Decarbonization of the Galapagos Islands. Proposal to transform the energy system into 100% renewable by 2050

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ABSTRACT

This research presents a completely decarbonized system structured with renewable energies for the fragile ecosystem of the Galapagos Islands of Ecuador, with a horizon to the year 2050. The transition process begins with clear legal actions and allocating economic resources that clearly promote a change in the energy matrix and the transition would be achieved until the year 2050. The Galapagos Islands are the second largest marine reserve on the planet, declared a World Heritage Site in 1978 for UNESCO. The archipelago, a beautiful ecological attraction, has tourism as its main economic source. The biggest problem is in the supply of energy that mainly comes from fossil fuels, in addition to that, the smell of fuel in several places is out of tune with the harmonious nature and its species. The efforts began to be noticed when in the Archipelago the new implementations of renewable energy began to become a reality with the purpose of stopping using fossil fuels. In this sense, there is the potential to take advantage of the resources available in specific sites, especially the photovoltaic and wind solar considered in the National Plan All a Life. The change in the productive matrix from the national level also implies a change in demand, including at the transportation level with the use of electric vehicles and the use of electric stoves in homes. The purpose is that energy services in the Galapagos Islands progressively increase, on the one hand, replacing fossil fuels and on the other, supplying the growing demand with a view to 2050, taking advantage of renewable energies until reaching 100%.

Keywords: Clean energy; Decarbonization; Renewable energy; EnergyPLAN; Energy transition.

Nomenclature

ARCONEL	*Electric Regulation and Control Agency*
CO_2	*Carbon Dioxide*
COP	*Conference Of Parties*
OCTOAD	*Organic Code of Territorial Organization Autonomy and Decentralization*.
CL	*Cooling load*
CMSS	*Coordinating Ministry of Strategic Sectors*
EU	*European Union*
GES	*Galapagos Electricity Sector*
GHG	*Greenhouse Gas*
GGC	*Galapagos Government Council*
GSEP	*Global Sustainable Electricity Partnership*
IEA	*International Energy Agency*
IDB	*Inter-American Development Bank*
INECEL	*National Institute of Technology of Ecuador*
ITT	*Ishpingo-Tambococha-Tiputini*
LMP	*Land Management Plan*
MEER	*Ministry of Electricity and Renewable Energy*
NEA	*National Energy Agenda*
NGO	*Non Governmental*
NISCE	*National Institute of Statistics and Censuses of Ecuador*
NPAL	*National Plan All a Life*
NZE	*Net Zero Emissions*
PE	*Primary energy*
PLANEE	*National Energy Efficiency Plan*
PLG	*Petroleum Liquid Gas*
PV	*Photovoltaic*
RE	*Renewable Energy*
SDG 7	*Seventh Sustainable Development Goal*
TOP	*Territorial Ordering Plan*
TPP	*Total Power Plants*
UNF	*United Nations Foundation*
UNDP	*United Nations Development Program*
WHS	*World Heritage Site*
ZFFG	*Zero Fossil Fuels in Galapagos*

1. Introduction

Reaching Goal 7 for Sustainable Development (SDG 7) means guaranteeing access to energy in an affordable, reliable, sustainable and modern [1]. An adequate energy supply is a latent need that involves millions of people around the world and most of them have many difficulties to develop economically [2],[3]. Historically, fuels have been an important source for the well-being and development of different countries, however it has also contributed with negative consequences, including the increase in the climate on earth [4]. Furthermore, the uses bring with them growing problems of an environmental nature, such as plastic, which, being a derivative of oil, has caused disastrous problems in marine species [5]. These fuels from the so-called Industrial Revolution, acquired prominence in the incipient industrial development, establishing a new economic order through the use of coal. Starting in 1913, with the invention of the oil-derived combustion engine, established a monopoly for obtaining energy used in transportation [6].

Industralization improved the processes at the beginning of the 21st century with the purpose of exploiting fossil fuels en masse, which put the international community in check [7]. However, due to the high levels of exploitation of fossil fuels, countries experience substantial reductions in their reserves, especially oil, experiencing global climate change that includes fuel shortage problems [8]. Examples of this type are lived in Latin America in countries such as Venezuela [9], [10], Bolivia [11], Chile [12], Ecuador [13], Brazil [14]. The common denominator of the countries is that the oil fields are being depleted at a rate never seen before and puts future development at risk [15], [16]. The transnational companies are seeking, as possible, concessions with government entities for the fields that still remain, even at the expense of those who live in those regions [17], [18].

Ecuador is a typical example in which foreign companies have exploited oil in the Amazon, leaving enormous consequences such as the destruction of vegetation where countless species live, which was denounced by the government of Rafael Correa, which even brought with it an international legal controversy [19]. Furthermore, the consequences do not stop there, a large part of the uncontacted peoples are affected by having to migrate to other places, which brings social problems and human habitat [20]. The fight for oil exploitation does not give truce and the few available sites are waging a merciless battle, the Yasuni ITT can be named where the fauna, flora and isolated towns are stalked by extractivists who win the fight against environmentalists and take possession of these limited species-rich sites. Ecuador at the end of 2011 promoted the initiative that had international repercussions. In fact, it was considered an example of the struggle to stop climate change, recognized as Yasuni-ITT action [21] [22]. The proposal started by leaving a large part of the oil deposits in the subsoil. The commitment that was envisaged is that the crude of the area Ishpingo, Tambococha and Tiputini (ITT) within the Yasuni is not exploited because it is an area very rich in biodiversity on the planet in exchange for a voluntary economic remuneration of natural or legal persons to world level [23]. This innovative proposal, for many, prevented that around 22% of oil fields from avoiding the emission of approximately 415 million tons of CO_2 into the environment [24].

To have a clearer view of the Ecuadorian panorama, in Yasuni Park in one hectare, there are 660 species of plants, in relation to a thousand species of plants that exist in all of North America [25], [26]. Actually with this statement we can take into account the repercussions that oil can affect in areas like these, for these reasons an energy transformation to migrate from toxic fuels to clean energies becomes very positive.

If this first part was of great interest, the part that we are going to analyze later becomes extraordinarily fantastic. We consider the Galapagos Archipelago as an icon of the beauty that nature offers, it belongs to Ecuador and is located in the Pacific Ocean (See Fig. 1). It is here that Charles Darwin English naturalist, renowned scientist who raised the theory of evolution [27].

This biogeographic region is considered a living museum and showcase of evolution, with a total area of 147135.4 km^2, of which around 97% corresponds to the Galapagos National Park registered as Cultural Heritage of Humanity [28]. Meanwhile, 3% is inhabited area. According to the political-administrative order of Galapagos [29], its capital is Puerto Baquerizo Moreno to the southwest of the island of San Cristóbal.
According to figures officially published by the National Institute of Statistics and Censuses of Ecuador (NISCE), currently 25244 people live in the archipelago, with an annual population growth of 1.8% [30]. It implies that there is a growing need for electrical service for end users, thus generating a greater demand for electricity. With these antecedents of population growth and the proposal of a new structure based on renewable energies in exchange for fossil fuels, as proposed in the government of President

Guillermo Lazo, the tie for 2050 with the so-called "ecological transition" is a challenge for the Galapagos Electricity Sector (GES) [31] and in this investigation the roadmap is drawn up to achieve this purpose.

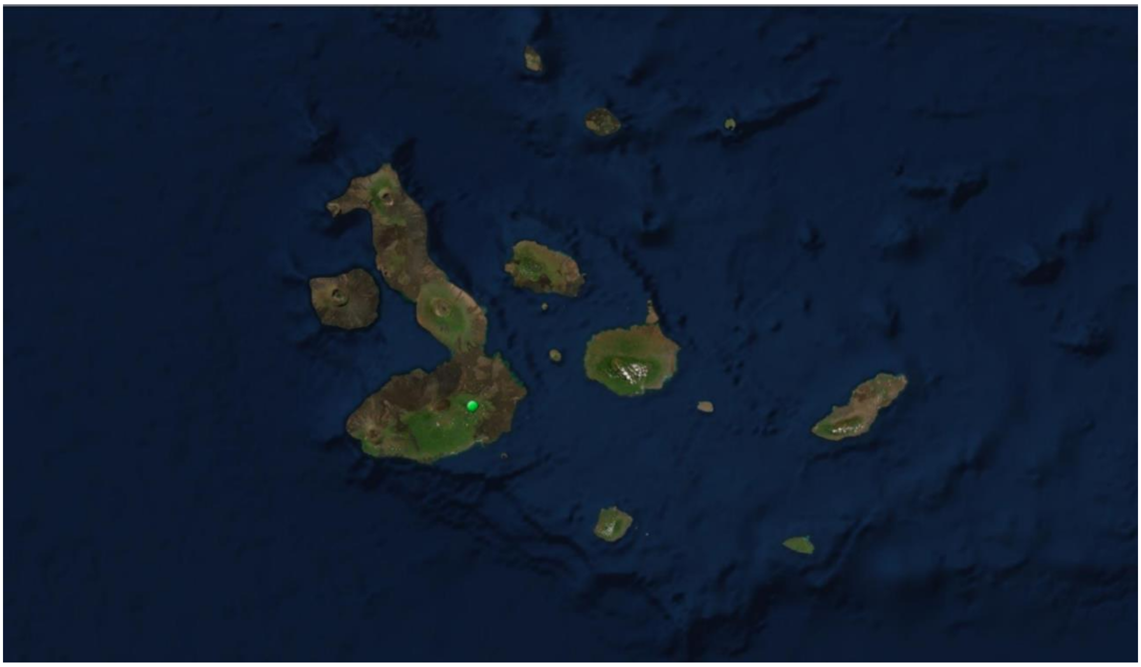


Fig. 1. The Galapagos Islands General view.

The beautiful natural landscapes of the Archipelago, the uniqueness and diversity of the species it houses, its geological dynamics, its volcanic origin are more than enough reasons to consider it as a living and evolutionary laboratory that does not exist anywhere else in the world. If there is something more to indicate about Galapagos to understand the importance and dimension for humanity, it is the first site in the world that was designated as a World Heritage Site (WHS) [32].

1.1 Current Situation

Actually the Galapagos Islands are of great value to the entire humanity. However, there is a problem that we need to address with concern and that is the main reason for this study, it is the electrical issue [4]. The Galapagos hislas throughout time have had as their main sources of energy supply those from fossil fuels [33]. In fact, it has been of enormous help in its beginnings for the economic development in the Archipelago. However, since 2007 there has been concern that polluting actions are taking place in this fragile ecosystem with an unexpected population growth [34], which makes it necessary to take actions aimed at de-carbonizing the islands and replacing them with clean energy, even thinking about the future demand for energy [35].

In this sense, the use of renewable energies is a very feasible option in decarbonization processes as carried out by different countries with the purpose of transforming their systems based on fossil fuels into one that is sustained in renewable energies [3].

During these last two decades, both governments, regulatory bodies and other private sector organizations have exposed the need to increase the proportion of renewable energies as a real option in the fight against climate change to reduce Greenhouse Gas (GHG) emissions [36]. The Paris Agreement in 2015 was of collective interest and above all it seeks to truncate the increase in global temperature below 2 °C [37]. These agreements, within their objectives, clearly establish the use of renewable energy (RE), application of energy efficiency and government maneuvers to reach social agreements with the firm purpose of reducing emissions to the atmosphere [38]. Among the main members is the European Union (EU) which set a goal of reducing emissions at least 40% compared to 1990 emission levels by 2030. In this regard, the EU also envisaged increasing the renewable energy mix by 27% by 2030 [39]. As we specify for the EU, there are different initiatives worldwide that make all the necessary efforts in order to comply with the Paris agreement, among them are the countries of Senegal [40], Japan [41], Guatemala [42], South Africa [43], which due to their budgets and legal order in Several of them are limited but seek to meet these objectives of having 100% renewable energy systems by 2050.

Individual countries can establish their own more ambitious goals. For example, Germany's goal is to 45% of renewable energy consumption by 2025, 55% -60% by 2035 and 80% by 2050 [44].The largest countries from the point of view of energy markets such as the United States and China, have defined mutual agreements on energy policy to promote the use of RE and mitigate climate change [45, p. 28], especially within its objectives it is contemplated to reduce the consumption of coal and to substantially improve the energy efficiency.

The International Energy Agency (IEA) [46] in its special report reveals how the world electricity sector can achieve deep decarbonisation by 2050. The established path specifies that the global demand for Electricity in 2050 is approximately 9% less than now, but it will have to serve an economy twice the current one and a population of 2 billion additional people.

This implies that the different energy units will have to do more work than is currently done in terms of mobility, cooling, heating, cooking food, etc. The trend of improving energy efficiency is gaining momentum in this regard and not only involves the transformation of fossil energy to sustainable renewable energy, but also its appropriate uses to meet the future needs of the world’s population.

As shown in the exposed literature, it is clear that there is a worldwide need for electrical power systems in different countries and regions to change to clean energies. Here the question arises as to how this transition should be carried out [37], [47]. This article presents a hypothesis that allows us to evaluate the future energy system for the Galapagos special regime, as it is even stated in the Ecuadorian Constitution of 2008 and we project it until 2050 [48]. An impact approach is provided in the reduction of the pollution that the archipelago lives today in a completely decarbonized one, considering a higher rate of feasible and exploitable renewable energies [33], [49]. Intelligent energy systems are already being proposed worldwide, this will also affect these territories in the not too distant future, however the process must be clear and orderly and the Ecuadorian electricity sector be energized [50]. All sectors must be involved and considered in these transition processes so that in addition to being an ecological contribution, it is also an economic and social contribution [51].

Advantageously, the policies in Ecuador have been routed in a good way, of course there may be much to improve, however the cornerstones are established. The challenge for the different governments to come is to make this common project feasible to provide the necessary support especially with sufficient resources. If necessary, make this so-called ecological transition viable from the legal side that the current president of the Republic of Ecuador It has declared it with a view to 2050 and that is found in national decree 56 [52]. These actions undertaken without being mean are fully linked to the policies of the Rafael Correa government embodied in the National Plan for Good Living and in the future these actions must continue along the same lines [53].

Hydroelectric plants have played an important role as a permanent source of energy worldwide. However, at the island level it has not been an important source of contribution due to its geographical conditions at the ocean level [54]. Consequently, historically they have been supplied by fossil fuels and are currently in a decarbonization process. Among them is the case of the island in Croatia [55], that of Porto Santo in Portugal that includes the use of electric vehicles [56], in the same way, in the Canary Islands they already have a transition model to use clean energy to supply electricity. electricity demand, which includes heating and cooling in hotels [57]. Other authors such as F. Calise et al. [58] and Sandrine Selosse [59] presented their studies to transform their energy systems from fossil fuels to one sustained in renewable energies but on a larger scale with aggressive investment.

Several authors consider that an energy transition must be responsible, always having as the main objective the availability and quality of energy for current and future demand [37], [57]. In this regard, the transition entails increasing higher levels of penetration of renewable energies in compensation for the reduction of energy produced by fossil fuels [60]. On the other hand, an increasing demand requires satisfying its energy demands, however due to the strategy it must be carried out with renewable energy [61]. It is here where policies, economic investments, technical analysis must be integrated into a single purpose, which is the protection of human beings and their environment [38].
At the island level, it is very positive to use renewable energy systems that can be used according to their meteorological potential. According to the different experiences, wind and solar energy have been of enormous benefit and form hybrid systems together with other contributions that in the medium term also include diesel and gasoline generators. Among these investigations we have the one carried out

by Paúl Arevalo [62] in which the performance of a hybrid PV/HKT/WT system is analyzed in conjunction with a diesel generator. N Ghorbani by reference [63] presented a hybrid system that includes a gasoline generator to solve the problems of shortage of electricity at affordable costs.

At the level of Ecuador, the country in which this study is carried out, after having bad experiences due to oil activity with dire consequences due to oil spills and damage to nature in the country, considered modifying the 2008 constitution to include important aspects such as providing rights to nature and the promotion of renewable energies [25], [34]. In the last decade, several national projects have been put into operation, among them the wind farm in the Loja province [64] and the hybrid wind-photovoltaic system for the Santa Cruz and Baltra islands in Galapagos [33] to more than the hydroelectric plants like Coca Codo Sinclair, Mazar, San Francisco [65]. The aim is not only to satisfy the current demand, but also the necessary energy of the future demand due to the increase in population [66].

Recent research by the Inter-American Development Bank (IDB), published in its gazette contemplate that climate change would cost the region between 1.5% and 5% of regional GDP [67]. For this reason, there are a series of actions undertaken in South America in order to take appropriate actions, including a series of renewable energy auctions, especially to implement wind and solar energy projects. Among the latest auctions are those in Colombia, in which it is confirmed that around 80 additional renewable energy projects will enter by the end of 2021 [68]. On the other hand, Ecuador announced a new 350MW Renewable Energy auction between photovoltaic and wind energy, and this year it will cover an investment of USD 300 million [69]. For its part, the National Energy Commission of Chile issued the Preliminary Bases for the National and International Public Tender for the Supply of Energy and Electric Power, which will auction 2,310 GWh to supply the energy needs of regulated customers of the National Electric System, to from the year 2026, for 15 years [70].

At the country level, there has always been great concern for the fragile Galapagos ecosystem, an economy based on the rational use of the natural resources available in the Archipelago has been promoted. The purpose has always been the conservation of the Islands, maintaining respect for the ecosystem and adding value to the services within the territory [27]. Additionally, there is a Territorial Ordering Plan (TOP) that governs the Province in accordance with the OCTOAD that gives Decentralized Autonomous Governments administrative, financial and economic autonomy [71]. However, in high investment projects, the Ecuadorian central government promotes various projects at the country level that, as the Galapagos Islands have a special regime, can achieve more benefits, which also depends on the inter-institutional efforts and agreements that they carry out in terms of energy policy and development sustainable [72]. To achieve effectiveness in the actions that are undertaken in the medium and long term, it is necessary to draw up a roadmap that is currently not available for the Galapagos Archipelago. In this research we consider it with 100% decarbonization by 2050 with the inclusion of potential renewable energy sources.

Among the objectives of the National Plan All a Life (NPAL) 2017-2021, in its fourth paragraph, it is considered to increase electricity generation through clean energy from 68.8% to 90% by the end of 2021[69]. The current government of President Guillermo Lazo also points to a line of environmental protection, which is why in his first days in office he issued Executive Decree No. 59, changing the name of the Ministry of Environment and Water to that of the Ministry of the Environment, Water and Ecological Transition. In that same decree in article 6, it is considered that public policies and public-private and community initiatives must be developed and complied with that promote the transition towards sustainable production and consumption systems that will lead Ecuador towards net zero emissions by the year 2050 [31]. Ultimately, the spirit of these policies is not only a production based on clean energy but also requires the migration of obsolete and polluting technologies at the demand level for more environmentally friendly systems. Progress in this sense is in constant progress and is based on the Montecristi constitution of 2008, although there are different kinds of questions, it must be recognized that it has become a legal tool that has allowed the positive articulation of energy policies [74]. The enactment of the energy efficiency law is seen as positive as they bring various requirements [75]. Among its clauses, it is intended that new purchases of public transport vehicles be electric from 2025. These actions will be joint and with the corresponding socialization of the citizens, so that together with the municipalities, effective strategies are established so that they become a reality in each territorial district. Other important initiatives are those carried out in the city of Cuenca, where the 4 Ríos tram was recently implemented [76]. On the other hand, the change from induction electric stoves to the typical PLG-based stoves are also contributing to increase the levels of energy efficiency at the household level [77].

In the comprehensive study of the world's energy interaction addressed by the IEA on how to make the energy transition to a net zero energy system by 2050 [78]. Among the purposes of the analysis is to guarantee a quality and affordable energy supply, providing universal access to energy and with it the localities have a solid economic growth. Having an adequate electrical service leads to an economically productive and profitable path in which no citizen in the world should be deprived of these benefits. The responsibility for the availability of electricity services belongs to the countries, in this sense the governments of the day must strengthen state policies that lead to the maximum levels of penetration in their territories [79]. However, it can be seen that the depletion of oil reserves in different countries becomes a risk of shortages if there are no effective and timely actions. The energy transition is a reality for fighting in favor of the planet and also in the fight against shortages in the face of growing demand. Countries that do not have energy development plans and still rely on oil may have serious future problems if they do not take precautions from now on [80]. As a result of a timely transition it leads to a portal to a clean, dynamic and resilient energy economy dominated by renewable energies such as solar and wind. There is still uncertainty about the strategic role that bioenergy, carbon capture and changes in the energy market will play to reach net zero [81].

In the Ecuadorian electricity market, you can already clearly see three competitors on different lanes that seek to supply energy and heat to growing economic sectors. This dispute is between coal, renewable energy and natural gas. Coal is the oldest but still in force that refuses to leave the market and that is not only present in Ecuador but in most of the countries of the world. New investment decisions have come to a standstill or are taking too long, except for the transnationals that are trying to get hold of new state concessions. They try to continue with the exploitation of certain infrastructures that use coal and in some way they have influenced by delaying the processes in favor of the protection of the planet [82]. Imran Hanif [83] presented an economic analysis with the use of renewable energies for Latin America and the Caribbean. On the other hand, David Jacobs et al. [84] presented an analysis to make the Latin American electricity market more attractive based on incentives with an accessible tariff structure. In this sense, renewable energies challenge coal and seek to permanently put it out of the game for a future that seems to be much more hopeful for these clean energies based on new investments. In relation to the third competitor that is natural gas in the Ecuadorian market, it also seeks to keep supplying the residential sector sustained on the basis of state subsidies but closely watches renewable energies that are penetrating the market with prices that tend to fall and that they are gaining ground little by little based on efficiency policies, especially with a model based on changing induction electric stoves for LPG.

The last governments have given incentives for citizens to choose to purchase electric stoves by establishing that consumers with less than 100 kWh pay lower prices. These government initiatives are provided thanks to the high levels of electricity production from the new renewable energy generation plants that were incorporated in the last 15 years. The IEA in its recent publication [85] announced that the power generation technologies that have a remarkable growth and that are sure to be the future of world energy are wind, solar photovoltaic and hydroelectric history that will remain in the time and is shown in Fig. 2. These technologies that are constantly developing more efficient products at lower prices than currently expected tend to outperform coal [86]. According to projections for 2040 [87], [88], sources with low carbon percentages will be present within the global energy mix in at least 50% of total electricity.

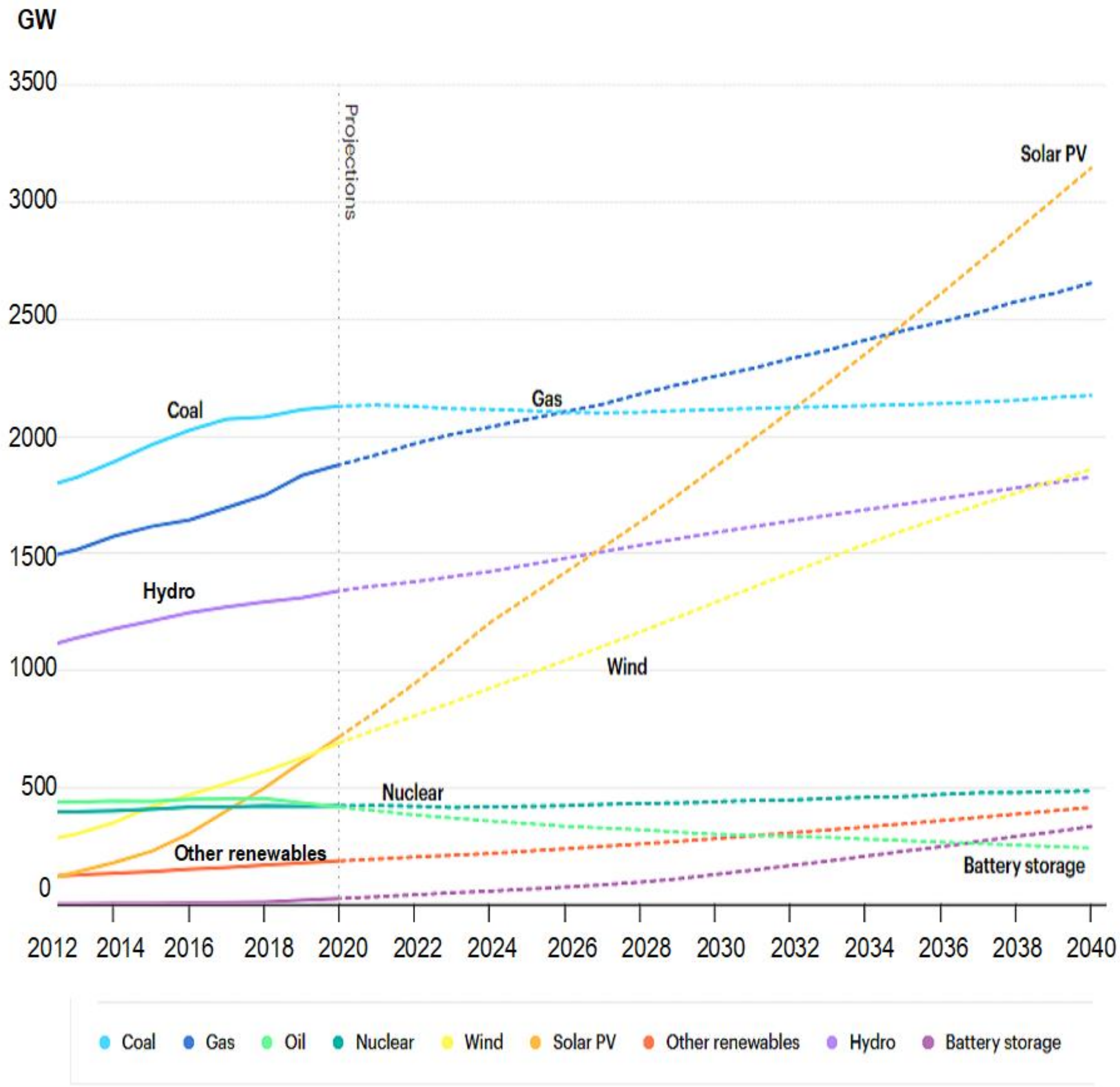


Fig. 2. World energy scenario to 2040.

It is clear that the key to transforming the world's energy systems depends on the rates of renewable energy production in each country with clear policies and important budgets. There is also another aspect of concern for international organizations, which is the promotion of energy efficiency improvements. It is not only a question of increasing production levels with clean energy, but that this energy is well used and, above all, at the demand level, the environment is not polluted. It does not make sense to have clean energy while there is a demand that pollutes incessantly. The needs are different and in Fig. 3, these areas are distinguished. Among the most important are those of lighting, district heating, refrigeration, transport [89].

In Ecuador there is an organic energy efficiency law issued on March 15, 2019, which is based on promoting efficient, rational use and sustainable energy in all its forms, in order to increase the country's energy security. This law promotes increasing energy productivity, promoting the competitiveness of the national economy, build a culture of environmental sustainability and energy efficiency, contribute to the mitigation of climate change and guarantee the rights of people to live in a pollution-free environment.

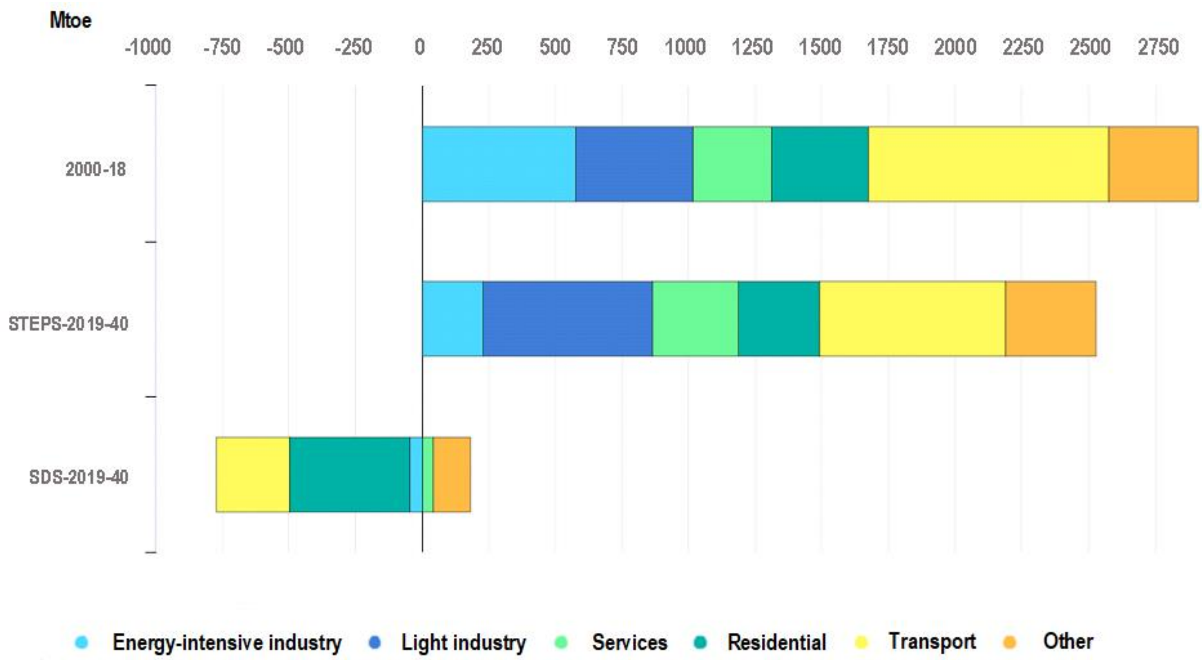


Fig. 3. Evolution of energy consumption worldwide by sector until 2040 presented by [90].

Different researchers around the world are committed to providing sufficient guidelines for the energy transition to be carried out in a planned way. P Laha et al. [91] maximizes renewable energy for India with a view to 2040, in the same way Hans Christian Gils and Sonja Simon [92] projected a 100% renewable system for the Canary Islands. Other authors consider that there are various factors that are affecting their renewable energy systems to reach 100% by 2040. However, they see positive the efforts made by different governments and consider it possible that policies and investments give good results to the year 2050. In this sense, several researchers presented their studies, among them: A Sadiqa et al. [93] outlines the roadmap for a 100% renewable energy system with storage for Pakistan. Vincent Krakowski et al. [94] conducted a prospective analysis to completely transform the French power system to 100%. Markus Doepfert and Rui Castro [95] conducted a study of techno-economic optimization for a 100% renewable energy system in Portugal with a view to 2050 with a large proportion of hydroelectric energy.

Analyzed in detail in the Latin American countries, there are few studies that present 100% renewable proposals [96], [97]. However, it is presumed that the region is making enormous economic and political efforts to leave behind the energy systems based on fossil fuels. Compared with the studies and roadmaps prepared in different countries of Europe and Asia, there is no point of comparison of the concern that other continents do have, which is even the motivation to carry out this research for the Galapagos Islands. In this regard, Ecuador, a country that, although it is striving to change its energy matrix, requires a long-term roadmap in both Continental Ecuador and Insular Ecuador (Galapagos) with the clear purpose of establishing how it would be carried out. carry out the energy transition by taking advantage of the potential sources of renewable energy that is very rich in this country. These reasons, motivate us to carry out the study and make visible important growth opportunities for the Galapagos Archipelago that will not only be beneficial for this country but for humanity itself as it is a unique ecosystem on the planet and requires concrete actions. In what is developing in the country, it can be indicated that the short-term scenario has the approval made by CELEC and MEER, they are entities that developed the 2016-2025 Electrification Master Plan. This plan contemplated the entry into operation of several generation plants in 2019, specifically 5 hydroelectric plants and 2 NGCC centrals. In 2020, other new power generation centrals came into operation with the technical contribution of China, of these 8 are hydroelectric. By the end of 2021, 2 renewable energy plants of 250 and 125 MW are expected to come into operation and some private producers will start operating with 150 MW in the coastal region. By 2022, it is considered that the operational tests will be completed and 2 hydroelectric plants of 915 MW will operate and other projects for the generation of renewable energy for 200 MW will also be completed. After 2022, different renewable energy projects, especially solar photovoltaic, such as Aromo, Villonaco II and III, Minas de Huascachaca, among others, have been planned.

The purpose of this article is to model a technically feasible 100% renewable energy system for the Galapagos Islands. Statistical data and penetration rates of certain technologies can be exploited on-site based on their energy potential and population growth [51]. On the other hand, the renewable energy projections that are made must progressively replace polluting energy sources. It is not possible to root out fossil fuels due to economic factors and, above all, it must be ensured that the electricity service is catered for on demand while maintaining the robustness of the system. The analysis also focuses on avoiding depending on a single generation technology and rather it is recommended to have a mix of technologies in order to maintain the balance of the electrical system with the support of storage systems. Another important point considered is the socioeconomic cost of new implementations and the cost of replacing polluting sources. The challenge is that the direct or indirect costs are the lowest possible and the projections allow to obtain effective solutions but never disturb the demand or affect the population from the monetary point of view, seeking a projection that is as realistic as possible and 100% renewable energy is reached by 2050 for Galapagos.

2. Methodology.

In this research, it is to draw the roadmap for the decarbonization of Galapagos. Special aspects are considered to draw the scenarios according to what is recommended by [95]. Is considered in the methodology the availability of resources for the use of new technologies based on certain feasible sources of renewable energy and subsequently evaluate the technical and socioeconomic impacts. There are three important phases during the methodological analysis: The data entry phase and the available resources, the adjustment or calibration phase subject to state policies that have a direct impact on the site under study. Additionally, indirect aspects are considered, such as the collateral effects of international pressure and global technological development, which above all allow access to products and services at economically accessible prices, ensuring flexibility in operations. Finally, the technologies and socioeconomic results valued according to the demand are presented. It is also important to highlight that it is vital to evaluate the initial state and for this it is considered a base year, the current percentages of fuels that are being used in the national market must also be assessed. Exact data of the CO2 that is currently and historically being emitted into the atmosphere are entered to correct and that in the future do not have a negative impact. By 2050, the complete decarbonization of the Galapagos Islands is considered, it implies a progressive process of reducing polluting sources and, on the other hand, an increase in renewables in the coming years, also covering the growing demand.

2.1. Long-term projection model

Currently it is very useful to rely on specialized software to carry out projections in the medium and long term. EnergyPLAN is a model used effectively to design smart energy systems. This model was worked on and developed by the Aalborg University [99]. It started with version 6.1 in 2006, very interesting and with great features, however, as different researchers used this tool, it has given rise to important modifications in which much more flexible analyzes can be carried out. There are 32 versions available and the latest one is 16.1 downloadable from July 2021. It is specialized software that allows the integration of medium and large-scale renewable energies within the energy system of countries, cities or regions [100]. Among the different outstanding investigations that have been carried out worldwide and that integrate renewable energies are: that of the Colombian case [101], that of Sichuan, China [102], that of Portugal [95], the Italian [103], among others. In the literature on energy transition and planning of renewable energy systems, there are different models, each with its own particularities. In this sense, there are excellent analyzes of the benefits of each one carried out by [95], [98]. It is also discussed very well in [75] to obtain optimal combinations of renewable energies according to the benefits of each territory. Different points of view and objectives are structured, including the inclusion of electric vehicles [97], heating and cooling services [57]. This model allows us to carry out simulations of 100% renewable energy systems for the Galapagos Archipelago or also known as the Galapagos Islands. The final stage it takes advantage of the renewable resources available and sufficient to supply the growing demand in accordance with the ordinances that govern the occupation of urban and rural land in Galapagos [4] as a special regime of Ecuador. The typical input parameters recommended by [100] are specifically the demands, capacities of each generation unit, storage systems, current consumption of fossil fuels by each sector, fuel costs, investments, operation and maintenance, costs fixed and variable [99].

Currently in the Archipelago fuel costs are excessively high, especially due to the transportation costs involved in moving to the islands, which is not commensurate with the country's economy by subsidizing these resources. Ecuador's oil reserves are in frank depletion, the times when a barrel of oil exceeded $100 in the international market to soften the economy was left behind and most countries do not consider supplying oil and rather their investments are focused on renewable. It is not intended to nip these polluting sources in the bud, the purpose is to reduce it progressively until 2050 with 100% of the renewable energy for Galapagos.

EnergyPLAN is a very reliable and currently established tool to carry out different investigations that involve the analysis and design of 100% renewable energy systems. This model in its recently available version 16.1 is shown in Fig. 4. The model has excellent features, much easier to use, very versatile, allows a technical analysis, energy exchange analysis between adjacent markets and feasibility studies. In the end, the energy balances are obtained as results, in addition to the detail of the annual production by source. It is possible later to evaluate the economic benefits that are achieved in the defined periods, including taxes and costs for CO2 emissions.

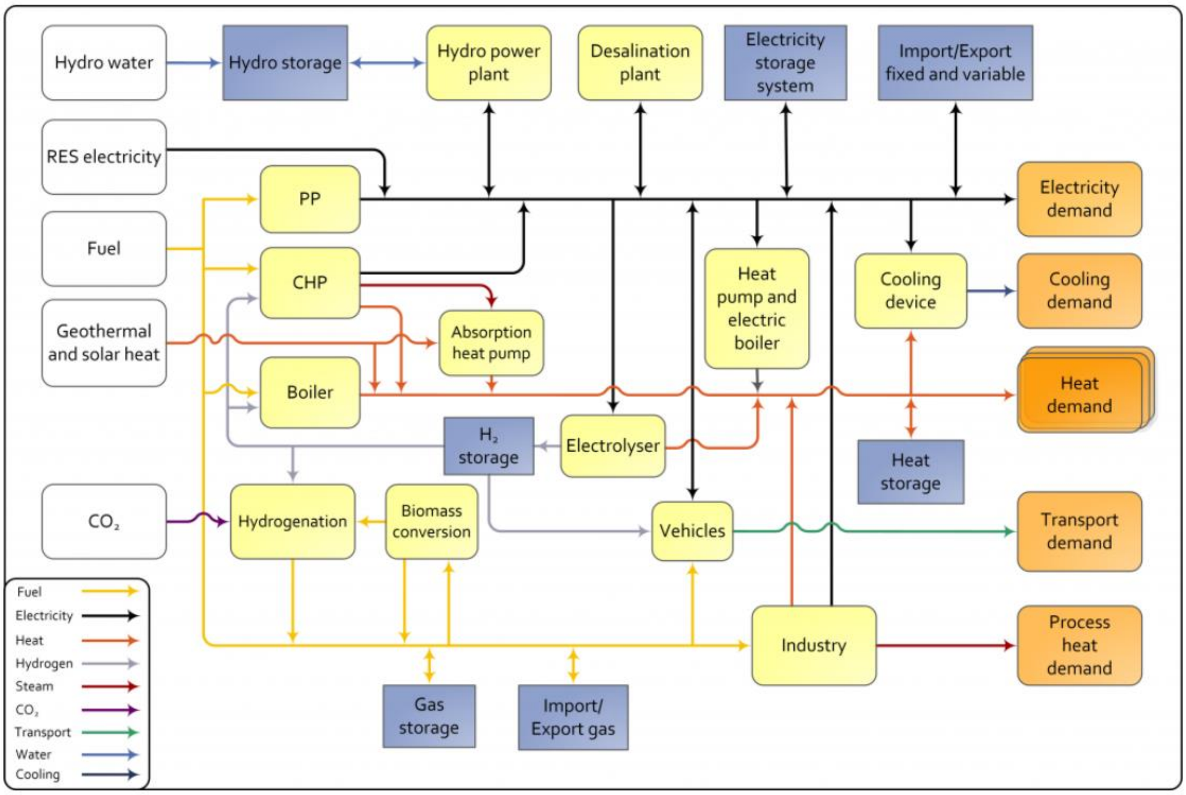


Fig. 4. Model for long-term analysis. Version 16.1 EnergyPLAN [99].

3. Energy matrix in the Galapagos Archipelago.

According to the official reports of the Electric Regulation and Control Agency (ARCONEL), the electric system operates independently by islands. The four inhabited islands are the following: San Cristóbal, Santa Cruz, Floreana and Isabela. From the very operation of the system, its evolution is accentuated in three stages. The first two stages had as a common denominator for a traditional use of fossil fuels for power generation. In the first stage, goes back to the year 1961 to 1999, the entity that was in charge was the National Institute of Technology of Ecuador (INECEL) being responsible for the management, operation and maintenance of the GES. At this stage the islands were sparsely inhabited, only the capital Puerto Baquerizo Moreno and the Charles Darwin station, had electricity service.

With the altruistic support of the United States, at the end of 1967 a gasoline generator was installed on the most inhabited island of Santa Cruz. In mid-1974, the construction of the local public electricity distribution network began. The interest in having electricity increased among its inhabitants by making use of the small local network implemented [104]. With this, in 1980 the islands already had three electric generators, two of 50 kW and one of 80 kW. The difficulty they had was the supply of fuel to power the installed generators. They had to have boats and travel once a month to the port of Guayaquil. After the national reforms at the end of this stage, the INECEL company was ceased and a new electricity distribution company created E. E. GALAPAGOS A. S. [105]. This company took over the entire existing electrical system that included the generation, transmission and distribution of electrical energy in the archipelago.

In the second stage, runs from 1999 to 2008, power generation increased in Galapagos given the growing demand, especially from foreigners and from continental Ecuador due to the excellent living conditions that were present in the inhabited islands. In this way, E. E. GALAPAGOS A. S. already established itself as a solid company and began to gain an image in the eyes of citizens by providing a high-quality 24-hour electrical service for the first time in 2001 [4]. In 2007, the archipelago's electrical system reached an installed power of 6.29 MW with the increase of fossil fuels [106]. In this period, although there was an increase in the production of electrical energy, Galapagos became dependent on fossil fuels to meet the increasing demand since then. It was unfortunate that in this period due to the high dependence on fossil fuels, the fragile ecosystem was the one that received the greatest impacts, such as fuel spills, the strong and suffocating smell of these fuels affected the flora, fauna and the same being human, that even tourists did not invite a new visit due to these conditions on the islands [107]. This did not stop there with the increase in greenhouse gas emissions, but several fuel spills ended the lives of species as sea travel began to be more recurrent. Examples of these bad experiences resulting from using fossil fuels are the Island of Santa Cruz [108] and the one that occurred in the capital Puerto Baquerizo Moreno located on the island of San Cristóbal [109].

In the third stage that includes from 2008 to the present, the new constitution of Ecuador is considered after promulgated, in which rights are granted to nature and one of the support pillars is renewable energy. At the beginning of this period, the figure of President Rafael Correa emerged, who firmly generated substantial proposals to be analyzed in the National Assembly and with it the legal framework to guide initiatives to change the energy matrix in the country [110]. The Ecuadorian government was really concerned about the Ecuadorian situation and in particular the Galapagos Islands for what was considered a special regime and with it, the ecological viability, economic and social sustainability [111]. From here, the Zero Fossil Fuels in Galapagos (ZFFG) initiative is promoted [112], which has as its main objective the decarbolization of the Galapagos Islands, thereby eradicating the use of pesticides, petroleum distillates, poor use of the soil and the search to exploit the existing renewable resources in the archipelago [113]. To achieve this purpose, it was taken into account that it was not enough to produce clean energy when, on the other hand, there was a polluting demand, for this reason several initiatives arose and the most influential one started with the National Energy Efficiency Plan (PLANEE), which aims to change inefficient refrigerators for new ones [115], the increase in electric vehicles, the efficient cooking program using induction electric cookers [116], among others. The urban order and the repowering of the electrical distribution networks were considered and extensively worked to move the aerial networks to underground after being resized. The drawbacks of a total and orderly decarbonization not only thinking about the present but also in future generations and achieving sustainability in the Galapagos Islands have been discussed by [117]. In addition, after putting into effect the new constitution and national policies to implement the CCFG, the challenge in the GES is very great and above all, sufficient resources are needed to reach 100% renewable energy. These unconventional power generation systems are viable in the archipelago thanks to the fact that mainly wind and solar photovoltaic resources are quite attractive. Currently, the provision of renewable energy in the GES is a reality, although much remains to be deployed. It is made up of photovoltaic and wind power plants. Thermal generation that depends on high levels of fuels, especially diesel, cannot be eliminated outright, but a systematic reduction of these contributions is required and renewable sources must be increased instead. This research presents the roadmap to fulfill this purpose in a horizon to 2050 in accordance with the national objective promoted by the current President of the Republic Guillermo Lazo [118]. Details are presented in the following sections.

3.1. Wind Power.

Several studies have analyzed with interest the preponderant role that renewable energies will play in the Galapagos Islands. Regarding wind energy, there are already two very good experiences with wind farms located on two different islands. The first project became a reality in May 2015 on San Cristobal Island, specifically on the El Tropezón mountain with coordinates (-0.892639 °, -89.498806°). According to data from the wind speed profile at the site provided by [119], a maximum speed of 12.8 m/s and an average of 5.7 m/s were obtained. The investment reached 10 million dollars, which consisted in putting into operation three identical AE-59 turbines of 800kW each, providing 2.4MW of installed capacity. The towers are 51.5 meters high and the blades have a diameter of 59 meters. This first project was recognized for being economically and financially sustainable, with a total turnover approximately 3.4 million USD during the 8 years of operation [120].
The framework agreement for the sale of energy was signed with the company local electricity company ELECGALAPAGOS S.A. in charge of covering operating costs and maintenance. It was capitalized under an innovative scheme with funds from the United Nations Foundation (UNF), United Nations Development Program (UNDP), the Ecuadorian Government, income tax donations from private

contributors and Global Sustainable Electricity Partnership (GSEP) member companies [121]. This was the first wind project in Ecuador, it began to operate regularly at the end of 2007 [122]. Since 2016, this system generates over 16 GWh of electricity.

The second wind farm was implemented under an agreement between the Ministry of Electricity and Renewable Energy (MEER) and the United Nations Development Program (UNDP) on the island of Baltra at cost of 10 million dollars [123], [124]. This park is located next to the Seymour airport (-0 ° 26 '31.2", -90 ° 15' 57.2") has a nominal capacity of 2.25 MW thanks to its three 750 kW Unison U57 turbines. This wind power plant is interconnected with a substation in Puerto Ayora through a 34.5kV transmission line. This line has a distance of 50km, has several sections between air, underground and submarine. Thanks to this implementation, 99763 gallons of diesel are saved per year, an amount equivalent to almost 300000 gallons of diesel used between 2014 and 2017 [125].

In Fig. 5 shows the wind map of Galapagos thanks to the reference [126] there are three substantial components that are identified. The first is that, being islands, the winds in the open sea are a bit unpredictable and turbulent, very different from those obtained at the level of the mountains of the continent. In the second it is identified that the currents of trade winds are limited due to the elevation levels of the volcanic areas, similar to ramps that create steep slopes that together form a kind of tunnels [119]. The wind at certain points coalesces and forms tunnels that can be better used for these power generation purposes.

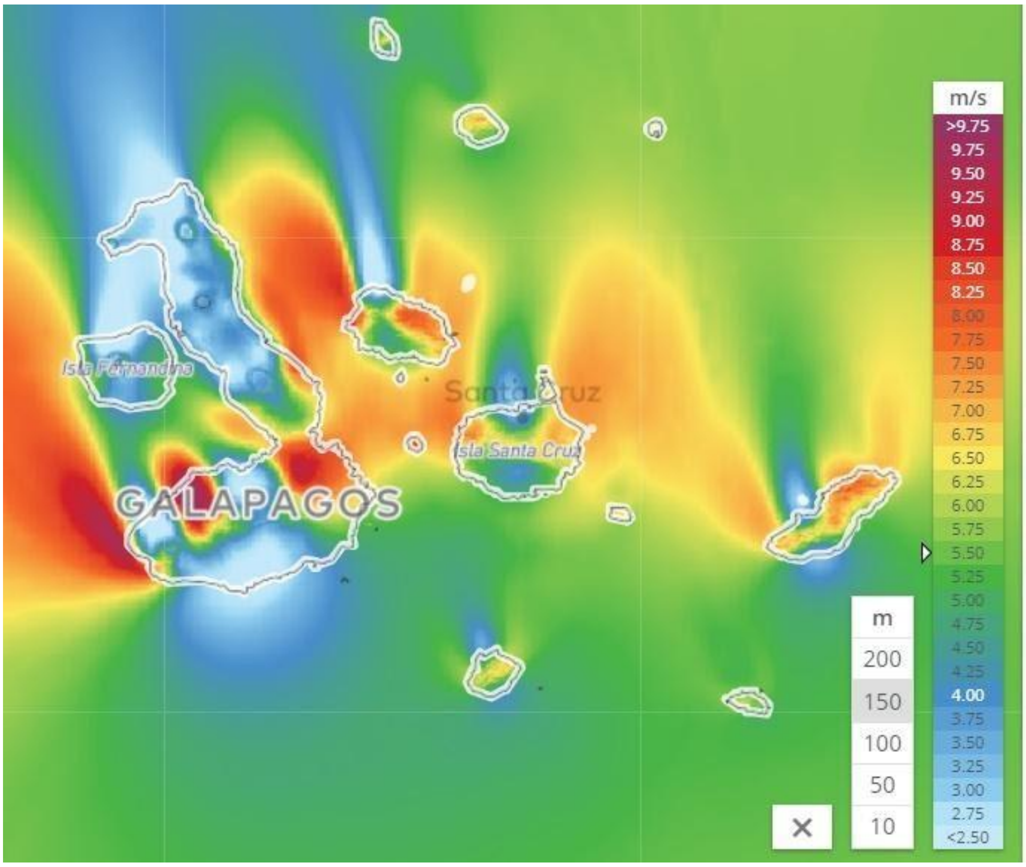


Fig. 5. Map of average wind speed in the Galapagos Islands. Adapted with Global Wind Atlas [126]

3.2. Solar Energy FV.

The archipelago has exceptional solar potential, receives a substantial amount of light as perpendicular as possible and is very aligned to the equatorial line. Using the Global Solar Atlas (GSA) shown in Fig. 6, the Global Horizontal Irradiance (GHI) values range from 1600 to 2250 kWh/m^2/year [55]. According to EMP, the areas with the highest potential for photovoltaic solar exploitation are: the coastal strip of Baltra, the coasts of Santa Cruz, central part of San Cristóbal, north and south of Florida and the port Villamil in the south of Isabela. Is important to note that although there is a high potential for photovoltaic energy generation in the vicinity of the volcanoes, especially on Isabela Island, it is not advisable to implement at these points for safety against volcanic eruptions that are forecast to occur on an average every six years [127]. The high solar radiation in the Galapagos Archipelago, becomes key to increase the generation of clean energy and make the long-awaited energy transition a reality.

To date, Galapagos already has solar implementations on its islands. Examples are: The Santa Cruz plant with an installed capacity of 1.52MW that supplies 7.03% of the island's electricity demand. The generated power is injected into the E. E. GALAPAGOS substation through an overhead transmission line at 13.8 kV, 0.7 km long [105], [128]. This plant cost around eight million dollars and was financed by the Ministry of Electricity and Renewable Energies (MEER), the Korea-KOICA International Cooperation Agency and E. E. GALAPAGOS [129].
Another solar plant is located in Baltra with installed power of 70kW and has a storage system for lead-acid batteries (500kW, 4000 kWh) and rechargeable lithium-ion batteries (500kW, 268 kWh) [130]. In addition, the Solar PV Eolicsa plant of San Cristóbal has an installed power of 10kW, while the Perla Solar PV plant on the island of Floreana has an installed power of 20kW. It also stands out that the Galapagos Islands have remote and private systems on the Isabela, Floreana and Santa Cruz Islands, each with an installed power of 10kW [131]. There are several projects planned by the state with a view to 2030, mainly on the islands Isabela and San Cristóbal, including seven photovoltaic solar plants with a total installed power of 12.9MWp [35].

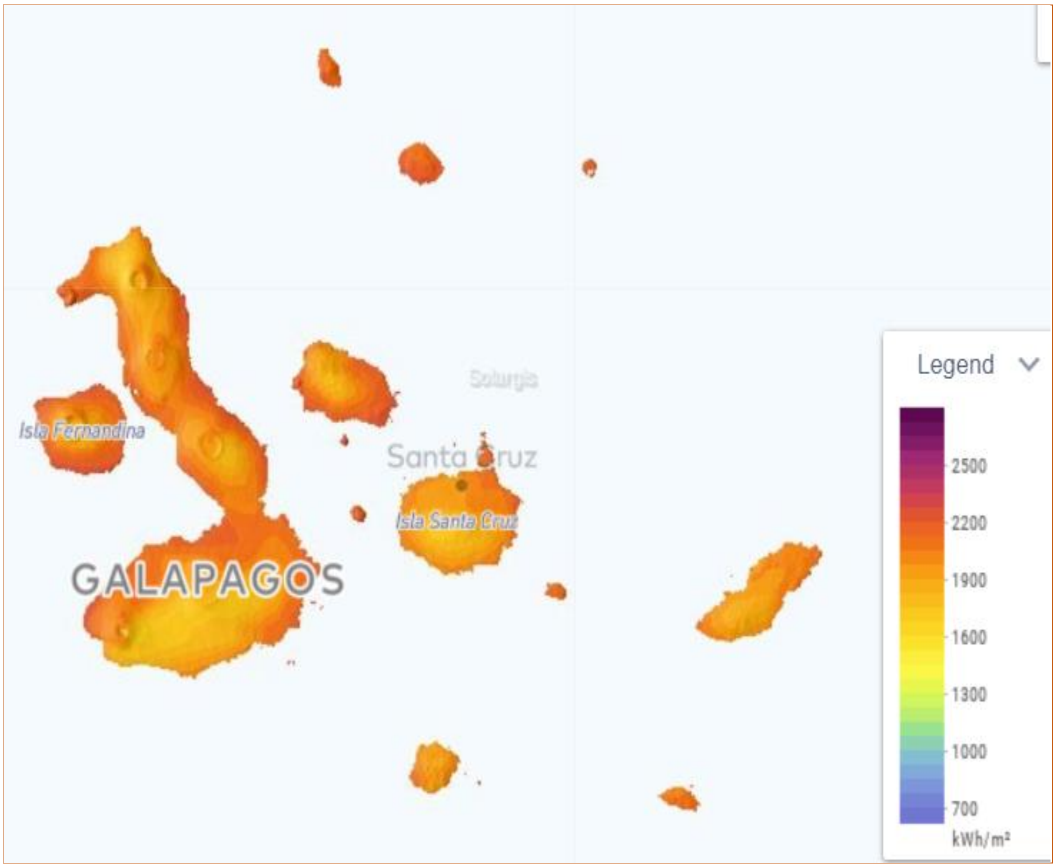


Fig. 6. Global Horizontal Irradiation (GHI) map in the Galapagos Islands. Adapted Global Solar Atlas 2.0 [132]

3.3. Geothermal Energy.

The Galapagos Islands contain individual volcanic peaks, Isabela Island is the largest and is made up of six peaks as shown in Fig 7. Most of the islands are the product of volcanic eruptions, only the Baltra and Santa Fe islands are elevations product of fault blocks, without central volcanoes. In Galapagos, a geothermal energy project (renewable energy obtained through heat from the interior of the earth) has already been studied since May 2019 to take advantage of the natural resources that the Archipelago has in a sustainable way [133]. Fernandina Island has been a study objective of high interest to generate electricity, heating, absorption cooling or direct use of the high temperatures achieved by keeping distances of security [134].

In all of Ecuador, the exploitation of 50MW in geothermal energy is planned in the short term, as officially stated by the Ministry of Energy and Non-Renewable Natural Resources of Ecuador [135]. Of these

50MW, given the special conditions in the Galapagos Islands, it is considered that at least 20MW can be exploited in the Archipelago.

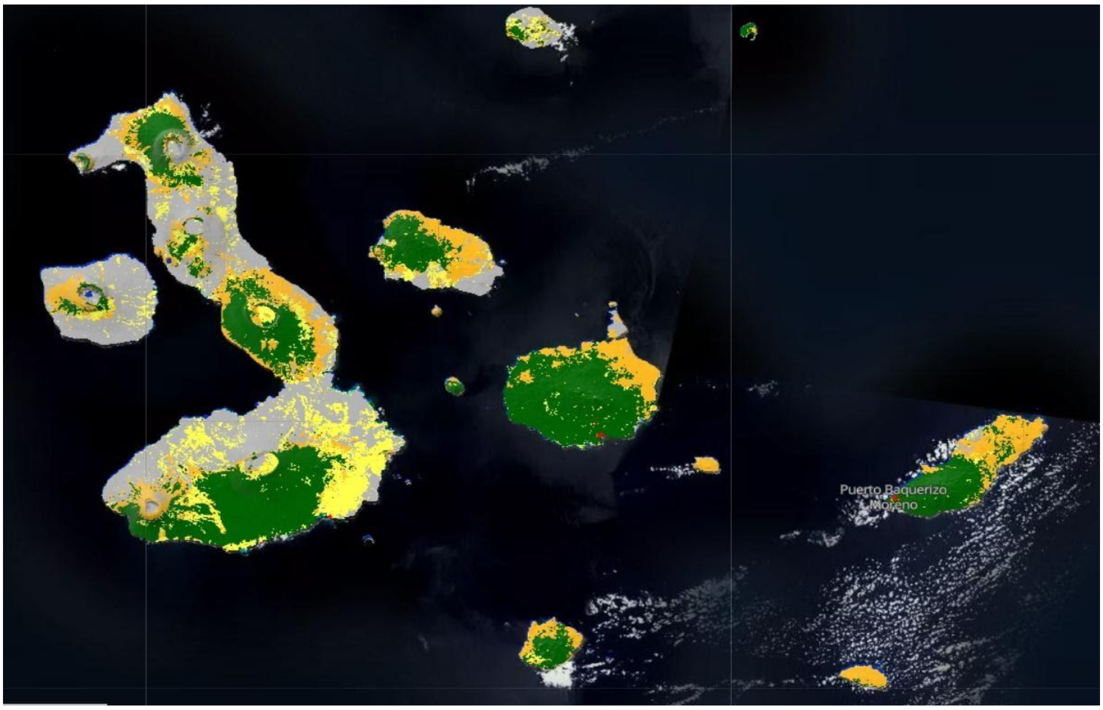
Earthquakes and eruptions are common on the islands. More than 50 volcanic eruptions have been recorded since the early 19th century. The islands show other signs of volcanic activity such as fumaroles, lava tubes, sulfur fields and pumice stone. One of the most notable characteristics of the volcanoes in Galapagos is their parasitic cones; there are about 2000 of them on the slopes of the 20 largest mountains, and many of them still erupt [136].

Fig. 7. Location of the volcanoes in the Galapagos Islands for the purpose of harnessing geothermal energy, adapted from [137]

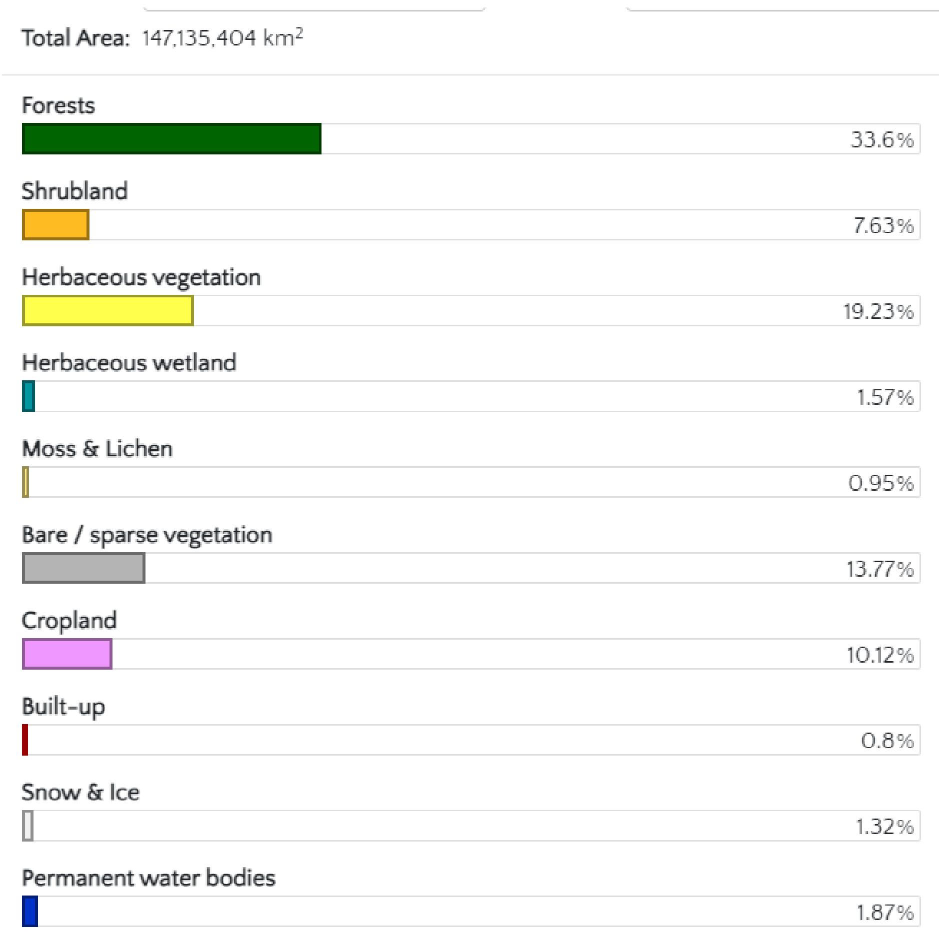
3.4. Biomass

The principle of obtaining energy from biomass can be of animal or vegetable origin. It is obtained naturally or artificially in plants implemented for this purpose. Matter is transformed into energy according to specific defined processes. Galapagos in particular has a large amount of forests and vegetation of different types that with proper planning can be used in the future and avoid setting fire in the open as is done today.

According to Fig 8 (a) and Fig 8 (b), the distribution of the soil of the Galapagos Archipelago is classified, comprising 147,135,404 total km^2. Forests occupy the largest amount of territory with 33.6% of the total area, while Herbaceous vegetation and Bare/sparse vegetation occupy 19.23% and 13.77% respectively. All these forests and types of vegetation require harvests at the right time, so all these wastes can be very well used on the islands for generation purposes and avoid the use of fossil fuels. Table 1 shows the distribution of the territory of the islands by segments.



(a)



(b)

Fig. 8. Classification of the territory in the Galapagos Islands. (a) The forest predominates (green color) and two types of vegetation (yellow and gray) (b) Percentages of soil distribution according to [138]

Another important part is the proper use of municipal solid waste. In 2018, around 9,000 tons of waste were collected in the three cantons of Galapagos: Isabela, San Cristóbal and Santa Cruz. This last

Canton is the one with the largest number of inhabitants and the presence of tourists and, therefore, the largest amount of garbage. There, waste collection went from 5,000 tons in 2015 to 6,100 tons in 2018.

Another important source of generation that is currently being useful is biogas. It arises from the high production of livestock in large areas that are very humid and available with grass. Currently Galapagos has a quality cattle population of around 10000 animal heads distributed in the four main islands. Even according to experiences in other countries, bobbin manure can be very useful for power generation purposes, which have not yet been carried out in the Galapagos Islands. The methane transformation rate by anaerobic digestion is 0.04 m^3 of CH4/kg in this type of manure due to the solid waste from these cattle oscillates between 10 and 15 kg/day [139]. A conventional tubular biogas digester can produce a quantity of 9450m^3/day of biogas and produces 56700 kWh of energy that becomes a promising alternative. Additionally, 16,500 m^3/month of biofertilizers can be marketed.

3.5. Wave energy

The Galapagos Islands are located 1000km away from the Ecuadorian coasts, they are located in the open sea and receive water currents from the Pacific Ocean, they have enormous potential to take advantage of wave energy [140], which would diversify the energy matrix Galapagos and would contribute to decarbonization. In this context, the MEER made contact in 2012 for the first time with SDE Energy Ltd with the purpose of taking advantage of this technology that can be very useful in the islands [141]. These wave power plants are expected to be implemented in all inhabited islands, covering at least 60% of the financing from the central government.

4. Analysis

A 100% renewable scheme for Galapagos has been of high interest to the governments of the day, but only in the government of President Guillermo Lazo a horizon to 2050 is proposed and a transition ministry is available [118]. However, the mechanisms are still lacking and long-term planned actions, which in this manuscript has been a motivation to draw up the roadmap. Because it is a biodiverse and fragile ecosystem and of high value for humanity, decarbonization in Galapagos should even be considered for a shorter period, however, being consistent and realistic with the limited economy of Ecuador, it is considered that 2050 is a possible year of fulfill the energy transition in the Archipelago as conceived by various regions and countries worldwide [91], [95], [98]. Oil is currently taking a back seat in the world, continuing with a scheme that is being relegated can be a serious mistake and the risk of shortages can end up paying a high price to future generations. As dire experiences were analyzed in the previous sections, particularly Galapagos has been hit hard by oil spills and the impacts of continuing to use fuels have been seen as negative aspects in the international community. The design of 100% renewable systems entails an immense but encouraging challenge in the search to integrate a high percentage of intermittent resources to the power system periodically with defined economic resources to cover the needs that this transition entails in the course of time until covering fully to the year 2050. It is an important time for the archipelago but it does not depend on a single government, it requires a true commitment at the country level to progressively meet the demands with the contribution of clean energy and the role is of the leaders of the day. The Galapagos archipelago has taken important steps to initiate this energy transition, but it is necessary to accelerate these processes and the local government is key to fulfilling this desire. The experiences that have been achieved in the Archipelago are highlighted in the previous sections of this manuscript in great detail and the power values that have been incorporated are specified.

In this section and the next ones, it is detailed how the energy system under study would be structured, the exploitable renewable energy resources available in the study area are channeled and for this the EnergyPLAN software is used as a proven and very useful tool to carry out these projections [100]. In the final part, the economic scenarios will be indicated, which is the most sensitive part of the economy, this is where the options available to satisfy this purpose of decarbonization of the Galapagos Islands are presented. EnergyPLAN is a powerful and versatile tool, very valuable to design 100% extractable energy systems according to the reality of each place, these statements can be verified in [142], [143] [144]–[147]

4.1. Referential framework of the EnergyPLAN Model for the Galapagos Archipelago

To carry out the transition process, EnergyPLAN considers a base year with installed capacity data as a reference and only from there is it fully studied, in our case 2020 to 2050. The EnergyPLAN tool is used to analyze the energy forecast comparatively with long-term future electricity demand. Historical data for 2019 are included to serve as a reference for the beginning of 2020 (See Table 2). Several studies have been developed and have served as a reference to understand the dynamics of energy systems between supply and demand, they are comprehensively evaluated and focus on the levels of contribution from each source and possible intermediate income from other sources in the period of analysis. For this reason, EnergyPLAN is a dynamic tool and has been characterized by its great benefits to analyze future energy systems that go beyond 20, 30 years or even many more. Since the first versions developed in the EnergyPLAN platform, different researchers have verified its excellent performance, even so there are new elements for improvement that allow the analysis of much larger energy markets, such is the case of the energy system for the entire European Union [148] or the case of China [149], among other cases with a view to 2050 and 100% renewable. In the strict case of the Galapagos Islands, the particular aspects and their reference parameters are considered according to their reality, this is the generation capacity by renewable energy sources, population growth, land use plan. The input scenario is of great importance, for this the analysis carried out in the previous sections are key aspects, the numerical input data obtained from previous studies, accountability reports from public institutions, data published and contrasted by newspapers are included. of prestige that are building the base year, which in this case is the year 2020. This initial scenario provides a general panorama in which parts of the system the renewable energy levels can be increased and in what proportion the incidence of fuels can be limited fossils to design a 100% renewable future scheme on that basis [142]. The analysis becomes fantastic and its results rest on a feasible structural basis but it also gives rise to the construction of scenarios according to the analyzes that are needed. In this case, it is analyzed from the economic point of view where investment is a key aspect that requires a special analysis, to the point that options are presented so that the purpose of having completely decarbonized islands is fulfilled. The data that will be supported to finally obtain the results of the scenario design until 2050 are considered feasible and recommendable.

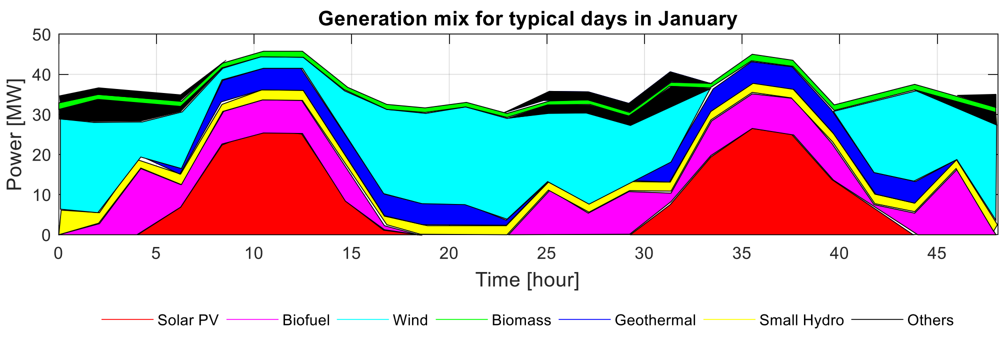
4.2. Reference electricity market 2020 and time horizon 2050

The reference electricity market in the Galapagos Archipelago is marked by a high rate of thermoelectricity in 3 of the four islands as detailed in Table 1. In 2050, all the energy supply is 100% renewable and, as they are islands, the hydropower is not considered on a large scale, except for the small hydro that can be harnessed from falling water.

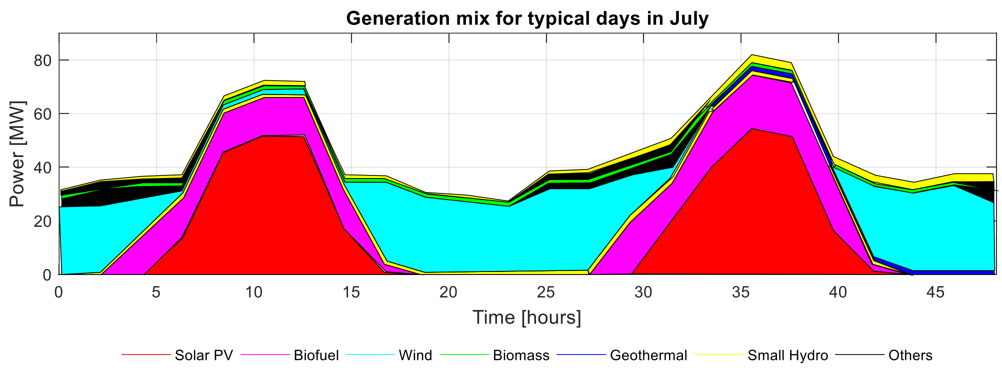
Table 1. Installed Power in Galapagos Islands

Island	Renewable Energy (kW)			Thermoelectricity (Kw)	TOTAL (kW)
	Biomass	**Wind**	**Solar PV**	**Diesel**	
Santa Cruz		2250	1575	14950	18775
San Cristobal		2400	12	9450	11862
Isabela			930	3250	4180
Floreana	138		26		164
TOTAL	138	4650	2543	27650	34981

The highest energy production is from photovoltaic solar thanks to the excellent solar radiation that the archipelago receives with 46.9% but above all because it is a proven technology that is beginning to be strongly deployed, followed by wind and biomass with a 29.5% and 8.5% respectively. The rest of the contribution in geothermal, wave and small hydro of low scale. With energyPLAN, the electric energy production profile can be seen in hourly samples during two typical days of winter and summer analyzed by recommendation of reference [150] and is shown in Fig 9.



(a)



(b)

Fig 9. Combination of energy sources on typical days (a) January (b) July

In reality, the technology that will dominate the energy market in the Galapagos Islands will be solar photovoltaic in summer. It is reasonable that this technology is the technology of the future due to the high extractable potential. From the statistical point of view, including photovoltaics in mixed systems is common and this can be seen in several markets [92], [95], [98], including the production costs of solar panels and complementary equipment tend to decrease and it has become a technology of greater access. Wind energy will also become of high importance, meanwhile biomass is already being very useful in low proportions and in the future it is considered relevant and to be taken into account. Mixed systems are highly recommended, it is not necessary to depend on one or two sources, no matter how cheap they are, diversification is the most appropriate. In reality, when investing economic resources, they must be very well analyzed, since 2020 a diversification of technologies is sought and avoid risking investments targeting certain energy sources. Currently, biomass has not had great relevance in the Archipelago as it has in other parts of Ecuador, however its use is a great option and should be considered within the energy mix. On the other hand, other smaller-scale contributions are incorporated such as small hydro, wave energy and geothermal energy that should not for any reason be relegated since the more diversified the electrical system is, the more robust it is achieved globally. Below in Table 2 the summary of the main parameters of the model used is presented.

Table 2. Validation of the reference model for the Galapagos Islands.

Design descriptive	**Solar PV**	**Wind**	**Biomass**	**Geothermal**	**Others minors**	**Oil**
Time of life (years)	40	40	40	40	40	30
Credit Capacity (%)	100	50	50	50	50	100

Sending order of merit	2	1	1	1	1	2
Fuel cost ($/TOE)	-	-	-	-	37.8	398.5
Maximum availability (%)	47	65	25	35	45	25
Capital costs (thousands of USD/MW of production capacity)						
2020	2543	4650	3320	680	2920	975
2050	15570	9600	1950	1900	5450	0
Cost of O&M (thousands of USD/MW of production capacity)						
2020	13	42	107	114	75	8.3
2050	10.5	62.5	88	75	55	6.6

According to the dynamic model, EnergyPLAN includes medium and large energy capacities with a time horizon set to 2050. Within the interaction of variables, there is no specifically defined criterion to determine the final scenario, which is precisely what distinguishes EnergyPLAN from various platforms. However, if specific criteria are not established, it is important that the design is consistent and well interpreted and its results do not go beyond the installed capacity and its allowable production levels. It is essential to have clear policies, Land Management Plans (LMP), legal and regulatory aspects that govern a region and in this case in the Galapagos Archipelago. This dynamic to build the final scenario is not trend-oriented, but allows an interesting prospect to be generated in the middle of a period under analysis, so it is possible to increase the levels of certain renewable sources, including gradually reducing the rates of fossil fuels. Alerts are generated when the input parameters are such that they affect the energy system globally or their contributions are uneven for a period of time in relation to another that prevent full decarbonization.

However, derailing fossil fuels from energy markets is a priority for the various reasons discussed in this study. However, the IEA [151] also has a new concern that has taken shape and that is on the table for discussion in the countries, perhaps not with the haste as related to energy transition, specifically the issue of energy efficiency. It is proposed that energy must have its proper uses and include saving concepts that prevent countries and regions from making excessive investments. In several cases, limiting resources, for example in developing countries where one of the priorities is also to comply with the zero hunger program. Studies also emerge to have the mechanisms that entail producing energy at the most efficient levels possible in current production systems, now recognizing the need to make greater efforts at the level of demand. It is there where the uses of energy are most analyzed and must be more sustainable and better used. In this regard, Table 3 already summarizes the energy efficiency plans and programs for the Galapagos Archipelago.

The OCTOAD indicates, in its article 111, that the leadership and definition of the management model of the strategic sectors within which the energy sector is located correspond exclusively to the central government. Only in the case of the province of Galapagos, the twenty-eighth general provision speaks of the attributions of the Government Council of Galapagos and indicates the promotion of the use of alternative energies.

The National Energy Agenda (NEA), prepared by the Coordinating Ministry of Strategic Sectors (CMSS), raised as one of its objectives an Ecuador with efficient use of energy, and establishes among the guidelines and actions for its achievement: i) maintain a solid institutional framework for energy efficiency to guarantee its transversality, ii) guarantee the implementation of energy efficiency based on adequate planning, iii) increase the quality and optimize the management of information on energy uses, iv) sustain efficiency energy on a solid regulatory framework, v) encourage the creation of market mechanisms and promote the management of financing schemes for energy efficiency, vi) promote the adoption of efficient behaviors in energy matters; and, vii) train and certify experts in energy efficiency.

In compliance with the provisions above, this State Portfolio presented the National Energy Efficiency Plan 2016-2035 (PLANEE) as a public policy instrument that seeks to improve energy consumption habits, through the incorporation of energy efficiency in sectors related to the provision and use of energy. With the implementation of PLANEE, Ecuador will be able to comply with international agreements in "Guarantee access to affordable, safe, sustainable and modern energy", a goal established by the United Nations on the Seventh Sustainable Development Goal (SDG 7) and “double the index global energy efficiency improvement”, an essential objective of the Sustainable Energy initiative for All (SE4ALL).

Table 3. Main strategies of PLANEE 2016-2035 in force that includes the Galapagos Archipelago [152]

Defined Strategy		Description
1. Project to reactivate, reconfigure and expand the vehicle RENOVA plan.	-	Incorporation of hybrid, electric and new technologies vehicles that are market in the future.
2. EECCRE Implementation project in Galapagos	-	Definition of control and inspection mechanisms for the implementation and continuous improvement of the EECCRE Standard - Energy Efficiency, Climate Control and Renewable Energy
3. Loss Reduction Plan	-	Program to reduce energy losses in the electricity distribution system.
4. Standardization and labeling program for energy consuming equipment in the residential and commercial sector	-	Promote the acquisition of efficient equipment in both the residential and commercial sectors.
5. Efficient electric cooking program	-	Change of electric induction stoves for liquefied petroleum gas stoves and water heating by electricity.
6. Replacement program	-	Substitution of inefficient light bulbs for low consumption light bulbs in the residential sector and the public lighting sector of the islands.
7. Training program for public workers	-	Promote the moderate use of electricity in public administration.
8. Energy management standards	-	Implementation of Energy Management Systems based on the ISO 50001 Standard in public institutions and the sector commercial of the islands.
9. Program for the dissemination of best energy efficiency practices	-	It has the purpose of hosting the good experiences achieved in the Galapagos Islands and replicating them when possible.

4.2. Results.

The results are presented considering the technical and socioeconomic viability aspects of the structured electricity system to 2050. The viability is marked to satisfy the demand over time, this implies not drastically reducing polluting energies if an or more renewable energy sources to replace it. Commonly, in the different systems where EnergyPLAN intervenes, it is considered constant or a lower rate of hydroelectric production as recommended by Dominković Dominik Franjo in reference [150] in order not to depend directly on this historically exploited source and rather to diversify the electrical system. In the case of the Galapagos Islands, specifically, none of the renewable energy contributions tend to remain constant or with a downward trend; moreover, hydroelectricity per reservoir is not present as there are no large rivers, only the small hydro will be useful in a way distributed without becoming of direct influence. Those that are going to play a leading role are solar PV with 30MW and wind power with 24MW. Also within the energy mix, biomass with 6MW, geothermal with 4MW, wave with 3MW, small hydro with 3MW, and others that could be included with 4MW as shown in Table 5 will be in a smaller proportion but not negligible. 2020 has an installed power of 35.18MW and by 2050 with 74MW. The plotted scenario is considered realistic recommended. In reality, there are resources such as wind and solar radiation that would give rise to a more aggressive exploitation, however it is important to indicate that the population growth in the islands is regulated according to current legislation and therefore the levels of exploitation Renewable energy should also be a matter of discussion and create ordinances that allow regulating the implementation of power plants and micro-power plants when the rates of access to electricity are close to covering 100% of the inhabitants. Several countries also contemplate plans or programs for the disassembly and recycling of equipment and devices, including solar panels, wind turbines, batteries, etc. and to take care of the environment. In Fig 7 it could be seen that through the chain of volcanoes it can be used to generate geothermal energy on a much more interesting scale than that shown in the final scenario. However, in this scenario, a level of exploitation that does not exceed 4% is considered. See Fig. 10 and Table 4.

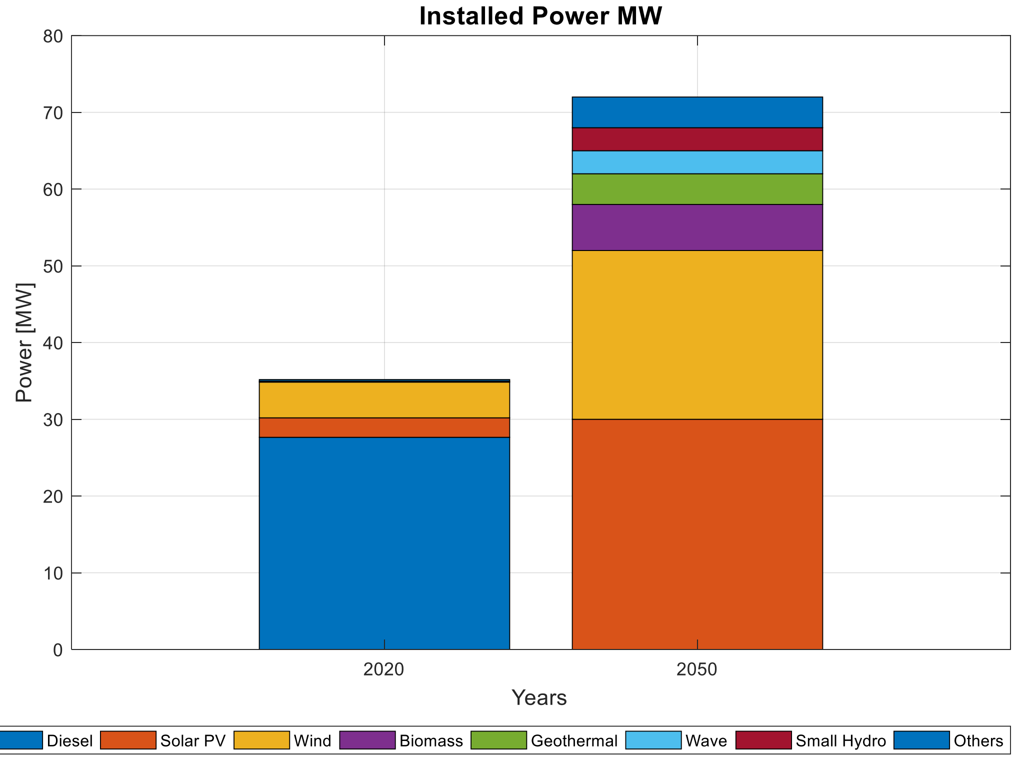


Fig. 10. Installed power per source in the 2020-2050 scenario in Galapagos Islands

Table 4. Installed Power 2020 to 2050

Source	2020	2050
Diesel	27.65	0
Solar PV	2.54	30
Wind	4.65	24
Biomass	0.138	6
Geothermal	0	4
Wave	0	3
Small Hydro	0	3
Others	0.2	4

In Fig 11 and Table 5, it is possible to identify the primary power supply in the base year and the 2050 horizon. In 2050, a supply completely integrated by renewable sources is achieved, based mainly on solar photovoltaic and wind power. There are small contributions from other renewable energies that make the global system more integral.

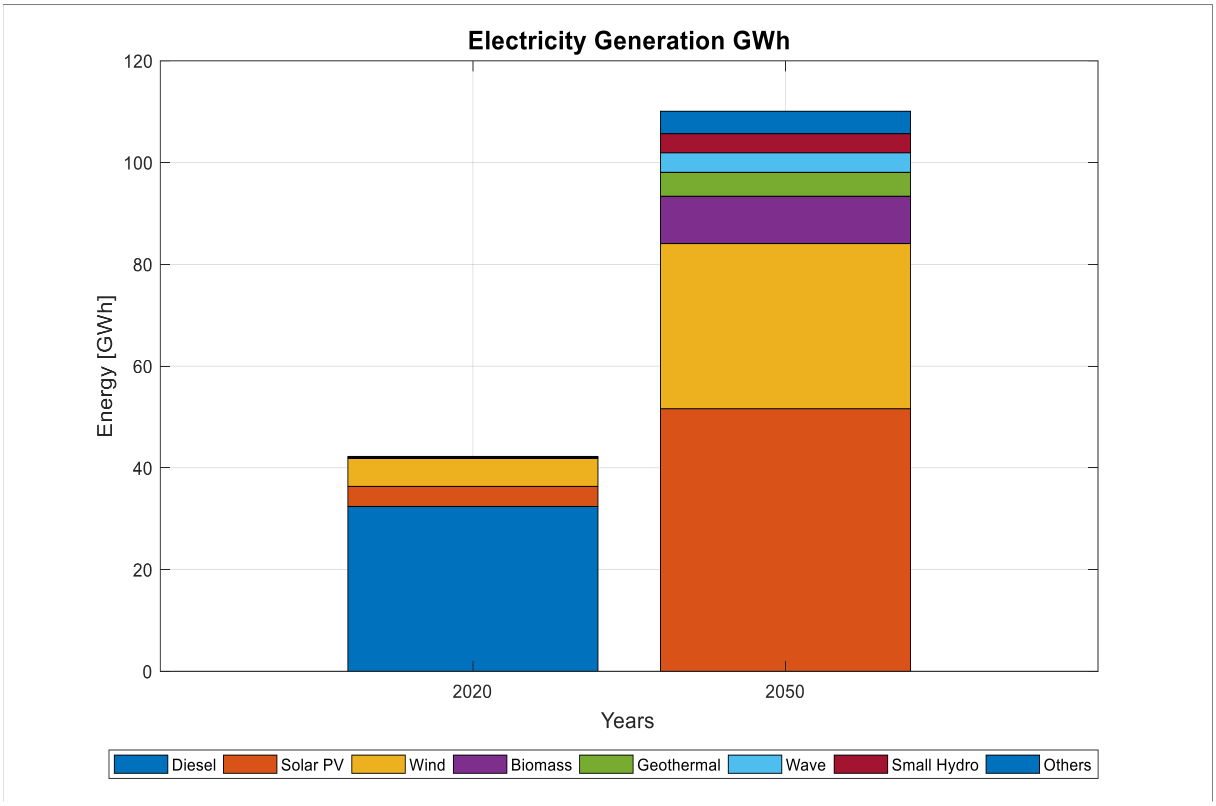


Fig. 11. Primary energy in 2020 and 2050 in the Galapagos Island

Table 5. Base scenario and scenario to 2050 100% content with renewable energy

Source	2020(GWh)	2050(GWh)
Diesel	32.4	0
Solar PV	4	51.6
Wind	5.42	32.5
Biomass	0.2	9.3
Geothermal	0	4.7
Wave	0	3.8
Small Hydro	0	3.8
Others	0.25	4.4

In Fig 12 the contribution percentages for each renewable energy source are presented as of 2050.

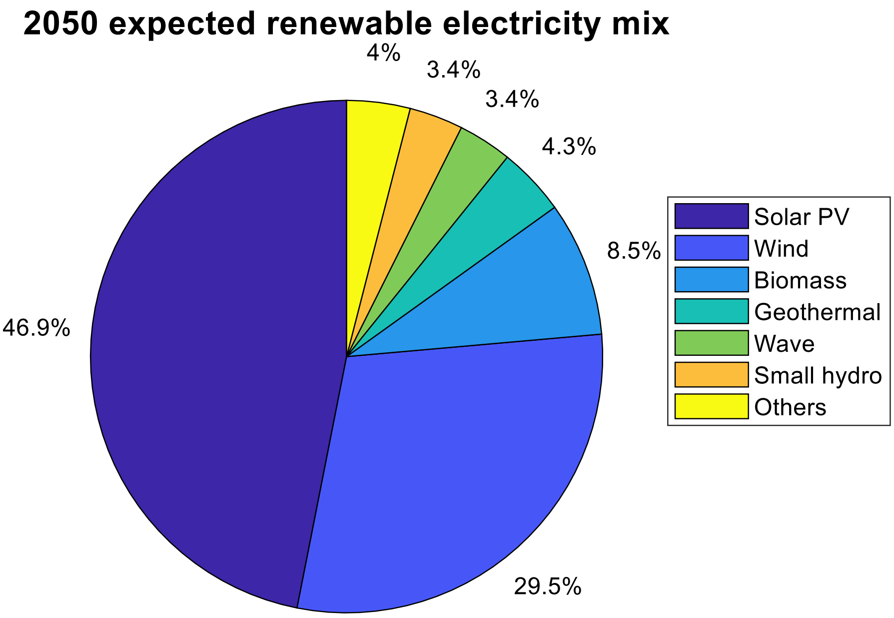


Fig. 12. Contribution percentages by renewable energy source by 2050 [GWh]

4.3. Socioeconomic Analysis

One of the problems that Ecuador permanently faces is related to the issue of subsidies. Various social groups, including transport, an indigenous group, have taken the issue of subsidies as a flag of demand to the governments of the moment before the reduction of the quality of life. The subsidies in continental Ecuador and Insular Ecuador (Galapagos) are not recent, they date from 1974 as part of the state policy as a compensation to energy for the exploitation of oil in various sectors, especially in the Amazon. At that time the international price of oil was very high and the compensations became an important incentive. In subsequent years, especially after 1995, prices tended to fall, which prevented the state from covering the subsidies, while the unions began to protest one or another measure and on many occasions the streets were the scene of protests. The issue of subsidies has been a situation that has generated over time a series of economic problems. In principle, the subsidies were focused on requirements of military transport and later it became generalized to all transportation under pressure from different social groups. This not only reached the level of transportation for oil derivatives, but different groups demanded the application of subsidies to liquefied petroleum gas (LPG) which governments gave in to avoid disturbances or overthrows, in many cases this issue of subsidies have been misused by figures with political interests [153]. Since the promulgated Constitution of Montecristi in 2008 in Ecuador, a break is promoted in the socioeconomic policies where a change in the energy matrix is promoted, especially where renewable energies are present. A firm government of President Rafael Correa was not intimidated by blackmail or impositions of the power groups, many called it an arrogant government [154]. However, in its period 2007-2018 there was no chaos in the streets, the economy re-emerged, the subsidies unfortunately remained, however it can be rescued that a policy emerged that encouraged the use of clean energy. Subsequently, due to the issue of subsidies, former President Lenin Moreno had to face a massive march that reminded us of the 1990s and early 2000s and had to annul Decree 883 on October 13, 2019, which eliminated the fuel subsidy [155]. In relation to the last government of President Guillermo Lazo, since his inauguration on May 24, 2021 and in a few months he already began facing a first march in protest of the cuts to fuel subsidies [156].
In summary, each government in Ecuador had to face the rejection of the elimination of fuel subsidies, some rulers have been more strategic than others and have known how to disperse protests or reach agreements to avoid risking the stability of the country, however the problem remains.

The way to avoid chaos in the streets and especially economic problems, is precisely that the energy transition of Ecuador that includes the Galapagos Archipelago, is in a very orderly way, with adequate investments, avoiding subsidies and not paying tribute to these decisions that then they get out of control. Advantageously, there is the potential for exploitation such as the wind and the sun, among others that are in very good proportions. Actually the Archipelago is very privileged, in fact, in all of Ecuador. It is precisely in this same section that the scenarios are outlined to make these implementations feasible. As has been demonstrated, the use of polluting technologies has brought serious problems to the country as a whole, not only environmental problems, but also social and economic problems. From this analysis, the need to give the Galapagos Archipelago a marked development path in renewable energies, which firmly contributes to the economic development of the islands, is much more established. The elimination of the fuel subsidy looks very difficult for each of the coming governments. The closest thing is to increase high levels of renewables and create aggressive policies that encourage demand to use systems powered by electricity. Savings can be obtained in the fiscal box around 2000 million dollars annually and that would very well serve to increase sustainable projects in different sectors of the Galapagos Archipelago and other Ecuadorian provinces.

According to data published by the Central Bank of Ecuador [157], in the period 2007 to 2016 the state has spent about 22 billion USD on fossil fuel subsidies. The most subsidized fuel is diesel, second is extra gasoline, then LPG with premium gasoline [19]. Meanwhile, opting for 100% renewable electric power systems can be obtained, for example, in the residential sector, rates equal to or lower than $ 0.10 per kWh [34].

After having the technical analyzes regarding the production levels by source, we continue with the economic analysis that is an essential point and provide options for financing the energy transition in the Galapagos Islands. In this study, three scenarios are analyzed as indicated in Table 6: The first scenario consists of a conservative one (S1), the second corresponds to the expected scenario (S2) and finally a third corresponding to the optimistic one (S3). The parameter that will vary between scenarios and that influences notoriously is the one related to costs, it is here that options are provided for an effective transition to 2050. The technologies involved would be between 150 and 450 million dollars. These are considerable values but given the experience of the implemented projects, it is possible to make agreements between different public and private institutions and make the energy transition a reality.

Table 6. Specific economic conditions in the structuring of scenarios with a term of 2050

Denomination	**Scenarios**		
	S1	**S2**	**S3**
Percentage growth in net electricity demand until 2050	45	35	17
Total costs to 2050 in millions of dollars	150	300	450
Average percentage of growth of electricity for non-public service until 2050	15	20	25
Technical losses of electrical energy in the transmission and distribution system by 2050 (12.39% in 2019) (%)	12	11	10
Growth in penetration of electric vehicles by 2050 (%)	30	50	80
Change of LPG for electric service to heat water in the residential sector (%)	20	40	60
Acquisition of electric stoves (%).	25	50	75

In Fig. 13, the curves are presented according to the proposed scenarios, the variability between each of them and the forecast of the final electricity production cost can be appreciated. The impact according to the required costs S3 are higher as it is an optimistic model and requires greater economic efforts. The curves show that the less investment the final electricity production cost is higher in the first 15 years, that is until 2035. All the curves S1, S2 and S3 tend to flatten in the last 15 years prior to 2050 (14.03 cents USD*kW/h). It is important to indicate that in none of the scenarios are cross subsidies, tax contributions, royalties, etc. considered. It is assumed that the technologies that are acquired will be completely new and under purchase orders. In reality, this reality may differ since technologies such as donations from friendly countries, contributions from NGOs, among others, can be acquired, which could make the transition process cheaper that would ultimately benefit the Galapagos Archipelago and its inhabitants.

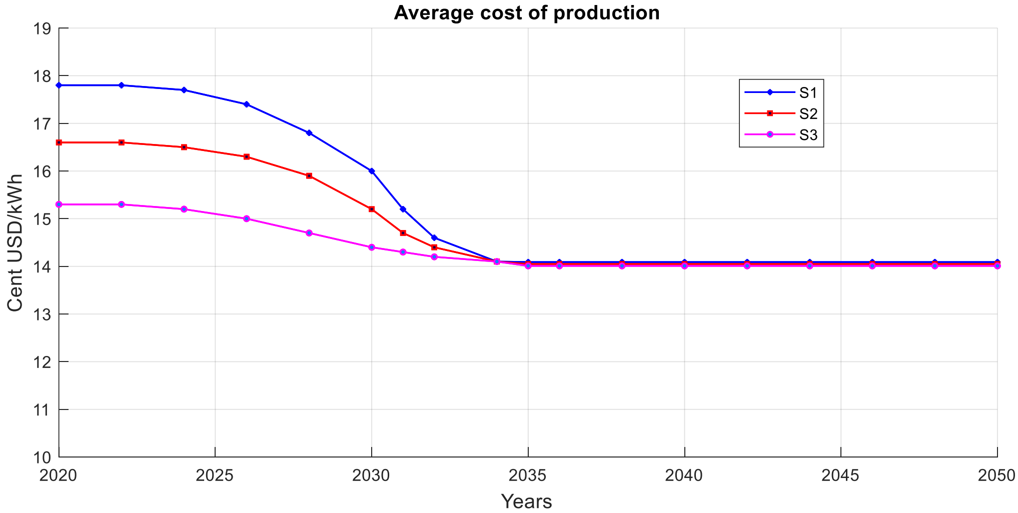


Fig. 13. Production cost scenarios.

5. Analysis and discusion

In relation to the results obtained when projecting scenarios S1, S2 and S3, it is possible to make investments for the decarbonization of the islands. It is the responsibility of the Ecuadorian state to meet these social demands. Likewise, the decentralized autonomous governments and the Galapagos Government Council (GGC) need to provide part of the economic resources in their management, which without being sufficient can become an important contribution. Several NGOs, support institutions for the care of the environment, among others, have also shown their altruistic interest to contribute economically, in fact Ecuador has on countless occasions been benefited with resources for social purposes. It is fair that this sensitive Natural Heritage, unique on the planet, be protected and developed, in accordance with what is stated in the 2008 constitution in article 71 in which nature is also endowed with rights and the regeneration of its vital cycles is required. In the same way, in the National Plan All a Life that has been in force since 2017 in objective 5: Promote the productivity and competitiveness for growth economic sustainable in a way solidarity and redistributive has been declared the goal for 2021 is to Increase from 68.8% to 90% the electricity generation to through renewable energy sources, something that has not been covered by changes of government and the health emergency due to COVID 19 but without a doubt must be covered in coming years.

Although the last governments have been of different tendencies, all have considered that renewable energies and the protection of the environment is a priority. In this regard, the Galapagos Islands, having a special regime, has been a priority objective until today, the projects implemented so far are evident. Without a doubt this is a beginning, there is an arduous work that is being carried out to decarbonise the islands.
The proposed energy transition will be determined by the modernization of the electricity system in the Galapagos Islands, this necessarily implies the allocation of economic resources, something that at first can give rise to many questions. However, the archipelago as a whole is entering a new framework of opportunities. Several islands are already in this line, the case of the Canary Islands, Azores, Cape Verde and they are showing that it is possible to carry out an energy transition. A decisive change with clear policies encourages development, but above all it is necessary to act in time after properly planning a roadmap before forcingly reacting on the fly. It is important to have an energy reserve system, considered on the continental equator as a rolling reserve. In the case of Galapagos, 7% is considered, that is, 7.7GWh of storage of the total 110.1GWh. It is also necessary to have electricity interconnections between the different islands, as is already available between Baltra and Santa Cruz to jointly supply energy to the islands, for eventual emergency situations, maintenance or even for commercial exchanges. When making these interconnections, it is important to avoid voltage and frequency variations in the networks so as not to affect the end user, which gives rise to new research in the future.

There is a legal system at the country level and for the Galapagos Islands, however, to make the decarbonization of the Islands more viable, new options for the commercialization of electric vehicles must be opened, and the commercialization of electric stoves must be retaken with greater interest, among other aspects. It is also important that new proposals arise from the National Assembly to speed up the energy transition in Galapagos with the use of renewable energy.

5. Conclusions.

This article presents in great detail the current state of the Galapagos Islands and the roadmap for decarbonization, aware that the economic aspect is the weakest point, but it offers the possible options for an orderly transformation of the electrical system. The way in which many countries are approaching the transition processes to migrate from an electricity production system based on a fossil fuel base to one that contains 100% renewable energy was highlighted in the literature. The proposed electrical system seeks to leave behind the dependence on fossil fuels in the Galapagos Islands and thus leave in history the negative impacts that affect the health of the people who live on the islands as well as their visitors. The affections are so great in several localities that the flora, fauna and air quality contain levels of lead and other chemical agents, a true decarbonization of the islands is required.

The projects implemented in the Galapagos Islands are just the beginning, in reality it is necessary that 100% of renewable energy be covered in the islands and for this there is a time horizon of 2050. The scenario that is being built for Galapagos is that of transform it into a development pole of Ecuador, serving as a reference for other regions. The extractable energy potential can be harnessed. The meteorological, technical, legal conditions, of territorial organization are favorable that will allow to fulfill this great purpose outlined. It is worth noting that the political outcomes are not included in this study, it is assumed that the constitutional, legal, regulatory provisions and plans of the region can be adequately channeled and would be covered over time. Seen from the social aspect, this transition process should not imply service suspensions that jeopardize the continuity and quality of service to the population. We can also conclude that future 100% renewable energy systems should contemplate a labor reintegration of workers who leave their jobs in the localities where energy is generated through polluting sources. Social responsibility is a task of the national government through the ministry of labor in coordination with local GADs. It is important to foresee that each measure that is available at the national or sectoral level must be socialized and the communication channels must be focused so that the actions that are undertaken keep the population well informed and that they are aware of the plans and projects that are drawn up.

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