18]. Cota has the weather of cold savannah (principally affected by altitude) that oscillates between 5-14 °C, with an average temperature of 13,7 °. The rainiest seasons of the year are April-May and September-December when 110 mm/month is achieved with an average yearly precipitation of 800 m^3 [19].

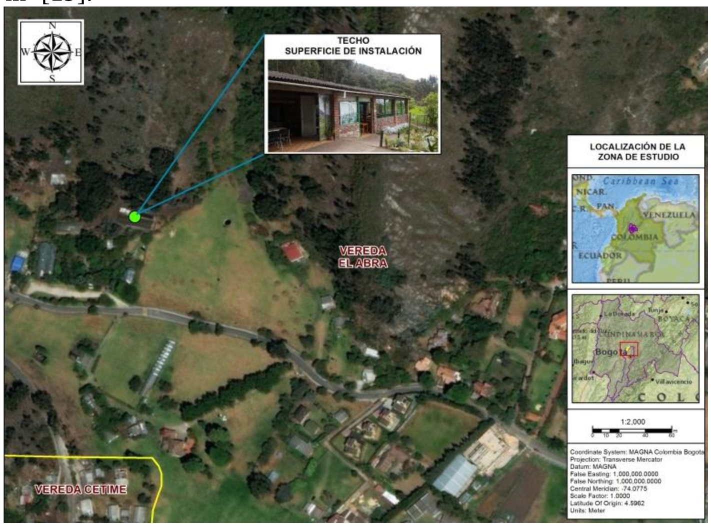

Fig. 1. Study area

2.2. Climatic measurements.

The Solar Radiation Atlas made by the IDEAM [20] and duly updated was taken as reference (Fig. 2).

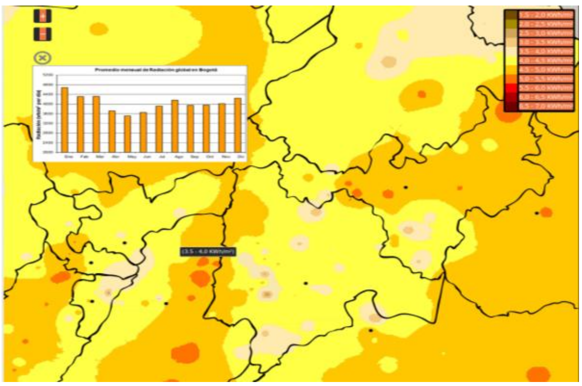

Fig. 2. Interactive MapIDEAM

In accordance with the solar map of the IDEAM, the zone of Cota can be appreciated where the average of the global solar radiation is between 4,0-4,5 kWh/m^2. Also is showing a typical solar profile of monthly averages. However, in the practice, the place of the installation is located in the hills that are composed by a semi-native forest, which frequently attract cloud systems thus configuring a different microclimate than the one presented by IDEAM.

For this reason, measures radiation samples were made with a digital pyranometer with a measurement range of 2000 w/m^2, 634btu (ft2xh), which allows measuring the generation potential that is in the installation place. With this gadget, the measure was made in a schedule between 9:00 - 16:00 h, with effective daily light of 7 hours, for 28 days. With the data, a real potential was identified in the zone that is approximately 3,0 kWh/m^2day. Base on that, the solar average of the photovoltaic plant design was 3,0 kWh/m^2day. For the location of the solar modules, the following was taken into account:

The design was made looking for the shadow effects of surrounding objects such as constructions, trees, landforms had the least possible impact and the orientation of the solar modules were towards the south side with an average inclination between 1 °-25 ° in accordance with the latitude of the installation place (Latitude: 4°48'29.67"N; Length: -74.07'00.51"W). Likewise a study about the maximum speed of the wind and the solar cinematheque with the aim of determining that the support structure of the solar modules has sufficient stability against possible gusts of wind.

2.3. Design of the solar system

The knowledge about the exact solar radiation is important, in terms of the planning of the energetic systems [21], therefore for the design of the solar system, irradiation solar data were taken with a pyranometer, which allows measuring the generation potential that is on the installation place. A generation potential about 3,0 kW/m^2day was assumed, taken into account that surrounding the installation place there is a shadow factor by the trees and mountain areas. The global efficiency about the design of the photovoltaic plant is about 70% with an energy generation of 55,92kWh/month and energy generation in all system lifetime of 13420.8 kWh

2.3.1. Daily power consumption.

In the design and assembly of a photovoltaic solar system is relevant to calculate the power consumption in the place where the system will be installed. From the study made with the freezer loads and LED luminaries, is obtained a total of 1710 kWh/day must be generated. The date of the studies are shown in Table 1:

Table 1. Daily power consumption

Type of load	Voltage	Power W	Quantity	Daytime hours of use	Daytime energy Wh/day	Total energy Wh/day
Freezer	120	125	1	12	1.300	1.300
LED Luminaires	120	36	2	8	576	576
Total				20	1.876	1.876
				Total daily consumption:		1.876Wh/day

2.3.2. Installed solar panels.

4 photovoltaic panels of 280 W (Table 2) with an inclination of 11 ° and a southeast orientation following the existing roof were installed. To this photovoltaic system, the solar panels are formed by cells made of pure polycrystalline silicon with added impurities of certain chemical elements, being able to generated every one between 2 and 4 amperes, in a voltage of 0,46 - 0,48 volts [22], are connected in mixed circuit in series pairs by two parallel to each other, in this way the average voltage of the regulator entrance or controller is 70VDC/16A.

Table 2. Main characteristics of installed solar panels.

Electrical data	Reference panel TSM-280PD05
Rated power-Pmáx(Wp)	280
Nominal Power Tolerance (W)	0/+5
Point tension Pmáx-V_{MP} (V)	31,4
Point current Pmáx-I_{MPP} (A)	8,92
Open circuit voltage-V_{OC} (V)	38,2
Short circuit current-I_{SC} (A)	9,40
Module Efficiency n_m%	17,1

2.3.3. Installation of the photovoltaic system.

The installation of an autonomous photovoltaic system was made taking into account the climate measures and the calculates made to the load of the freezer and LED luminaires for the place that was pretending to energizer. An electric quantification was made, required by the panels, solar charge regulator, protections, batteries, conductors, inverter and electrical distribution board. The summary of the operation of the photovoltaic system starts with the solar panel which receives the sunlight that is transformed in CC voltage, which is injected to the inverter, charges the battery bank and at the same time to the DC/AC voltage to be used when there is solar radiation, otherwise (absence of solar radiation) the energy is the battery bank [23].The single line diagram is made of all the solar plant including panels, regulator, batteries, inverter, protection systems, conductors and pipeline (Fig. 3). The topology of the installation was designed taking into account all the RETIE and NTC 2050 normativity. Also was taken into account the demonstrative and didactic character according to the location and visual accessibility.

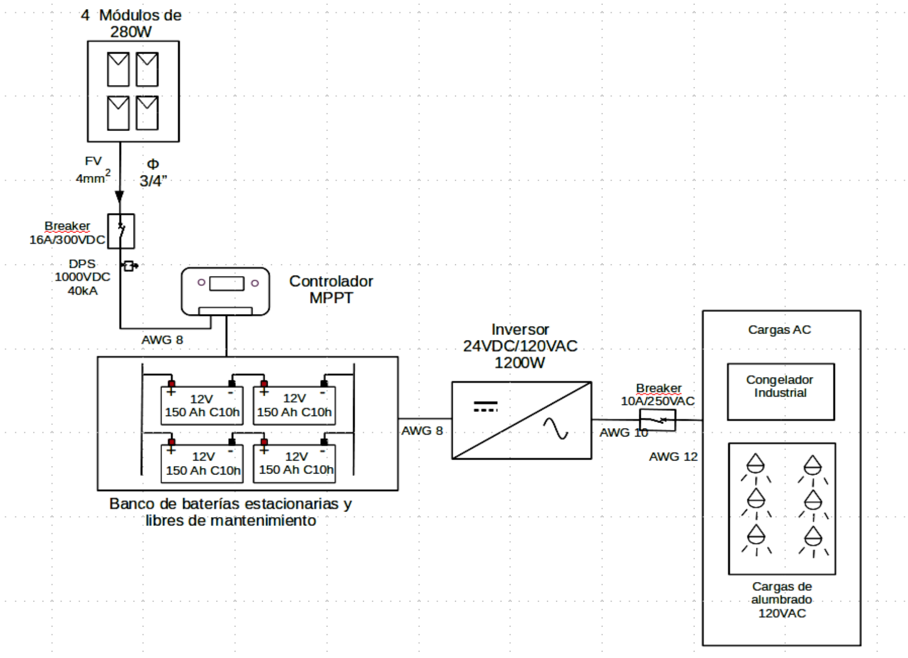

Fig. 3. Self-Line diagram of the photovoltaic solar plant installed.

The self-line diagram represents a scheme of the design plans which the system topology are indicated, the different equipment that configures the installation, interconnection and electric data. The diagram illustrates a topology that corresponds to a photovoltaic system isolated from the electricity grid (Off-Grid) or also denominated autonomous system. In the diagram the 4 photovoltaics modules of 280W are represented, that is connected and powered with a controller with MPPT load, which powered 4 batteries of 12V and 140 Ah, and the inverter with voltages of entrance and exit of 24 VDC, 120 VAC and 1200 W. The inverter provide energy of 120 VAC, that finally powered the electrical loads of a freezer and luminaries.

For interpretation and statistics analysis a modeling of temporal series was made, where a prediction about the following was obtained: electric energy consumption of the bioparque, electric energy consumption in kWh in the photovoltaic solar plant, electricity bill payment, electricity bill payment without the photovoltaic power plant (simulated) and the $KgCO_2$ quantity that can be emitted monthly. With this information a prove of modeling temporal series was made, where UCL means the higher boundarie, that means, the maximum value that the prediction can take and LCL is the lowest boundarie, that corresponds to the minimum value that the prediction can take. For the handling of this information the software SPSS V. 24. was used.

3. Results and Discussion

3.1.Photovoltaic solar system working

The photovoltaic solar system works with an autonomy of three days, attending to a electric demand of 1876Wh/day that corresponds to a freezer and two LED luminaries. In the case of the solar energy, while the availability of daily light determines its principal supply, the battery use and other type of storage can also determine the availability [24].

3.2. Quantification and values associated with the photovoltaic solar system

3.2.1. Prediction of the consumption of electric energy.

In this types of research is important to calculate the consumption of electric energy, consequently establish the energy produced from the installation of the photovoltaic solar system is needed. Once the photovoltaic solar plant is installed, modeling and prediction of electric energy consumption in general of the bioparque is carried out, which eleven months are taken into account (Table 3).

Table 3. Time series modeler and prediction of electric power consumption

	Model	Consumption of electric energy kWh-Model_1		
		Prediction	UCL	LCL
Prediction	mar-19	2.045	3.223	866
	apr-19	2.045	3.264	825
	may-19	2.045	3.304	786
	jun-19	2.045	3.342	747
	jul-19	2.045	3.379	710
	aug-19	2.045	3.416	673
	sep-19	2.045	3.451	638
	oct-19	2.045	3.486	604
	nov-19	2.045	3.519	570
	dic-19	2.045	3.552	537

In the Table 3 can be observed that when made the modeling of the temporal series and the prediction of the electric energy consumption, is possible to predict that the electric energy consumption in the months between March and December of 2019 will be in average 2.045 kWh. With a minimum consumption of 537 kWh and maximum consumption of 3.552 kWh. The data register in the months of November and December of 2018 showing an electric energy consumption increasing (Fig. 4), by this date in the Bioparque animal's species in rehabilitation were attended, which required constant energy through incubators and be monitored with cameras 24 hours 7 days week.

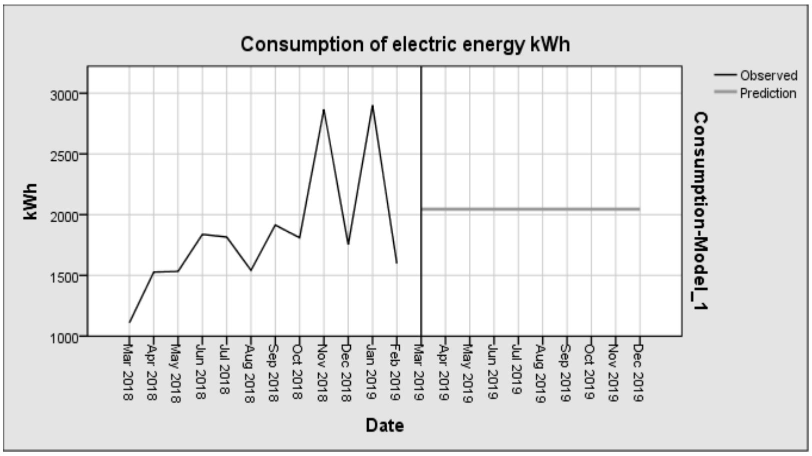

Fig. 4. Modelling of temporal series and prediction of the energy electric consumption.

3.2.2. Prediction of the electric energy generation of the solar plant.

Actually, the saving of electric energy and the use of solar energy is required to optimize some of the electric energy requirements. The solar plants feed electrically to a freezer and two LED lights and like a system has its own electric consumption depending on the solar radiation. Solar power systems must cope with the uncertainties in energy supply because we cannot control the amount of energy gathered from fixed size solar panels that depends on the environmental and the atmospheric conditions such as season of the year and clouds in a day [25], is predicted then a maximum and minimum value of electric consumption with a time prediction of 9 months (Table 4).

Table 4. Modelling of temporal series and prediction of AC electric generation in kWh

	Model	AC Generation kWh of the photovoltaic solar plant-Model_1		
		Prediction	UCL	LCL
Prediction	abr-19	49,03	53,02	53,02
	may-19	46,38	46,38	46,38
	jun-19	48,10	48,10	48,10
	jul-19	51,70	51,70	51,70
	ago-19	54,90	54,90	54,90
	sep-19	52,74	52,74	52,74
	oct-19	52,74	52,74	52,74
	nov-19	53,30	53,30	53,30
	dic-19	55,92	55,92	55,92

It is evident, in Fig. 5, that when performing the modeling of the temporal series and prediction of AC electric generation in kWh of the photovoltaic solar plant, between March and December of 2019, will be a progression up to 55,92 kWh/month in December. With a minimum AC generation of 46,38 kWh and a maximum of 55,92 kWh/month. The kWh photovoltaic solar plant consumption is calculated and projected through the information collected since August 2018.

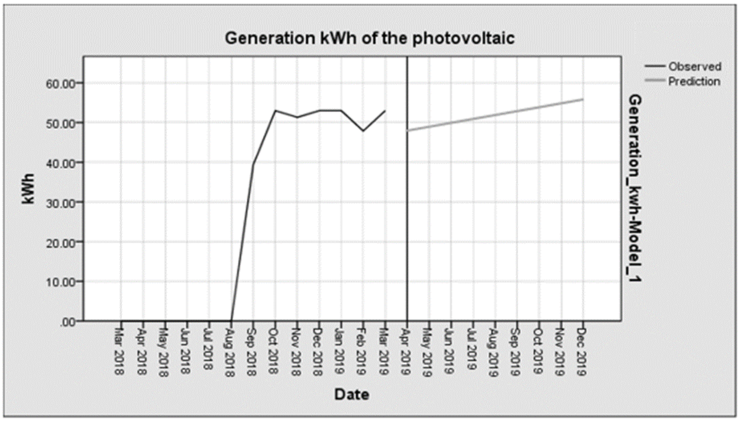

Fig. 5. Modeling of Temporal series and prediction of the electric energy consumption

3.2.3. System economic evaluation

The installation of the photovoltaic solar system demands an investment in the purchase of specialized equipment and installation value (materials and skilled labor). The system efficiency of an electricity generation system using PV panels depends on the efficiency of each system component [26]. The total investment in the photovoltaic system was USD 5.909,08. One of the relevant aspects is being able to quantify how much is the save that can be generated through the use of this type of solar systems. Save projection is calculated taken into account the total consumption of the Bioparque (Table 5).

Table 5. Modeling of temporal series and prediction of the electricity bill payment. (USD)

Model		Electricity bill payment-Model_1		
		Predicción	UCL	LCL
Prediction	feb-19	358.12	558.66	157.65
	mar-19	358.12	558.66	157.65
	apr-19	358.12	558.66	157.65
	may-19	358.12	558.66	157.65
	jun-19	358.12	558.66	157.65
	jul-19	358.12	558.66	157.65
	aug-19	358.12	558.66	157.65
	sep-19	358.12	558.66	157.65
	oct-19	358.12	558.66	157.65
	nov-19	358.12	558.66	157.65
	dic-19	358.12	558.66	157.65

In the Table 5 can be observed that when making the modeling of temporal series and prediction of the electricity bill payment, is possible to predict that the consumption energy electric payment in the months between March and December of 2019 will be on average 358.12 USD. With a minimum payment of 157.65 USD and a maximum payment of 558.66 USD (Fig. 6).

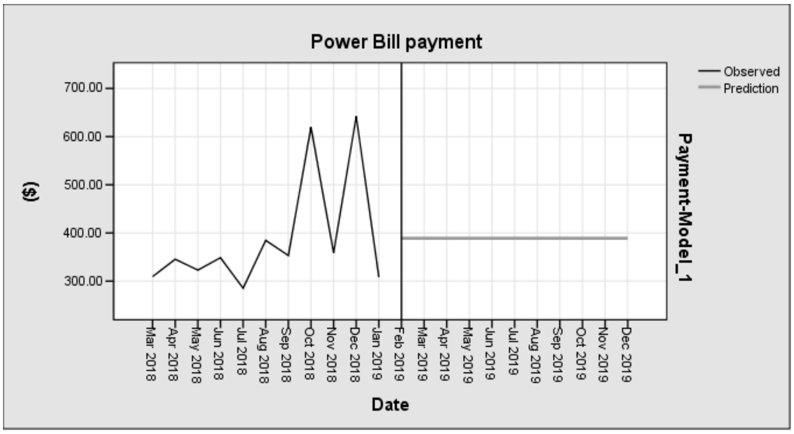

Fig. 6. Modeling of temporal series and prediction of the electricity bill payment

3.2.4. Prediction of the energy payment without the photovoltaic solar plant

Regarding the costs and the electric energy saved through the working of a photovoltaic system, is important to make clear that it varies depending on the solar radiation, shadow effect of the vegetation, climatic conditions, and sunshine. To the Cota municipality yearly average about hours/day of sunshine varies between 3,7 and 4,1 presenting absolutes maximums registers on the months of December and January (5,1 hours/day) and absolutes minimums in June (3,5 hours/day). With oscillation of 1,6 hours/day during the year [27]. Also is relevant to determine, through a simulation, the electric energy payment in the Bioparque without contemplating the photovoltaic solar plant (Table 6). It can be evidenced that in some occasions the energy consumptions fluctuates taking into account that there are times where the energy can be more used, which means that the payment increases. This is presented by the existence of some animals that in the rehabilitation stage or by the attention of some health requirement need constant energy consumed in incubators or monitoring cameras.

Table 6. Modeling of temporal series and prediction of the energy payment without the photovoltaic solar plant (simulated USD)

	Model	Energy payment without the photovoltaic solar plant-Model1_1		
		Prediction	UCL	LCL
Prediction	feb-19	363.45	568.67	155.50
	mar-19	363.45	568.67	155.50
	apr-19	363.45	568.67	155.50
	may-19	363.45	568.67	155.50
	jun-19	363.45	568.67	155.50
	jul-19	363.45	568.67	155.50
	aug-19	363.45	568.67	155.50
	sep-19	363.45	568.67	155.50
	oct-19	363.45	568.67	155.50
	nov-19	363.45	568.67	155.50
	dic-19	363.45	568.67	155.50

It is observed in Table 6, that when making the modeling of temporal series (simulated), it can be predicted that the payment of the electricity energy consumption without the photovoltaic solar plant in the months between March and December of 2019 will be in average 363.45 USD, with a minimum payment of 155.50 USD and a maximum payment of 568.67 USD (Fig. 7). When the prediction of electrical energy consumption of the solar plant by the price of the kWh is made, it can be established that the daily save is 0,31 USD, what means that monthly 9,36 USD are saved.

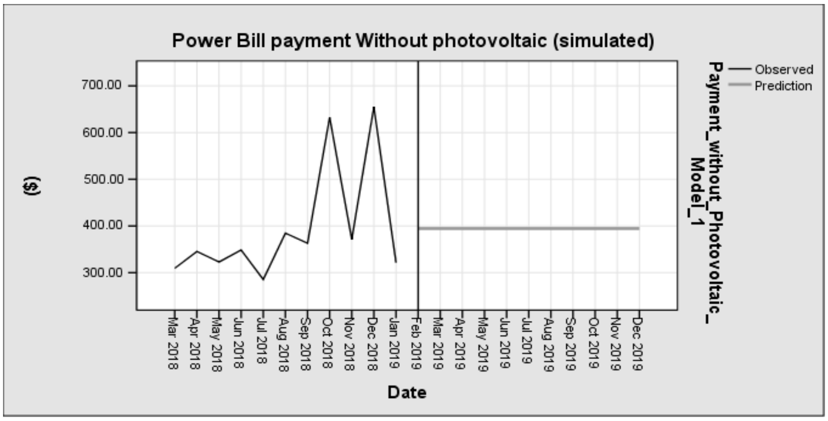

Fig. 7. Modeling of temporal series and prediction of the energy payment without the photovoltaic solar plant.

In Colombia Law 1715 of 2014, aims to promote the development and use of Non-Conventional Energy sources, principally renewable type. Consequently the people or entities that promote this type of energies can access to tax incentives meeting with established requirements. The incentives become into benefits, for instance, in the Special Deduction in the determination of income tax, Exclusion of goods and services of VAT and Exemption of tariff levies for the purchase and import of machinery, equipment, materials and supplies for installation of renewable energy systems

3.5.5 Predictions of $KgCO_2$ emissions

The implementation of renewable energy, in the particular case of solar energy through the installation of a photovoltaic solar system decreased the consumption of electric energy and allowed to reduce the CO_2 emission in the environment. The renewable energy, especially solar energy is a boom and have the tendency to increase in the measure that is been implementing the technology and actually compete with the traditional energies in general in the electrical sector. The ever-increasing conversion of solar energy represents one of the largest new businesses that are emerging in any sector of the economy [28] .The other important aspect is the contribution in the mitigation of the climatic change, for the solar energy is quantify in the reducción of the Ton CO_2 that stop to be emitted to the atmosphere. To estimate the prediction values of the maximum and minimum CO_2 levels that are not longer produce is made (Table 7).

Table 7. Modeling of temporal series and Monthly $KgCO_2$ prediction that stops emitting to the environment due to the generation of photovoltaic solar power plant

	Model	KgCO2 stops emitting - Model_1		
		Prediction	UCL	LCL
Prediction	Apr-2019	11,38	11,38	11,38
	May-2019	11,38	11,38	11,38
	Jun-2019	11,38	11,38	11,37
	Jul-2019	11,38	11,38	11,37
	Aug-2019	11,38	11,38	11,37
	Sep-2019	19,82	19,82	19,81
	Oct-2019	22,75	22,76	22,75
	Nov-2019	22,39	22,39	22,38
	Dic-2019	22,75	22,76	22,75

Subsequently, with the installation of the photovoltaic solar system, 51,30 kWh/month are consuming. which equivalates to 615,6 kWh yearly. That means that stops emitting about 2,37006 $KgCO_2$. It is evident in Table 7, that when the modeling of temporal series and monthly $KgCO_2$ prediction that stops emitting to the environment due to the generation of the photovoltaic solar power plant is made, between the month March and December of 2019 will be in a progressive up to 22,75 $KgCO_2$ (Fig. 8). With a minimum consumption of 22,75 $KgCO_2$ and a maximum consumption of 22,76 what equivalates monthly to 0,02 $TonCO_2$.

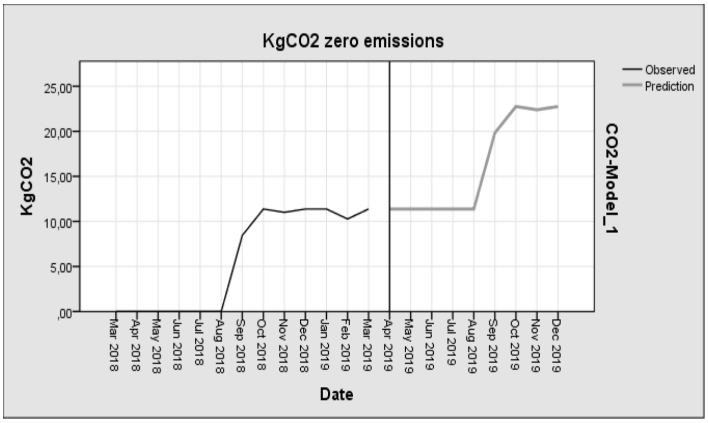

Fig. 8. Modeling of temporal series and Monthly $KgCO_2$ prediction that stops emitting to the environment due to the generation of photovoltaic solar power plant

4. Conclusions

The installation of a photovoltaic solar system of 1 kW represent advantages in energy saving and efficiency. Monthly, it is stop consuming approximately 3,36 kWh/month in electric energy. which represents a monthly saving of 122.31 USD/year. Regarding the greenhouses gases, it stops emitting to the atmosphere around 2.37006 $kgCO_2$ monthly, yearly represent 28.44072 $kgCO_2$ (0,028 Tn CO_2), this results is equivalent to 2.9893 gallons of ACPM or 3.6523 gallons of gasoline.

The analysis model by prediction allows evidencing a tendency and behaviour of the information, that means, through an statistical model an autocorrelation of variables such as prediction of electric energy consumption, prediction of electric energy consumption of the solar plant, prediction of the energy billing without the photovoltaic solar plant and the prediction of KgCO_2 emissions in a unit of time could be established.

A place like Cota, Cundinamarca, generates good indices of solar radiation in summer periods and despite of the shadow effects caused by the amount of trees and mountainous areas in the bioparque, the working of the photovoltaic solar system from the energetic production, generates significant contributions in reduction of CO_2 emission, what becomes Cota in a local and regional referent, by promoting the use of non-conventional energy source specially the solar energy, and thus contributing to reduce the greenhouses gases emissions to achieve a contribution for the climatic change mitigation.

In Colombia is necessary to strengthen the politics related with the photovoltaic energy that encourage the knowledge transfer and social innovations every time more friendly with the environment and allow the development projects of solar energy in small, medium and large scale fulfilling the environmental challenges of the future.

Conflict of Interest

The author declares no conflict of interest.

Author Contributions

J. M. provided and analyzed the data, conducted research, interpretation of the results and wrote the paper. The author approves the final version.

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References

[1] Hosseini S, Saifoddin A, Shirmohammadi R, Aslani A. Forecasting of CO_2 emissions in Iran based on time series and regression analysis, 2019; 619-631.

[2] Estupiñán M, Puerto J, Beltrán M. Development of a mendocino motor as a teaching tool in the application of renewable energies and generation of energy alternatives. Innovation and technological development. *Loginn Magazine,* 2017; 1(1), 78-89.

[3] Ramírez M, Zambrano R. *Proposal for the use of solar and wind energy as electricity in the Laguna de Conache ecotourism complex*. Undergraduate thesis. University National de Trujillo, Trujillo-Perú. 2018.

[4] Jiménez C. *Design study of a photovoltaic solar plant of 10 MegaWatts in Gaborone Botsuna*. (Thesis). Universidad Politécnica de Madrid, Madrid, España. 2018.

[5] Ellaban O, Alassi A. Integrated economic adoption model for residential grid-connected photovoltaic systems: An Australian case study, 2019; 5: 310-326.

[6] Alvarado R, Ponce P, Alvarado R, Ponce, K, Huachizaca V. Sustainable and non-sustainable energy and output in Latin America: A cointegration and causality approach with panel data. 2019.

[7] Alarcón J, Sánchez P, Aguilar H, Llorens A. Design of an intelligent structured skin to capture solar energy: International interdisciplinary cooperation experience, 2018; 43 (11).

[8] Oliveria L, Dias A, Damieri N, Azevedo G. Comparative study of solar tracking techniques for the generation of photovoltaic solar energy. *Brazilian Applied Science Review*. Braz. Ap. Sci. Rev. Curitiba, 2019; 3(3):1551-1563.

[9] Nuñez Rodriguez J. Potential of alternative energy in the development of the north department of Santander, Colombia. *Journal*, 2017; 2 (4): 7-14.

[10] Volvo S, Garipov I, Lastochkin D, Medyakov A, Onuchin E, Ostashenkov A. Study of the reliability of the power supply system based on the solar power plant. *Journal Espacios,* 2019; 40(3): 29.

[11] National Development Department. *Development Nacional Plan (2018-2022). Bases of the National Development Plan Pact for Colombia Pact for Equity*. 2018.

[12] IDEAM, PNUD, MinAmbiente, DNP y Chancellery. *Executive summary of the third national communication of* Colombia *to the United Nations Framework Convention on Climate Change* (CMNUCC). Bogotá: IDEAM, PNUD, MADS, DNP, CANCILLERÍA, FMAM. 2017.

[13] Rua R, Cely L, González A, Granados A. Ramirez R. Structural transport design for photovoltaic solar powered portable pumping system for the department of Boyacá. *Environmental Magazine: Water, Air and Soil*, 2018; 9(2).

[14] Nishiura E, Matsuhashi R, A Study on unit commitment taking uncertainties in forecast of renewable energy outputs into consideration. International Journal of Smart Grid and Clean Energy, 2019; 8(4): 392-396.

[15] Rosas M, Fontes F, Arrais M, Andrade E. Solar photovoltaic distributed generation in Brazil: The case of Resolution 482/2012. *Energy Procedia*, 2019; 159: 484-490.

[16] Cardozo D. Simulation of a isolated photovoltaic system in Matlab/Simulink. *Mundo Fesc,* 2017; 9(17): 16-22.

[17] Martínez R, Ortiz H. Methodological Guide (*Harpia harpyja*). For the education in conservation of birds of prey of the biopark the Cota reserve. Undergraduate thesis. Universidad Pedagógica Nacional, Bogotá, Colombia. 2014.

[18] Becerra D. *Planted vegetation monitoring in an area in restoration process located in lands of the Bioparque la Reserva (Cota* Municipality Cundinamarca). University Militar Nueva Granada, Bogotá, Colombia. 2014.

[19] National Development Department (2016-2019). National Development Department of Cota. Municial Council of Cota. 2016.

[20] IDEAM. Atlas of solar, ultraviolet and ozone radiation from Colombia. *Interactive Atlas.* 2015.

[21] Ener S. Performance evaluation of a coupled method for the estimation of daily global solar radiation on a horizontal surface. *Atmósfera,* 2014, 31(4): 347-354.

[22] Arencibia G. The importance of the use of solar panels in the electric energy generation, *REDVET. Electronic Veterinary Magazine,* 2016; 17(9): 1-4.

[23] Penning J, Ucker A, Finkler R. Solar energy: Case study of a residence in the city of Caxias do Sul/RS. *Brazilian Journal of Animal and Environmental Research. Curitiba*, 2019; 2 (2): 732-744.

[24] Kumar A, Ferdous R, Luque-Ayala A, McEwan C, Power M, Turner B, Bulkeley H. Solar energy for all? Understanding the successes and shortfalls through a critical comparative assessment of Bangladesh, Brazil, India, Mozambique, Sri Lanka and South Africa. *Research on Energy and Social Sciences,* 2019; 48.166-176.

[25] Lee Y, Park M, Energy management for solar-powered IoT devices with performance adjustment. *International Journal of Smart Grid and Clean Energy*, 2019; 8 (1): 22-30.

[26] Zhihua W, Xinyu P, ZhiLin Z, Minquan G, Chenglin M, Peng Y. Power supply system for No. 0 station of substation based on photovoltaic energy storage. *International Journal of Smart Grid and Clean Energy*, 2019, 8(1):91-97.

[27] Cujia J, Reyes J. Environmental management plan of the slippery wetland in the Municipality of Cota, Cundinamarca. University Santo Tomás, Bogotá, Colombia. 2017.

[28] García F., Pérez A, Veloz M. Determination of solar irradiance in Ciego de Ávila and Morón, for use in solar energy utilization systems. 2019.