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Smart strategies for the penetration of 100% renewable energy for the Ecuadorian Amazon Region by 2050

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ABSTRACT

This research presents a 100% renewable system configured based on its real potential and use of renewable energies for the Ecuadorian Amazon, considered one of the places with the greatest diversity of native plant species on the planet. The transition processes that are born from the central state seek to take a radical turn in the electricity sector but there is still no defined roadmap, this is where this research will allow it to be an important reference for its long-term transformation. The current system is based on fossil fuels and in this study an energy transition process is planned with the support of the EnergyPLAN tool that puts into practice the concept of intelligent energy, progressively and systematically achieving 100% renewable energy for 2050. Finally, after analyzing the results, it is concluded that the energy mix for 2050 can consider 36.47% hydro, 33.04% solar photovoltaic, 29.73% wind energy and other technologies to a lesser extent with 0.74%. Surpluses can be injected into the interconnection sites with Colombia and Peru, also achieving economic income to preserve and expand the infrastructure of the electricity sector. Decision makers can consider this study as a reference before committing economic resources and carrying out modern energy planning.

Keywords: Renewable energy; Energy transition; EnergyPLAN; Clean energy; Decarbonization; Smart energy system; crude oil underground.

Nomenclature

BAE	*Bioenergetic Atlas of Ecuador*
CCE	*Constitutional Court of Ecuador*
CCP	*Council for Citizen Participation*
COE	*Cost of Energy*
DNI	*Declaration of National Interest*
EAR	*Ecuadorian Amazon Region*
EU	*European Union*
ESR	Energy Supply Ratio
GL	*Good Living*
IEA	*International Energy Agency*
ITT	*Ishpingo-Tambococha-Tiputini*
MENRNR	*Ministry of Energy and Non-Renewable Natural Resources*
NIS	*National Interconnected System*
NPC	*Net Present Cost*
PV	*Photovoltaic*
TAPE	*Total Additional Projected Energy*
USDE	United States Department of Energy
YNP	*Yasuní National Park*

1. Introduction

Since the eighties of the last century, more oil has been consumed in the world than is discovered. The ratio is approximately four to one. Although the percentage that oil represents of the total primary energy consumption in the world has been falling in recent years (in 1973 it represented 46%, while now it is approximately 35%) [1], the demand for this energy resource has not stopped increasing (85 million barrels per day, currently, with a growth of 1% per year) [2]. The economic emergence of countries such as China or India has made oil an even more desirable source of energy worldwide, and the regions from which the known proven reserves are extracted squeeze their wells and seek new deposits to cushion the decline of their proven reserves current [3]. According to various international organizations such as the International Energy Agency (IEA) [4] or the United States Department of Energy (USDE) [5], currently proven world reserves are about 165,000 million tons. The most recent predictions reduce the expected production for the next few years, since at most it will reach 106 million barrels per day in 2030 [6]. According to these data, if humanity consumes oil at the same rate as it has done so far, oil reserves are expected to run out in 40-50 years [7].

In this context of growing demand for oil, we are very close to reaching, if we have not already surpassed it, as some experts and world institutions point out, the point at which maximum production is achieved and half of the initially existing oil is reached, known as peak oil or zenith oil. Most governments know that this peak oil exists, the global energy strategy has not been able to change the trend and provide real solutions applicable in the medium term [8]. Countries whose economy depends on a high percentage of oil imports will have to introduce large-scale structural changes in their energy system if they want to project their current level of growth into a more robust one in the long term: saving and efficiency, renewable energies and diversification are concepts that will characterize the future global energy system [9]. The search for and innovation in terms of new energy sources will be other factors that will contribute to drawing a new world energy scenario.

In Ecuador, it is a clear example of oil affection, specifically foreign multinationals exploited oil wells without severe plans to protect the ecosystem and the consequences were diverse, from the destruction of vegetation to the invasion of territories and homes of uncontacted indigenous peoples and nationalities [10]. The center of contention is an important area of the Yasuní National Park that contains the Ishpingo, Tambococha and Tiputini (ITT) oil reserves [11]. These fields contain approximately 850 million barrels of oil, which represents a fifth of Ecuador's total oil reserves [12].

These abuses allegedly occurred by the Chevron company and other pressures exerted to exploit the ITT were addressed by the then president of Ecuador Eco. Rafael Correa Delgado in 2007 [13]. After this precedent, a pioneering and innovative scheme was launched that offered to keep the oil underground in exchange for international monetary support in favor of the Amazon [14]. This idea was widely valued in Ecuador and in the international context as a model to stop oil exploitation, deforestation and protect the habitat of uncontacted native peoples.

The intense fight to win spaces to carry out oil exploitation in the Ecuadorian Amazon [15], there is no respite and the available sites are permanently stalked by international companies and they are after each government giving ways for their exploitation. For those who are unaware of the ITT area within the Yasuní, it is considered the most exhuberant territorial extension in biodiversity in the word. In this context, it is considered essential to carry out this research to provide a perspective of transformation of the Ecuadorian energy scheme and evaluate the impacts that oil can have. A change in the energy model in the Ecuadorian Amazon in the long term becomes extremely positive, 2050 is a good benchmark for progressively migrating from fossil fuels to clean energy [16]. Fig 1 shows the provinces that make up the Ecuadorian Amazon, the place of analysis of this study.

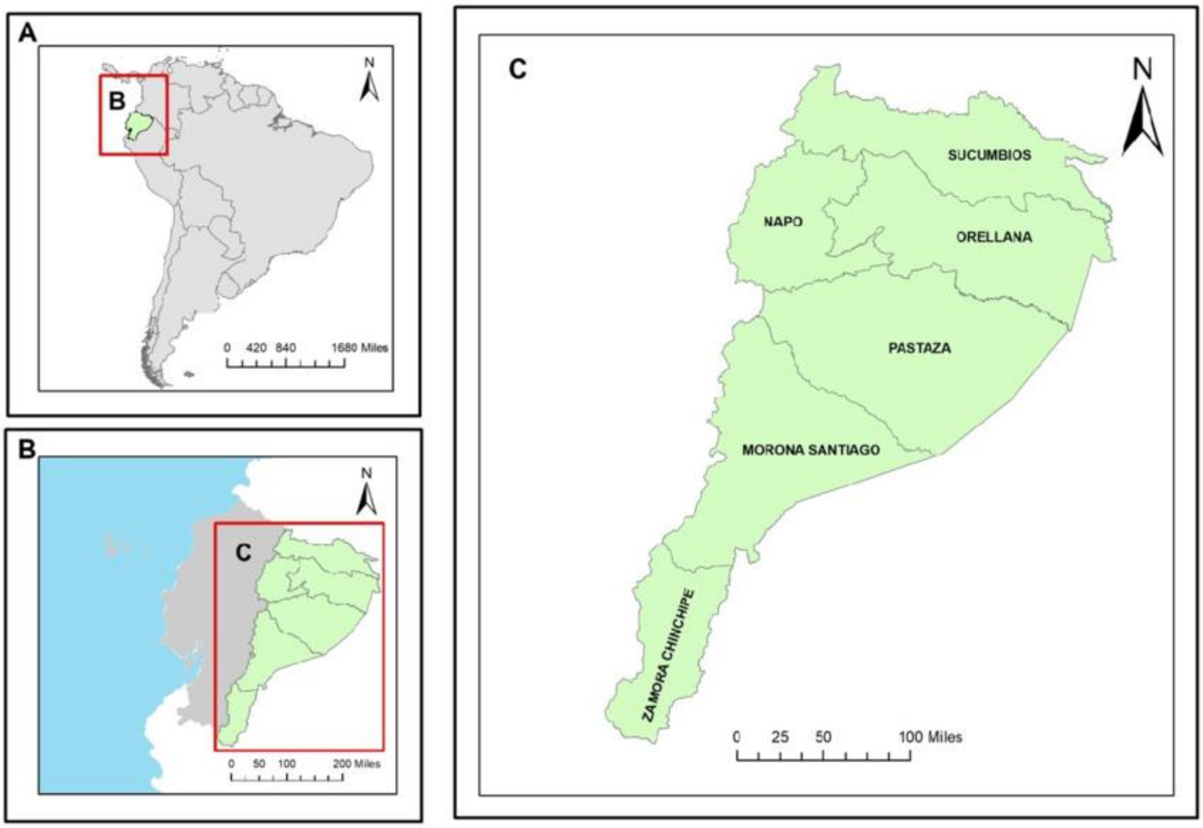


Fig. 1. Study area: (A) Geographical location of Ecuador; (B) Amazon region of Ecuador; (C) provinces belonging to the Amazon region [17].

1.1. Previous work

Several countries began to change their energy matrix based on new renewable energies and replace fossil fuels [18]. It has not been easy to start this energy transition, first it was necessary to identify the impact of climate change, some methodologies have been created to assess the resilience of people, places and systems to the threats of climate change, we have the case study in coastal communities in Bangladesh [19]. Ghaffar Ali et al. [20] presented a preliminary approach to estimate sectoral sources of carbon dioxide (CO_2) using actual energy use data from a mega city in a developing country. CO_2 sources were identified to have increased almost eight times in the city from 1971 to 2011. Xiaomei Yan et al. [21] presented a study in the city of Xiamen, China regarding the carbon footprints of residential buildings, the results showed that the average carbon footprints per household and per capita were 4.11 tCO_2/year and 1.4 tCO_2/year, respectively.

In the Ecuadorian Amazon, some studies have already been carried out that analyze hybrid systems, but they do not present a long-term focus on transforming an entire system currently based on oil and fossil fuels into one that is much more environmentally friendly, as in this case through renewable energies. P Benalcazar et al. [22] carried out optimal design and programming of multisource energy systems for the Galapagos Islands and the Ecuadorian Amazonian province of Morona Santiago. In his study, he applied a mathematical model to assess the technical and economic capacity of autonomous renewable energy systems in rural Ecuador. This study suggested that hybrid systems are solutions of the future to reduce the historical dependence on fossil fuels. In the case of Morona Santiago, an isolated photovoltaic/diesel/battery system was analyzed and an LCOE of $0.37/kWh was assessed. Jean-Michel Clairand et al. [23] made a Techno-economic evaluation of a microgrid based on renewable energies in remote zones of the Ecuadorian Amazon. The hybrid system was analyzed in HOMER where photovoltaic and hydraulic are included. The results defined that the most appropiate option from an economic point of view is to invest in a photovoltaic-hydraulic-diesel microgrid, which results in a Net Present Cost (NPC) of $2.33M, and its Cost of Energy (COE) of $0.194 for kWh. However, from the point of view of contributing to the environment, the system must be designed with a 100% renewable approach.

Other studies were pigeonholed into designing the specific equipment such as wind microturbines for the Ecuadorian Amazon, as is the case of the study carried out by D. Icaza et al. [24] which can also be useful for other sites such as the Galapagos Islands. These microturbines have a nominal power of 800W, they have a novel orientation once the direction of maximum wind flow is sensed. Sarah Feroh et al. [25] evaluated the sustainability of different programs that are carried out for electrification in isolated areas of Ecuador, with emphasis on programs aimed at indigenous communities in the Amazon region. Their study is complemented by semi-structured interviews with experts. There is a consensus that energy should be available to all, this explains in part the persistent efforts of each government through different ministries to define budgets for the use of renewable energy. However, by not having maintenance plans in the case of photovoltaic plants in certain isolated areas of the Amazon. It is important that in future projects funds are allocated for the effective operation of all energy systems, compromising the normal and continuous operation of photovoltaic systems.

Other studies were carried out in the Brazilian Amazon: CS Andrade et al. [26] criticize governance based on the predatory extraction of its natural resources. It refers to the fact that the populations are supplied with good quality electricity and that from renewable energies is a good option. In his work, he considers that the supply of electricity is considered as part of a plan to generate wealth and employment for the inhabitants of the region, preserving the environment. Similarly, Simone Athay et al. [27] carried out a mapping of potential hydroelectric plants for sustainability. T Bicalho [28] analyzes and proposes a land use change within the European Union (EU) sustainability criteria for biofuels using oil palm. Julio Martínez-Bolaños et al. [29] carried out an interesting study proposing topologies for microgrids in isolated, non-interconnected communities.

A. Moawad et al. [30] considers that there is a potential to shift the fuel consumption of light vehicles until 2045. Around this year a break in the use of fossil fuels and a special reorganization to accommodate 100% renewable systems by 2050 is considered. The goal specified with long-term planning is to innovate "quick-leap" technologies that allow American citizens greater flexibility in mobility and energy continuity, while reducing costs and protecting the environment. In that same time horizon, at 2045 A Delorme et al. [31] presented a cost-benefit analysis of advanced propulsion systems starting at 2010 as the base year and projecting to 2045. C Venereau et al. [32] analyzes other areas of interest such as the residential sector to 2045. Evaluates the impact of the heating network of residential buildings in relation to the electrical power requirements and requirements and resiliency of the California network for the years 2030 and 2045.

Several studies have shown that renewable energies are effective solutions for the supply of electricity in rural areas and for cities in constant growth. The alternative that best fits is to take advantage of the renewable energy potential of the same localities to provide sufficient electrical power to the demand. Depending on each area, the technologies will be coupled very well in isolation or forming hybrid systems according to proper planning [33]. Various studies warn of the need to carry out adequate planning to carry out the energy transition processes in the countries and face the climatic changes that are beginning to affect them [34]. For this, it has been considered to draw the roadmaps of the transition processes and in 2050 fuels will have been completely derailed and oil will have been left aside. The use of specialized software are very suitable tools to define the best options and define the most advisable development scenarios according to the performance of each country or region before carrying out efforts and investing economic resources [35]. The main technologies so far called to play a relevant role worldwide are solar photovoltaic, wind, biomass and hydraulic. Faced with the imminent need to modify the current energy markets, new renewable energy systems that allow large-scale use will hardly emerge from one moment to the next. It is highly proven that these renewable energies integrate well with each other, forming hybrid systems with connection to the grid or isolated. D Connolly et al. [36] presents a detailed compendium of the main computational tools that allow studying the aggregation of renewable energies in various energy markets. Dominkovic et al. in [37] presents a base scenario with a mixture of renewable and polluting energies and through the energyPLAN tool developed by the University of Aalborg [38] traces the optimal energy scenario for 2050 and replaces it with renewable energies in southeastern Europe.

Andrew Blakers et al. [39] features a 100% renewable energy mix for Australia. Along the same lines of long-term market planning with 100% renewable electrical systems, A García-Olivares et al. [40] presents an electrical system totally supplied by renewable energy destined for transport. JZ Thellufsen et al. [9] presents the general context of smart energy that can be an effective solution for different countries worldwide and achieve a 100% renewable energy supply that includes all sectors, residential, industrial, transport and heat.

1.2. Motivation

This research presents the ways to transform the electrical system of the Ecuadorian Amazon, considering a large part of the proposal of the Econ. Rafael Correa's 2007 decision to leave the oil on land according to the ITT project (acronyms taken from the name of the three exploration wells drilled in the area: Ishpingo-Tambococha-Tiputini) is one of the innovative initiatives to fight against global warming [11]. It is about not exploiting some 850 million barrels of oil located in the Yasuní Park, which is a nature reserve with one of the most important biodiversity in the world [41]. In addition to this initiative, it is necessary to consider approximately 5,000 million barrels of oil from the rest of the Amazon that may remain underground in perpetuity [42]. This proposal may generate alarm and surprise for the extractivist sectors and decision makers at the government level, they will surely consider that ceasing to exploit would be losses for the country, but if we consider how beneficial oil exploitation has been and how much it has contributed for the Amazon, this extractivist model has generated greater problems for the country than real benefits.
Figure 2 below shows the map of the unique historical project known as the Yasuní-ITT Initiative, which consists of giving up the extraction of nearly one billion barrels of oil in the ITT oil fields. a 6,100-square-mile Biosphere Reserve located in the Amazon Basin [43].

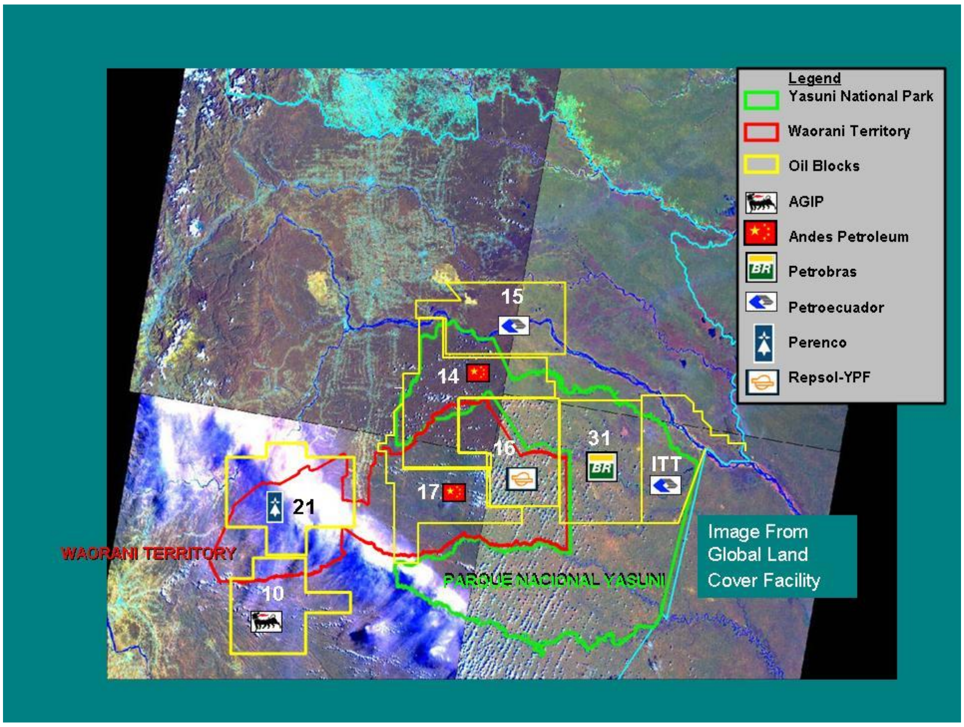


Fig. 2. ITT Block of Yasuní Park, located north of the intangible zone [44].

The scientific methodology is organized: In this first section, a review of the state of the art and the motivations involved in carrying out these studies is carried out. Section 2 presents the methodology and the use of EnergyPLAN as a useful tool for designing long-term scenarios. Section 3 analyzes the current situation in the Ecuadorian Amazon in the energy aspect. In section 4, the energy aspect is analyzed in great detail, defining the base year of analysis to design future scenarios with a view to 2050, diversifying the potential sources of 100% renewable energy. The results are analyzed and discussed in section 5. Finally, in section 6 the conclusions are presented.

2. Methodology

In this research, the roadmap for the transformation of the energy market of the Ecuadorian Amazon is presented with the purpose of progressively leaving crude oil on land, accepting the new ITT initiative and, on the other hand, increasing the levels of participation of renewable energies until reaching a

100% participation. Leaving the oil in the subsoil should be seriously considered at the Ecuadorian level and why not at the global level as an effective option to leave behind the contamination of the planet. Initiatives of this type were recognized and had broad support as specified in reference [45], including countries such as Iran, Spain, the United Arab Emirates, Germany and Turkey. The methodology assumes the existence of sufficient renewable energy resources for energy use and subsequently evaluates the techno-economic impacts. The three phases that involve the strategy analysis consist: Data entry of usable resources in the territory, adjustment or regulation that include legal locks to keep crude oil underground in perpetuity, and the results. Indirect aspects are also evaluated, such as technological renewal in energy matters, in the economic aspect they include services at affordable prices, ensuring flexibility from the technical and economic point of view. At the end, the technical and economic results are presented, contemplating the import/export relationship that guarantee future energy demand, which in this case is established as a reference to 2050.

2.1. The energy analysis tool

EnergyPLAN is an analysis and simulation tool for deterministic smart energy systems that depends on input data in the base scenario and obtain the long-term output results. The tool is specifically prepared to design long-term energy planning strategies as contribution links in broad regimes, whether national or regional, here lies the usefulness and support of researchers and makes the difference with other energy system design tools. As detailed in Ref. [46], EnergyPLAN is available as free software on its official website www.energyplan.eu. It is used by different researchers worldwide, within the analyzes they appear in [47] 35 places, between cities, countries and regions. Also identified within the case studies are 18 analysis technologies. The algorithm was developed at Aalborg University in Denmark, specifically by the Sustainable Energy Planning Research Group.

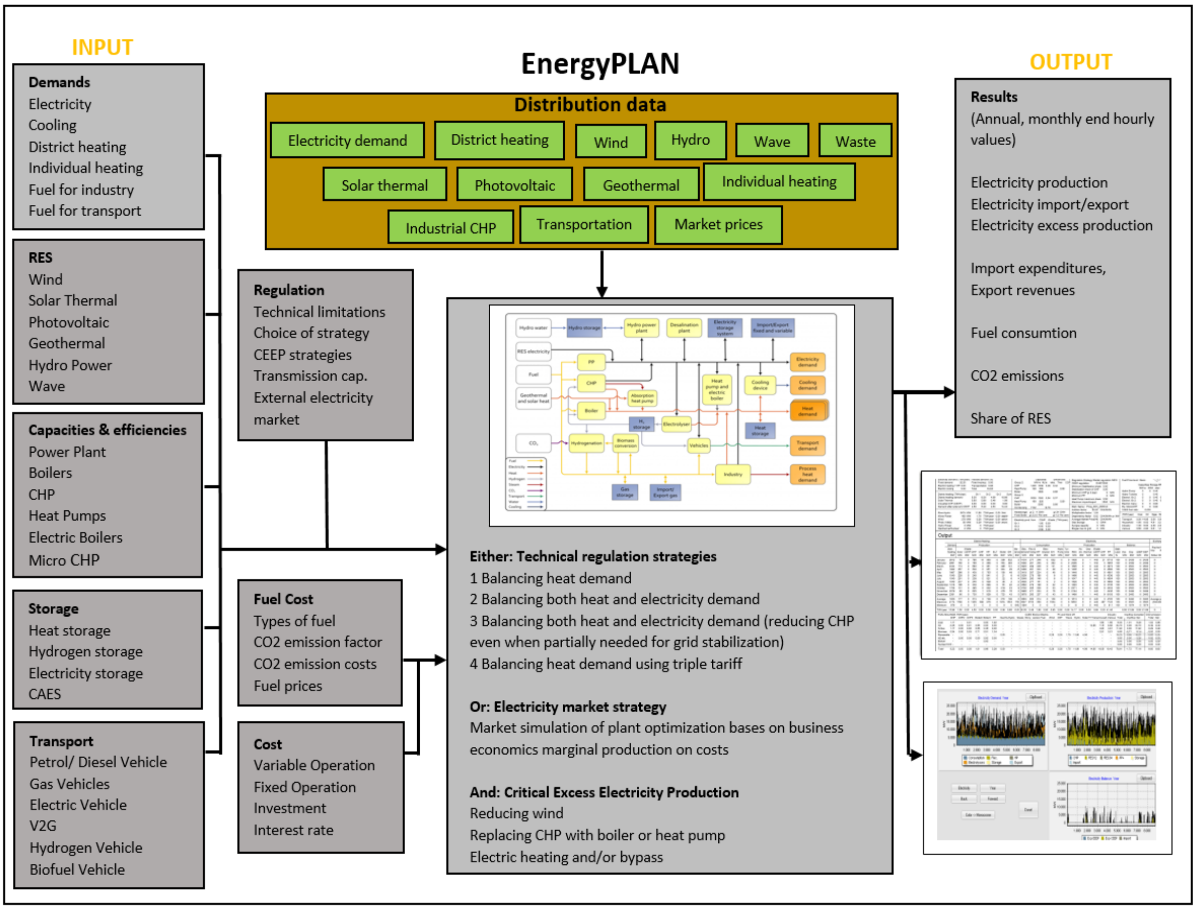


Fig. 3. EnergyPLAN V16.0 analysis model for intelligent energy planning [48].

3. Base situation and renewable energy potential in the Ecuadorian Amazon

It is estimated that currently 1.1 billion people still do not have access to electricity in the world [49]. In Ecuador, the electricity coverage index is 97.33% according to the report presented by [50], with the Ecuadorian Amazon Region (EAR) being the area with the lowest rate of electrification, ironically the area with the greatest oil exploitation in history [51]. As discussed in the literature, oil has not given substantial answers to the needs of the Amazon and the country, there is no explanation that in the twilight of an oil era something is achieved in favor of this Amazonian and Ecuadorian territory. The RAE, in addition to having the greatest diversity of indigenous nationalities of the country, is the scene of affectations by oil companies. In its territory there are emerging various proposals for social transformation that are articulated around Good Living (GL), terms conceived in the 2008 constitution and in force that put the human being ahead of capital [52], questioning the traditional approach to development.

3.1. Solar photovoltaic Power

Photovoltaic energy is very useful in places where there are no electricity supply networks or where it is sought to transform its energy matrix based on oil or fossil fuels into a 100% renewable one [53]. Although in this region there is a high degree of diffuse radiation, due to the presence of clouds with a high occurrence of precipitation or rain [54], it remains an important option in the region in the long-awaited energy transition that Ecuador is carrying out. in the global context [55]. Figure 4 shows that in the north of the Amazon there is a greater potential for the use of photovoltaic resources with an average solar irradiation of 4.6 kWh/m^2/day and in the south with 3.6 kWh/m^2/day.

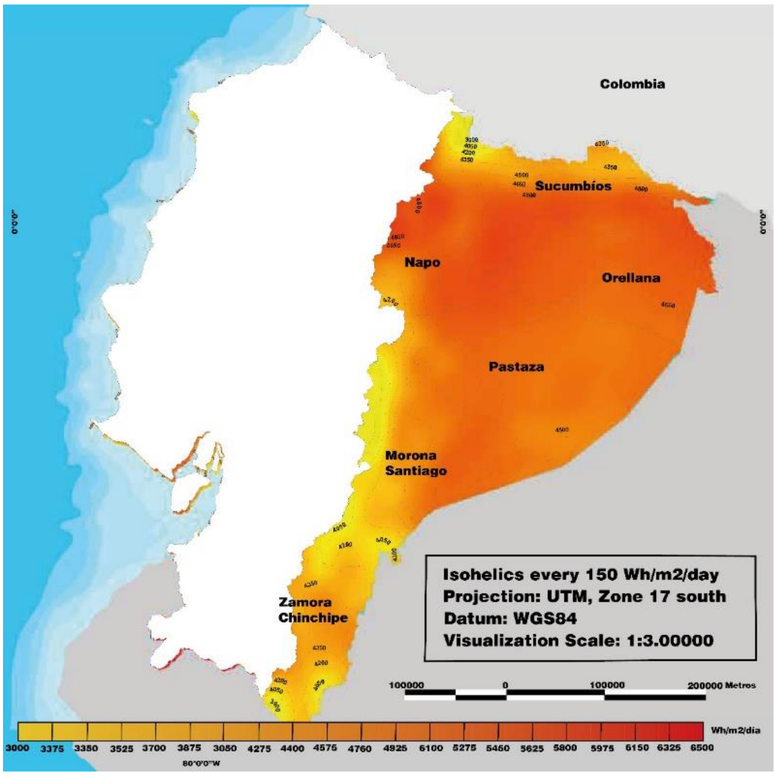


Fig. 4. Solar map of the Ecuadorian Amazon for purposes of electricity generation, adapted from [56].

3.2. Wind Power

In relation to wind energy, the opposite arises to solar energy. The southern zone of the Amazon has a greater wind potential than the northern zone with an average annual power density between 150 and 200 W/m^2, nor can it be ruled out that the northern zone has certain places with interesting potential in Orellana and Napo. South of the equator. Fig 5 shows the average annual power density of the Ecuadorian Amazon.

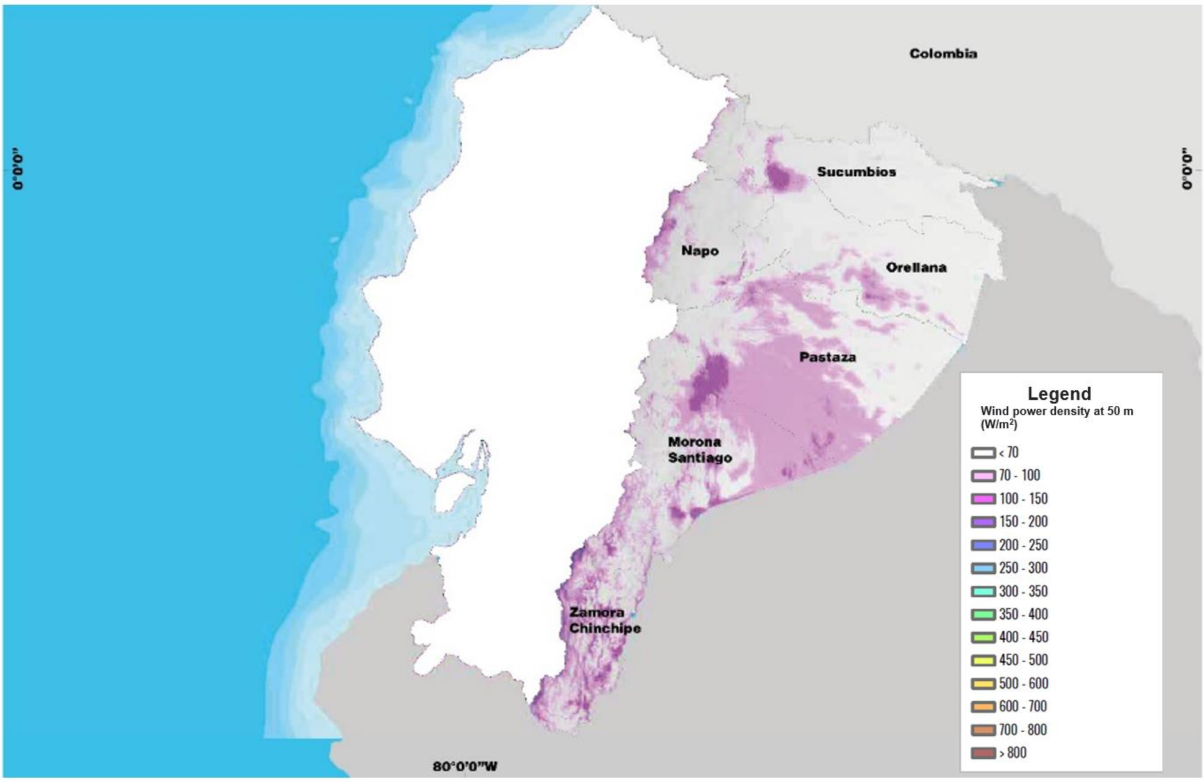


Fig. 5. Wind map Average annual power density of the Ecuadorian Amazon, adapted from [57]

3.3. Hydropower

Ecuador has high water availability estimated at a volume of water per capita of 20,700 m³/habitant/year [58]. This is 12 times higher than the world average (1,700 m³/habitant/year). However, this high water availability is not uniformly distributed, concentrating in the Amazon slope up to 81% of country availability [59]. The high annual rainfall ((>6,300mm in some foothill areas) and the presence of the Cordillera de the Andes, determine the high hydric and hydroelectric potential of this country area.

The main hydroelectric generation plants in the country are located on the Amazonian slope (Agoyán, Paute, Pisayambo, San Francisco, and Mazar) [60]. Similarly, in the Amazon region is the country's largest plant, Coca Codo Sinclair with 1500 MW. Other projects are in the study phase. More details can be seen in Fig 6.

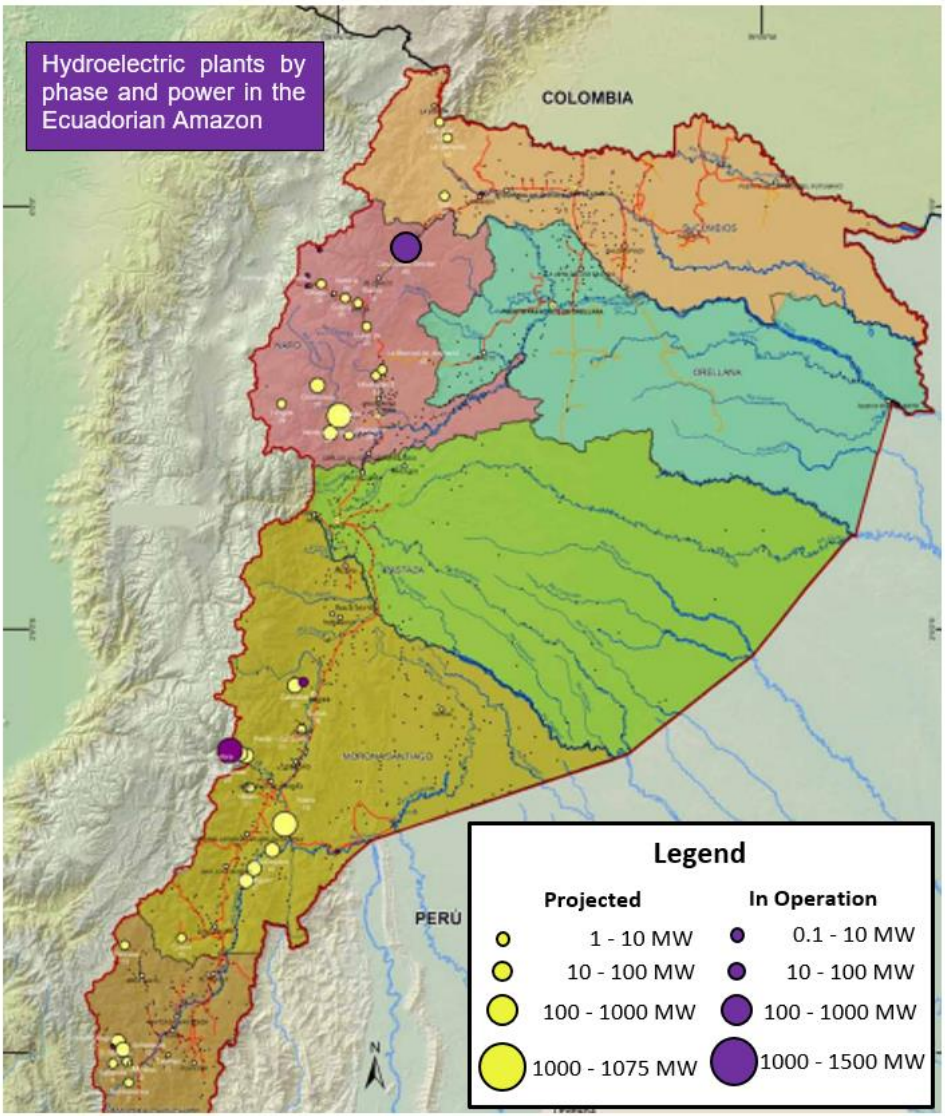
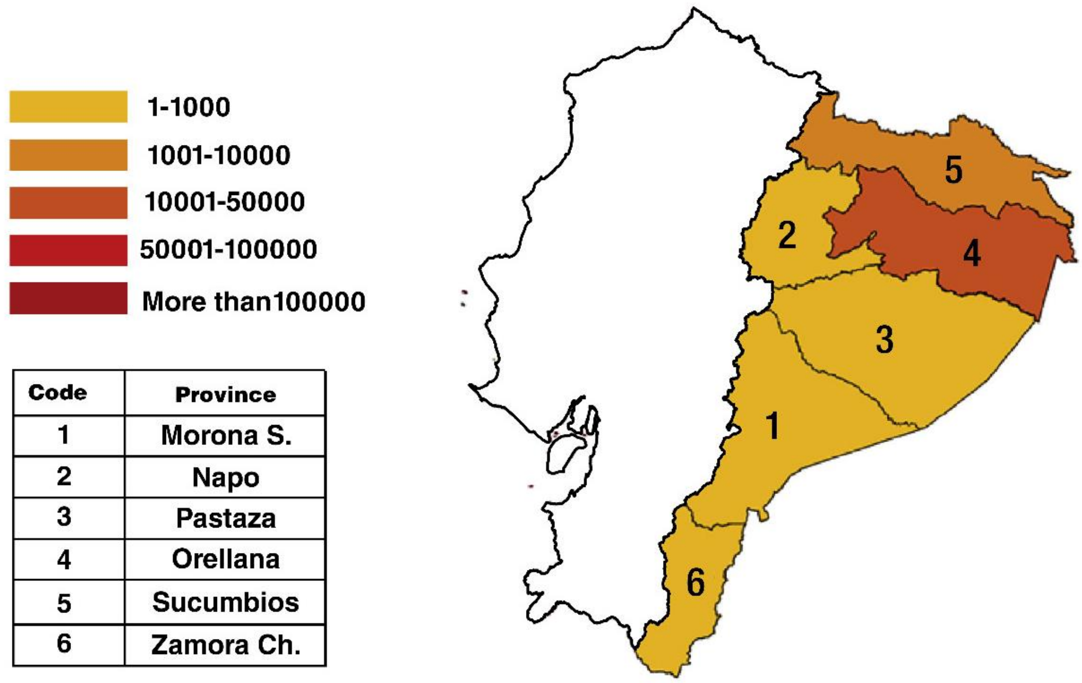


Fig. 6. Current water map and government projections for hydroelectric generation purposes, adapted from [61].

3.4. Biomass

Soil carbon inclusion also affects to the distribution of carbon stocks among types of land cover. Almost half of carbon in the biomass of Ecuador (46%) is stored in the evergreen forests of the lowlands of the Amazon, but this vegetation, which occupies 25% of the land area, contains only 27% of total storage national carbon footprint when taking into account soil carbon.

The main source of official information that was adopted in this research regarding the potentialities that can be obtained from biomass was through the of Bioenergetic Atlas of Ecuador (BAE) [62] in which it is presented in detail information related to the geolocation of the main areas and crops for raising cattle. In what corresponds to types of residual agricultural biomass, the main products were defined to determine the amount of waste biomass generated during its production cycle, mainly cocoa, rice, banana, coffee, sugar cane, corn, banana, oil palm, palm hearts and pineapple [63]. These crops make up 83% of the total national agricultural production in Ecuador and approximately 63% in the Amazon [64]. These crops correspond to approximately 47% of generation of residual biomass in eastern Ecuador by seasonal crops [65]. Fig 7 is presented below.



Code	Province
1	Morona S.
2	Napo
3	Pastaza
4	Orellana
5	Sucumbios
6	Zamora Ch.

Fig. 7. H_2 production by province in the Ecuadorian Amazon (ton/year) - Gasification, adapted from [63].

4. Long-Term system analysis

In this section, the recommendable feasible energy mix object of this research is structured. In the previous section, the renewable energy resources in the region were already evaluated and for this, it is supported by the EnergyPLAN design tool, recommended and used in doctoral theses [66] by researchers from different universities who make their long-term projections [67]. EnergyPLAN has high performance to model large systems under the concept of smart energy and to structure 100% renewable markets according to the reality of each region.

4.1. Simplified mathematical model with long-term expectation

4.1.1. Technological structure

EnergyPLAN defines a reference year, it is essential when using the software. The purpose is to evaluate the current impact and future prospects of renewable energies. The Renewable Factor (R_F) is evaluated using the general equation (1) and is expanded in detail in (2):

$$R_F = \left(1 - \frac{\sum P_{non-rene}}{\sum P_{rene}}\right) x100 \qquad (1)$$

$$R_F = \left(1 - \frac{\sum P_{oil} + \sum P_{coal} + \cdots \ldots \sum P_{others\ non-rene}}{\sum P_{PV} + \sum P_{wind} + \sum P_{hydro} + \cdots \ldots \sum P_{other\ rene}}\right) x100 \qquad (2)$$

Non-renewable energies are basically exploitable from oil and its derivatives, as well as coal and other non-renewable ones $\sum P_{oil} + \sum P_{coal} + \cdots \ldots \sum P_{others\ non-rene}$. Other smaller scale contaminant sources can also be evaluated.

On the other side are the renewable energy sources that are involved in the energy matrix of the region under study. Such as solar, hydraulic, wind, biomass, among others that are of renewable origin $\sum P_{PV} + \sum P_{wind} + \sum P_{biomass} + \cdots \ldots \sum P_{other\ renewables}$. In a system made up of 100% renewable energy, RF is equal to 1.

Considering the energy balance in the base year it can be quantified, from the base year the long-term scenarios transcend. Eq. (3) projects the future energy scenario:

$$TAPE = \sum P_{rene\_long-term} - \left(\sum P_{rene\_reference} - \sum P_{non-rene}\right) \quad (3)$$

TAPE is the Total Additional Projected Energy, $P_{rene\_long-term}$ is the total supplied power evaluated in the year 2050, $P_{rene\_reference}$ is the power balance in the base year as a reference resource that must be increased in the long term, $P_{non-rene}$is the generated power non-renewable, coming from polluting sources that must be replaced by renewable energy sources typically produced in the base year.
The Energy Supply Ratio (ESR) it is considered as the real and effective use that the renewable energies in the region satisfy the future demand for electricity in a period of time t1 to t2, as expressed in eq. (4).

$$ESR = \sum_{t1}^{t2} \frac{P_{rene-2050} - P_{DEMAND\_2050}}{P_{rene-2050}} \quad (4)$$

Where $P_{rene-2050}$: Is the total renewable power supplied in 2050, P_{DEMAND_2050} is the projected load demand in 2050.

When $P_{rene-2050} > P_{DEMAND\_2050}$: There will be a surplus of energy by 2050 in the region.

When $P_{rene-2050} < P_{DEMAND\_2050}$: There will be a shortage of energy by 2050 in the region.

When $P_{rene-2050} = P_{DEMAND\_2050}$: Balance point between future energy supply and demand.

4.1.2. Cost of energy (COE)

The COE is determined as the average cost per unit of electrical energy produced by a renewable hybrid system during the entire useful life of the system.
The COE is a well-known and important factor that makes it possible to clearly determine the viability and profitability of the entire production system in the long term, it is evaluated by eq (5):

$$COE = \frac{TNPC}{\sum_{H=1}^{H=8760} PL} \ x \ C_{RF} \quad (5)$$

Where;

TNPC is a total net current cost in $, PL is the hourly energy consumption in kWh.The C_{RF} is a ratio used to calculate the current estimate of economic benefits, that is, a progression of equivalent annual monetary flows. C_{RF} is the capital recovery factor. It is expressed by Eq. (6) [68]:

$$C_{RF} = \frac{\text{ɨ}(1+\text{ɨ})^{j}}{(1+\text{ɨ})^{j}-1} \quad (6)$$

j: Number of years.
ɨ: Real interest rate.

4.2. Reference framework 2020 and long-term projections 2050

The data that is considered for the base year is that provided until the end of 2020. In the reference, a high proportion of thermoelectricity is appreciated, meanwhile in renewable energies on a smaller scale despite the interesting potentials of generation that are available in the Ecuadorian Amazon as highlighted in the reference [22] and [61] especially for the hydroelectric, is detailed in Table 1 and Table 2. In the proposed roadmap to 2050, zero fossil fuels must be met according to the Paris summit [69] and all estimated energy supply will be 100% renewable. In this study, if a growth of hydroelectric energy is contemplated according to the projects outlined by Ecuador in different parts of the Amazon, its fulfillment is assumed by 2050.

Table 1. Installed Power in the Ecuadorian Amazon [70].

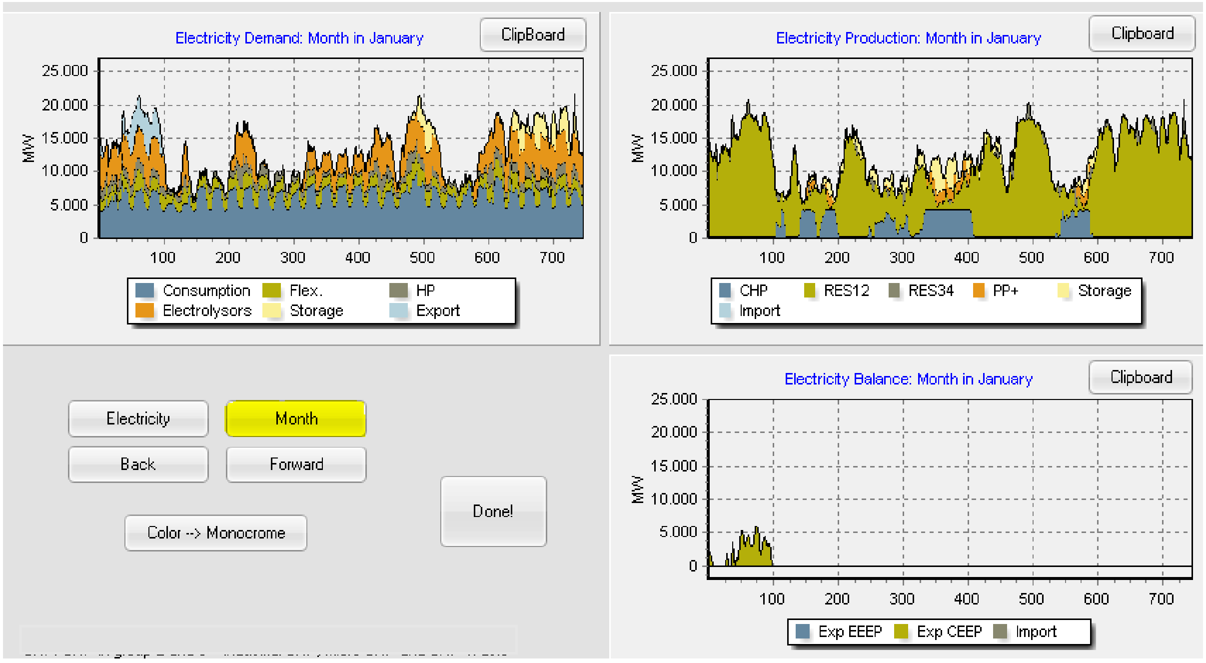
Province	Renewable Power			Non-Renewable Power		
	Number of Plants	Nominal Power (MW)	Effective Power (MW)	Number of plants	Nominal Power (MW)	Effective Power (MW)
Sucumbios	1	64.3	64.3	64	483.55	374.79
Napo	5	1557.5	1532.65	5	77.63	54.44
Orellana				88	783.18	604.19
Pastaza	1	0.2	0.2	3	61.1	50.97
Morona Santiago	4	138.38	137.89	1	4.5	4
Zamora Chinchipe	2	182.4	182.4			
TOTAL	**13**	**1942.78**	**1917.44**	**161**	**1409.96**	**1088.39**

Table 2. Installed Power of renewable energy [70].

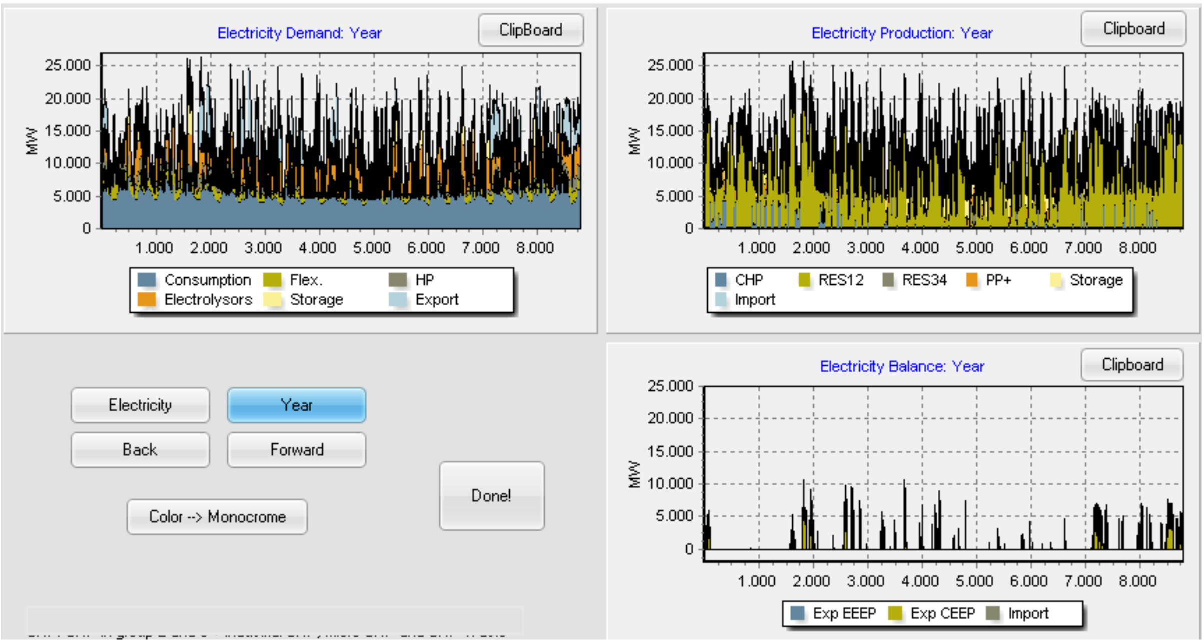
Province	Renewable Energy (MW)			
	Hydro	Solar PV	Wind	Others
Sucumbios	50	10		4.3
Napo	1550	3	4	0.5
Orellana				
Pastaza		0.2		
Morona Santiago	135	1	2	0.38
Zamora Chinchipe	180	0.7	1.2	0.5
TOTAL	1915	14.9	7.2	5.68

4.2.1. Scenario modeling and Case Study

Fig. 8a and Fig. 8b show the simulations in EnergyPLAN up to 2050, representing the typical accumulated monthly and annual behavior in hours of the electrical system at the level of energy demand and production. This system maintains the balance between generation and consumption, its surpluses can be transferred to other provinces through the Ecuadorian interconnected ring, it can also be exported to Colombia and Peru as the case may be.



(a)



(b)

Fig 8. (a) Typical profiles of demand, production and balance of typical monthly electricity projected to 2050. (b) Typical profiles of demand, production and balance of typical yearly electricity projected to 2050.

4.3. Results

The results are presented in 10-year scales from the base year defined in 2020 given the complete radiography of the electrical system related to the Ecuadorian Amazon region. Aspects of technical and economic feasibility are highlighted in the construction of scenarios period by period until 2050. The structure of EnergyPLAN defines as a priority meeting the electricity demand in each period and the renewable component is designed based on the energy potential available in the region. This does not imply drastically displacing polluting energies, but rather it is systematically required to replace renewables with polluting ones, since there is a social responsibility to protect, specifically jobs. In the particular case of the Ecuadorian Amazon, a greater contribution of hydroelectric energy is contemplated in 15% of the current 1915 MW that are already planned to be incorporated in the future. However, Dominković Dominik Franjo [71] declares to carry out a sensitivity analysis of hydroelectricity, from which it follows that it is better to diversify the sources of renewable generation and not only replace them with polluting sources. In the present case of analysis, higher penetration rates of feasible sources such as solar photovoltaic and wind power are included, which according to the base scenario are derisory and should have a greater incidence until 2050. In the case of the Amazon, none of the energy contributions renewable energy remains constant according to the base scenario, but polluting energies and those equivalent to oil extraction are progressively reduced until 2050. The renewable sources that are going to have the greatest penetration are solar PV with 1994.75MW and wind 1795.33MW. Also within the energy mix, biomass with 12.3MW, small hydro with 17.9MW, and others that would be included without difficulty also appear in the energy mix. By 2020 it has an installed power of 3352.74MW and by 2050 with 6037.33MW. In reality, there are sufficient resources such as wind and solar radiation that, without being of excellence, are not negligible, which would lead to more aggressive exploitation according to population growth. See Table 3 and Fig. 9.

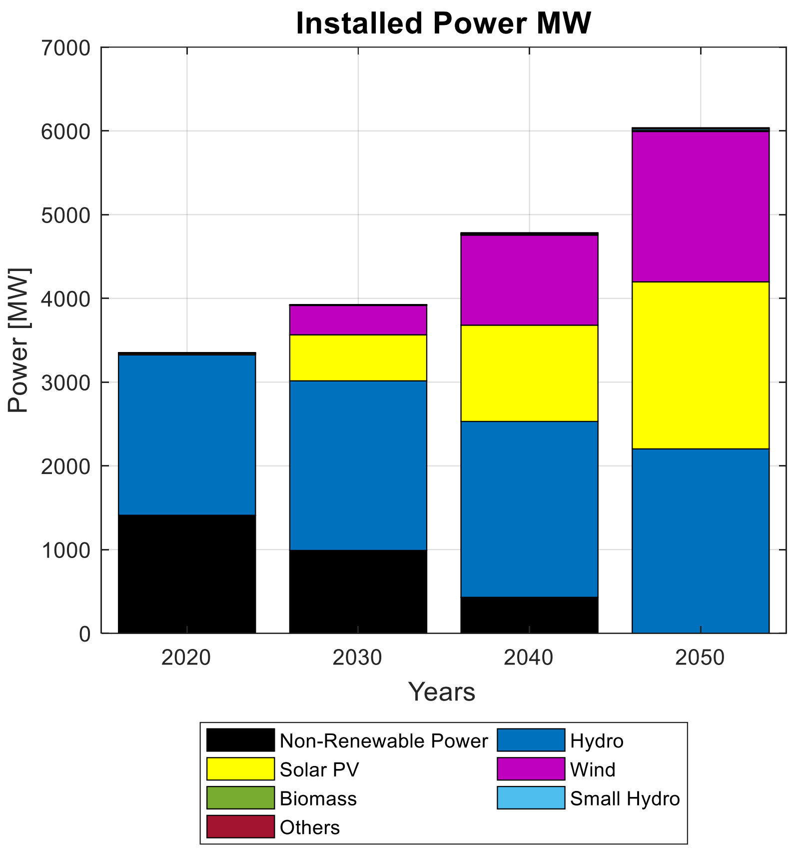


Fig 9. Installed power in the 2020 to 2050 scenarios in the Amazon Region

Table 3. Installed Power 2020 to 2050 in MW

Source	2020	2030	2040	2050
Non-Renewable Power	1409.96	990	430	0
Hydro	1915	2025	2100	2202.25
Solar PV	14.9	550	1150	1994.75
Wind	7.2	350	1075	1795.33
Biomass		4	8.5	12.3
Small Hydro		3	11.5	17.9
Others	5.68	4	9	14.8
TOTAL	**3352.74**	**3926**	**4784**	**6037.33**

In the different periods scaled with 10 years, the energy of polluting origin would be progressively reduced, while renewable energies would be on the rise. By 2050, the electricity supply will be completely integrated by renewable energy sources, with hydraulic energy continuing to be the most important, followed by solar photovoltaic and wind energy. Other small contributions are not neglected and integrate the energy mix for the Amazon. Table 4 and Fig. 10 detail the scenario until 2050.

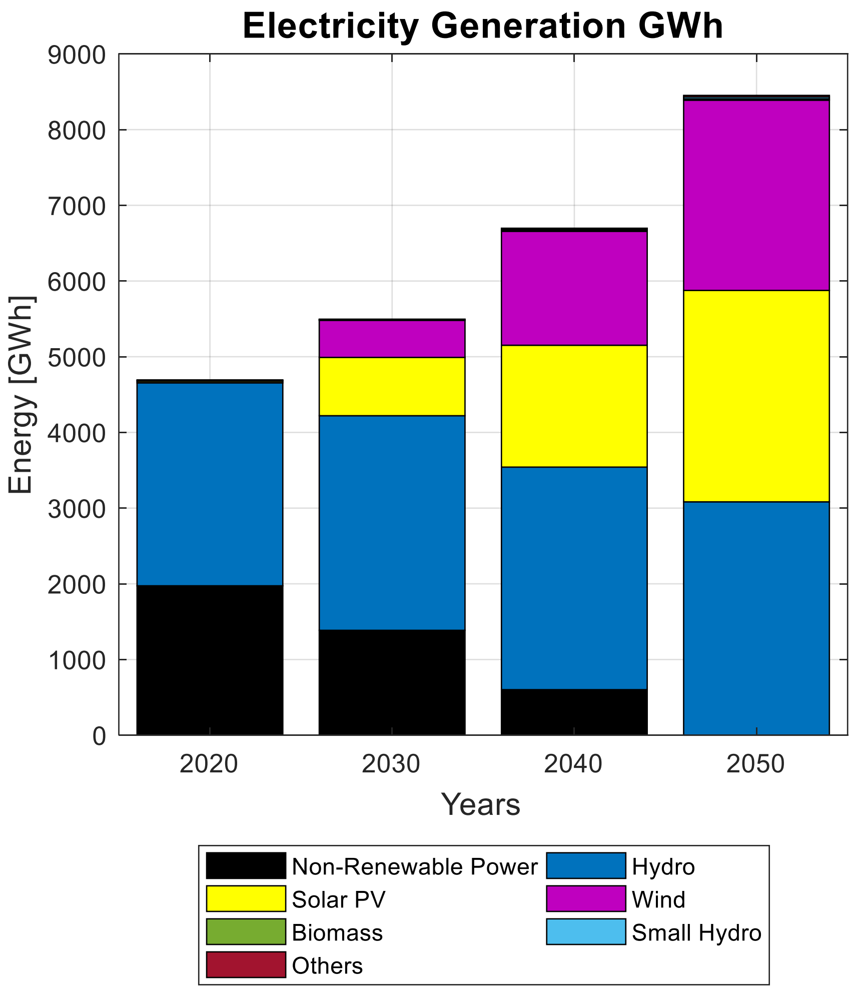


Fig 10. Energy supplied from 2020 to 2050 in the Amazon Region

Table 4. Projection to 2050 with 100% RE (GWh)

Source	2020	2030	2040	2050
Non-Renewable Power	1973.94	1386	602	0
Hydro	2681	2835	2940	3083.15
Solar PV	20.86	770	1610	2792.65
Wind	10.08	490	1505	2513.46
Biomass		5.6	11.9	17.22
Small Hydro		4.2	16.1	25.06
Others	7.95	5.6	12.6	20.72
TOTAL	**4693.84**	**5496.4**	**6697.6**	**8452.26**

Below, in Fig. 11, the contribution rates by renewable source to 2050 are shown.

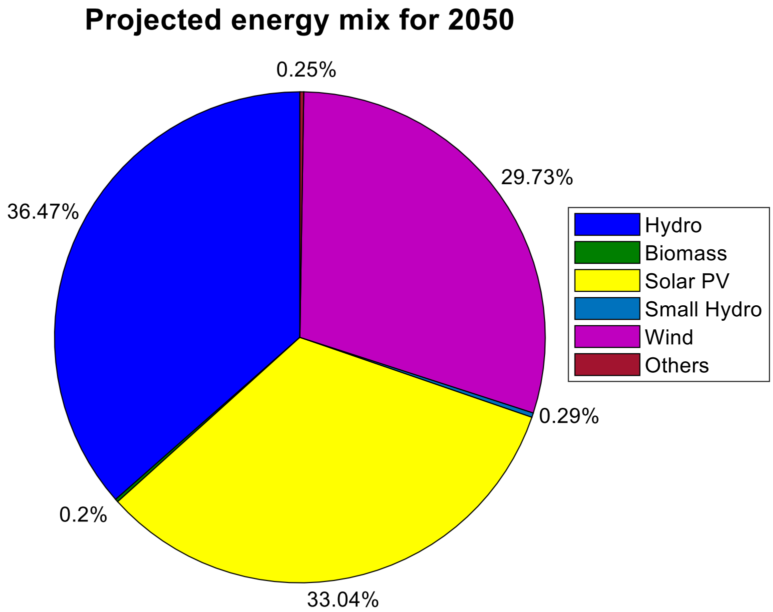


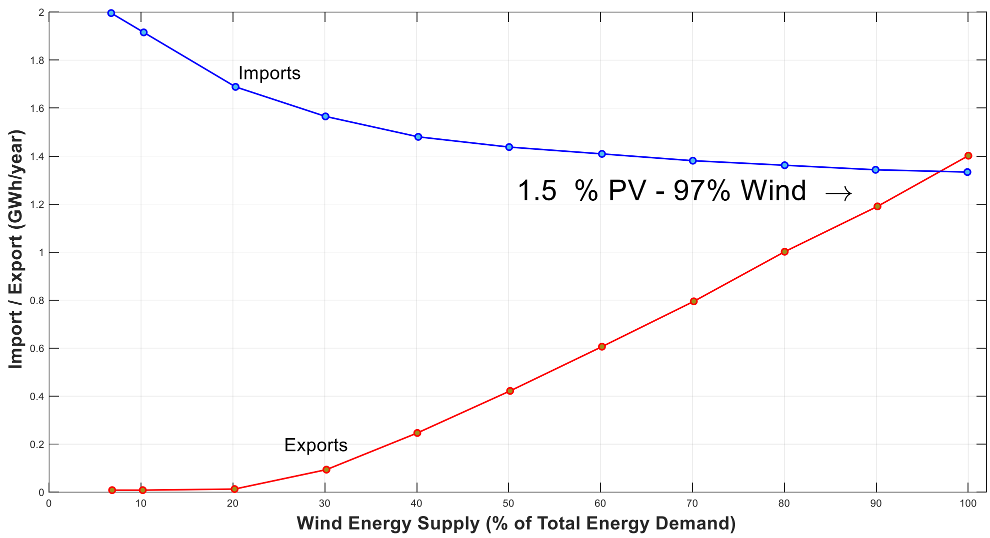
Fig. 11. Projected energy mix for 2050 in the Ecuadorian Amazon

4.4. Smart renewable energy strategies applied to the electricity market

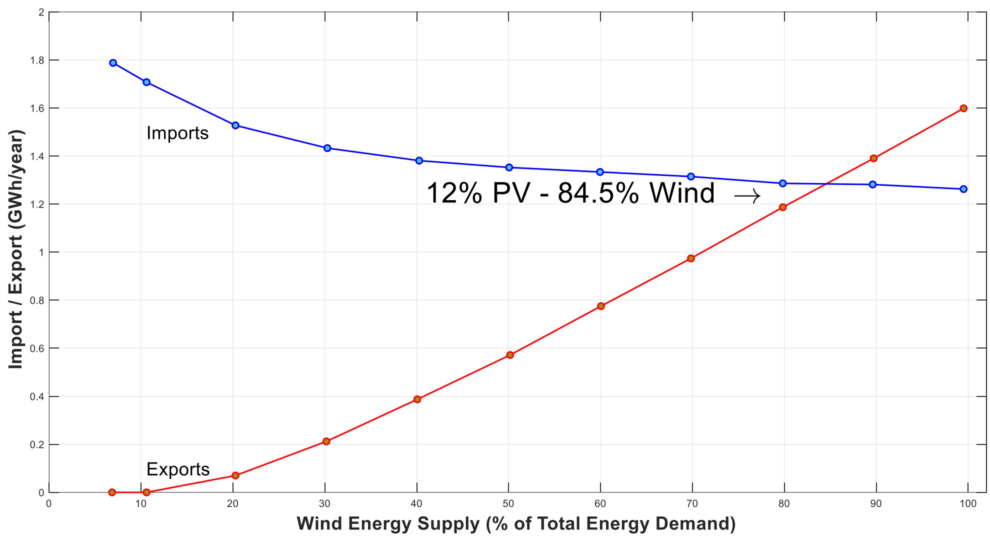
The long-term scenario was analyzed, assuming that the contribution of hydraulics remains regularly stable, as has been the case in recent years. The influence that solar photovoltaic and wind energy would have on the energy mix and its influence on imports and exports of electrical energy is analyzed, knowing that solar photovoltaic energy contributes with 33.04% and wind energy with 29.73%. Between the two contributions they add up to 62.77% of the total energy mix in the Amazon region.

These analyzes are recommended by Deminkovich [71] and Pedro Cabrera et al. [72] who states to study the sensitivity of at least one energy source for the final purposes in 100% renewable systems. The influence on the production of wind and photovoltaic solar energy is detailed in 11 scenarios.

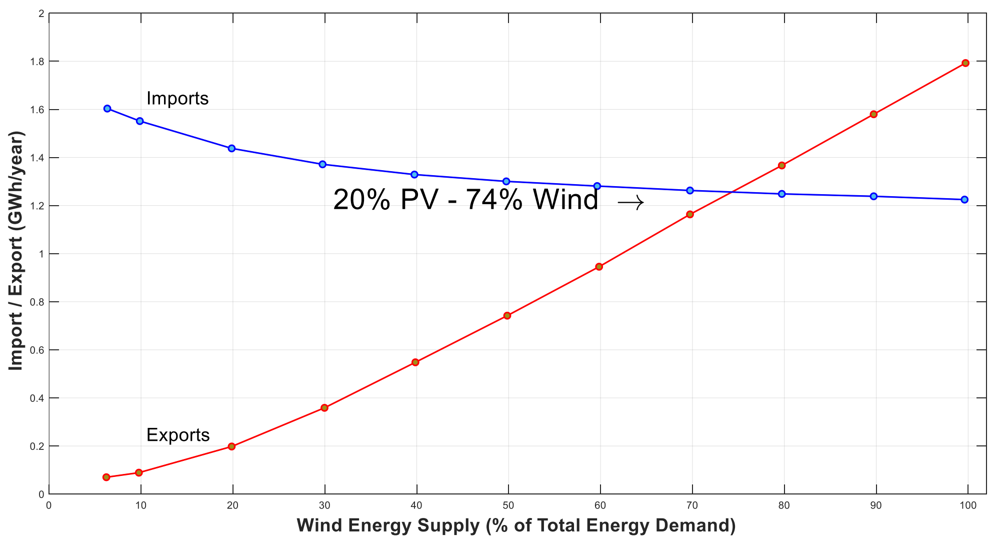
When analyzing the behavior scenarios for solar and wind energy, it starts with a low percentage of 1.5 solar energy that corresponds to 97% wind, as shown in Fig. 12a. In the same way, under this same procedure, the percentage of solar PV is progressively increased and the wind levels begin to decrease, as can be seen in Fig 12b to Fig 12k. In these graphs it has been detected that the minimum import/export point is 1.27GWh. It is identified as a particularity that at 90% increase in solar energy there is no longer an intersection point between import and export according to Fig 12j and Fig 12k.


Imports
Exports
1.5 % PV - 97% Wind →
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)

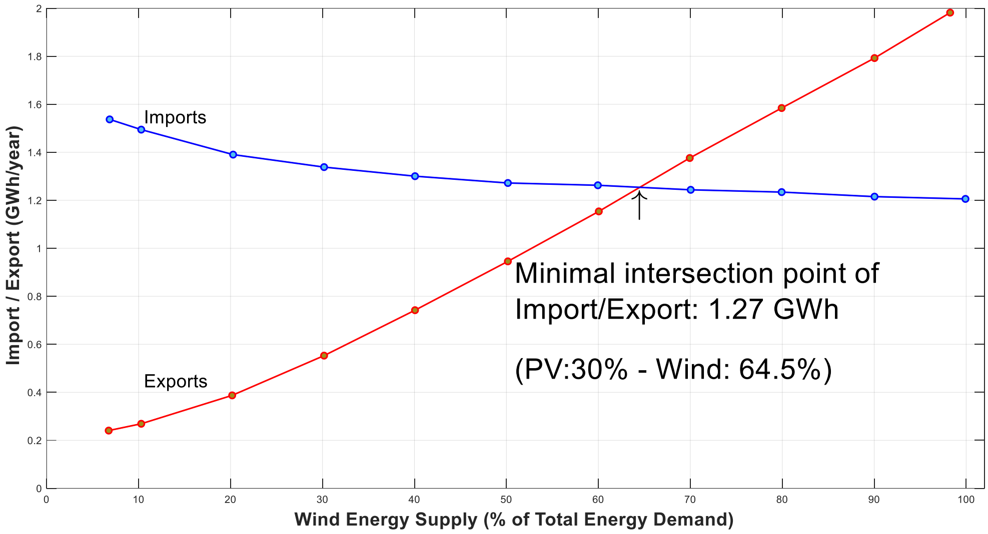
(a)


Imports
Exports
12% PV - 84.5% Wind →
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)

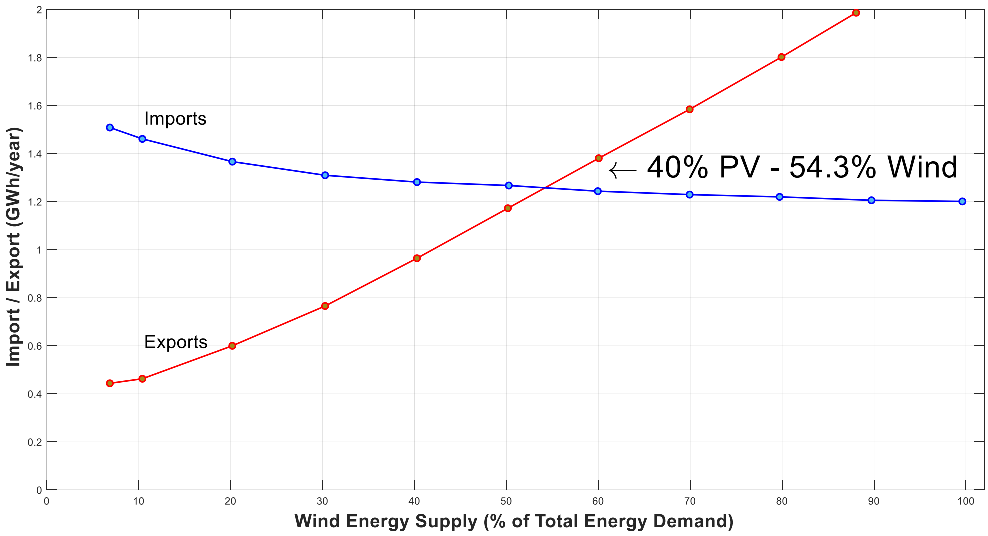
(b)


Imports
Exports
20% PV - 74% Wind →
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)

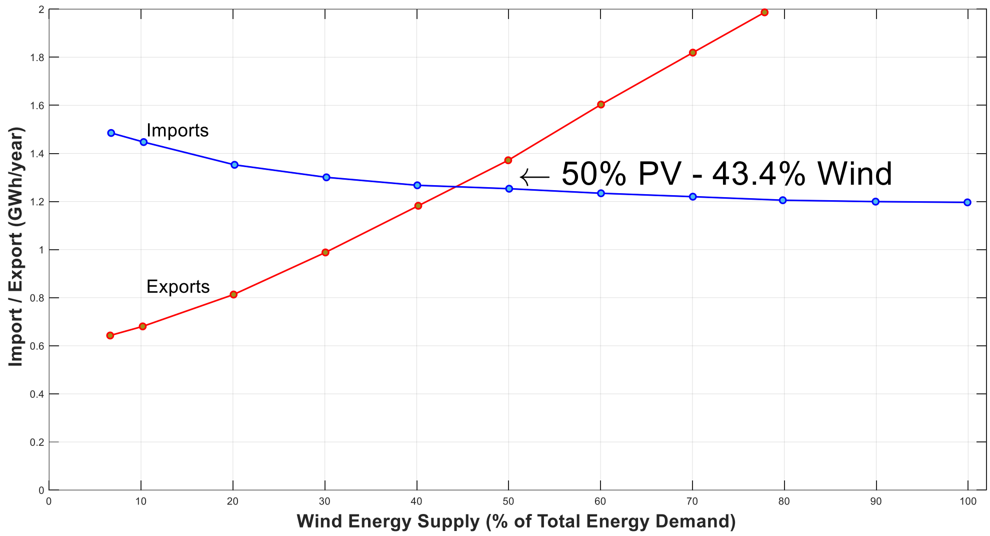
(c)


Imports
Exports
Minimal intersection point of
Import/Export: 1.27 GWh
(PV:30% - Wind: 64.5%)
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)

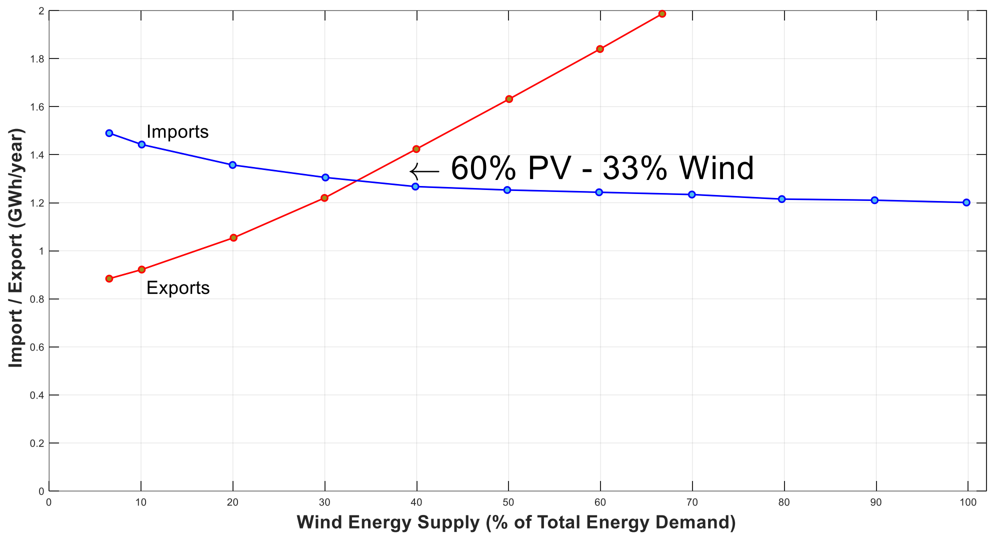
(d)


Imports
Exports
40% PV - 54.3% Wind
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)

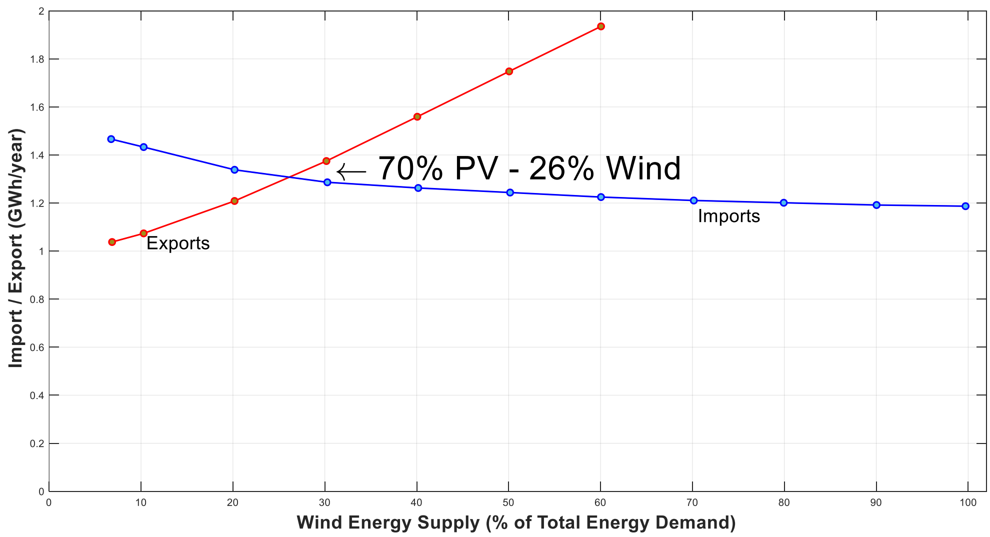
(e)


Imports
Exports
← 50% PV - 43.4% Wind
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
10
20
30
40
50
60
70
80
90
100

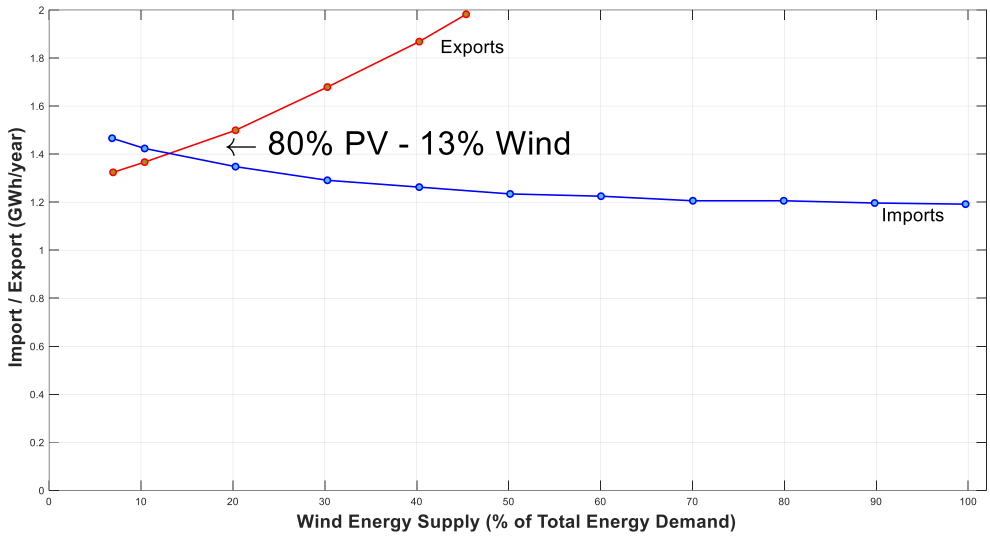
(f)


Imports
Exports
← 60% PV - 33% Wind
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
10
20
30
40
50
60
70
80
90
100

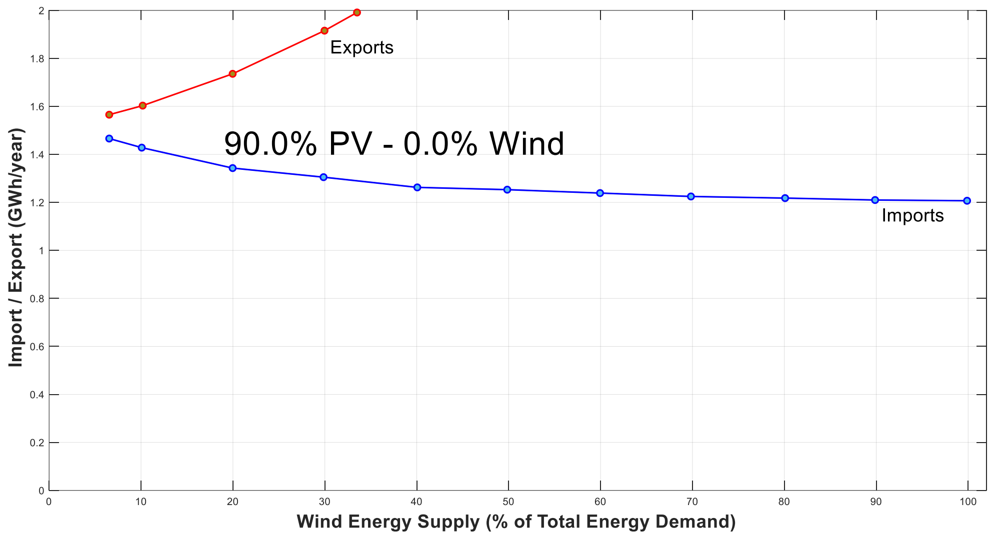
(g)


← 70% PV - 26% Wind
Imports
Exports
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
10
20
30
40
50
60
70
80
90
100

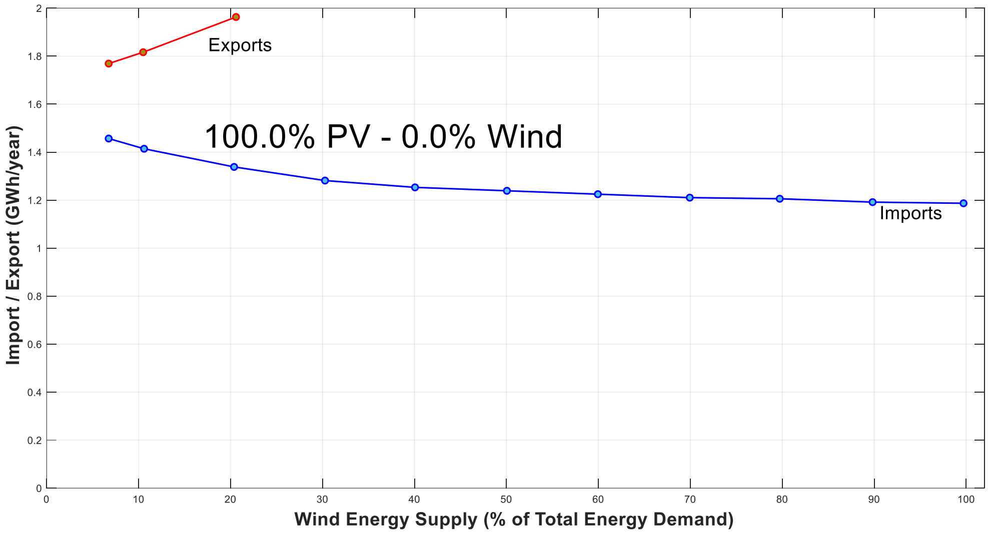
(h)


Exports
← 80% PV - 13% Wind
Imports
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)

(i)


Exports
90.0% PV - 0.0% Wind
Imports
Import / Export (GWh/year)
Wind Energy Supply (% of Total Energy Demand)

(j)



(k)

Fig. 12. Representative import/export graphs referring to the contributions of solar and wind energy. Import (in blue color) and export (in red color).

The execution of each of the Wind/PV combinations produced a total of 183 states of Import/Export, 9 convergence scenarios and 2 divergence scenarios (S10 and S11) having zero values of wind. The scenarios are presented in summary in Fig 13. The minimum Import/Export ratio corresponding to scenario S4 (Wind:64.5% - PV:30%) is also identified.

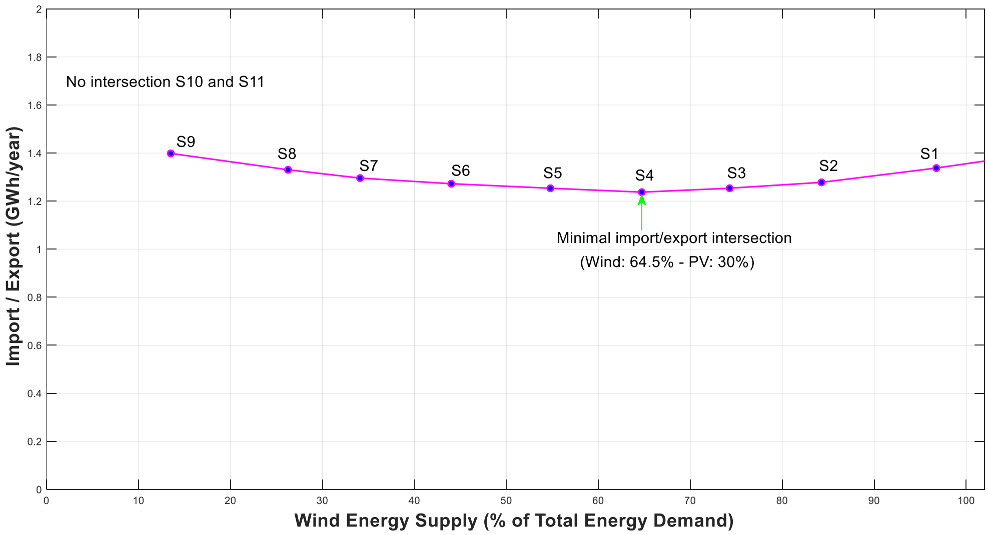


Fig. 13. Scenarios of each wind/PV combination and obtaining the Import/Export relationship.

5. Discussion

After making the projections to 2050 based on the results obtained with the support of the energyPLAN tool, it is possible to leave behind the production of fossil energy in the Ecuadorian Amazon. Renewable energy is the hope of many countries and regions to change the world, a world that is still sustained by oil and that must take action to prevent the increase in temperature on the planet and that we are all involved in doing something from the countries or regions that we meet. In relation to the results obtained, the proportions of solar PV (33.04%) and wind (29.73%) are reasonable percentages of contribution in the Ecuadorian Amazon that accompany the old hydraulics (36.47%) and configure a much more balanced energy mix with some minor contributions of renewable energies by 2050. The analysis goes further to identify the values between wind and solar PV that can satisfy future demand and their surpluses can be transferred to the Ecuadorian interconnected ring for export purposes. By plotting the 11 scenarios at different percentages of solar PV contribution, it is determined that the minimum Import/Export ratio is 1.27GWh in a combination scheme (HP: 30% - Wind 64.5%). In these projections to 2050 it is not admissible to have null contributions from wind power, these data are translated into the need for energy from the neighboring countries Colombia and Peru. This research also considers avoiding extracting more oil in the Amazon, in reality the region, despite having these resources, has historically not been well served in its basic services. It is reflected that since this region has not been properly attended for at least four decades since oil has been exploited on a large scale, the confusion remains that at present this reality will not change and it would be better to leave it underground. Rather, as a result of large-scale extraction, its inhabitants and the fragile and unique nature on the planet have been violated with high levels of contamination, its inhabitants, who have decided on their own initiative to remain isolated in the Amazon, have been forced to seek a new habitat for the indiscriminate felling of trees by transnational companies that seek to exploit oil at all costs.

6. Conclusions.

This research presents with great clarity the current state of the Amazon region in Ecuador and the roadmap to transform the region's energy system based on fossil fuels under an extractivist oil scheme for one 100% in renewable energies. The design of the energy system in the long term is analyzed to supply enough energy to the region and maintain energy availability for export to neighboring countries. The levels of wind and photovoltaic solar energy that should prevail in the future energy mix while maintaining measured levels of hydroelectricity are analyzed in detail. The literature detailed how energy markets are changing thanks to the support of renewable energies and preventing future generations from committing to oil-based structures. In fact, countries aware of this reality are abandoning oil. Their legislation is being adequate and purposefully linked to promoting an environment without contamination that achieves sustainability and sustainability. A roadmap is provided for decision-making in Ecuador and particularly in the Amazon region, and the strategies will allow, according to its energy potential, to have a 100% renewable system by 2050. The alterations in the social order have been a reason for concern, oil spills and the alteration in the habitat of the native peoples not in contact with industrialization have also been a matter of discussion in this study.

With the support of EnergyPLAN, the 100% renewable energy scenario was drawn up for 2050, in which three renewable energy sources are the main ones to influence in the future, these are: the current hydroelectric plant that will grow by 15%, achieving 2202.25 MW of installed capacity, having a 36.47% share of the energy mix. Similarly, the second most important source called to affect the Amazon is solar photovoltaic with 1994.75 MW with a 33.04% share. The other source is wind power, which can reach 1,795.33 MW and a 29.73% share. There are other small contributions from other technologies that should be considered in the energy mix and not be neglected, the more diversified the energy system, the more energy security can be guaranteed.

It is fair that nature and mainly the Ecuadorian Amazon, which has unique species on the planet, be protected. In the same constitution of Ecuador, it is identified that nature has rights just as if it were a common person, it is here where the Ecuadorian state must make these rights prevail. Particularly in this research, the routes are traced to transform the energy system into one that is more friendly to the environment and that can lead to further discussion in new studies both in the region and internationally. Similarly, in the current National Development Plan 2021-2025, it is identified in the territorial guidelines in policy 11.1- E8: Promote the use of techniques for the exploitation of renewable natural resources that minimize the impact on the environment and that respect the cycles of biological regeneration. Similarly, in Pol. 12.3. D4. specifies: Promote a sustainable market economy that generates employment opportunities and consider the particularities of each ecosystem, particularly in Galapagos and the Amazon. From this perspective, it is necessary to take direct actions to achieve the purposes in the region.

As future works, a strategic planning to leave the crude oil on land can be addressed in greater detail. Roadmaps can be outlined to fulfill this purpose while including greater proportions of renewable energies and meeting the growing demand.

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