Energía & Sostenibilidad

Volumen 1, Número 1, 2025

GEOVOLTAICA

Revista de Energía y Sostenibilidad

Donde la energía del sol y la tierra se unen para construir un futuro sostenible y en armonía con el ambiente.

ISSN: En trámite

Información Legal

Geovoltaica Revista de Energía y Sostenibilidad, Año 1, Número 1. Enero-Abril 2025, es una publicación cuatrimestral, editada por el Dr. Néstor Daniel Galán Hernández, Coto 12 Número 4902, Real del Valle, 82124 Mazatlán, Sinaloa, México, https://www.revistageovoltaica.com E-mail: editor@revistageovoltaica.com. Editores responsables: Dr. Eber Enrique Orozco Guillén, Dr. Guillermo Rubio Astorga y Dr. Erik Vázquez Fernández. Reserva de derechos al uso exclusivo En trámite, ISSN: En trámite. Ambos otorgados por el Instituto Nacional de Derechos de Autor. Responsable de la última actualización de este número, Dr. Néstor Galán. Real del Valle, Coto 12, Núm 4902. Código Postal 82124. Fecha de última Actualización 07 de Marzo de 2025. Las opiniones expresadas por los autores no necesariamente reflejan la postura de los editores de la publicación.

GEOVOLTAICA

Revista de Energía y Sostenibilidad

revistageovoltaica.com

Editorial

Innovar, colaborar y transformar: Nuestro rol en la construcción de un futuro sostenible"

En el escenario actual, donde los desafíos energéticos y ambientales demandan soluciones innovadoras y sostenibles, nace Geovoltaica, una publicación dedicada a explorar y analizar las intersecciones entre energía, sostenibilidad y desarrollo tecnológico. Este primer número marca el inicio de un espacio de diálogo y reflexión sobre temas de importancia para el sector académico, profesional y público en general. La crisis climática ha dejado de ser una advertencia para convertirse en una realidad que exige acciones inmediatas y efectivas. El incremento en las emisiones de gases de efecto invernadero, junto con el agotamiento de recursos naturales, nos urge a repensar nuestros modelos de producción y consumo energético. En este contexto, las energías renovables son alternativas viables para la supervivencia y el desarrollo sostenible.

Geovoltaica se propone como una plataforma para explorar investigaciones e innovaciones en tecnologías limpias, desde los avances en energía solar fotovoltaica y eólica hasta las prometedoras aplicaciones del hidrógeno verde. Nuestro compromiso es presentar investigaciones rigurosas, análisis técnicos y casos de estudio que demuestren la viabilidad y eficiencia de estas soluciones. La calidad y eficiencia energética ocupan un lugar central en nuestra agenda editorial. Entendemos que la transición hacia un futuro sostenible requiere no solo de nuevas fuentes de energía, sino también de una gestión más inteligente y eficiente de los recursos existentes. Las Smart Grids, el almacenamiento energético y las tecnologías de gestión de la demanda son temas que requieren análisis en profundidad.

El cambio climático, como fenómeno global, exige respuestas coordinadas y multidisciplinarias. Por ello, nuestras páginas darán cabida a voces expertas de diversos campos: ingeniería, ciencias ambientales, economía y política energética. Esta aproximación holística nos permitirá abordar la complejidad de los retos actuales desde múltiples perspectivas. Geovoltaica nace con la convicción de que el conocimiento y la difusión de información técnica especializada son fundamentales para impulsar la transición energética. Invitamos a investigadores, profesionales y expertos del sector a contribuir con sus conocimientos y experiencias en los próximos números.

En este primer número, presentamos una selección de artículos que abordan desde innovaciones en tecnología fotovoltaica para alumbrado público, hasta estrategias de control y eficiencia energética en entornos rurales con mecanismos de automatización. Cada texto ha sido cuidadosamente seleccionado y se ha adoptado el sistema de arbitraje doble ciego para ofrecer información relevante y actualizada, manteniendo el rigor técnico que caracterizará a nuestra publicación.

En un mundo donde la sostenibilidad energética se ha convertido en un imperativo global, Geovoltaica se compromete a ser un referente en la difusión de conocimiento técnico y científico sobre energías limpias y desarrollo sostenible. A quienes investigan, desarrollan y cuestionan los paradigmas actuales: esta es su plataforma. Porque cada hallazgo, cada modelo y cada solución aplicada nos acercan a un mundo más eficiente, resiliente y equitativo.

Esperamos que este primer número sea el inicio de un diálogo productivo y constructivo sobre el futuro energético.

Dr. Néstor Daniel Galán Hernández

Editor en jefe

Geovoltaica

Revista de Energía y Sostenibilidad

CONTENIDO

Viabilidad sostenible de sistemas de alumbrado público y videovigilancia alimentados con energía solar fotovoltaica en las Islas Galápagos

Sustainable viability of public lighting and video surveillance systems powered by photovoltaic solar energy in the Galapagos Islands

Daniel Icaza Álvarez[1], Fernando González-Ladrón-de-Guevara[2]
[1]Universidad Católica de Cuenca, Centro de Investigación, Innovación y Transferencia Tecnológica, Cuenca, Ecuador, dicazaa@cacue.edu.ec
[2]Universitat Politècnica de València, Valencia, España.

Resumen

El interés por sistemas de alumbrado público y videovigilancia en sitios específicos de las Islas Galápagos asistidos por energía solar fotovoltaica es reconocido como una solución efectiva y un aporte a los procesos de transición energética que lleva adelante el Archipiélago. Este estudio evalúa y compara la viabilidad económica de dos tipos de sistemas: conectados a la red y aislados para la operación de sistemas de alumbrado público y video vigilancia en las Islas Galápagos. Se evalúan dos sistemas de paneles solares con y sin conexión a la red en un período de un año calendario. Se desarrolla un modelo de simulación del sistema para su funcionamiento en diferentes condiciones ambientales. Los resultados muestran que, para sistemas de alumbrado público y videovigilancia donde se utilizan paneles solares fotovoltaicos de silicio monocristalino, estos presentan una operación normal gracias a la posible generación eléctrica, logrando menores emisiones y mayor desempeño ambiental. Se han considerado 150 emplazamientos en los que se pueden implantar estos pequeños sistemas en una primera fase. Se incluye el uso de energía solar fotovoltaica por ser renovable y acogida por los gobiernos locales del Archipiélago de Galápagos.

Palabras clave: Energía solar fotovoltaica, Transición energética, Alumbrado público, Videovigilancia, Energías renovables, Galápagos.

Abstract

The interest in public lighting and video surveillance systems in specific sites of the Galapagos Islands assisted by solar photovoltaic energy is recognized as an effective solution and contribution to the energy transition processes carried out by the Archipelago. This study evaluates and compares the economic viability of two types of systems: connected to the grid and isolated for the operation of public lighting and video surveillance systems in the Galapagos Islands. Two solar panel systems with and without connection to the grid are evaluated in a period of one calendar year. A simulation model of the system is developed for operation in different environmental conditions. The results show that, for public lighting and video surveillance systems where monocrystalline silicon photovoltaic solar panels are used, these present a normal operation thanks to the possible electrical generation, achieving lower emissions and greater environmental performance. 150 sites were considered where these small systems can be implemented for a first stage. The use of photovoltaic solar energy is included as it is renewable and welcomed by local governments of the Galapagos Archipelago.

Keywords: Photovoltaic solar energy, Energy transition, Public lighting, video surveillance, Renewable energy, Galapagos

Recibido: 10/01/2025; Aceptado 21/02/2025; Publicado 17/03/2025

Introduction

<u>General Context</u>

Renewable energies are energy sources that are gaining popularity due to the level of development and the solutions they continue to provide to society [1]. Their defining characteristic is their ability to regenerate naturally without depletion [2]. They are considered fundamental and transcendental during the energy transition that aims to abandon fossil fuels, thus counteracting global warming [3].

According to reference [4], globally in 2021, fossil fuels accounted for 83%, renewable energy, mainly hydroelectric, wind and solar, accounted for 12.6%, and nuclear energy accounted for 4.4% of total energy consumption in 2020. In the case of Galapagos, around 83.6% of the energy supply depends on the use of fossil fuels, which pollute the air, land and sea, so local and national initiatives are required to transform its energy matrix into a much more sustainable one [5]. They are considered clean energies that protect the environment and human health [6].

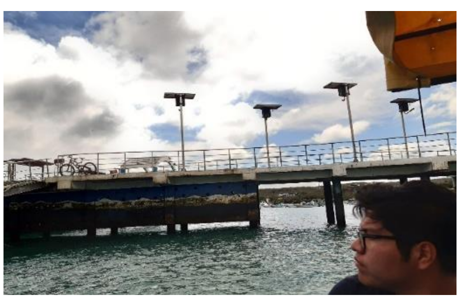
<u>Photovoltaic Solar Energy</u>

Among renewable energy technologies, solar energy systems have experienced significant advancements [7]. Solar panels have become a suitable option for making the best use of solar radiation during the day and converting it into energy [8]. The challenge for researchers is always to achieve greater performance through increasingly sophisticated materials and internal arrangements that operate effectively [9]. Photovoltaic solar energy production systems have achieved a significant level of maturity in recent years and are still far from reaching their maximum ceiling; they continue to develop and be applied at the same time [10]. The energy market increasingly relies on this renewable source, and it is the hope of many countries, regions, and communities to carry out their energy transition processes [11].

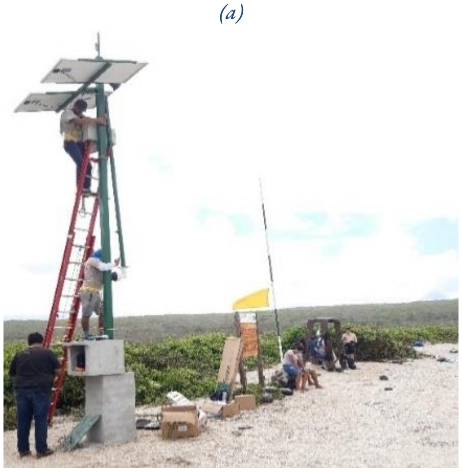
<u>Application in Galapagos</u>

Currently, countless applications integrate photovoltaic (PV) solar systems, including those for public lighting, video surveillance systems, applications at the home level, land and sea transport, etc. [12]. Several systems operate connected to the grid or autonomously, depending greatly on the geographic location of the sites of interest [13]. In the case of studies that integrate photovoltaic systems into heritage sites, the legal regulations that govern these sites must be fully considered, considering that it is possible to protect the environment while protecting the built or natural heritage [14]. The case of the Galapagos Islands is considered a highlight as it is a World Heritage Site and must be protected as it is one of the most sensitive sites of high global interest [15]. In this archipelago, unique on the planet due to its wealth of flora and fauna, it is essential to identify effective strategies to reduce dependency on fossil fuels and harness one of its most abundant resources, such as solar radiation [16].

Regarding public lighting, the defined sites of interest must remain illuminated to provide better service to tourists and native people of the place [17]. Implementing public lighting systems massively is impossible due to their effect on the species; thorough studies are required. It is necessary to maintain appropriate rest without light sources that, in many cases, are confused with the moon, as is the case with turtles [18]. Likewise, the color of the emitted light also plays an important role [19]. This is the subject of further research, and one of the researchers, Santiago Pulla Galindo, is focused on and constantly researching visible light [20].



(a)



(b)

Figura 1. *Solar energy systems for Galapagos. (a) Public lighting systems using solar panels. (b) New video surveillance systems using solar PV systems.*

Additionally, comprehensive video surveillance systems are being deployed throughout the Galapagos Islands. These systems serve a dual purpose: protecting the Archipelago's resources and monitoring tourist activities to ensure compliance with legal regulations while providing security against potential adverse weather events [21].

Galapagos, despite having an important resource such as solar radiation, only uses 4.9% to supply energy through solar panels, this implies the need for planning to make better use of this resource [22]. One of the alternatives is to use the roofs of homes and buildings to generate their own energy and inject the surplus into the public network.

Figure 1a shows an example of a public lighting system with solar panels in the Galapagos Islands. Figure 1b shows the installation of a video surveillance system on the beaches of San Cristobal Island in the Galapagos.

Study Objectives

This research aims to:

- Evaluate and compare the economic viability of two types of photovoltaic systems in the Galapagos Islands: grid-connected and isolated systems.
- Analyze the performance of these systems for public lighting and video surveillance operations.
- Determine, through simulation models and year-long data collection, the optimal configuration for sustainable energy solutions.
- Provide recommendations that respect the unique environmental requirements of this World Heritage site while ensuring reliable power supply.

The findings of this study will contribute to the ongoing energy transition efforts in the Galapagos Islands while establishing a framework for similar implementations in other protected areas worldwide.

Review of previous work

The generation of energy from distributed photovoltaic systems is carried out on a small and large scale [23], [24]. On a small scale, they are used directly to supply the load for specific applications such as those presented in this study [25]. On a large scale, their territorial reach is wide, so they can supply regions [26], countries [27], islands [28] or communities [29]. Several authors discuss how these systems can be best used and have developed several techno-economic analyses and long-term designs. Among the techno-economic analyses: Muhammad Shahzad Javed et al. [30] performed a techno-economic evaluation of a stand-alone solar-wind-battery hybrid system for a remote island using a genetic algorithm. The performance, effects of loss of power supply probability (LPSP), load variation and renewable energy resources, and the system costs involved were analyzed. Mohd Bin Mohd Azlan et al. [31] analyzed the feasibility of an integrated renewable energy system composed of PV-wind-hydro-biogas using the HOMER optimization tool. The current net cost of the PV-W-H-B configuration was RM 130k and that of the highest PV-W-H was RM 231k. Abdulla Al Wahedi and Yusuf Bicer [32] performed a techno-economic optimization of new stand-alone electric vehicle charging stations based on renewable energy in Qatar. The net present cost of the optimal cases ranges from $2.53 million to $2.92 million, and the cost of electricity ranges from $0.285 to $0.329 per kWh. Mohan L. Kolhe et al. [33] performed a technical-economic sizing of an off-grid hybrid renewable energy system for rural electrification in Sri Lanka. This system was able to supply electricity at an approximate levelized cost of 0.3 $/kWh.

Regarding large-scale studies, Vasilis Fthenakis et al. [34] raised in their study the technical, geographic, and economic feasibility of solar energy to supply the energy needs of the US. Based on the expected improvements of PV technologies, the authors showed that with this technology it is possible to supply 69% of the total electricity needs and 35% of the total energy needs of the US by 2050. Amrita Sen et al. [35] in their recent study consider it important to design roadmaps for the transition towards value chains with net zero emissions, focusing on the chemical industry. Steven Chu et al. [36] outlined the path towards sustainable energy, in their study they emphasize that research in materials science is contributing to progress towards a sustainable future. Nian Liu et al. [37] identified rice husks as a sustainable source of nanostructured silicon for high-performance lithium-ion battery anodes, proving useful for renewable energy backup systems. Alla Toktarova et al. [38] performed a high-resolution long-term load projection for all countries in the world. They identified in their model that the sum of several sine functions can be used to project and calibrate electricity demand for any country in any year of a given period. Jun-Ki Choi and Vasilis Fthenakis [39] considered it relevant to carry out crystalline silicon photovoltaic recycling, so they consider planning from now on from the macro and micro perspectives.

Methodology

Process

In this study, computer-based renewable energy simulation tools were used, with previously obtained meteorological data. The Ecowitt EasyWeather-WIFI3B45 station was previously installed on San Cristóbal Island, and its data are recorded in the Laboratorio de Energías Renovables y de Simulación en Tiempo Real (ENERSIM) of the Universidad Católica de Cuenca. The data were subsequently analyzed and typical solar irradiation and ambient temperature profiles that influence the production of electrical energy were obtained. Finally, the simulated results are presented in terms of power. With these results, the deployment options for these small photovoltaic solar energy infrastructures that are useful for public lighting and electricity supply for video surveillance systems in the Galapagos Islands can be analyzed.

Research location

The Galapagos Islands, also named as the Galapagos Islands and officially known as the Archipelago of Colón or the Galapagos Archipelago. They were declared a World Heritage Site by UNESCO and a Biosphere Reserve. In Ecuador, they are a true living laboratory; it is the second largest marine reserve on the planet. It is said that the Islands themselves are a visible paradise. Those who are willing to explore the coasts of the islands and enter aquatic sites are amazed and recognize that the best is under water, where countless species that have never been seen before can be seen. The Galapagos National Park was created in 1959 and covers 97% of the surface of the archipelago. The remaining 3% of the surface is inhabited on the 4 islands, Santa Cruz, San Cristóbal, Isabela and Floreana. Figure. 2 shows the conformation of the Galapagos Archipelago.

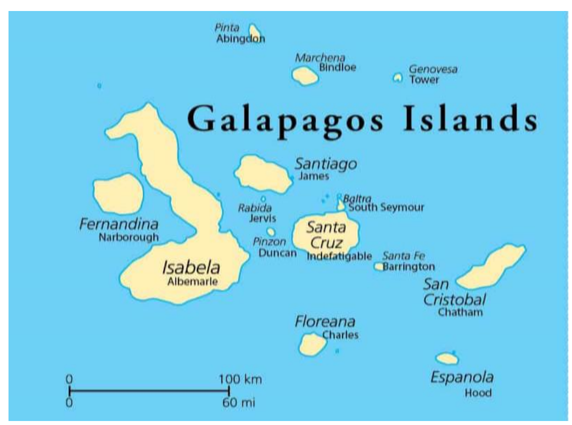


***Figura** 2. Galapagos Islands of Ecuador.*

Mathematical Model

In the mathematical model of the solar panel shown below in figure 3, the most representative parameters that will affect the production of electrical energy by taking advantage of solar radiation are considered. This process involves determining the meteorological aspects of the Galapagos Islands that will directly influence the production of energy for both the lighting systems and the video surveillance systems.

Photovoltaic System

The union of several cells or solar cells forms the photovoltaic solar panel. For the analysis of energy production as other systems are modeled such as transmission lines, electrical machines and other equipment, it is possible to easily evaluate their operation. For this reason, an equivalent circuit is available that represents the solar cells as shown in figure 3.

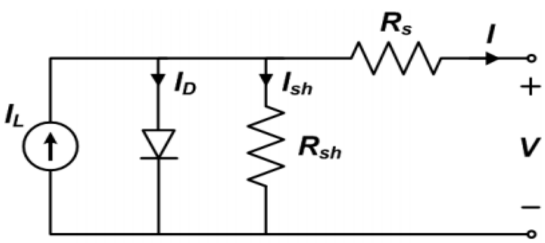


Figura 3. *Mathematical model of the solar photovoltaic module.*

Equations (1)-(4) are those that represent the mathematical model expressed above regarding the behavior of photovoltaic cells.

$$I = I_{Scr} + \frac{K_i(T-298)G}{1000} \quad (1)$$

$$I_D = I_{Scr}\left(\frac{T}{T_r}\right)^3 * e^{\frac{qV_{oc}}{Bk}*\left(\frac{1}{Tr}-\frac{1}{T}\right)} \quad (2)$$

$$I_{rs} = \frac{I_{Scr}}{e^{\frac{qV_{oc}}{N_S kAT}}} - 1 \quad (3)$$

$$I = N_p I_L - N_p I_D * \left(e^{\frac{q(V_{PV}+I_{PV}*R_S)}{N_S AkT}} - 1\right) \quad (4)$$

Where:

K: Boltzman constant.
Ns, Np: Number of solar cells in series and parallel.
q: Charge of the electron.
Rs : Series resistor
T: Working temperature of the solar panel in ° C.
Rp : Parallel resistance.
ID: Inverse saturation current of the diode.
IL: Short-circuit current Isc.
Voc: Open circuit voltage.

The energy absorbed by the photovoltaic system as a function of solar radiation is expressed by Equation 5;

$$P_{pv} = \eta_p * A * G_1 \quad (5)$$

Where;

η_p= Solar collector efficiency.
A= Solar collector area (m2)
G_1= Solar irradiation (W/m2).
η_{pv} = Photovoltaic system performance.

Battery charging

During the charging period, the voltage-current relationship can be described [9, 10];

$$V = V_1 + \frac{I\left(\frac{0.189}{(1.142-soc)+R_i}\right)}{AH} + (soc-0.9)\ln\left(300\frac{I}{AH}+1.0\right) \quad (6)$$

$$V_1(V) = 2.094[1.0 - 0.001(T - 25°C)]$$

R_i : Internal resistance of the cell.
T: Ambient temperature.
AH: Ampere hour rating of the battery.

$$P = V\, I_{OUT} \quad (7)$$

Where I_{OUT} represent the total output current in DC.

System and component configuration

Public lighting systems or video surveillance systems are supplied by photovoltaic solar energy. In figure 4(a) the system connected to the public electricity grid is presented, in this case ELECGALAPAGOS EP is the supplier and the other is the system presented in figure 4(b) completely isolated, which are basically the video surveillance systems that are in remote areas and far from the public grid, there are also specific points or riverbanks where isolated public lighting is important for specific tourism. The grid-connected system presented in figure 4(a) has a direct current photovoltaic solar panel, a DC battery as an electricity storage system, as well as an inverter that converts electricity from DC to AC.

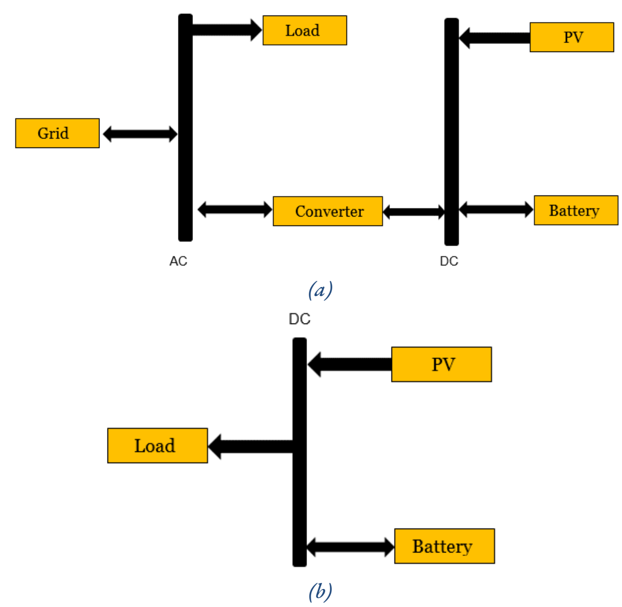


Figura 4. *System Settings. (a) On grid connected photovoltaic system. (b) Off-grid photovoltaic system.*

The configuration of the isolated system is much simpler than the one connected to the public grid, as presented in figure 4(b), it has a solar panel and a storage system.

Data input

Below are the data recorded by measurements made in the Galapagos Islands using the Ecowitt EasyWeather-WIFI3B45 meteorological station, which records, among other parameters, ambient temperature and solar radiation. Although there are data for a longer period of time, the data were taken in a single calendar year (8760 h) from January 1, 2024 to December 31, 2024. Figure 5(a) shows the ambient temperature profile, which generally ranges between 24.5°C and 27.5°C. figure 5(b) shows the solar radiation profile.

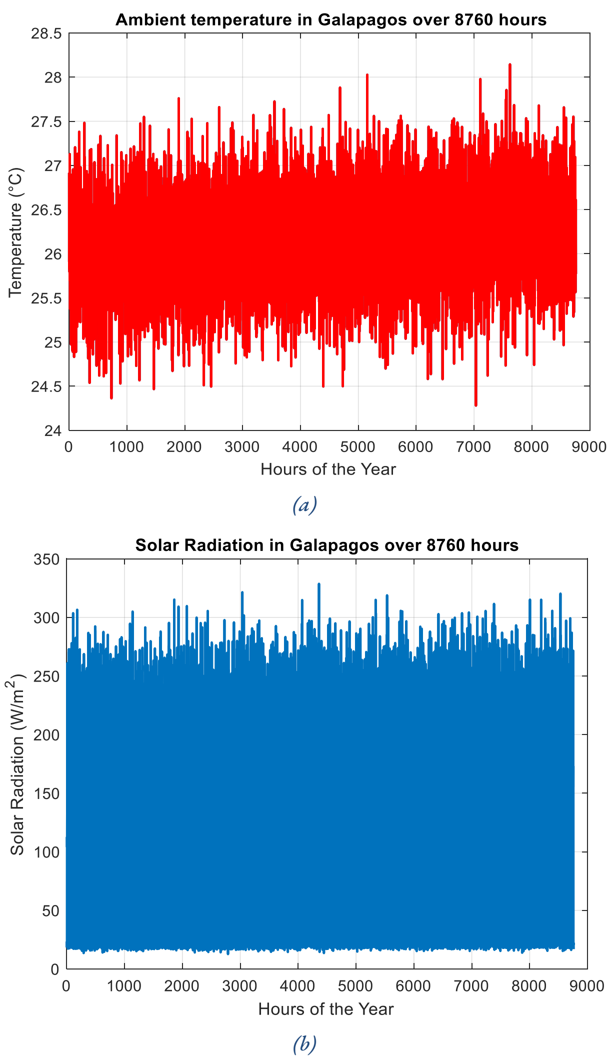


Figura 5. Meteorological profiles in the Galapagos Islands. (a) Ambient temperature. (b) Solar radiation.

Subsequently, based on a priority analysis according to the places frequented by tourists where the flora and fauna are not affected, the public lighting points were projected, which in their majority must be replaced by the current systems based on incandescent bulbs but maintaining the appropriate colorimetry and lighting levels. The video surveillance systems were also projected to maintain the order and security of the visitors and original inhabitants of the islands. These systems also have the possibility of alerting through loudspeakers in case of any natural or other threat, situations that fortunately are not common on the islands but may arise in the future. Figure 6 shows the 150 specific points (blue) where these small systems are beginning to be installed, considered for a first stage.

By bringing the operating voltage closer to the highest power point, we are implementing the MPPT for variable weather conditions.

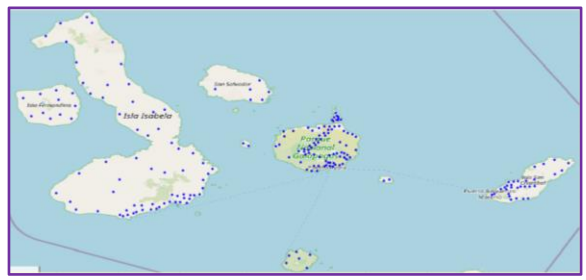


Figura 6. Specific sites where it is recommended to continue replacing photovoltaic systems for public lighting and to continue installing video surveillance systems.

The operation of the solar cells depends fundamentally on the levels of solar radiation available in the archipelago. The ambient temperature is important when designing a system for better use of the equipment. The solar panel is integrated with a DC-DC converter and a control algorithm to permanently track the maximum power.

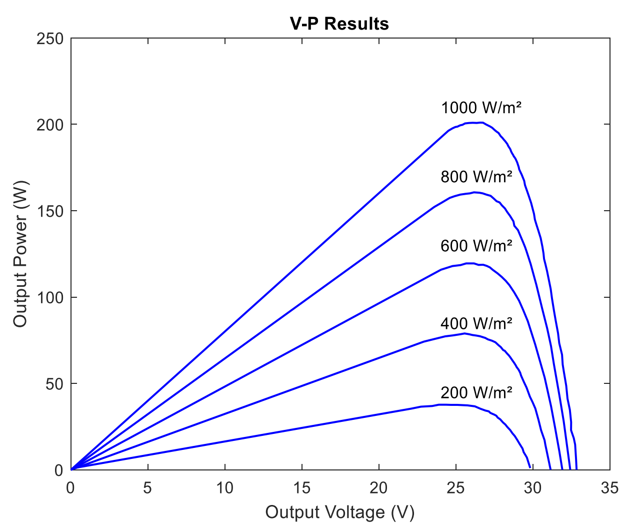


Figura 7. V-P results of a solar panel at different levels of solar radiation.

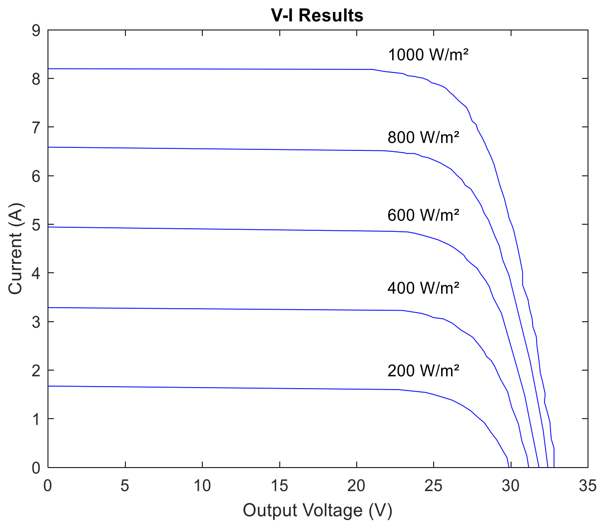


Figura 8*. V-I results of a solar panel at different levels of solar radiation.*

The MPPT provides the constant voltage to the required load. The photovoltaic arrays are evaluated using the P-V and V-I graphs under different solar radiation conditions. The desirable value is a higher solar radiation value, of course, this no longer depends on the installed system, but rather on the environmental conditions of the place. The curves drawn are not linear, as can be seen in figure 7 and figure 8.

Results

The results are expressed in power values, charge and discharge levels of the storage system. The power generated by the solar panel is calculated based on the irradiance and efficiency of the panel. The power is limited to 300 W due to the maximum power of the panel. The load is 180 W, a maximum of 20% variability in the load is considered. The SOC is updated every hour considering the power generated by the solar panel and the energy consumed by the load. The SOC never falls below 40%. The variation of the SOC (dSOC) is calculated as the difference between the current SOC and the previous SOC. Four graphs are presented in figure 9 as general results over the span of 8760 hours of the year. The first graph shows the power generated by the solar panel throughout the year. The second graph shows the SOC of the battery during the year. The third graph shows the variation of the SOC (dSOC), which indicates how the SOC changes hour by hour. The fourth graph shows the variable charging power consumed during the year. The power generated by the solar panel will follow a daily pattern, with peaks during the day and zero at night.

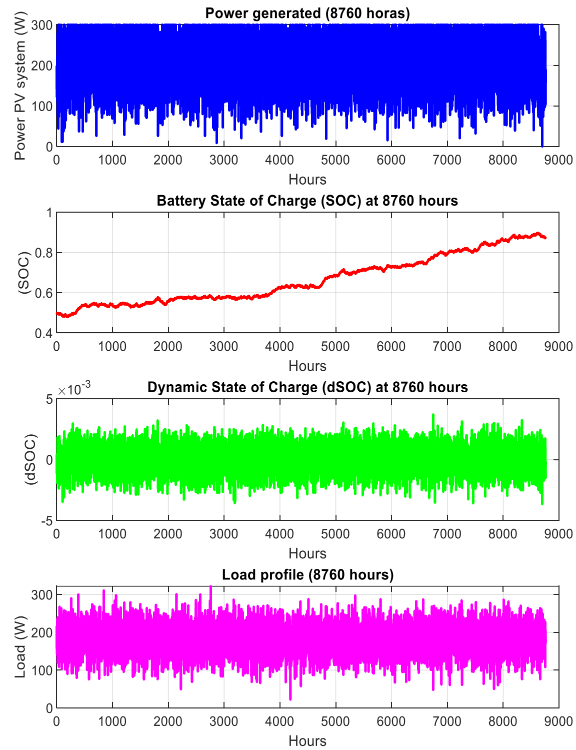


Figura 9. *General results of the off-grid PV solar system for the Galapagos Islands evaluated for a calendar year.*

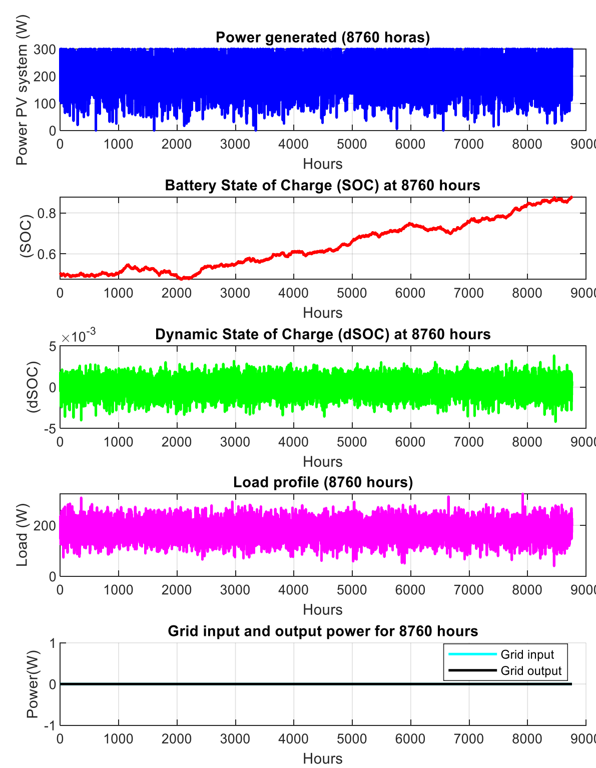


Figura 10. *General results of the on-grid PV solar system for the Galapagos Islands evaluated for a calendar year.*

Figure 10, presents the results obtained from the simulation for a calendar year (8760 hours) of the on-grid system. The same parameters of the previously analyzed system are considered, now the connection is to the public electrical grid. Given the importance of these systems and the need to guarantee the continuity of the service, a battery system was included, as well as the possibility of maintaining connection to the grid for events that may occur such as scheduled maintenance or untimely outages. It can be seen in the last graph of figure 10 that throughout the year no energy would be absorbed from the grid. However, in reality it is possible that in short periods of time it may be necessary to take energy from the grid for the reasons explained above.

Conclusions

Small photovoltaic solar energy systems represent an important alternative to solve everyday problems that arise. Lighting services in strategic sites of the Galapagos Islands are unavoidable and must be attended to in the most appropriate and prompt way possible. In the same way, security is a duty of the Ecuadorian state towards citizens, both national and foreign, so it must be channeled in the best possible way. The systems proposed here are sustainable alternatives and do not affect the environment; on the contrary, they promote the energy transition processes necessary for sites as important to humanity as Galapagos. These infrastructures are easy to implement, they require adequate profiles and do not generate anomalous visual effects. On the contrary, they are safe and sufficient to support the weight of the panels and complementary equipment that go in a box at a considerable height, while the batteries would be at an average height of 1.20 m from the floor. The Galapagos Islands are considered a special regime of Ecuador, they are regulated in relation to human settlements and require adequate services such as electricity and security.

As future work, it is planned to evaluate the solar photovoltaic component within the general energy mix. A long-term energy transition process is being proposed and solar photovoltaic systems will play a leading role in the future. Solar panel farms are also planned at specific points to reduce the use of fossil fuels, which is the objective of the Ecuadorian state. Currently, there are light pollution measurement systems to monitor the starry vault of the entire Puerto Baquerizo Moreno and identify to what extent the lighting systems are creating reflections towards the outside of the islands.

References

[1] M. Rambabu, R. S. S Nuvvula, P. P. Kumar, K. Mounich, M. E. Loor-Cevallos, and M. Gupta, “Integrating Renewable Energy and Computer Science: Innovations and Challenges in a Sustainable Future,” in 2023 12th International Conference on Renewable Energy Research and Applications (ICRERA), Aug. 2023, pp. 472–479. doi: 10.1109/ICRERA59003.2023.10269392.

[2] S. Gawusu et al., “Renewable energy sources from the perspective of blockchain integration: From theory to application,” Sustain. Energy Technol. Assess., vol. 52, p. 102108, Aug. 2022, doi: 10.1016/j.seta.2022.102108.

[3] J. Sanz Cedrón, “Measuring transition risk in the energy sector : evidence of a green factor influence on stock returns,” 2023, Accessed: Jan. 01, 2025. [Online]. Available: https://repositorio.comillas.edu/xmlui/handle/11531/78738

[4] J. L. Holechek, H. M. E. Geli, M. N. Sawalhah, and R. Valdez, “A Global Assessment: Can Renewable Energy Replace Fossil Fuels by 2050?,” Sustainability, vol. 14, no. 8, p. 4792, Jan. 2022, doi: 10.3390/su14084792.

[5] A. Barreto-Cuesta, A. Zakaria, V. Herrera-Perez, and S. Z. Djokic, “Transition to a 100 % renewable power supply in galapagos islands: Long-term and short-term analysis for optimal operation and sizing of grid upgrades,” Renew. Energy, vol. 234, p. 121207, Nov. 2024, doi: 10.1016/j.renene.2024.121207.

[6] M. Yadav, R. Aneja, and W. Ahmed, “Do clean energy transition, environment degradation, and energy efficiency influence health expenditure: Empirical evidence from emerging countries,” J. Clean. Prod., vol. 428, p. 139355, Nov. 2023, doi: 10.1016/j.jclepro.2023.139355.

[7] A. C. Lazaroiu, M. Gmal Osman, C.-V. Strejoiu, and G. Lazaroiu, “A Comprehensive Overview of Photovoltaic Technologies and Their Efficiency for Climate Neutrality,” Sustainability, vol. 15, no. 23, p. 16297, Jan. 2023, doi: 10.3390/su152316297.

[8] A. Shufian, Md. Z. Hossain, S. Mazumder, S. Kabir, M. S. Rashid Mahin, and N. Mohammad, “Investigating Clean Energy Generation from Unoccupied Roof-top Space in University Premises,” in 2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM), May 2023, pp. 1–6. doi: 10.1109/RESEM57584.2023.10236170.

[9] R. Dallaev, T. Pisarenko, N. Papež, and V. Holcman, “Overview of the Current State of Flexible Solar Panels and Photovoltaic Materials,” Materials, vol. 16, no. 17, p. 5839, Jan. 2023, doi: 10.3390/ma16175839.

[10] T. Rehman et al., “Global perspectives on advancing photovoltaic system performance—A state-of-the-art review,” Renew. Sustain. Energy Rev., vol. 207, p. 114889, Jan. 2025, doi: 10.1016/j.rser.2024.114889.

[11] F. J. M. M. Nijsse et al., “The momentum of the solar energy transition,” Nat. Commun., vol. 14, no. 1, p. 6542, Oct. 2023, doi: 10.1038/s41467-023-41971-7.

[12] B. Singh and C. Kaunert, “Photovoltaic (PV) Glass for Smart City and Sustainability: Solar Energy Integration Tumbling Impacts on Human Healthcare and Environment,” in Explainable Artificial Intelligence and Solar

Energy Integration, IGI Global Scientific Publishing, 2025, pp. 227–252. doi: 10.4018/979-8-3693-7822-9.ch008.
[13] J. Rodriguez and P. Cortes, "Model Predictive Control," in Predictive Control of Power Converters and Electrical Drives, IEEE, 2012, pp. 31–39. doi: 10.1002/9781119941446.ch3.
[14] E. Lucchi, "Chapter 8 - Active solar design principles for natural and architectural heritage," in Solar Energy Technologies in Cultural Heritage, E. Lucchi, Ed., Elsevier, 2025, pp. 215–259. doi: 10.1016/B978-0-443-23989-2.00008-2.
[15] J. Ayala-Pico, D. Arcos–Aviles, A. Ibarra, C. Fernandez, F. Guinjoan, and W. Martinez, "Current development of electricity generation systems in the Galapagos Islands – Ecuador," Renew. Energy Focus, vol. 46, pp. 88–102, Sep. 2023, doi: 10.1016/j.ref.2023.06.003.
[16] P. A. Vega-Mariño, I. A. Jimenez, T. Villacres, and E. L. Houck, "Review of One Health in the Galápagos Islands (Part 2): climate change, anthropogenic activities, and socioeconomic sustainability," Front. Conserv. Sci., vol. 5, Oct. 2024, doi: 10.3389/fcosc.2024.1351716.
[17] C. Mateus et al., "Anthropogenic emission inventory and spatial analysis of greenhouse gases and primary pollutants for the Galapagos Islands," Environ. Sci. Pollut. Res., vol. 30, no. 26, pp. 68900–68918, Jun. 2023, doi: 10.1007/s11356-023-26816-6.
[18] A. K. Jägerbrand and C. A. Bouroussis, "Ecological Impact of Artificial Light at Night: Effective Strategies and Measures to Deal with Protected Species and Habitats," Sustainability, vol. 13, no. 11, p. 5991, Jan. 2021, doi: 10.3390/su13115991.
[19] J. Lin et al., "Several biological benefits of the low color temperature light-emitting diodes based normal indoor lighting source," Sci. Rep., vol. 9, no. 1, p. 7560, May 2019, doi: 10.1038/s41598-019-43864-6.
[20] S. P. Galindo, D. Borge-Diez, and D. Icaza, "'Special Regime - Galapagos islands' analysis of the electricity and public lighting service: Current status," Energy Strategy Rev., vol. 54, p. 101452, Jul. 2024, doi: 10.1016/j.esr.2024.101452.
[21] L. Mai, "Navigating transformations: Climate change and international law," Leiden J. Int. Law, vol. 37, no. 3, pp. 535–556, Sep. 2024, doi: 10.1017/S0922156524000062.
[22] F. Vega, "¿Quién se beneficia de la Energía subsidiada en Galápagos?," Bitácora Ambiental. Accessed: Jan. 10, 2025. [Online]. Available: https://www.bitacoraec.com/post/copia-de-quién-se-beneficia-de-la-energía-subsidiada-en-galápagos
[23] M. R. Tur, İ. Colak, and R. Bayindir, "Effect of Faults in Solar Panels on Production Rate and Efficiency," in 2018 International Conference on Smart Grid (icSmartGrid), Dec. 2018, pp. 287–293. doi: 10.1109/ISGWCP.2018.8634509.
[24] R. Cossent, T. Gómez, and L. Olmos, "Large-scale integration of renewable and distributed generation of electricity in Spain: Current situation and future needs," Energy Policy, vol. 39, no. 12, pp. 8078–8087, Dec. 2011, doi: 10.1016/j.enpol.2011.09.069.
[25] R. Panigrahi, S. K. Mishra, S. C. Srivastava, A. K. Srivastava, and N. N. Schulz, "Grid Integration of Small-Scale Photovoltaic Systems in Secondary Distribution Network—A Review," IEEE Trans. Ind. Appl., vol. 56, no. 3, pp. 3178–3195, May 2020, doi: 10.1109/TIA.2020.2979789.
[26] D. Icaza-Alvarez, F. Jurado, and M. Tostado-Véliz, "Smart energy planning for the decarbonization of Latin America and the Caribbean in 2050," Energy Rep., vol. 11, pp. 6160–6185, Jun. 2024, doi: 10.1016/j.egyr.2024.05.067.
[27] F. Cucchiella, A. Condemi, M. Rotilio, and V. Annibaldi, "Energy Transitions in Western European Countries: Regulation Comparative Analysis," Energies, vol. 14, no. 13, p. 3940, Jan. 2021, doi: 10.3390/en14133940.
[28] A. S. Sánchez, E. P. Junior, B. M. Gontijo, P. de Jong, and I. B. dos Reis Nogueira, "Replacing fossil fuels with renewable energy in islands of high ecological value: The cases of Galápagos, Fernando de Noronha, and Príncipe," Renew. Sustain. Energy Rev., vol. 183, p. 113527, Sep. 2023, doi: 10.1016/j.rser.2023.113527.
[29] F. Envall, D. Andersson, and J. Wangel, "Gridlocked: Sociomaterial configurations of sustainable energy transitions in Swedish solar energy communities," Energy Res. Soc. Sci., vol. 102, p. 103200, Aug. 2023, doi: 10.1016/j.erss.2023.103200.
[30] M. S. Javed, A. Song, and T. Ma, "Techno-economic assessment of a stand-alone hybrid solar-wind-battery system for a remote island using genetic algorithm," Energy, vol. 176, pp. 704–717, Jun. 2019, doi: 10.1016/j.energy.2019.03.131.
[31] M. A. Mohd. Azlan, Z. Ab Muis, W. S. Ho, and L. K. Lim, "Feasibility of an integrated renewable energy system (PV-wind-hydro-biogas) by HOMER optimization.," presented at the 2nd Process Systems Engineering and Safety Symposium 2021, ProSES 2021, Pahang, Malaysia - Virtual, Online, Sep. 2023, p. NA-NA. Accessed: Jan. 01, 2025. [Online]. Available: http://dx.doi.org/10.1063/5.0148587
[32] A. Al Wahedi and Y. Bicer, "Techno-economic optimization of novel stand-alone renewables-based electric vehicle charging stations in Qatar," Energy, vol. 243, p. 123008, Mar. 2022, doi: 10.1016/j.energy.2021.123008.
[33] M. L. Kolhe, K. M. I. U. Ranaweera, and A. G. B. S. Gunawardana, "Techno-economic sizing of off-grid hybrid renewable energy system for rural electrification in Sri Lanka," Sustain. Energy Technol. Assess., vol. 11, pp. 53–64, Sep. 2015, doi: 10.1016/j.seta.2015.03.008.
[34] V. Fthenakis, J. E. Mason, and K. Zweibel, "The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US," Energy Policy, vol. 37, no. 2, pp. 387–399, Feb. 2009, doi: 10.1016/j.enpol.2008.08.011.
[35] A. Sen, V. Thakker, G. Stephanopoulos, and B. R. Bakshi, "Designing roadmaps for transitioning to value chains with net-zero emissions: Case of the chemical industry," in Computer Aided Chemical Engineering, vol. 52, A. C. Kokossis, M. C. Georgiadis, and E. Pistikopoulos, Eds., in 33 European Symposium on Computer Aided Process Engineering, vol. 52. , Elsevier, 2023, pp. 2483–2488. doi: 10.1016/B978-0-443-15274-0.50395-4.
[36] S. Chu, Y. Cui, and N. Liu, "The path towards sustainable energy," Nat. Mater., vol. 16, no. 1, pp. 16–22, Jan. 2017, doi: 10.1038/nmat4834.

[37] N. Liu, K. Huo, M. T. McDowell, J. Zhao, and Y. Cui, "Rice husks as a sustainable source of nanostructured silicon for high performance Li-ion battery anodes," Sci. Rep., vol. 3, no. 1, p. 1919, May 2013, doi: 10.1038/srep01919.
[38] A. Toktarova, L. Gruber, M. Hlusiak, D. Bogdanov, and C. Breyer, "Long term load projection in high resolution for all countries globally," Int. J. Electr. Power Energy Syst., vol. 111, pp. 160–181, Oct. 2019, doi: 10.1016/j.ijepes.2019.03.055.
[39] J.-K. Choi and V. Fthenakis, "Crystalline silicon photovoltaic recycling planning: macro and micro perspectives," J. Clean. Prod., vol. 66, pp. 443–449, Mar. 2014, doi: 10.1016/j.jclepro.2013.11.022.

Author Biographies

Daniel Icaza Álvarez, Coordinador del Centro de Investigación, Innovación y Transferencia Tecnológica, Laboratorio de Energías Renovables y Simulación en Tiempo Real (ENERSIM), Universidad Católica de Cuenca, Cuenca, Ecuador.

Fernando González Ladrón de Guevara, Profesor a Tiempo Completo en la Universitat Politècnica de València, Valencia, España