

Relation of the Efficiency and Energy Potential of the Galapagos Islands Through the Use of Renewable Energies

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Abstract: Known as an iconic location for biodiversity conservation, the Galapagos Islands face a significant challenge due to their reliance on fossil fuels, making them more vulnerable to climate change and other environmental threats. With the purpose of addressing this problem, this article presents a bibliographical review focused on the use of renewable energies and offers an exhaustive analysis of its efficiency and energy potential. The fundamental objective of this research was to identify and evaluate the different sources of renewable energy available and their impact on the conservation of the study site. To achieve this purpose, a qualitative and descriptive analysis of alternative energies was carried out. The information was collected and classified according to the type of energy generated, the CO₂ reduction associated with each source and its general contribution to the sustainability of the islands. Three types of clean energy implemented in the region have been identified. Wind energy stands out as the main source of supply for the local population, contributing 52% (8500 Kw). Photovoltaic energy which contributes 36% (5570 Kw), and finally, thermal energy, based on pine nut oil biodiesel, contributes 12% (1760 Kw) of the total energy supplied, in addition to all of these, avoiding the propagation of 25,660 tons of CO₂ and the use of 35,900 liters of diesel per year, with the findings found in this investigation it is concluded that the different sustainable energy projects implemented in the Islands comply with their efficiency by reducing gas emissions greenhouse effect thus promoting environmental sustainability and increasing energy potential.

Keywords: Biodiesel, Environmental Quality, Energy Efficiency, Wind, Photovoltaic, Sustainability

1. Introduction

Currently natural, and sustainable sources are employed as forms of electrical energy. According to the 2018 Intergovernmental Panel on Climate Change report, "by 2050, approximately 80% of global electricity will be needed to come from renewable sources" [17]. In Ecuador, the Ministry of Environment, Water and Ecological Transition [25], has the initiative of the continuous search for new electricity generation alternatives that respond to the needs of the local community and the tourism sector, above all, being committed to research and exploration of various electricity generation options that are environmentally friendly and promote the reduction of carbon emissions.

To minimize environmental impact and conserve the natural environment, the Galapagos Islands have promoted the development of renewable energy. According to [20], the implementation of sustainable energy has a great impact on biodiversity conservation and the protection of the unique ecosystem in the region. It is important to consider that the archipelago, unique for its biological richness, is considered a World Heritage Site (UNESCO), for this reason it is the object of protection by the Ecuadorian government and several international conservation organizations [19].

The International Renewable Energy Agency indicates that solar and wind energy have been identified as sustainable alternatives to fossil fuels in the Galapagos Islands [18]. Solar radiation in the region is high and there are consistent

winds that can be harnessed for both wind and photovoltaic power generation respectively. By combining these two renewable energy sources, the archipelago can diversify its energy matrix and reduce its dependence on non-renewable energy sources such as fossil fuels.

The methodology used for the research is a literature review to determine the different renewable energies that exist and influence the conservation of the archipelago, in addition to gathering information about the relationship between efficiency and energy potential using renewable energies. The main objective of this study is to understand how renewable energy sources can contribute to satisfy the energy needs of the islands in a more efficient and sustainable way.

Finally, this research focuses on investigating the different aspects of the generation and the benefits of using renewable technologies, through a comparative analysis of the level of efficiency and energy potential including directly to environmental sustainability focused on the reduction of CO₂ emissions. The importance of the study lies in analyzing project initiatives to reduce their energy dependence on fossil fuels and mitigate climate change in the vulnerable region.

2. Materials and Methods

The research focused on the Ecuadorian archipelago, with a focus on the search for alternative energy sources, the amount of energy generated and the reduction of CO₂ emissions. The islands investigated were Isabela with an area of 4588 km² and a population of approximately 3000 inhabitants, its coordinates are 715160.90; 1160800.48 UTM [29]. Floreana has an area of 173 km², with a population of about 100 inhabitants and its coordinates are 85634.40; 58009.90 on the other hand, Santa Cruz, covers an area of 986 km² and has a population of 15,701 inhabitants, it is located at coordinates 9930292; 793853 [46] San Cristóbal, on the other hand, has an area of 558 km² and a population of 5500 inhabitants, its coordinates are 30124.90; 9229.40, finally, Baltra Island was analyzed, which has an area of 27 km² and is located at coordinates 4255.40; 52048.80 [4].

The article is based on a bibliographic type of research, which provides detailed knowledge about the different events established on the subject. To carry out this research, the methodology proposed by [38] was adopted, structured in three phases. Each of these phases is described in detail below, with the purpose of providing greater clarity and understanding of the information.

In the first phase of the research, a search for bibliographic information was carried out to compile, compare, and analyze existing data on alternative [5]. The sources selected for this study were chosen based on rigorous criteria of quality, relevance, and scientific soundness. In particular, Scielo articles addressing the topic of "Energy efficiency and

photovoltaic energy in the Archipelago" were used due to their relevance in terms of sustainability and environmental conservation in a unique and vulnerable region. In addition, the prestigious journal Elsevier was used for in-depth research on "Wind energy". The research on "Thermal power plants with pine nut-based biodiesel and the energy matrix" was carried out in the Scientific-Professional Journal specializing in energy and technologies, which made it possible to obtain relevant technical information. Likewise, the "Benefits of alternative energies in the Archipelago" was investigated in the journal Redalyc, which provided valuable perspectives on the potential benefits of renewable sources. To explore "Energy Potential", the journal Nature, known for its impact on global scientific research, was consulted. Finally, "Mechanisms of technology transfer to reduce CO₂ emissions" was investigated in the journal of Higher Education in Latin America, providing a comprehensive framework for understanding how technologies can be transferred and applied effectively to reduce emissions.

During the second stage, the data obtained was organized to ensure a clear and coherent presentation of the information [22]. Information such as institutional origin, project start date and amount of energy generated was compiled. In the specific case of wind energy, the number of wind turbines installed was recorded. Thus, it provides a complete view of the evolution of clean energies. In the third phase, the information evaluation stage, once all the carefully organized information was obtained, we proceeded to analyze and determine the growth of renewable energies over the last few years. The sector that has experienced the greatest increase in energy generation in the region and the reduction of CO₂ emissions was identified, identifying the most significant adoption trends and developments in the Galapagos Islands.

It is essential to recognize some limitations in this study. First, the availability of bibliographic sources could have affected the research; although an effort was made to carefully select the sources of information, the lack of access to certain publications could have restricted the breadth of the data collected. In addition, it is important to mention that the lack of specific data on the Galapagos Islands could have reduced the accuracy of the results obtained; however, we sought to obtain the most current and relevant information, some figures and specific details could have been absent or difficult to find due to the geographic location and isolation of the region. Finally, it is important to mention that this study did not consider economic, political, and social factors, as it was conducted through a literature review by student and these elements often require more extensive, complex research and may involve collaboration with experts in related areas [11]. Despite these limitations, a rigorous analysis was attempted with the available information, with the objective of providing an overview on the topic of alternative energies.

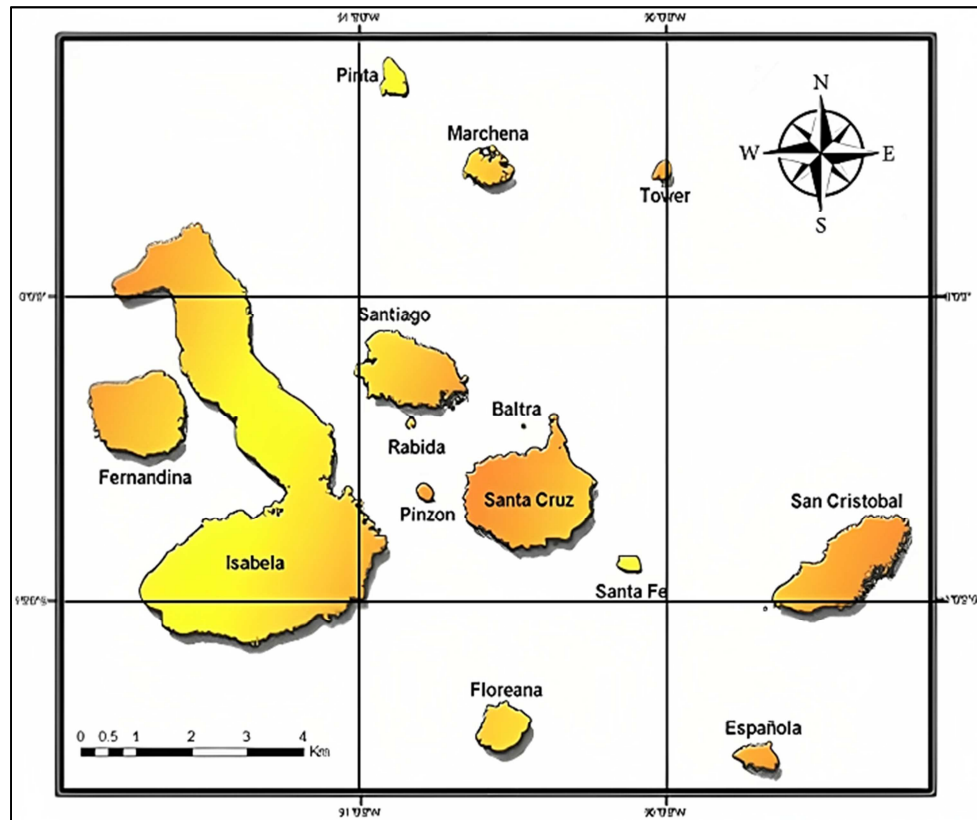


Figure 1. Galapagos Islands location map.

3. Results

Currently, energy demand in the Galapagos Islands is steadily increasing due to the growth of tourism and the local population [39]. This demand has historically been met primarily by importing fossil fuels, which makes the cost of energy high and sustainability questionable. [37] Dependence on this type of fuel represents a vulnerability since any interruption in supply can have serious consequences for the population.

3.1. Energy Potential of the Galapagos Islands

According to Burbano Vozmediano, V. E. [8], "the Galapagos Islands are a privileged place for the adoption of renewable energies due to their geographic location". Solar and wind energy are two resources that can be efficiently exploited in this island environment. With high solar radiation and consistent winds, they possess the potential to generate clean energy [40]. In addition, geothermal energy can also be a resource to consider due to its volcanic activity [48]. However,

in the latter, its costs can be very high compared to the other sustainable sources.

The archipelago has initiated an innovative lighting project based on renewable energy. According to [15], "this advance represents a perfect conjunction between nature and technology, with the purpose of boosting the environmental sustainability of the region". Energy efficiency is a fundamental pillar in the implementation of clean energy sources. According to [26], this concept refers to "the ability to obtain the maximum utility from a given amount of energy supplied", that is, as the system becomes more efficient, energy loss is minimized and its use is maximized, generating economic benefits, and contributing to the preservation of the Islands.

Local authorities, together with international organizations and society, have undertaken a series of initiatives to move towards a more sustainable energy model. This is why the five populated islands have adopted clean technologies and the use of renewable energies, offering the possibility of reducing carbon emissions, preserving ecosystems, and improving the quality of life of their inhabitants [47].

Table 1. Clean energy systems implemented in the Galapagos Islands.

Island	Type of energy implemented	Composition	Energy Generated (Kw)	Environmental Benefits
Isabela	Photovoltaic energy	3024 Photovoltaic panels	952 Kw	88 Tons of CO ₂ reduction
	Thermal power plant with biodiesel	5 Generator sets (325 Kw each one)	1625 Kw	Avoid the use of 33000 liters of diesel
Floreana	Photovoltaic energy	381 Photovoltaic panels	126 Kw	12 Tons of CO ₂ reduction
	Thermal power plant with biodiesel	2 Generator sets (69 Kw each one)	138 Kw	Avoid the use of 2900 liters of diesel.
Santa Cruz	Wind energy	3 wind turbines	3400 Kw	180 Tons of CO ₂ reduction

Island	Type of energy implemented	Composition	Energy Generated (Kw)	Environmental Benefits
San Cristóbal	Photovoltaic energy	6006 Photovoltaic panels	1500 Kw	200 Tons of CO ₂ reduction
	Wind energy	3 wind turbines	2400 Kw	180 Tons of CO ₂ reduction
Baltra	Photovoltaic energy	4500 Photovoltaic panels	1500 Kw	1000 Tons of CO ₂ reduction
	Wind energy	3 wind turbines	2250 Kw	16000 Tons of CO ₂ reduction
	Photovoltaic energy	4500 Photovoltaic panels	1500 Kw	8000 Tons of CO ₂ reduction

Note: This table shows the types of energy implemented, their composition, and benefits on the populated islands of the archipelago [7, 13, 49].

3.1.1. Isabela Island

In order to find a friendlier and more sustainable energy solution that protects Isabela's delicate ecosystem, UNESCO formulated an application in collaboration with SIEMENS to implement a fully renewable project that combines solar energy with another sustainable fuel source, pinion oil [23]. Table 1 describes in detail the two types of renewable energy that have been implemented in Isabela, which together contribute 2577 Kw of electrical power to its inhabitants, thus managing to avoid the release of 88 tons of CO₂ emissions into the environment, while dispensing with the use of approximately 33,000 liters of diesel. These environmental contributions represent a major contribution to the preservation of the natural environment and biodiversity of the area [42].

3.1.2. Floreana Island

On Floreana Island, according to Table 1, two types of clean energy have been implemented, specifically, photovoltaic energy and a thermal power plant that uses biodiesel based on pinion oil, a clean fuel derived from the seed of the same name through a transesterification process to convert triglycerides into methyl or ethyl esters [16]. These renewable energy systems contribute 264 kW to the population. This energy solution is considered as a renewable source, coming from vegetable raw materials, and plays a vital role in reducing the dependence on fossil fuels in the Island's thermal power plant. The environmental benefits are remarkable, avoiding the release of 12 tons of CO₂ and the consumption of 2,900 liters of fuel in the thermal power plant, which contributes significantly to climate change mitigation.

3.1.3. Santa Cruz Island

On Santa Cruz Island, according to Table 1, two types of renewable energy have been implemented as a significant contribution to the preservation of the island's environment and its biodiversity. This has established a wind farm that is interconnected with the wind energy system of Baltra Island [21]. In addition, it has a photovoltaic power plant in Puerto Ayora, together they provide a total of 4900 Kw of energy to its population [36]. Together, these initiatives manage to avoid the release of 380 tons of CO₂ into the environment, which represents a significant contribution to the conservation of this valuable ecosystem.

3.1.4. San Cristóbal Island

According to [9], "two clean energy systems have been implemented on San Cristóbal Island: the wind farm and the photovoltaic plant". These systems together provide a capacity of 3900 Kw of energy, according to Table 1. These sustainable

solutions are key to achieving a significant reduction in carbon dioxide emissions. According to [12] "Thanks to this combination of renewable sources, the emission of approximately 1180 tons of CO₂ into the environment is avoided". This positive environmental contribution represents an important step towards preserving the environment and mitigating climate change on San Cristobal Island.

3.1.5. Baltra Island

According to Table 1, Baltra stands out for its wind power system, which, together with its photovoltaic project, contributes a total of 3,750 kW to its population. Thanks to the combination of these two systems, the release of around 24,000 tons of CO₂ into the environment is avoided [43-44]. The implementation of renewable energies at this point is a clear example of a supply.

In relation to the exposed data of each island, according to [30], "it is observed that photovoltaic energy is present in each one of them, that is to say, solar energy is taken advantage of which due to the location of the same possess a high potential". Wind energy is another of the resources harnessed, which provides significant energy to the local population [10].

Last but not least, diesel from hydrocarbons has been replaced by pinion oil, which is considered, according to [32] "a potential biodiesel that feeds the thermal power plants of two islands: Isabela and Floreana, which together with the photovoltaic power plants form a hybrid system of clean energy". This type of energy avoids the spread of greenhouse gases into the environment, helping the sustainability and conservation of the Galapagos [33].

3.2. Total Energy Generated by Each Type of System

The Galapagos Islands have three different types of energy (photovoltaic, wind, and thermal with biodiesel), each of which provides a significant benefit to the environment.

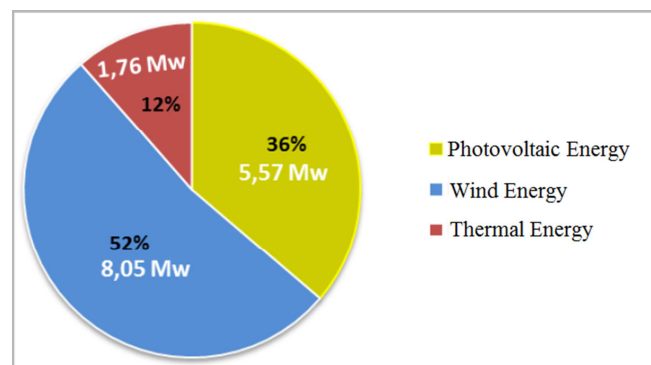


Figure 2. Percentage of Energy Generated by each type in the Galapagos Islands.

The three types of energy implemented contribute a total of 15,380 kW of electrical energy for the local population. As shown in Figure 2, 52% of this energy comes from wind sources, taking advantage of the considerable potential due to the region's exposure to constant trade winds. Likewise, photovoltaic systems present an important contribution of 36%, highlighting the significant solar energy potential, thanks to its equatorial location and abundant sun availability. However, it is recognized that the implementation of photovoltaic energy implies higher costs compared to other clean sources [3-30].

On the other hand, as expressed by [14], "thermal energy represents 12% of the electricity generated, operating through the use of biodiesel, which is not yet widely exploited". However, it highlights the high potential that this type of energy must replace hydrocarbon-derived diesel in the future. This perspective predicts an increase in the use of thermal energy in the coming years, with the commitment to move towards more sustainable and environmentally friendly sources.

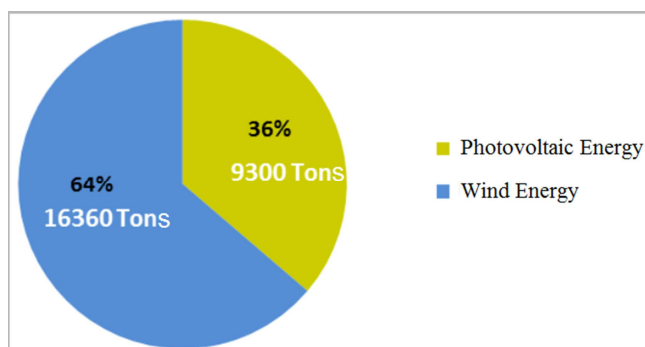


Figure 3. Percentage of CO₂ reduction by clean energy in the Galapagos Islands.

The reduction of carbon dioxide (CO₂) through the use of clean energy is of vital importance to address climate change and its associated impacts, as it is essential to mitigate pollution, improve air quality, promote sustainability and stimulate the green economy, protecting both the environment and the welfare of biodiversity [34] therefore the implementation of clean energies has meant a significant reduction of CO₂ because according to (Figure 3) wind energy annually reduces 16360 Tons of CO₂ (64%), while photovoltaic energy reduces 9 300 Tons of CO₂ per year (36%), meaning an important contribution to the environment and its conservation. In addition to this important CO₂ reduction, thermal energy with Biodiesel reduces 35,900 liters of fossil diesel per year, which is also an important contribution to the conservation of the Galapagos Islands.

3.3. Benefits of Implementing Clean Energies

Clean energies bring several environmental, social, and economic benefits, creating a sustainable model that demonstrates how responsible and environmentally friendly development is possible.

3.3.1. Environmental Benefits

According to [27] "collaborates with the decrease in the release of greenhouse gases, including carbon dioxide, which helps mitigate climate change and preserve the health of the island ecosystem". In addition, the implementation of clean energy plays a fundamental role in the conservation of biodiversity. According to [2] "avoiding the burning of fossil fuels and reducing pollution protects the habitat of endemic and endangered species, thus helping to maintain the biodiversity that characterizes the archipelago".

Another relevant benefit is the reduced visual and acoustic impact of clean energy technologies, such as wind farms and photovoltaic systems. These infrastructures have a lower aesthetic and noise impact compared to more traditional structures, which helps to preserve the natural beauty and tranquility of the environment, thus preserving the authenticity and attractiveness of the islands for residents and visitors [41].

3.3.2. Social Benefits

The implementation of this type of energy brings with it a series of benefits in social aspects. In the first place, the generation of local employment because of the installation and maintenance of these sustainable infrastructures stands out. These job opportunities, "boost economic development and contribute to the prosperity of the community". In addition, the adoption of clean energy leads to a significant improvement in air quality. By reducing air pollution, the health of residents is protected by reducing the incidence of respiratory problems and improving the quality of life of the general population [35].

Another important social benefit is the promotion of sustainable tourism. The choice of clean energy and environmental conservation practices can attract responsible and environmentally friendly tourism [28]. This type of sustainable activity stimulates the local economy, generating income and opportunities for the community, while promoting greater awareness of the importance of protecting the unique ecosystem of the Galapagos Islands.

3.3.3. Economic Benefits

The diversification of energy sources has resulted in greater energy independence, reducing dependence on imported and expensive fuels. With the adoption of clean energy, such as wind, photovoltaic and thermal with biodiesel, according to [31], "the islands now produce 60% of their energy locally, significantly decreasing the need to import fossil fuels". In addition, these sustainable technologies have demonstrated significant long-term cost savings. Although the initial investment in clean energy infrastructure is high, the lower operating and maintenance costs have saved money over the use of fossil fuels [1]. These savings directly benefit the community, allowing resources to be allocated to other development and social welfare projects.

The implementation of clean energy has also stimulated innovation and technological development in the region. Thanks to collaboration between local authorities, international organizations, and NGOs, according to [6], "the

efficiency of wind and photovoltaic energy systems has been improved, achieving a 15% increase in energy production over previous technologies". This continuous innovation has positioned the Galapagos Islands as a leader in clean technologies in the region and has inspired other communities to follow suit on the road to a more sustainable and resilient future.

4. Discussion of Results

According to the results obtained, in the Galapagos Islands such as Floreana, Isabela, San Cristóbal, Santa Cruz, and Baltra: Floreana, Isabela, San Cristobal, Santa Cruz and Baltra, various wind, photovoltaic and bioenergy technologies are implemented to generate electricity, among these, specifically the most used is photovoltaic, which allows an energy supply for the local population.

The adoption of renewable energies is of great relevance from the environmental point of view, being energy from clean and non-polluting sources, such as the sun, wind and vegetable oil from pine nuts, a significant reduction of carbon dioxide emissions into the atmosphere is achieved, preserving the delicate ecosystem in the Insular region of Ecuador, contributing to maintain a cleaner and healthier environment for the diverse flora and fauna that inhabits them, which are known for their high biodiversity and the large number of endemic species that this area is home to. These species have evolved and adapted over time to the unique conditions offered by each of the islands. Given their ecological importance, it is essential to address the management of atmospheric emissions carefully and responsibly in these delicate ecosystems, and the use of renewable energy represents a key strategy for minimizing environmental impact and protecting biodiversity in the long term.

Santa Cruz Island stands out for its remarkable installation of photovoltaic energy, with a total of 6,006 solar panels, this significant amount is the result of the population density and the extensive territory of the island, being an important tourist destination with a high demand for electricity to meet the needs of its inhabitants and visitors. The benefit of the intense solar rays, favored by its sunny climate, is crucial for the use of a considerable amount of renewable energy, this captured solar energy is efficiently converted into electricity, allowing the island to maximize the use of this clean and sustainable resource. The implementation of many solar panels on Santa Cruz Island is an example of its commitment to the use of renewable and sustainable energy sources, with the capacity to transform solar radiation into electricity, provides significant advantages in environmental terms, as it decreases dependence on non-renewable sources and, therefore, reduces greenhouse gas emissions.

The analysis revealed that San Cristobal Island leads in renewable energy production, reaching a total of 3.9 MW (megawatts), this production is divided into two fundamental components, the first part is achieved through the exploitation of wind energy, taking advantage of local wind power to generate 2.4 MW, using three high efficiency generators, the

second part of the energy generation comes from photovoltaic technology, obtaining a yield of 1.5 MW thanks to the implementation of 4,500 solar panels. San Cristobal Island stands out significantly by achieving the highest renewable energy generation among the other islands studied, this outstanding performance is attributed to the effective combination of both wind and photovoltaic technologies, taking advantage of the natural resources available in the island environment. The focus on renewable energy generation is a prime example of its commitment to sustainability and dissipation of greenhouse gas emissions. By maximizing renewable energy production, the island contributes to the reduction of its carbon footprint and the conservation of the environment.

After the comparative data analysis, Baltra Island stands out as the territory with the greatest reduction in carbon dioxide emissions. A notable reduction of 16,000 tons of is achieved thanks to the use of wind energy, implemented through three generators, additionally, the application of photovoltaic energy through solar panels achieves an additional reduction of 8,000 tons of carbon dioxide, resulting in a total value of 24,000 tons of that are avoided to be emitted to the environment. This significant decrease in emissions leads to a positive impact on the environment. It can be inferred that the surrounding air in these islands is of great purity and conducive to the health of flora, fauna, and inhabitants, by reducing pollution. Emission mitigation plays an important role in protecting our planet's ozone layer by preventing harmful solar rays from penetrating intensely without proper atmospheric protection.

Ultimately, these clean energy solutions have proven to be highly efficient and effective, drastically reducing dependence on fossil fuels while lowering energy costs. By harnessing renewable sources such as solar, wind and bioenergy, a path towards a cleaner and more sustainable future is created, ensuring the conservation of the environment for future generations. According to Macancela (2018) [24], the primary objectives of governments is to use locally available sources of renewable energy, managing to avoid the use of diesel generators, most of the islands have photovoltaic panels and wind turbines, making the islands environmentally friendly and avoiding pollution of the various ecosystems that have each of the islands, Each island analyzes the cost benefit of the implementation of the type of renewable energy to be used, in some cases the islands have very strong winds that can be used and transformed with wind turbines into electricity, in other islands the amount of solar energy provided on the islands is greater than in others so they make the decision to opt for the use of solar panels.

In the Galapagos Islands the use of renewable energy is very important because it does not pollute the planet with the use of fuels, avoiding the generation of within the islands, most of the inhabitants choose to use means of transportation such as bicycles or electric motorcycles as they help to avoid the generation of to the environment, the types of energy used in the island are photovoltaic, wind and bioenergy, the highest percentage of production of amount of energy used in the

islands is focused on photovoltaic and wind as it is provided by nature. According to [45], the pine nut is an economically important shrub, due to its various industrial uses. It is very important for the development of bioenergy, due to the high concentration of oil in its seeds, which is why it is used to produce biodiesel, while the shells of its fruits can be considered to produce ethanol due to their high cellulose content. The residue obtained after the oil extraction process is a useful organic by-product that contains considerable amounts of macro and micronutrients and is suitable for agricultural use as an organic fertilizer.

The use of bioenergy energy generates biodiesel through pine nut oil, which benefits the environment by avoiding the emission of tons of, is a great contribution to society and the economy. The use of these renewable energies has been essential for the development of the inhabitants and the non-contamination of the diverse ecosystems of flora and fauna that can be found. The environmental culture that the island has is something very wonderful since they encourage the government to stimulate the use of renewable energies, with the objective of preserving the beauty of the nature in which they live.

5. Conclusion

After reviewing the research, it is concluded that the projects for the use of sustainable energies in Galapagos are part of energy efficiency and excellent ecological performance as part of the same, taking care of the ecosystem and increasing the electrical potential, the information collected in the research determines the use of renewable energies as an impulse for the reduction of emissions, indicating that as the main objective of these projects have to increase the use of sustainable energy determining an efficiency and energy potential in addition to the zero use of fossil fuels in the Galapagos Islands.

The unlimited resource of wind and continuous sunshine in these islands make it possible for energy to be unlimited, in addition to energy efficiency, quality, continuity, resilience, security and coverage of public electricity services, in this research highlights the Santa Cruz Island, the generation that this island has is impressive and encourages others to perform other sustainable projects.

The results of this project demonstrate in a principle the reduction of is the main objective in creation of sustainable projects, the advances in sustainable energy projects benefit considerably to the reduction of Carbon Dioxide emissions and electrical independence considering the advances of the mentioned projects.

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