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Analysis and proposal of energy planning and renewable energy plans in South America: Case study of Ecuador

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ABSTRACT

This research evaluates the South American Electric Energy System and its features related to the inclusion of renewable energies into the transition processes to leave fossil fuel-based energy systems behind. Analysis of the Ecuadorian case is a novel approach because in the first instance its matrix was based on the use of fossil fuels, with dire consequences of pollution, especially in the Amazon. Interest is growing in terms of economic, legal and social renewal, leaving behind the rapidly depleting oil systems which have been a polluting source. This research presents a novel analysis of the state of the Ecuadorian electricity system and after a flexible analysis in Energyplan, proposes the feasible renewable energy sources and their shares to guarantee the new demand in 2050 and an Ecuadorian 100% renewable electricity generation system, having a positive impact on the monetary, increasing production levels and improving the quality of life of its citizens. Installed power by 2050 is expected to be 20 GW and will require an annual production of 72.24 TWh. Hydro (6.02 GW), solar PV (5.7 GW) and wind (5.61 GW) will have the most impact on the Ecuadorian energy matrix. The average production cost of 1 MWh will be approximately 18 US cents.

1. Introduction

1.1. Background

The need for adequate energy supply carries the attention of millions of people around the world [1,2]. The fuel is used in various fields of daily life, its uses bring increasing ecological and social problems, including human interaction with nature [3]. At the beginning of the 21st century, industrialisation accelerated processes with the intention of massively extracting fossil fuels to a level that alarms the international community [4]. Global climate change also includes the problem of fossil fuel shortages [5]. The energy requirement in its most appropriate and timely form is for millions of people worldwide. It can be fuel, widely used at present in transport, electrical energy for lighting loads and motorised systems in the industry, etc. At the beginning of this new century, the levels of industrialisation increased markedly with respect to the previous century; there is much talk about the Internet of Things (IOT), robotics at extraordinary levels and in itself several substantial improvements at a global level. However, the levels of massive extraction of fossil fuels alarmed globally. Global climate change has added to the problem of scarcity of fossil fuels, however, given this situation, it is imperative to strengthen or begin to set our sights on other energy production systems, which in this case may well be renewable energy. It is very difficult in some countries to break this traditional scheme based on the consumption of energy from oil extraction, it has been for decades the support to undertake many developments and in fact, there have been great advances, however, it is a reality that these reserves are running out Little by little, it is required that the world energy matrix be reviewed and that their governments be clear about this problem that sooner or later will hit hard. In this sense, 2015 was one of the most positive years in relation to mitigation measures and adaptation to climate change, since at COP21 (Climate Summit), held in the French capital [6,7], the international community was He committed to developing a global action plan that put the global

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Nomenclature

ACM	Absorption Cooling Machine
CAPEX	Capital Expenses
CELAC	*Community of Latin American and the Caribbean*
COE	Cost Of Energy
COP	Coefficient of Performance
CRF	Capital Recovery Factor
ECLAC	Economic Commission for Latin America and the Caribbean
EEC	Economic European Community
ESR	Energy Supply Ratio
ESRL	Electricity Sector Regime Law
EU	European Union
FPC	Flat plate collectors
GEP	Generation Expansion Plan
HDI	Human Development Index
HL	Heating Load
HVAC	High Voltage Altern Current
HVDC	High Voltage Direct Current
IDB	Inter-American Development Bank
IEA	International Energy Agency
IOT	Internet of Things
IRES	Integrated Renewable Energy System
ITT	Ishpingo-Tambococha-Tiputini
LAFTA	Latin American Free Trade Association
LPG	Liquefied Petroleum Gas
N	Number of years
NCRE	Non-Conventional Renewable Energies
OPEX	Operating Expenses
PE	Primary Energy
PV	Photovoltaic
RE	Renewable Energy
RF	Renewable Factor
TAPE	Total Additional Projected Energy
YNP	Yasuní National Park

Formulae

$f_{max_{SE}}$	Element of maximum consumption of surplus electrical energy
$P_{LY/C}$	Energy yearly electricity consumption per capita in kWh/yr/person
P_{SE}	Annual system surplus energy in kWh/year
$f_{maxp_{load}}$	Element that allows increasing the annual AC load and that the maximum surplus energy can be used.
n_{HUMAN}	Number of people consuming power generated from the hybrid system

warming limit well below 2° Celsius. Four years later, a new meeting was planned in Santiago de Chile, which unfortunately was cut short by social protests and COP25 moved to Madrid, unfortunately, optimism was reduced by having countries that opposed it [8], but finally a text called Declaration of Chile and Madrid [9], which encourages countries to make their efforts that are the most ambitious in order to generate commitments that add to reducing their emissions and avoid disparities between countries in compliance with the Agreement on Paris.

The issue of reducing CO_2 emissions also impacts state finances; therefore more than one prefers to be cautious, despite the fact that in Latin America three quarters of the population consider climate change to be one of the major global risks. According to studies by the Inter-American Development Bank IDB, it is calculated that the modification of the climate will determine the region about 1.5–5% of Regional GDP. It involves more actions than well-intentioned speeches, as well as allocating financial capital and effective public policies that allow the adaptation of the regional energy matrix to one that is based on a more environmentally friendly system. Below is the illustrative image of the 100% renewable system by 2050 for South America and Ecuador (Fig. 1).

In 2020, Ecuador reached a total net energy production of 33760.52 GWh distributed as follows: 24,887.3 GWh hydroelectric generation; 8288.58 GWh non-renewable generation; 584.64 GWh unconventional generation.

On comparison to 2019, year in which net production was 27,532.24 GWh distributed as follows: 24,458.10 GWh hydroelectric generation; 8302.36 GWh non-renewable generation; 402.62 GWh unconventional generation. Given the strong impulse of the different governments in investments in renewable energy plants, especially in wind and solar. The current energy matrix will begin to change radically with the increase of renewable energies in the energy mix when they come into operation in subsequent years.

The total energy consumption registered in 2020 reached a total of 25,975.12 GWh, from of which 94.84% corresponds to the energy demand of companies distributors and 5.16% to exports through international links. Approximately 61.23% of national consumption concentrated on the business units: CNEL EP - Guayaquil with 20.02%, E.E. Quito with 14.64%; CNEL EP - Guayas Los Ríos with 9.49%, CNEL EP - Manabí with 7.68, CNEL EP - Gold with 5.13% and E.E. Central South with 4.27%. Whereas, if analyzed by companies, it is evident that 59.37% of total consumption, concentrated on CNEL EP and E.E. I remove 14.64%. The consumption is detailed below registered during 2020.

1.2. Previous work

Renewable energy tends to be an effective solution for supplying electrical energy in rural communities and others that connect to larger topological systems. Utilising the renewable resources available in each locality is the best way to cover energy requirements. In relation to the characteristics of the site, the different technologies can be selected independently according to an adequate transition, seeking that the citizen is not affected by the service [10].

The most common systems such as photovoltaic, wind, small hydroelectric energy are viable options, and above all, they are giving success in different countries. Dominkovic et al. in Ref. [11] presents a starting scenario based on polluting energies and with the support of energyPLAN a program developed by Aalborg University [12] makes projections for the year 2050 and replacing it with clean energy in the Southeast of Europe. Dimitri Bogdanov in his reference [13] considers a mix of 100% renewable energy for Northeast Asia, on the other hand, Michael Child et al. [14] proposes an energy system based on clean energy in the Aland Islands with a slow level of penetration for the year 2030. On the other hand, D. Conolly et al. [15] proposes an Intelligent Energy System for Europe, analyzes the technical-economic viability with totally renewable energy. According to Energy Monitor [16], the demand for renewable energy in Latin America is 212 GW based on 2015.

Research shows that it is feasible for energy systems supplied by RE will significantly reduce the carbon footprint [17] since most technologies related to renewable energies are showing tremendous growth in most countries around the world, and internal

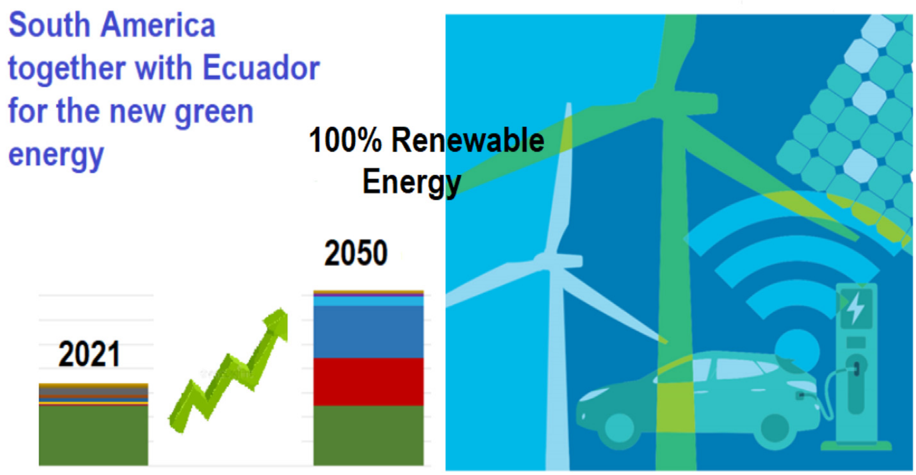

Fig. 1. Illustrative image of the 100% renewable system by 2050 for South America and Ecuador.

policies are being restructured in order to increase their penetration levels [18]. With the aim of closing this gap between countries that are at a more accelerated rate in the use of renewable energy technologies and those that are beginning a transition phase in Ref. [19], he presents us with financing options and can be exchanged with green bonds. H. Lund and BV Mathiesen [20] showed in the Denmark study on time models that full renewable energy deployments is technically feasible and economically acceptable. K. Hansen et al. [21] considers that in Germany if 100% renewable energy can be included by 2050, however Michael Child [22] considers that the generation of energy should be flexible and with storage systems using batteries.

Kevin Lo, through [23], makes an important criticism that policies must have a rapid and efficient development in relation to renewable energies and exposes the case of China, while Ma Minda et al. in Ref. [24] emphasises that it should Consider energy efficiency at the building level after having reviewed the Chinese case in the last decade. Curran Louise [25] considers that to carry out effective actions and increase the levels of implementation with RE, it is important to carry out synergies and, in this sense, De Alegría Mancisidor et al. [26] provides an analysis of Spain, AAN Jami et al. [27] analyses the case of Canada, D. Van Beers [28] explains the case of a region of Australia.

T. Bossmann [29] emphasised that the actions carried out to supply the demand have allowed a greater penetration of renewable energies in the current electricity system and that as these technologies become more popular, costs tend to decrease. Their analysis was exhaustive taking 117 related publications, and in most of them, the load had to be adjusted to the Renewable Energy System. F. Shariatzadeh [30] proposes to provide effective responses to the demands of sustainable energy systems without limitations and restrictions, which is why S. Kakran [31] considers that it is necessary to provide these systems with smart grids to make supply and demand and especially when having storage systems as considered by Chauhan A. and Saini RP [1]. sizing and control methodologies can be applied. Several researchers have proposed an Integrated Renewable Energy System (IRES) to electrify areas where there is no access to distribution networks of local trading companies [32–37]. The energy demand of these areas is met by taking advantage of their energy potential from existing renewable resources locally, that is, they take advantage of the existing resources of the site such as solar, wind, small hydroelectric, biomass, etc. that is achieved Transform into electrical energy. It is even possible to form hybrid generation systems as much as possible, so as not necessary to depend on a single generation system, this will make it possible to guarantee much more energy supply on demand. The integrated use of the different renewable generation sources minimises the energy storage requirements by means of batteries or, in turn, the storage units are less, additionally, it increases the reliability of the system and the quality of the energy increases.

Currently, photovoltaic solar systems on rooftops are popular in urban areas [38–41], even if we have the supply of electrical energy by the marketing company, we can also carry out these implementations and guarantee the continuity of the energy service that at the end of the month ends up paying a cheaper bill having a solar panel system that is the most common [42,43]. In several countries where their legislation is aimed at encouraging the consumer to carry out these facilities, they are rewarded by comparing the consumption levels of the home against the internal energy production by the home. For this purpose, the measurements are made by installing bidirectional meters [44–46]. The control system is the fundamental basis of the renewable energy system that provides the fluctuation range of incoming energy with the intention that the downstream equipment is not affected by an eventual anomaly due to surges or short circuits [47]. The system controls the production of renewable energy sources and also emits the signals for the programming of the storage subsystems in the established limits between voltage and current. As there is excess energy available, it is sent to the Storage System, very commonly arranged by a battery bank, to finally take advantage of it in the different activities of the home, such as water heating, cooking, refrigeration, etc. under special conditions where generation drastically exceeds regular consumption in the home with loads such as lighting and common outlets [48].

Actually, there are very few relevant articles that analyze the current state of renewable energies in South America, the ones that best approach us are [49,50]. The approach presented is a novel approach since, above all, Ecuador had to go through an energy matrix based on fossil fuels, leading to various adverse situations that were consider in the next section, so that based on these experiences it begins to transform its sustained energy matrix into diversified renewable energies.

Of the literature reviewed, the most relevant is that provided by studies carried out in countries of Europe and Asia, which mainly show various methodologies to design 100% renewable electricity markets. These experiences have substantially nurtured our development base, allowing us to design the future Ecuadorian electricity market with its own problems and potential. It includes a systematic analysis of energy transformation limiting the participation of fossil fuels to finally determine the cost of electricity production. This development can be useful to continue with new studies where the economic aspect is a limitation and requires strategies to comply with having a 100% renewable electricity market.

In this study, after an exhaustive analysis of the South American context, the case of Ecuador is deepened and a possible route is provided to transform the energy matrix into a 100% renewable one by 2050. In addition, possible economic scenarios are outlined in order to provide options for the purpose outlined. This study will become a clear reference for making national decisions, researchers will have a solid reference to continue with new research.

The scientific methodology is divided into: In this first section a preliminary review of the state of the art. In section 2 presents the data and methodology. In section 3 the results and discussion are presented. Finally, in section 4 the conclusions and recommendations are issued.

2. Dada and methodology

The method used in this study consists of four phases. In the first, a review of the literature corresponding to the history and current affairs of energy in South America is carried out, considering above all the oil situation, the implication of hydraulics and thermal capacity, and the level of use of renewable energy. The second part presents statistical data on installed capacity and detailed energy production by source, in nine countries in South America: Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Peru, Uruguay and Paraguay. The third part, the country of Ecuador, a small country in the territory but with an enviable ecosystem that has been working on a change in the productive matrix marked by oil exploitation and pollution, is taken as an analysis point, for one that marks the efficient use of its renewable resources and that arouses interest in radicalizing this change.

Finally, in the fourth part presents the results of our contribution in which the 100% renewable scenario for Ecuador is drawn according to the Latin American context. The elimination of energy production using fossil fuels is contemplated, but it implies a process of reducing times and the increase of new technologies. To present the scenario with reference to 2050, the EnergyPlan model is used, which presents a flexible methodology for making long-term projections involving fully renewable energy production systems.

In the general context of this document, it seeks to clarify which are the current energy development instruments in South America with a rigorous analysis country by country, revealing each development, something that no author synthesizes. However, it makes it possible to make a rich analysis of the literature that is as up-to-date as possible, from here we start to land on the Ecuadorian energy system, considering from its historical aspect, and evaluating the current state of the energy matrix. This article presents a novel and updated approach that considers renewable energies as the substantial element of development. With this analytical and critical basis, the scenario is drawn to 2050 in which the transformation of the energy matrix to a 100% renewable in Ecuador is radicalized. The approach presented here constitutes an outstanding and transforming element of the processes to build the electricity market for the new generations.

2.1. EnergyPLAN model

A model developed, especially for the modelling of intelligent energy systems, is EnergyPLAN, worked and developed at Aalborg University [12], specialized in large-scale integration of renewable energies in the energy system [11,20,21]. Currently, various models allow us to carry out energy planning. There are excellent reviews in Refs. [38,39], optimal combinations of renewable energies in Ref. [26], the inclusion of the transport system in the energy sector [51,52] and avoiding constant contamination [53]. Simulations of 100% renewable energy systems are carried out here with the scenario that the energy produced in Ecuador supplies the growing demand according to the expansion plans drawn up according to land use [54] and for identification of the most suitable market auction configuration for electricity in fossil-free energy systems [47,48]. The typical input data suggested according to each country reality recommended by Refs. [55,56] are demands, RES, capacities of the generation unit, storage capacities, fuel consumption in the individual sector, transport and industry, Fuel costs, investment, operation and maintenance, variable and fixed costs of different units, CO2 emission factors of fuels and different regulation strategies [57,58]. Although at present several countries including Ecuador still maintain these sources of generation using fossil fuels, above all to regulate and balance the electricity system, it is no less accurate that their reserves will be depleted and from now on this new era of energy. Nor is it intended to suspend these polluting sources immediately, but progressively until reaching 100% renewable energy by 2050. The security of energy supply in Ecuador depends directly on the resources available for autonomous supply in solidarity with the cities, contribute with the surpluses to the interconnected national ring.

EnergyPLAN is a well-established tool for modelling 100% renewable energy systems. This model is presented in Fig. 2. Furthermore, the model can be used for technical analysis, market exchange analysis and feasibility studies. The results are the resulting energy balances and annual productions. The exchange analysis of each plant is optimized based on the economic profits of the companies, including taxes and CO_2 emission costs. For the analysis, EnergyPLAN [12], version 15.September 0, 2019 was used.

EnergyPLAN is an hourly simulation model, unlike models based on annual demand and production with aggregation. Consequently, it is possible to analyze the influence of intermittent renewable energy systems that interact in the system as a whole. The model optimizes the operation of a system under study unlike the classic models that consider the optimization of investments in the system. However, after analyzing the different systems globally, it is possible to consider the investments, the model can be used in order to identify that these investments are feasible.

Despite the great benefits of EnergyPLAN that were mentioned above and that make the difference with other models, it is also necessary to point out that there are some drawbacks and that they must be considered. The main drawback of simulating the base year lies in the conception of the EnergyPlan platform, since in principle the simulator was developed to simulate future scenarios but not to model the current operation of energy systems.

2.2. Situation in South America

South America is made up of 12 countries and Brazil is the largest in extension [49]. From LAFTA (Latin American Free Trade Association, created in 1962) [50,55] to CELAC (Community of Latin American and the Caribbean States, created in 2011) [59], there are many initiatives taken in the region to act jointly. These efforts began in the early 1960s largely inspired by the European Economic Community (EEC) [60], which has since then continued to evolve into the current European Union (EU) [61]. Meanwhile, in Latin America, the multiple regional initiatives have made significant contributions to their countries [55,56], but are still far from giving results due to internal crises in the countries compared to the EU

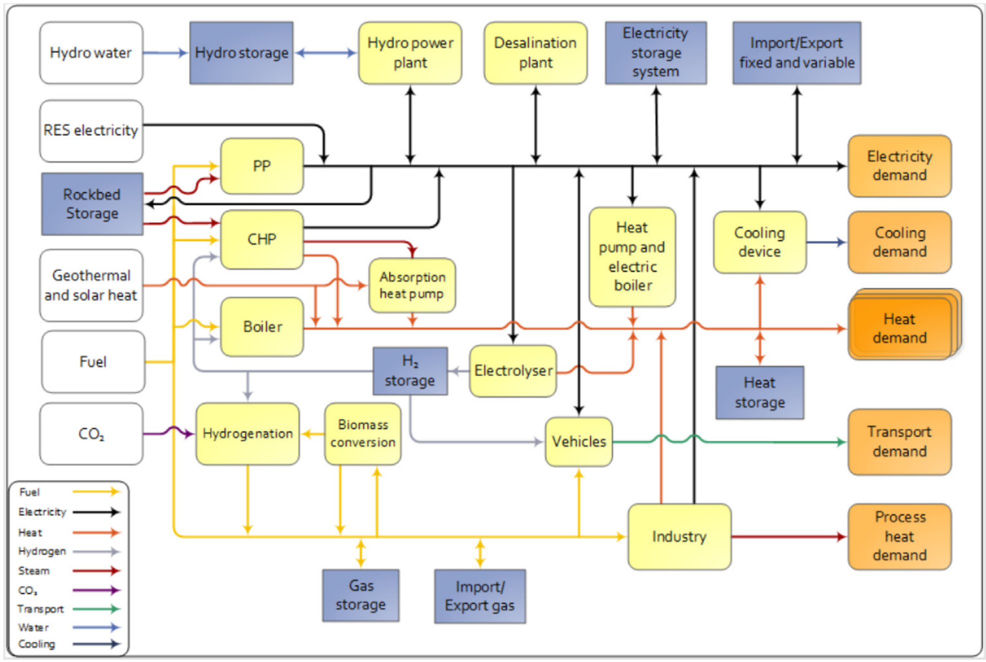

Fig. 2. The energyPLAN model in version 15.0 [12].

[57]. The most recent of these occurred when 7 of the 12 members of the Union of South American Nations (Unasur) announced their decision to suspend their participation in the meetings of that Agency.

South America has extraordinary wealth, its own problems and economic importance in its ecological reserves and freshwater tributaries, their fauna, and vast forests that are the lungs of the world, concentrated mainly throughout the Amazon and southern Chile [58,62]. Its sources of energy generation in a very good part are mainly based on hydroelectric production when building reservoirs of its prominent rivers. Historically, most of the South American countries have been dependent on oil production to satisfy various internal needs and boost their economies [63], however, little by little, countries are reorganising themselves, beginning to adjust their laws in order to change their energy matrices to a different model consisting of renewable energies that contribute to the conservation of their ecosystems [17] and by 2050, replace the supply of thermal energy with environmentally friendly renewable energies [64]. South America has always been interested in conservation initiatives because it has an incredible number of ecosystems and very sensitive to human action [65]. In addition, freshwater tributaries are being intervened by companies that have extrativist purposes that historically had not occurred, especially due to the oil derivative such as plastic that affects marine species, protective forests, wild flora and surface fauna terrestrial [65]. Several researches show an increase in the levels of contamination in freshwater where various species live [66], affecting at least 20% of the fish at the level of world and 72% of the mussel species in North America in danger of extinction, vulnerable or extinction according to the criteria of the world conservation union. This slope of destruction has remarkably influenced South America, the product of living in a globalised world, causing problems both from abroad and from internal policies [67,68].

The Mega-diverse South America arrived at the COP25 summit in Madrid with a series of advanced proposals to curb the climate crisis, which is seriously affecting the region in the form of natural disasters and threatening key sectors of the economy such as agriculture [69–71], after the summit there was a bittersweet taste as it did not have the unsupported support of other countries, but it was not demotivating either. In the publications presented by the Economic Commission for Latin America and the Caribbean (ECLAC) [72–75], it is evident that all the countries are engaged in the fight against climate change and, above all, they are beginning to act, aware that the region is highly vulnerable to the negative impacts caused by this phenomenon. ECLAC provides the strategic lines to efficiently promote the dynamics of the economies that correspond to Latin American and the Caribbean, based on equal opportunities and environmental sustainability in the context of the 2030 Agenda [75]. On the other hand, this organism has created various observatories to analyze the socio-economic situation of the region, even calls for taking advantage of the experience of the COVID-19 pandemic to build a new development model and strengthen regional integration to face the crises, without marked differences and inequities to advance with the 2030 Agenda for sustainable development [72,74]. The ECLAC Executive Secretariat considers that a “New Green Deal” is necessary with Europe for a more democratic, less unequal and more sustainable world. International organisations consider that in order to meet the challenge of truncating global warming to 1.5 °C by 2030, it is critical that all countries must increase the level of ambition of their climate plans by the end of 2020, something that South America has already raised [74].

Many countries in this region have already announced their intention to make more ambitious promises with the challenge of truncating global warming to 1.5 °C. It is up to the international community to make a collective and concerted effort to ensure that we move in that direction, explained the head of the Climate Change division of the Inter-American Development Bank (IDB). It was planned that by the end of 2020 better results would be achieved and the “so-called” COP of ambition’ will return with better results and play a key role with facts to lay the groundwork with national climate plans aligned with the purpose of reducing emissions and increase resilience to climate fluctuations [62], that even when we are experiencing the COVID 19 pandemic we cannot loosen the anchors and the plans that are still in force for the good of the region [76], there are no margins of tolerance in order to continue polluting the environment.

Efforts in South America have increased along with the risk for the region, increasingly exposed to rising temperatures, which has contributed to the dramatic setback such as the destruction of the Andean glaciers [77], to extreme events such as floods and droughts, and deforestation, linked to fires that occur in the Amazon [78]. In other places, the fall in precipitation has produced events of water stress, and its effects can be noticed when severe droughts or harsh, weather associated with climate change have struck, but also to the economic model of strong extractives. The greatest impact of climate change in South America is on the water, with rising rainfall in some nations and drought in others, in addition to rising sea levels. These circumstances affect nations that depend on fishing, livestock, tourism, and especially agriculture.

2.2.1. South America energy expectation

In 1980, the transition of the electricity system to competitive markets began in South America [79,80]. Chile started liberalising its energy system in 86 [81], the first country worldwide to do so, progressively other countries in South America joined in the 90s, including Argentina, Colombia and Brazil [79]. Deregulation positively influenced the region, allowed the vertical integration of the electrical power system (Generation, transmission and distribution) and, above all, allowed private investment to be present establishing national wholesale markets and the interconnection between neighboring countries, allowing the establishment of a referential framework of public policies between supply and demand [82]. South America is experiencing an increasing demand for electrical energy, especially for the progressive population growth, as well as economic growth [83–85]. This region has based its energy matrix on hydroelectricity with 76%, properly for having important freshwater sources in all countries and facing the need for energy, as well as the region for having very good oil reserves is present a large part of thermal energy production with 20% of its own from the use of petroleum-derived fuels, while the remaining 4% in clean energy, especially solar, wind, and biomass [86]. From the year 2000, little by little, its energy structure and the need for changes to increase the penetration rates of renewable energies in South America became of great concern. There are important plans, especially regarding transition and energy strategies [62].

The energy sector of the countries of the region are already in constant growth and development, it has not been easy for countries to move towards this much-needed transition, for their legal frameworks to be modified. Currently it responds to the challenges and needs of an energy transition [87,88] that seeks a greater diversity of clean energy sources in the general electricity matrix, and in the electricity generation matrix, as most countries are doing worldwide and South America must tune in to these currents that they are trying to protect the planet [89]; increasingly seeking a greater share of renewable energy sources not only with good intentions but also more realistic and of execution. Fig. 3 shows the diversification of energy by source for electricity generation at the regional level.

At the end of 2018, as can be seen in Fig. 2, in Latin America, there is a total of 414,644 MW of installed capacity for the generation of electrical energy. The most important source of electricity generation corresponds to the production of hydroelectric plants, with 44.5% followed by generation by non-renewable thermal plants (41.9%). Electricity generation by non-conventional renewable energy sources (NCRE) such as biomass, wind, geothermal and solar (renewable thermal) contribute 13% of the total installed capacity in the region by 2018. In fact, Latin America has the highest percentage of hydroelectric generation with respect to the total generation in the world [90]. However, there is a trend in the decrease of this record from the last decade of the 20th century, which is related to a greater social sensitivity towards the environmental and socio-economic impacts associated with this technology [60,74], since the transition that is taking place throughout the region towards a diversified and resilient generation matrix [62] in the face of the impact of drought episodes as a result of phenomena typical of climate change, as well as to mitigate the economic effects derived of the volatility of the price of fossil fuels that above all are affecting in this 2020 all South America dependent on oil [91]. In this sense, in order to avoid continuing to live these critical situations and at the expense of whether the value of oil rises or falls, this transition is necessary, which is being leveraged mainly on natural gas and non-conventional renewable energies as stated by IRENA in reference [62]. Concerning the LPG industry, it is necessary that the countries that maintain subsidies implement border control policies to avoid the contraband that is commonly related, such as the Ecuadorian situation [92].

The evolution that wind technology is registering in the region is highlighted, including Argentina [93], Brazil [94], Ecuador [95], Chile [96], among others. The insertion in the regional energy matrix is mainly located in this last decade, in which around 25% of the total new electrical power installed in the region comes from this technology, which has gone from being irrelevant in the electrical matrix in 2010 to represent 6% of the total installed electrical power. The wind source is attributed more than 80% of all the installed capacity of NCRE, in that period in the region [62]. The development of NCREs in the region, and especially of wind technology, is undoubtedly due to the first results of the adoption of public policies by the states in South America [97], specifically aimed at reinforcing security and continuity of supply of electrical energy by diversifying energy sources. It is possible that the Paris Agreements on the reduction of emissions of polluting gases against climate change have prompted the implementation of these systems, it should also be noted that their governments were key elements to continue advancing towards decarbonization in the accompanied states with the environmental policies adopted by the governments adhering to such commitments. The importance of this sum of efforts brings with it an accelerated transformation of the electricity generation matrices, particularly in the systems that are most dependent on fossil fuel consumption technologies for their decarbonization.

The IDB in Ref. [98] which places the region as one of the areas with the highest growing demand for electrical energy, is above the world average. In Fig. 4 identifies the countries of South America to which the Southern Cone and the Andean Region correspond to which have a growing demand and therefore it is essential to take the corresponding actions in time to supply this demand.

There are certain technologies, as shown in Fig. 5, considered to be directly involved in the energy matrix at a global level. To represent the energy mix, MATLAB 2020a Toolbox for EnergyPLAN was used [99]. Reference [62] notes that achieving the Paris climate goals will require a significant acceleration of investments across a range of sectors and technologies and that among all low-carbon technology options, wind power, along with solar energy, would open the way for the transformation of the world electricity sector. It is expected that onshore and offshore wind energy from the Atlantic and Pacific slopes is expected to generate approximately more than a third (35%) of total future electricity demand [88], implying that it will be the first source of generation in 2050. Kissel JM makes a decade ago through [97] it has already called for locating the pillars of the clean energy legislation for emerging markets in South America and has set Brazil as an example to follow due to its good practices.

LAC Installed Capacity (MW)

Hydro	186395
Non-Renewable Thermal	173937
Nuclear	5353
Geothermal	1603
Wind	25716
Solar	4732
Others	474
Renewable Thermal	20868
TOTAL	419079

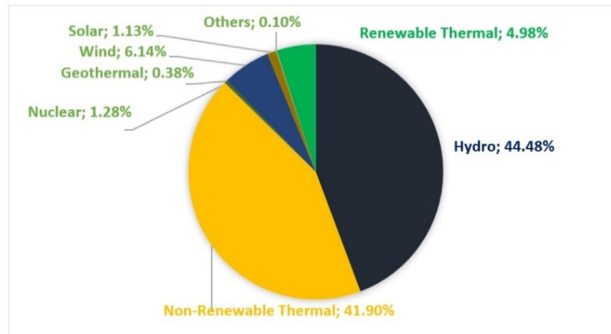

Fig. 3. Installed electric generation capacity in LAC [87].

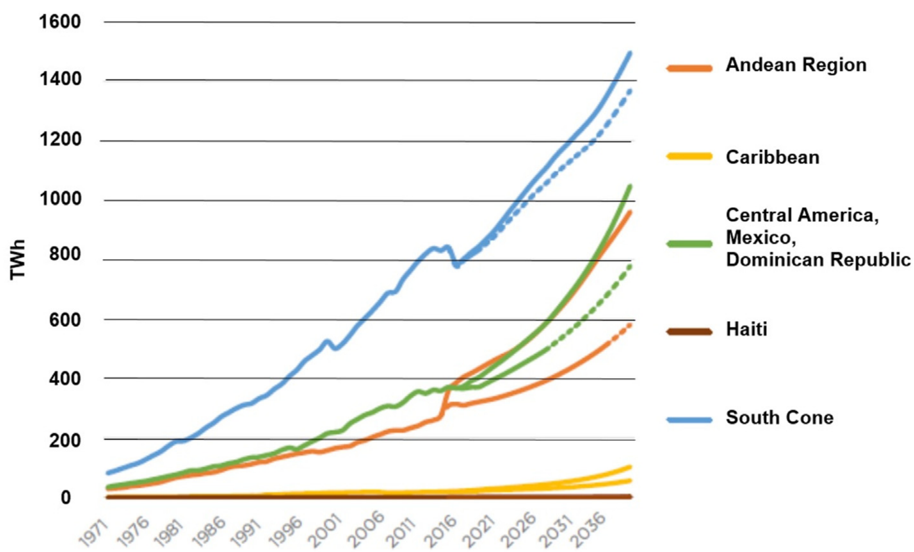

Fig. 4. Electricity demand by subregion to 2040. Weighted GDP demand: Continuous line. Historical Trend Demand: Dotted Line [98].

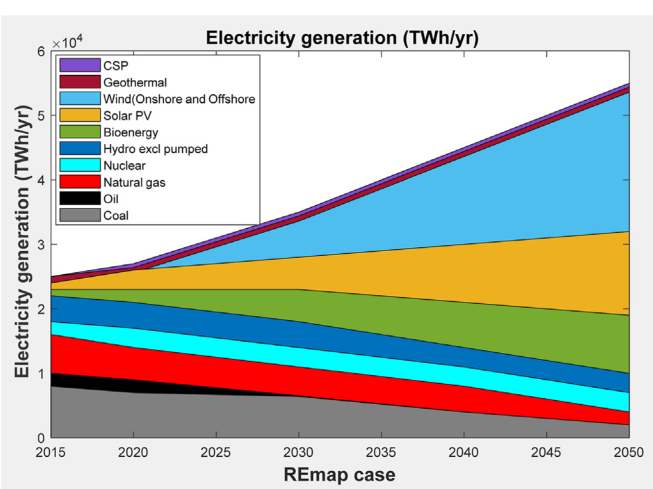

Fig. 5. Projection of electricity generation worldwide in 2050.

2.2.2. Incidence of renewable energies in South America

Other renewable energy sources are on the rise, but the hydro is still at the top. Hydroelectric power remains at the top as the most important source among renewable energy generation sources [100]. Still its importance is slowly decreasing and energy sources especially solar and wind are gaining strength [101]. According to the Energy Monitor [16], it considers that in 2000 this source made up 95% of the South American renewable energy mix, but it was reduced by around 80% in 2015 with 172 GW of the total 212 GW of renewable energy. According to the recent IRENA publication [102], the decrease in hydroelectric power has not been in a drastic drop, but it is observed that the South American countries are diversifying their generation mix, especially in wind and solar energy, as shown in Fig. 6. The result of this modification in the energy matrix is due to fear of droughts, environmental impacts such as deforestation, the emergence of national environmental protection policies that have intensified in recent years. At the same time, socio-economic advantages linked directly to the consumer are visualised, since having renewable energy in their territories is leading to an increase in appetite for solar energy, wind energy and biomass.

The cost of hydroelectric power generation has been decreasing from $ 65/MWh in 2010 to ~ $ 50/MWh in 2016 until 2019 due to heavy investments and technological advancement [90,100,102]. This means that it continues to compete with the cost of fossil fuels ranging from $ 40/MWh to $ 150/MWh, but with very little gap for further cost reductions due to its level of maturity established in the market [16,86].

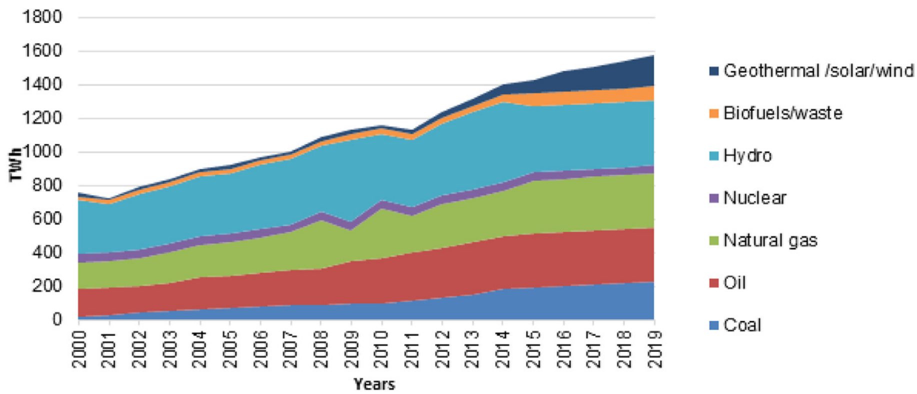

Fig. 6. Latin America Power generation mix. Presented by Ref. [16] and adapted according to data from Ref. [102].

2.2.3. South America and predisposition for renewable energy

South America compares favourably for hosting renewable energy compared to the entire world. As presented by Ref. [16] and ratified by Refs. [90,98], the energy supply in South America is around 25%. Globally, the energy supply that comes from renewable energies is 13%. It implies that this global figure is practically doubling in South America. Although the region compares favourably with the rest of the world, it should also be recognized that fossil fuel continues to have a large presence in the energy mix to date. Fig. 7 presents all the South American countries in the order of their installed renewable energy capacity according to the statistics provided by Energy Monitor [16] and adapted according to the data presented to 2019 by IRENA [102] in which identifies that Brazil is the country with the highest participation in South America.

For the transmission of electricity, generally most of the transmission lines are built for high voltage alternating current HVAC technology. However, to achieve greater efficiency, current technology is generally used for long distance high voltage continuous HVDC. It is possible to alternate alternating current and direct current networks within the existing subregions. Even so, considering that it is a technologically viable option compared to the current model, the costs of the distribution network are not accessible in all countries, which it can lead to a poor estimate of the costs of the distribution network. Given this situation in which renewable energies are going to play a leading role soon [100], the scenario for 2030 and reconfigures the distribution system in South America as shown in Fig. 8, considering the costs of capital (CAPEX) and operating expenses (OPEX).

In this section it is emphasised that the region has historically been rich in hydroelectricity. However it is very clear that there is a deterioration in the water resources in the region and projections worldwide are aimed at creating a mix of renewable energy [89] and the region has understood that this is the line of action [72,100] proposes an integrated scenario in South America that interacts with Central America. In Fig. 9b we can identify that a regional storage system of 124 GW is necessary, before a regional electrical capacity of 1175 GW shown in Fig. 9a.

Due to the different motivations of countries around the world and the wave of inevitable transformations that are driving us to enter the world of renewable energy, it is not enough just isolated and well-intensified efforts. S. Arango-Aramburo, in Ref. [86] shows that the thermal and hydraulic capacity has remarkably influenced all the countries of South America in recent times [104]. The previous literature leads us to recognise that renewable energies are the future of the region, so it is important to recognise that in all the countries of South America there are future plans and in others, even a legal order that requires travelling on a wide route so that the Renewable energies will be the protagonists for years to come, it is identified in Table 1.

Kissel J. in Ref. [97] highlights that Brazil is an example in South America in which since 2009, it has already doubled its capacity close to 100 GW compared to Argentina, Colombia and Chile along with 51 GW. Within the Region, Brazil is considered a pioneer country in good practices in the use of renewable energy, accompanied by the political weight of its technological development in the electricity market. Regarding Venezuela, it can be identified by Ref. [107] that if it considers within its Plan of the Homeland 2019–2025 possibilities of taking advantage of renewable energy. Unfortunately, the internal crisis in which the country lives has not allowed further development in these areas, and there are no short and medium-term plans. Colombia has about 10 MW of installed capacity. There is Law 1715 issued in 2014 that allows for a 15%

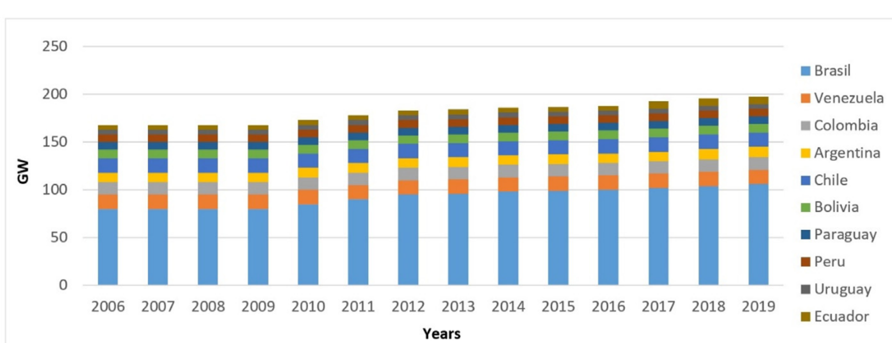

Fig. 7. Renewable energy capacity in South America. Presented by Ref. [16] and adapted according to data from Refs. [102,103].

Fig. 8. Transmission lines in South America configured by distance [100].

increase in electricity exclusively with renewable energies for the year 2029. According to Ref. [121] it is possible to include it in the mix from Colombia, 474 MW from wind, 143 MW from solar, 275 MW from geothermal and 314 MW from biomass. Argentina, increasing its energy generation based on renewable energies in the last five years, in 2017 achieved 257 MW [110,111], likewise [122] declares that the range of renewable energies made up of wind, solar, biomass, biogas and the hydroelectric plant only increased in 2019 around 50 MW, thus reaching 2472 MW total. According to the report of the Chilean generators [123] as of November 2019, this country has an installed capacity of 25248 MW. 48.3% of installed capacity corresponds to renewable sources (27.0% hydraulic; 10.8% solar; 8.6% wind; 1.8% biomass; and 0.2% geothermal).

Bolivia has obtained very good results in recent years in its implementation of renewable energy projects, especially in wind energy [124]. discloses that by 2019 the Qollpana wind farm in its two phases reaches a total installed capacity of 27 MW injected into the SIN national interconnected system; in addition to the Warnes, Cotoca and El Dorado wind projects in Santa Cruz, and La Ventolera in Tarija; that contribute to the mitigation of global warming and the generation of clean and environmentally friendly electricity. According to the Inter-American Development Bank [125], it estimates that Bolivia is the country that will have the highest growth in demand by 2030 and that its projects are on the right track. Three major projects are underway, the San Julián wind farm will be located in the municipality of Cotoca and will have 11 wind turbines; the El Dorado wind farm will be built in the municipality of Cabezas with the location of 15 wind turbines; and finally, the Warnes wind farm in the municipality of the same name, and will locate 4 wind turbines, highlights [124]. With respect to Paraguay, it has an installed capacity for the generation of electrical energy of 8825 MW [126]. This covers the demand for 6.9 million inhabitants. The largest capacity corresponds to Itaipú, a hydroelectric plant

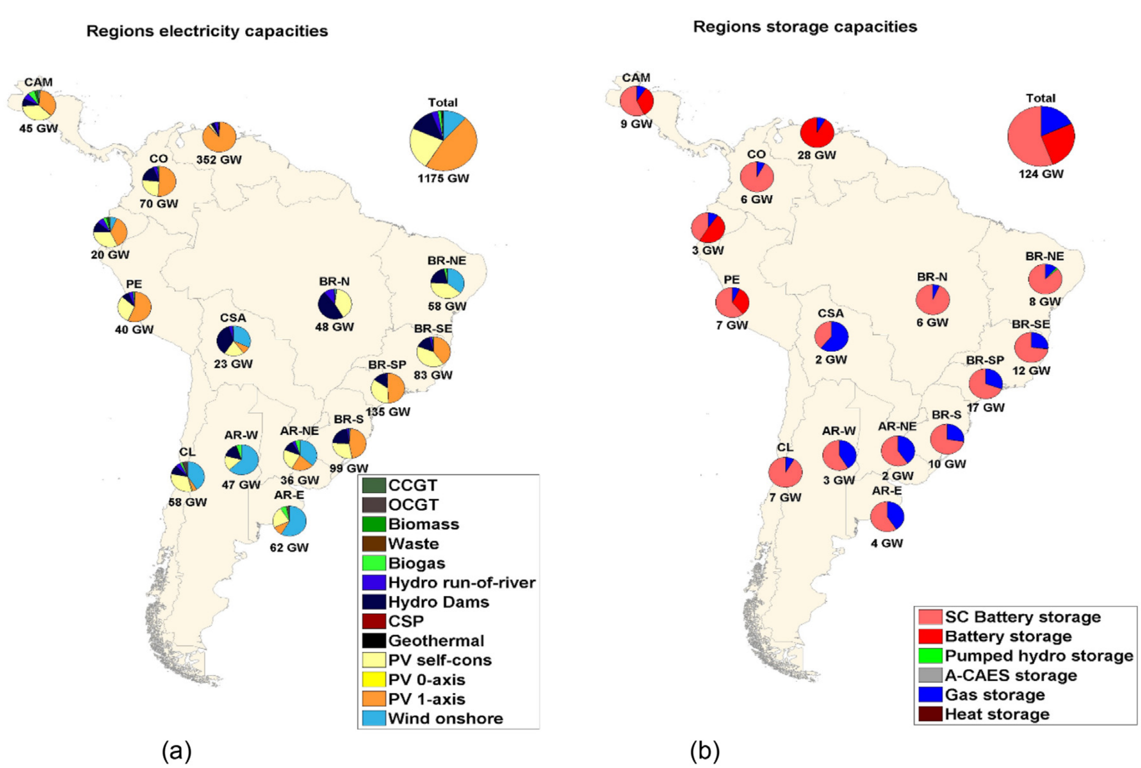

Fig. 9. a and 9b. Installed capacity of RE (a) [100] and its energy storage capacities (b) system for South America by 2030 in an integrated scenario.

Table 1
Plans, Polices or Targets to increase the penetration levels of RE in the different countries of South America.

Country	Plans, Polices or Targets for Renewables	Source
Brazil	A primary electricity production of 42.5% is estimated by the year 2023.	[105]
	86% of supply through RE is considered by the year 2023.	
	20 GW of wind energy will be included in the national system.	[106]
	Additional revenue for the year 2030: Wind 3.3 GW and Hydropower 34.5 GW.	
Venezuela	Plan of the Homeland 2019–2025 of Venezuela.	[107]
	5.1.5. Promote the generation of clean energy, increasing its	
	Participation in the national energy matrix and promoting technological	
	Sovereignty.	
Colombia	6.5% increase in electrical capacity by the end for the year 2020 in a distributed manner, without building huge hydroelectric plants.	[108]
	Inclusion of renewable energies in a percentage of 15% in the energy matrix by the year 2029.	[109]
	Law 1715 of 2014.	
Argentina	- A goal of 10000 MW of RE is set by the year 2025	[110]
	It is approved by law 27191 to increase total consumption by 20% by the year 2025.	[111]
Chile	- The goal to achieve to 20% increase in electrical capacity by the year 2025.	[112]
	- It is expected that at least 60% of the energy supply will be through hydroelectricity, which implies that it is higher than 20 MW	[113]
	As a goal for 2025 to have 45% of installed capacity.	[114]
Bolivia	Bolivia aims to reach 183 MW of RE generation by the year 2025	[115]
	Conseived goal of increasing 10% of the RE in the mixture in the next 5 years to 120 MW in geothermal energy.	
Paraguay	Energy Policy 2016–2040 that has as a goal that 10% of the generation matrix is with renewable energy.	[116]
Peru	It is considered as a goal by the end of 2021 incremental 5% of total energy (excluyding hydro).	[117]
	Increase more than 60% of total generation by the year 2025.	
Uruguay	Within the policies for the year 2030, the promotion of RE sources is considered.	[118]
	By 2030 it will invest another 500 MW of solar energy PV, 280 MW of wind and 10 MW of biogas.	[119]
Ecuador	277 MW of electrical energy sources that are incorporated into the current	[120]
	mix excluding hydro electricity with a goal by the year 2022.	

shared with Brazil with 7000 MW, followed by Yacyretá, shared with Argentina with 1600 MW. In third place is Acaray, Paraguayan in its entirety with 200 MW. Only 25 MW corresponds to thermal generation, which places the Paraguayan state as the one with the most renewable energy available; , however, there are no policies to diversify its sources due to having sufficient and well-consolidated hydroelectric sources. In Peru, non-conventional renewable energies are being used very well and carrying out important work such as solar, wind and biomass, which generated a total of 1990 GWh as of September 2019 [127], which represents 4.69% produced for the Peruvian electricity market, while 22839 GWh were generated from hydroelectric plants. Peru is estimated to have a hydroelectric potential of 69445 MW, a wind potential of 20493 MW, solar radiation of between 4.5 and 6.5 kWh/m^2 and a geothermal potential of 3000 MW [102–104].

Uruguay is fourth in the world in wind and photovoltaic energy generation [128]. During 2018, 97% of the electricity produced in the country was based on renewable sources, if we add hydraulic energy and biomass (from the Montes del Plata and UPM pastures). In 2019 the International Energy Agency (IEA) [129] ranked Uruguay as the largest energy producer of solar and wind in Latin America and ranked fourth worldwide. Ecuador is listed as the fifth country that presents guarantees in the energy security system worldwide according to Ref. [130]. The Electricity Master Plan (PME) is aligned with the National Development Plan 2017–2021 - “All Life”, prepared by the National Planning Council (CNP). A fundamental part of the PME is the Generation Expansion Plan (GEP). There was a great boost to the Ecuadorian electricity sector in the 2007–2017 decade, as discussed in Ref. [131]. Currently, the projects do not stop. The CIER through [104] gives us the level of penetration of renewable energy by country to 2017 in which we identify in Fig. 10, while in Fig. 11 the level of generation by source can be seen.

In South America, we can see that both the largest and smallest countries are on a huge highway transiting the world of renewable energy, each with its own internal problem but fighting against climate change, the well-being of citizens and the permanent development of their lands [132]. Fig. 12 shows the electrical energy coverage index of the South American and Central American countries. It is observed that the highest levels of coverage are in the countries of South America.

Fig. 13 made using the data shown in Ref. [104] presents the statistics on the participation of the final consumer sectors in the energy invoiced in 2017.

Large countries such as Brazil have a significant presence worldwide, they are continuously included in world statistics. In this article, we are going to pay attention to Ecuador, a small country in terms of territory but one that has taken enormous steps in energy matters after having undergone several changes in its model.

2.3. Ecuadorian energy context

Historically, Ecuador has defined to modify its energy matrix, these changes have been the result of a long time of having been deeply dependent on oil prices, which have been the main source of exportation and national wealth, the income from which has always been special importance for the Ecuadorian State. For example, between 2007 and 2014 the price of a barrel of oil rose to as high as $ 83 [133], which allowed the government to build infrastructure works, including energy generators with renewable sources such as the Coca Codo Sinclair hydroelectric plant. These are the largest in the country with 1500 MW, and which are still under construction as the Toachi Pilatón.

Oil also caused problems for the country, especially due to the serious contamination in the Ecuadorian Amazon [133], where severe and lethal extraction techniques were used for environmental degradation and the health of ethnic groups not contacted by society [134], reaching a legal battle in international courts between the Ecuadorian country and the survivors of the Chevron company that merged with the oil extrativist Texaco that operated in Ecuador between 1964 and 1992 [135]. The bad lived experience, unresolved conflicts and the still latent consequences of pollution led Ecuador to launch in 2011 the initiative that promotes stopping climate change by creating a new paradigm, known as the Yasuní-ITT initiative [136–139], in which it consisted of leaving in

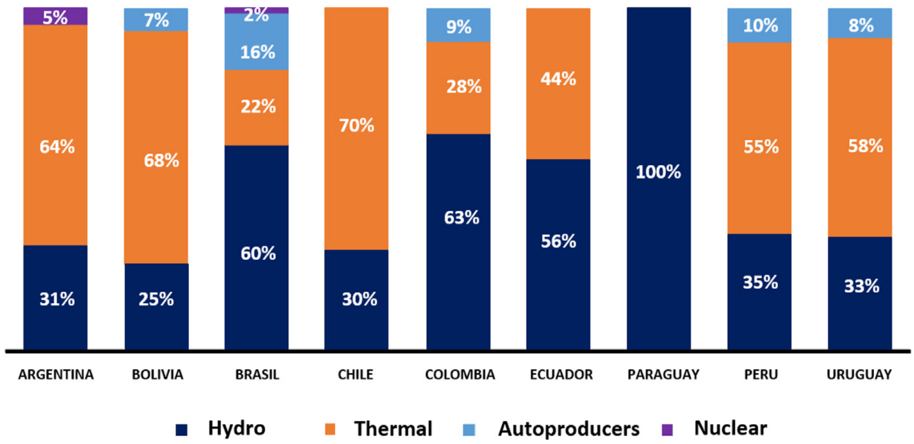

Fig. 10. Electric Power installed in the South America countries.

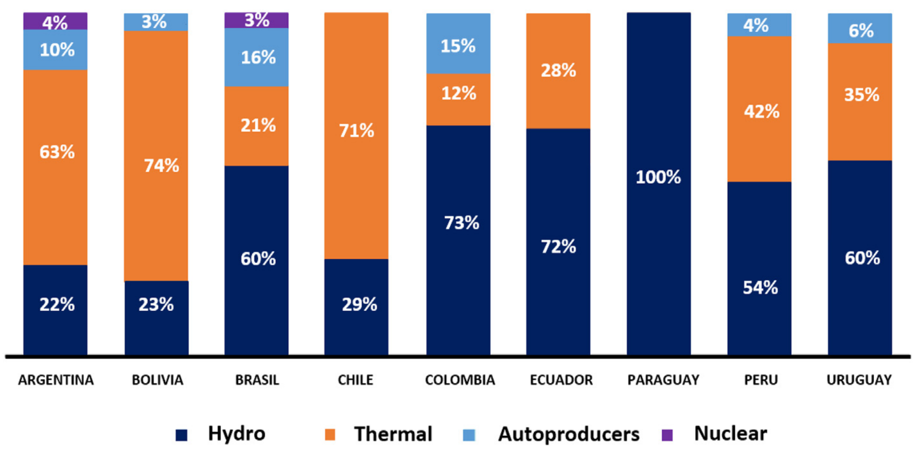

Fig. 11. Energy generation by source in the South America countries.

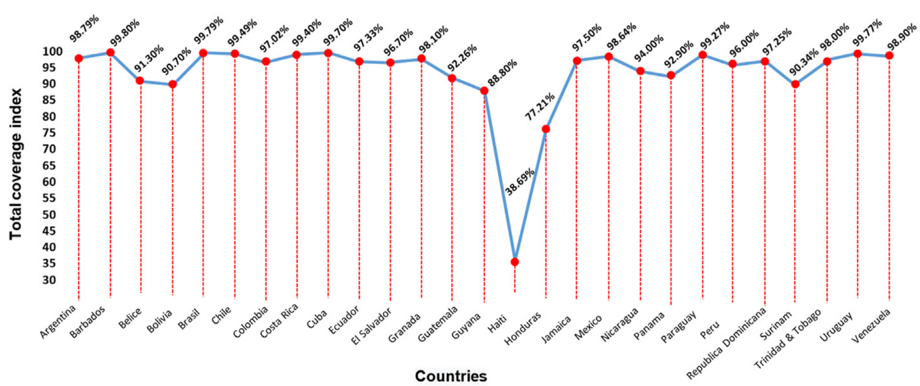

Fig. 12. Total coverage index for access to electricity in Central and South America.

perpetuity, unexploited and underground, part of its oil reserves in one of the most biodiverse areas in the world, committing not to exploit the crude oil of the Ishpingo-Tambococha-Tiputini field (ITT) located in the parquet Yasuní National, in the Ecuadorian Amazon in exchange for economic compensation from governments, institutions and even citizens from anywhere in the world [136]. This idea considered totally innovative had the concept of leaving coal underground, considered 20% of the Ecuadorian oil reserves, almost one billion barrels, to avoid the emission of 410 million tons of CO_2 into the atmosphere [137,138]. In the Yasuní National Park all records of species concentration are broken. For example, in 1 ha, we have more than 650 tree species, compared to a thousand species that exist throughout North America [136,138]. Sovacool B. in reference [139] analyses in more depth and talks about energy justice in the oil context of the Yasuni-ITT and makes comparisons with other areas worldwide and puts this area of the Ecuadorian Amazon as the most important for the abundant flora and fauna, Table 2.

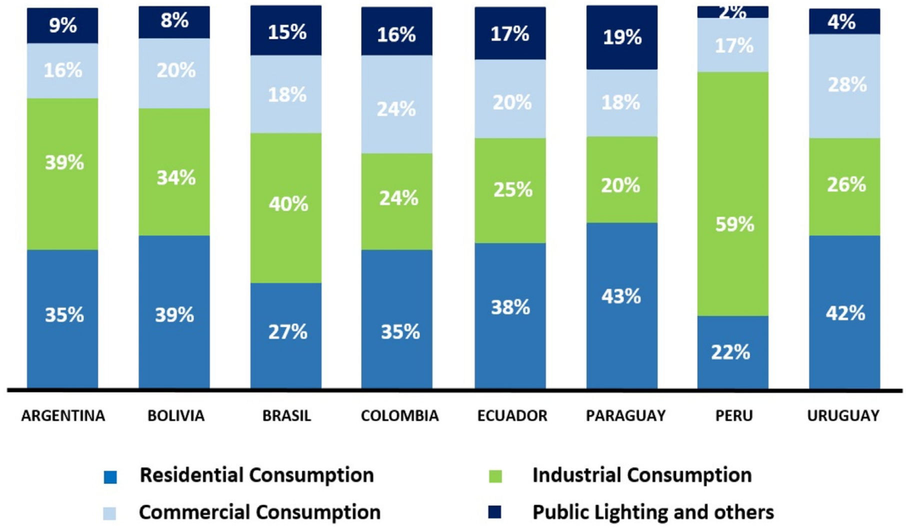

Fig. 13. Statistics of participation of the final consumer sectors in different South America Countries.

Yasuní-ITT implies protecting a diversity of species throughout its field, but it is also the space considered for the survival of its inhabitants, especially for hunting activities and virgin lands where ancient vestiges and natural healing plants of the indigenous people. The YNP is the life and reason for existing of the Huaorani and Quechua peoples, their ways of life and home are concentrated there, indigenous peoples in voluntary isolation to more than the Tagaeri and the Taromenane.

The four uncontacted groups indicated in the previous paragraph make up about 9800 people scattered throughout the park who live directly from hunting and harvesting wild fruits to appease hunger. Only the Huaorani will settle in an area with 612000 people, a space granted by the Ecuadorian state in 1983; on the other hand, the Quechuas live in the northwestern area of the YNP; meanwhile the oldest Tagaeri and Taromenane tribes live in the central and southern areas completely uncontacted from other civilizations of their own free will.

The destructive hand of man advanced to levels never seen before, especially due to the extraction of oil regardless of the lives of these primitive peoples, for this reason and for the different reasons that we address in this article, the energy transition to RE is the most appropriate option, added to the indiscriminate felling of plants, on the other hand tourism that seeks to contemplate these uncontacted civilizations, in addition to the incursion of researchers and missionary groups that seek to gain followers have invaded these areas altering the harmonic life of those who have historically lived at their own primitive style and have been happy in this way. However, Tagaeri and Taromenane do not maintain a peaceful contact with the outside world who invade their territories, they are not expected to mercilessly attack the unwanted, including workers from the oil companies.

Oil exploitation without a doubt it's a threat permanent to the cultural vitality of these groups, also to their subsistence and the ability to remain free from their organization [134,139]. In Fig. 14 the Yasuní park and the ITT block can be identified.

Finally, this initiative did not manage to obtain sufficient resources to leave the crude oil on land, and the ITT field was not exploited either. There are still several countries that are supporting the continuation of this initiative for the good of humanity [138,139]. The contamination by oil spills and the accelerated depletion of its reserves, additionally, the shortage of electrical energy in certain periods of estimate, such as those that occurred continuously between 1992 and 2007, led to having cuts or rationing of electrical energy, a situation that changed after 2007 [131], in which the national government launched the so-called change in the Energy Matrix, in which a series of large-scale renewable energy projects were planned [140–144]. Currently, the National Development Plan 2017–2021 - “All Life” is in force. Within the Plan, Objective 5 defines one of its goals as increasing electricity generation from renewable energy sources from 68.8% to 90% by 2021 [145]. As in all of South America, hydroelectric plants in Ecuador form an essential part as a permanent energy source, play a special role in energy generation, partly to stop using fossil fuels and, on the other hand, to their efficiency and immediate generation availability [146–148], currently is the main source of energy generation in the country and the largest employee

Table 2
Comparison of the richness of shrubs and tree species in different countries [139].

Place	Country	Small tree species/hect.	Large tree species/hect.	Position
Yasuní National Park	Ecuador	655	251	**1**
Lambir Hills National Park	Malaysia	618	247	2
Pasoh Forest Reserve	Malaysia	495	206	3
Khao Chong Wildlife Refuge	Thailand	380		4
Yunnan Province (Xishuangbanna)	China	292		5
Bukit Timah Nature Reserve	Singapore	276	113	6
Korup National Park	Cameroon	236	87	7
Palanan Wilderness Area	Philippines	197	100	8
Barro Colorado Island	Panama	169	91	9
Okapi Faunal Reserve (Ituri)	R.D. of Congo	161	57	10

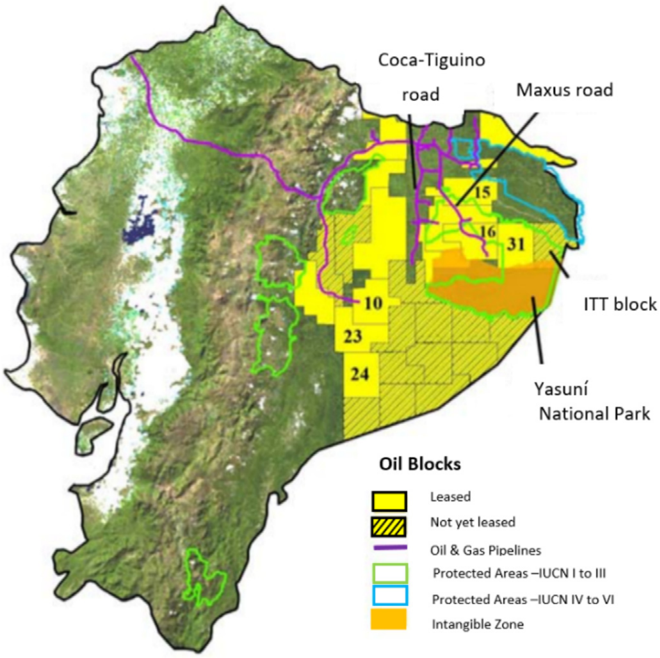

Fig. 14. Protected areas and oil concession in the Amazon of Ecuador.

[149–162]. According to the National Electricity Operator CENACE [163] presents the historical record of energy production for the period 1999–2019 in Fig. 15, the increasing trend is observed in accordance with the growth in demand, observing a decreasing trend in the generation of energy with thermal resources since 2016. This represents savings in the use of fossil fuels, causing positive effects on the country's trade balance and in reducing environmental impacts. It is also evident that since 2012, significant values of generation catalogued as Non-Conventional have been presented, also noting the considerable decrease in imports of electrical energy from 2016.

It is evident that the Ecuadorian market has restructured its energy matrix, as a result of concrete actions that have required innovation and we highlight in this research how it is: stop depending on electricity from neighboring countries, rely on renewable energy, and progressively limit energy presence of thermoelectric plants.

2.3.1. History of net energy production

Hydroelectric power generation reached the highest percentage in the last decade. After the incorporation of five plants that use this source, 81% of this resource was produced with these systems, in 2018. This percentage is so far the highest in energy generation with water sources, released in the National Energy Balance 2017 and National Energy Operator (Cenace) [164]. This has made Ecuador the main producer of water-based energy in the region. In Colombia and Peru, this source generates around 60% of energy. Years ago, in 2009, the generation of this resource depended almost equally on hydroelectric plants (51%) and thermal plants (48%) [164,165]. The latter use diesel, fuel oil, bunker and other derivatives, which are imported and pollute the environment. Over time, that relationship changed when they began to operate progressively, since 2015, Manduriacu, Sopladora, Coca Codo Sinclair. And, since the end of 2018, Delsitanisagua and Minas-San Francisco. Surely, with the operation of the Toachi-Pilatón, Mazar-Dudas and Quijos hydroelectric plants, the percentages of renewable energy generation with water sources will be higher. With this, the goal of increasing from 68.8% to 90% of 90% will be met. Electricity generation through renewable energy sources contemplated in the National Plan for a Lifetime 2007–2021 in its objective 5 [145]. In all this new infrastructure, the country has invested around USD 5.6 billion, until last January. The incorporation of the five, whose construction began in the previous Echo Government. Rafael Correa in the 2007–2017 decade, which is extensively addressed in Ref. [131] Ponce-Jara, M. A.

It is important to understand that with the Electricity Sector Regime Law (ESRL), of October 10, 1996, the Wholesale Electricity Market is established in Ecuador with the participation of generators, distributors and large consumers that are part of the SNI, as well as International Electricity Transactions. Two types of

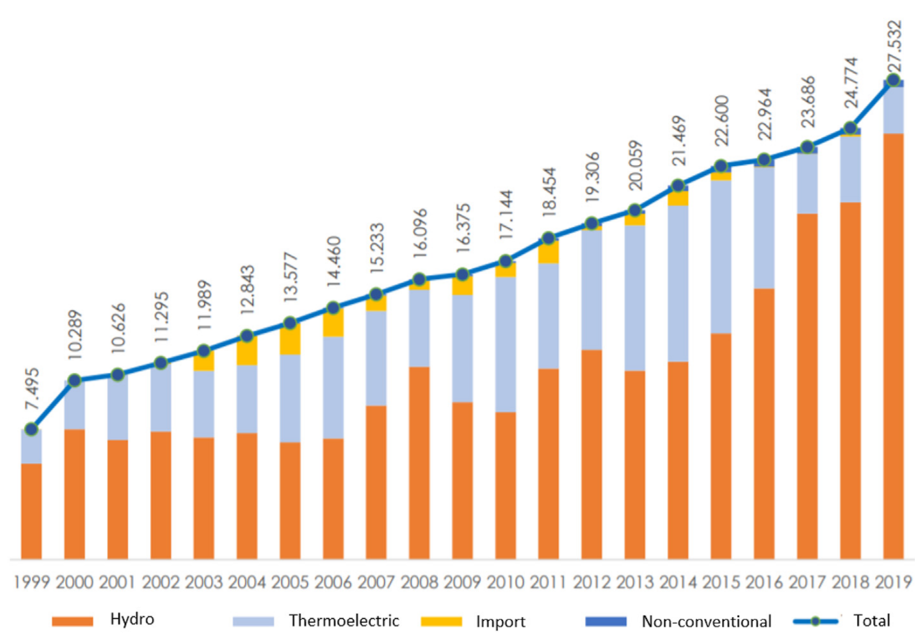

Fig. 15. Power generation by type of production in Ecuador (GWh), 2019.

commercial transactions are established in this market: transactions in the occasional market or spot market and the forward contract market. The Constitutional Mandate No. 15 of July 23, 2008, published in the Official Registry No. 393 of July 31, 2008, is issued to fulfill the responsibility of the country regarding the provision of public electric energy service, under the principles of efficiency, responsibility, universality, accessibility, continuity and quality, through the establishment of norms that allow reform of the operating structure of the Ecuadorian electricity market. One of the main reforms was the elimination of the marginalist model and greater participation of a long-term market, through contracts: regulated term contracts that, as a result of public tenders, are signed between private generators and distributors; Regulated term contracts signed between generators in which the country has participation, without exception, and distributors; and, freely agreed term contracts between those private generators and large consumers that are duly empowered. In this context, Fig. 16 shows the change in structure in the commercial operation of the electricity market, with transactions appearing through regulated contracts that until January 2018 were the only contracts that existed between participating companies. Thus, the elimination of unregulated contracts since 2009 is also evident.

Table 3 shows the relationships and differences of the Ecuadorian electricity system in the 1999–2007 period and the 2007–2017 period highlighted by Ref. [131].

2.3.2. Energy production by generation source

Within the last CENACE publication [163] to 2019, it's specified that the net energy produced by the plants considered in the block transactions in 2019 was 27532.24 GWh, with a participation of 88.83% of the hydroelectric production, followed by thermoelectric source with 9.68%, a 1.46% share of energy from unconventional generation and 0.02% of international electricity imports (See Fig. 17).

The National Electricity Operator, CENACE, through the National Government, generates technical and strategic information necessary for the development of the Ecuadorian electricity sector as shown in Fig. 18. This information can be obtained updated every hour. The record of maximum demand of 3949.9 MW was registered on May 8, 2019 at around 7:00 p.m. with a supply of 91% with hydroelectric power.

In relation to thermoelectric production, 46.58% of the generation was produced with fuel oil, one of the least expensive fuels within the thermoelectric generating park, and only 5.09% was produced with diesel. With respect to renewable energies that are entering the mix of energy production in the country, excluding energy from hydroelectric power, it can be seen in Fig. 19 that biomass is renewable energy with very good acceptance with 62.12% per year 2019.

Despite the great advances in aspects of hydroelectric production at the national level, the development of this sector cannot be limited. In recent years, solar, wind and biomass energy projects have also been developed [142] according to the change in the Ecuadorian productive matrix. Proof of this is the construction of the Villonaco wind farm in the Province of Loja [149,150] and the solar energy park in Galapagos [151], among others. There are also projects under development, such as the Minas de Huascachaca Project, which will have 50 MW capacity with 11 wind turbines [166], the Villonaco II and III wind project with an installed capacity of 110 MW, and the El Aromo Project, which instead of The Pacific Refinery will house the Photovoltaic Power Plant with an installed capacity of 200 MW [167]. The approach is that it is not only necessary to satisfy the current energy needs but also the energy needed due to the transfer of using energy from fossil fuel energy and the increasing demand for the increase in the population [103,148]. For more than a decade, Ecuador has been promoting a change in the productive matrix, transferring a productive matrix based on fossil fuels for that of clean and renewable energy, as stated in the Constitution of Ecuador, as it is a right to Good Living in its chapter II to live in a healthy environment [152]. In Chapter VI the rights of nature are considered, one of the few constitutions together with that of Bolivia that provides these rights and guarantees [152,153]. In the previous Plan for Good Living, as in the National Plan for a Lifetime in force, the use of renewable energies is promoted, clearly specified in the Fifth objective: Boosting productivity and economic sustainability.

2.3.3. History of total demand

The historical information on energy demand allows us to appreciate an increasing trend, consistent with the information previously presented in the history of energy generation. It is necessary to indicate that the demand presented in Fig. 20

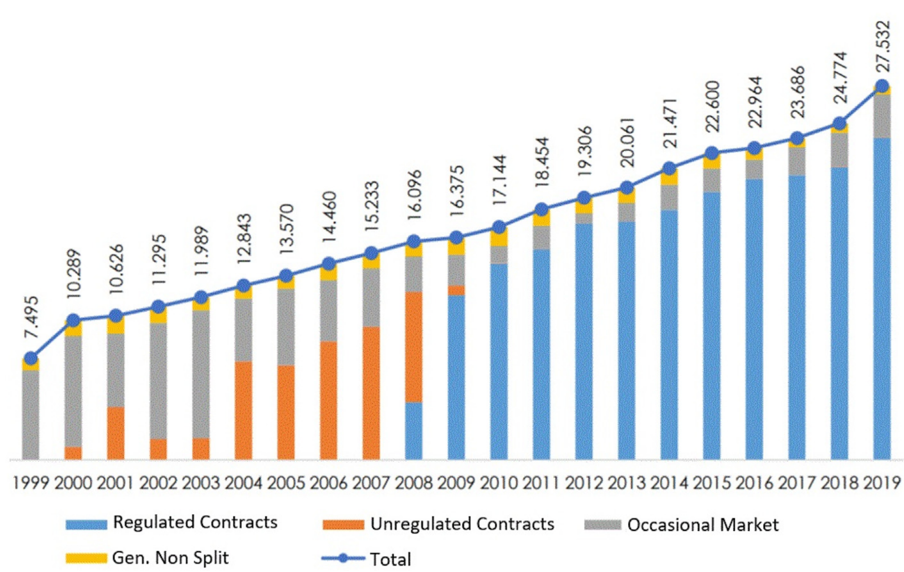

Fig. 16. Power generation by transaction type in Ecuador (GWh), 1999–2019.

Table 3
Characteristics of the Ecuadorian energy context.

Singularities	Lapse 1999_2007	Lapse 2007_2017
Legal aspect	Electricity Sector Regime Law approved in 1996.	The LRSE was terminated. Subsequently, the Organic Law of the Public Electricity Service (LOSPEE) was put into effect.
State organization	CONELEC controlled and regulated the electricity sector, CENACE in charge of the wholesale commercial aspect.	Made up of government institutions: MEER, ARCONEL, CENACE, CELEC and CNEL. Also its business units. Very few private companies in charge of electricity generation.
State action	The State regulated and controlled the electricity sector.	The State administers, regulates, controls and manages the entire electricity sector (generation, transmission, and distribution).
Market	Liberalised	Regulated
Tariff aspect	Considered by the market	Considered by the ARCONEL

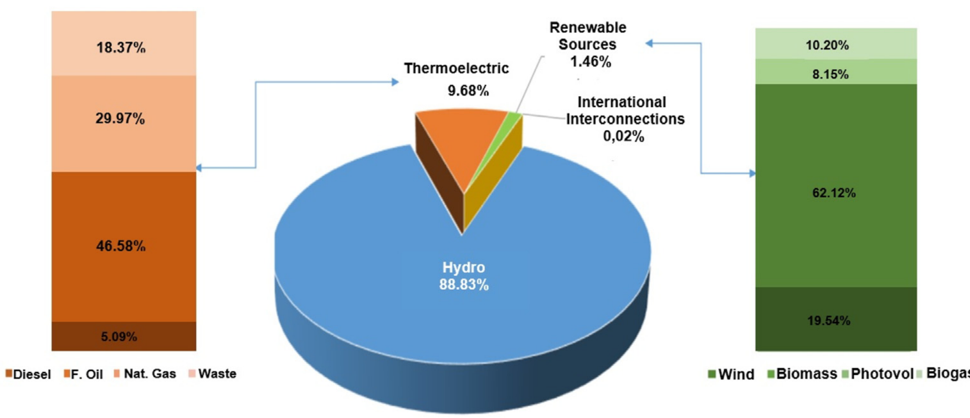

Fig. 17. Percentage generation by type of production in Ecuador, 2019.

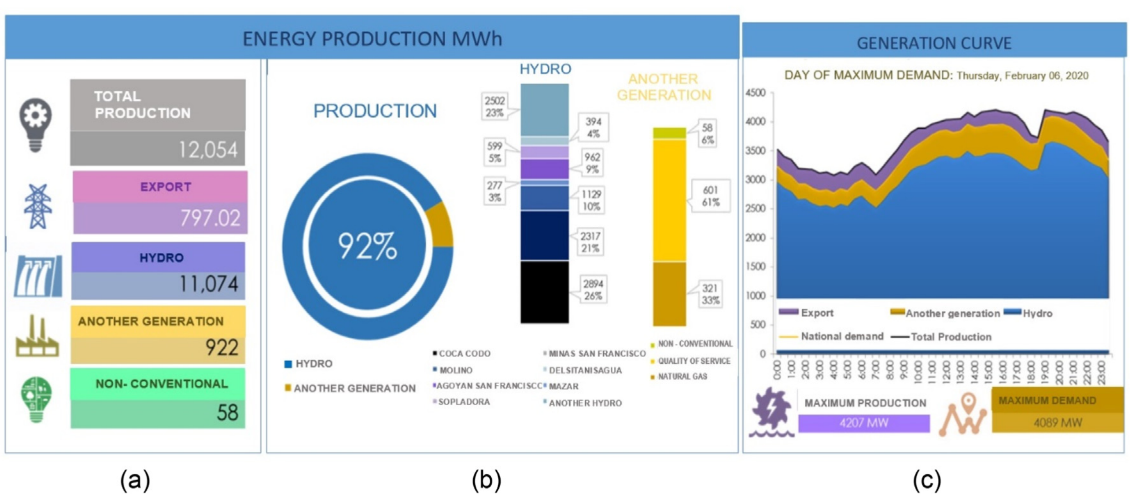

Fig. 18. Annual operating information in Ecuador as of June 11, 2020. (a) Energy production by source in GWh. (b) Percentage contribution of the generation system (c) Electricity generation profile, February 2019–February 2020.

considers the commercial demand for electricity exports.

For 2019, approximately 99.98% of production has been generated with the country's generation plants (27532.24 GWh), while only the remaining 0.02% (5.83 GWh) has been covered by electricity imports as shown in Fig. 20a. On the other hand, approximately 93.13% of the system's commercial demand (26,568.66 GWh), has been for the country's consumption, while the remaining 6.87% corresponds to electricity exports. During 2019, the import values correspond to unforeseen minimum exchanges due to the operation of the closed interconnection in synchronous mode under the command of automatic generation control.

2.3.4. International electricity transactions with Colombia and Peru

Regarding energy exports considered in Fig. 21b, in February and March 2019, the highest values were presented because the generating park had hydrological conditions that allowed it to offer surplus energy to Colombia. It is necessary to mention that Ecuador

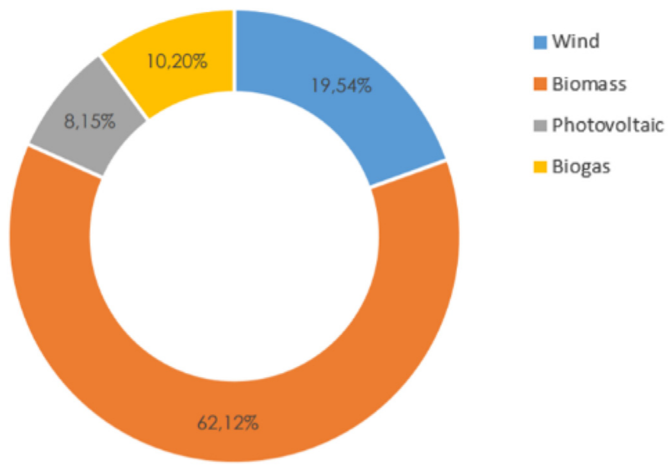

Fig. 19. Energy production with renewable sources in Ecuador (GWh), 2019.

and Colombia operate with the four circuits at 230 kV closed; that is, the countries are always interconnected; therefore, there are permanently energy exchanges, which are called unforeseen exchanges and are settled as an import or export as appropriate. For 2019 there were no imports of electricity, thanks to the country's hydrological conditions presented in most of the year; Only exports occurred due to specific contingencies presented in the Peruvian electricity system, which enabled transactions with the neighboring country to become viable.

In 2016, the highest average prices in the history of electricity imports and exports with Colombia were recorded; however, in this same year, imports decreased by 90% and exports increased by 737% in relation to 2015. It is important to note that, in 2019, exports increased by 657% compared to 2018, as seen in Fig. 22a. In Fig. 22b, transactions carried out in the last five years with Peru are recorded, mainly for electricity exports.

2.3.5. Energy efficiency strategies

Ecuador also works to migrate obsolete and polluting technologies at the demand level, since it is not enough to produce clean energy when there is a demand that still contaminates [154]. Progress in this regard is in constant progress. We can cite the promulgation of the new law on energy efficiency that requires that from the year 2025 electric public transport vehicles be purchased [145,154] however, it is noteworthy that more than the law is the cooperation of municipalities and citizens aware of these changes in order to protect our environment, giving rise for example to the implementation of new electric taxis in the city of Loja [155], the launch of the 4Rios tram in Cuenca [156,157], the slow but important change from LPG cookers to electric cookers [158,159]. The demand for natural gas in Ecuador has affected households and, as it is subsidized, the majority of citizens prefer its use for cooking food and heating water; however, the government is looking for ways to offset this growth with electricity subsidies where 100 kWh is not exceeded given its increase in energy production from RE sources that were incorporated in the last decade and continue to penetrate the national energy market. Table 4 summarises six energy efficiency plans or programs that are being applied by the previous government that are currently being applied (see Table 5).

According to the literature exposed in the previous sections, it is clear that South America and the entire world are strongly modifying their energy matrix and as their main ally, they have renewable energies. There are clear advances and penetration of clean energy technologies at increasingly accessible prices. With these motivations, they are minimising the risks of their oil-dependent energy system and, Promptly, carry out their plans to modify their energy generation systems. In this sense, Ecuador is working hard to make a reality with the change in its energy matrix and increasing production from renewable energy sources. In Fig. 23 we can identify the energy supply sources made up of renewable energies and oil derivatives, and at the exit, we can identify the demand classified by sectors as of March 2020 provided by Ref. [172].

In Ecuador there are very good prospects for continuing to modify the productive matrix, it was largely analyzed that the legal and regulatory part creates a good environment so that renewable energies can get closer to Ecuadorian Cities, added to government programs and plans for National development generates these opportunities. It is true that hydroelectricity continues to play an important role with more than 80% of generation, new projects are also underway, and the diversification of removable energy sources is possible thanks to the budgets that are allocated annually by the

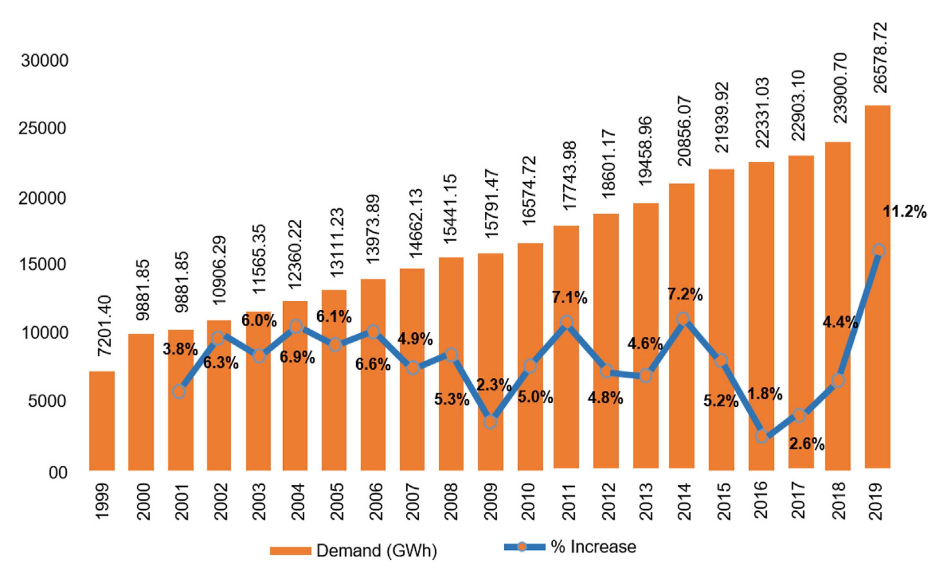

Fig. 20. Historical behavior of total demand in Ecuador (GWh), 1999–2019.

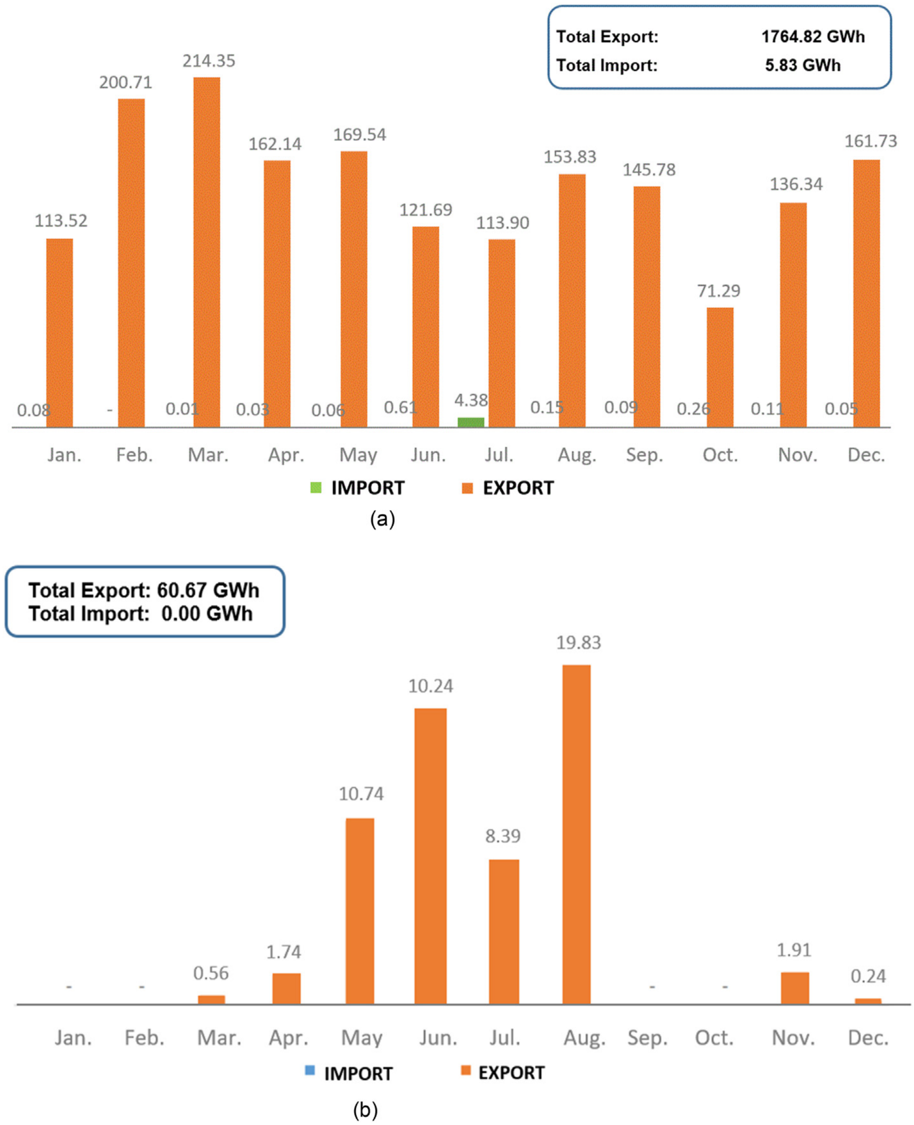

Fig. 21. International electricity transactions in 2019. (a) Colombia. (b) Peru.

National government. In this sense, several authors have already released their forecasts, among them Golla, S.et all [173]. in which he ends the oil and traces a scenario considering an energy mix. Additionally, Arroyo M [170].clearly highlights that renewable energies will play a leading role for sustainable energy governance and environmental policies to mitigate climate change in Ecuador. It proposes that the electricity sector carry out innovation and, above all, make long-term plans.

In consequence with these approaches and the data available here in a more precise way, Ecuador is moving towards decarbonization and not depending on oil directly. In this sense, as a contribution of this research, it is also considered to propose the 100% renewable scenario to 2050 using a methodology similar to that recommended by Ref. [12] and presented in a summarized way in several reference investigations such as [11,13,15,20] in which the main purpose is to guide the way forward for decision-making and develop coherent actions to meet these purposes. These planning systems today have become innovative and clearly present the development horizon to which it must be promoted in the energy aspect [174]. It does not contemplate political or socio-cultural trends. In this sense, without being the main objective but conscious of providing answers and long-term development paths for Ecuador. We allow ourselves to present the results considering the recommendation of [175,176] to diversify renewable energy sources, according to the available energy potential. In this sense, references [140,174] highlight the rich energy potential available in different areas of the country, including Galapagos [177]. Wind, solar, hydroelectric, biomass, geothermal and others on a small scale stand out [178].

The results are highlighted below when proposing a novel 100% renewable scenario with the support of Energyplan software and what is transcendental is that what Ecuador has advanced until today, both in the legal aspect, infrastructure and allocation of economic resources serve as the basis for make projections to 2050 and determine in an adaptable and flexible way the renewable energy sources that will be integrating the energy mix.

2.4. Energy model with a vision to 2050

2.4.1. Technical effects

Renewable energies are generating confidence in the countries, currently there are diverse experiences worldwide and in the

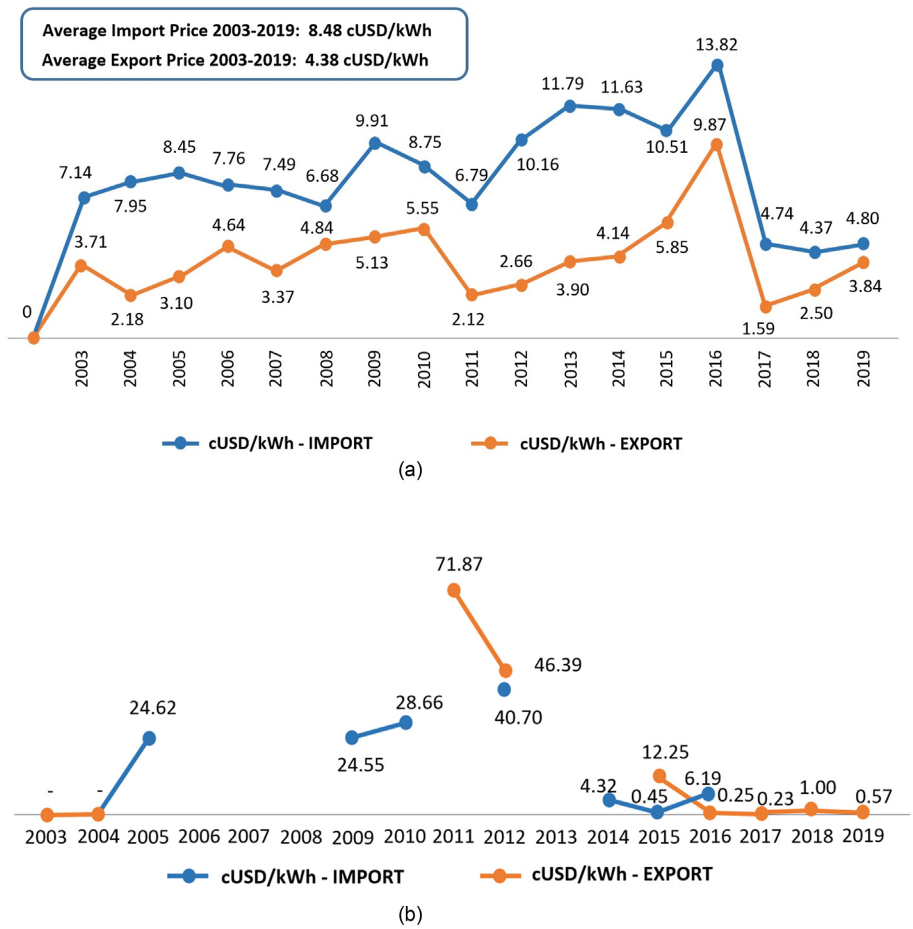

Fig. 22. (a) TIE Colombia average prices 2003–2019. (b) TIE Peru average prices 2003–2019.

Table 4
Ecuadorian energy efficiency programs [168–171].

Programs	Denomination
1. Technical loss reduction program.	The purpose is to minimize technical losses in electrical transmission and distribution.
2. Energy efficient and safe cooking program.	Cooking using electric induction stoves.
3. Equipment standardization and coding program.	Its objective is to promote the acquisition of highly efficient equipment in the residential area.
4. Effective replacement program.	Replacement of appliances such as inefficient freezers and refrigerators. Replacement of high-consumption light bulbs with low-consumption light bulbs that provide adequate levels of lighting at the residential level and in public spaces where there is lighting.
5. Education and training for public sector personnel program.	Promote energy saving in public sector buildings and facilities.
6. Management indicators.	Implementation of the ISO 50001.

countries of South America they are gaining strength. It is highly advisable to have a diversity of energy sources in a country, by 2050 we project it as a reference year in which it is possible to achieve a 100% renewable system [179–182]. However, it is important to evaluate the level of incidence of renewable energies in the year defined as the transition base through Renewable Factor (RF) indicated below (1) and (2):

$$Renewable\ Factor\ (RF) = \left(1 - \frac{\sum P_{non-renewable}}{\sum P_{renewable}}\right) x100 \quad (1)$$

$$RF = \left(1 - \frac{\sum P_{diesel} + \sum P_{gasoline} + \sum P_{coal} + \sum P_{coal} + \ldots\ldots \sum P_{others\ non-renewables}}{\sum P_{PV} + \sum P_{wind} + \sum P_{hydro} + \ldots\ldots \sum P_{other\ renewables}}\right) x100 \quad (2)$$

Table 5
Current and projected installed capacity by 2050 in MW. Taking into account the recommendation of Dominković Dominik Franjo et al. in Ref. [180] where it states that it is important to consider the sensitivity of hydraulic energy and for the purpose of analyzing long-term energy scenarios, it recommends maintaining or reducing the percentages of hydraulic energy production up to 50%. In our case, we maintain the percentage of hydraulic contribution until 2050 as shown in Table 4. The intention is to diversify the energy matrix with other feasible sources of exploitation, especially wind and photovoltaic.

SourceSource	2020	2050
Hydro	6020	6020
Wind	10	5610
PV	10	5700
Geothermal	2	903
Biomass	6	301
Natural Gas	1000	
Residual Fuel Oil	850	
Diesel Oil	1700	
Crude Oil	850	
Propane LPG	100	
Others	700	1493.2

Non-renewable energies are mainly those from oil and coal derivatives expressed with $\sum P_{diesel} + \sum P_{gasoline} + \sum P_{coal} + \sum P_{coal} + \ldots\ldots \sum P_{others\ non-renewables}$. Other sources of a pollutant type can also be evaluated depending on the reality of each country. Regarding renewable energy sources, they are all those that intervene in the energy mix such as wind, solar, hydraulic energy, among others that are of renewable origin $\sum P_{PV} + \sum P_{wind} + \sum P_{hydro} + \ldots\ldots \sum P_{other\ renewables}$. By 2050, this factor is expected to be mathematically 1 ($RF = 1$).

Evaluating the electrical system in the base year that will serve as a reference and above all it is possible to quantify an energy development horizon is proposed, which is to 2050 in our case, the mathematical relationship is established below (3):

$$TAPE = \sum P_{rene-2050} - \left(\sum P_{\ rene\ base\ year} - \sum P_{non-rene}\right) \tag{3}$$

Where TAPE corresponds to the Total Additional Projected Energy, $P_{rene-2050}$ is the total supplied Power evaluated in the year 2050, $P_{\ rene\ base\ year}$ is the nominal power supplied in the base year that serves as a reference to carry out the projections, $P_{non-rene}$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) is characterized by the possibility that the renewable energies implemented in a country satisfy the demand for electrical energy for a range of time 0 to T, as expressed in relation (4).

$$ESR = \sum_{0}^{T} \frac{P_{rene-2050} - P_{DEMAND\_2050}}{P_{rene-2050}} \tag{4}$$

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 is a surplus of energy per target year that can be used for export to neighboring countries.

When $P_{rene-2050} < P_{DEMAND\_2050}$ There is a shortage of energy in the target year which represents a serious inconvenience in the development of the country.

When $P_{rene-2050} = P_{DEMAND\_2050}$ There is a balance between production and consumption of electrical energy, it is a risk point of energy shortage.

An energy storage system is important to avoid falling into a shortage range and to take advantage of hours of excess energy.

2.4.2. Cost of energy

This section describes the renewable energy system design based on the cost of energy (COE), which is a well-known and important factor in obtaining an optimal and profitable system. The average cost per kWh of the useful electrical energy generated is known as COE [183]. The evaluated COE:

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

Where, PL is the hourly energy consumption in kWh, TNPC is a current net total cost of $ and CRF is the capital recovery factor CRF. The CRF is a ratio used to calculate the current estimate of benefits, that is, a progression of equivalent annual monetary flows. It is evaluated by the following equation [35]:

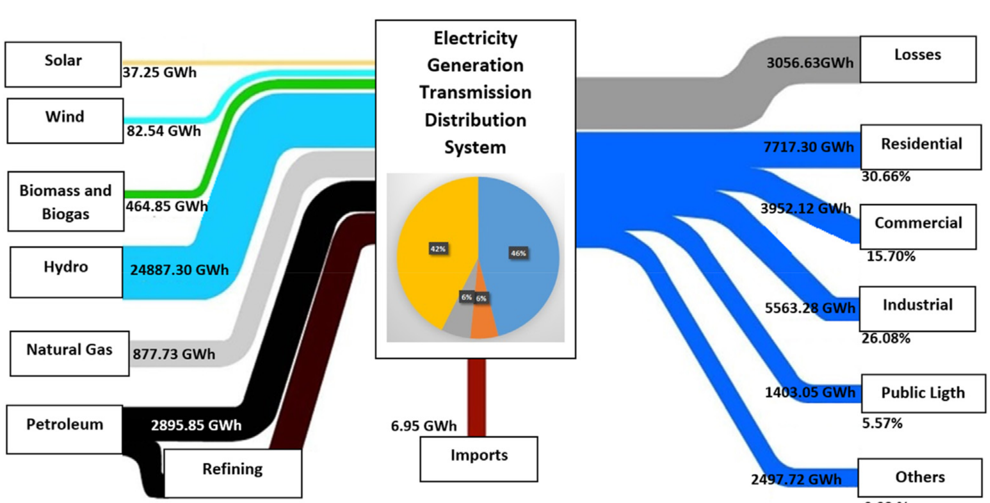

Fig. 23. Ecuadorian balance of electric power system cut March 2020.

$$C_{RF} = \frac{I(1+I)^N}{(1+I)^N - 1} \tag{6}$$

I is the real interest rate, N is the number of years.

2.4.3. Human Development Index (HDI)

In general, the Human Development Index (HDI) is used as a statistical instrument to scale the overall achievements of a nation in its social and financial measures. Yashwant Sawle et al. [183] represents the HDI as the sum of the elements “y" and the control approach “z" evaluated based on equation (7) expressed below:

$$HDI = 0.091\ ln\left[P_{LY}/_{C}\right] + 0.07214 HDI_{y,z} = 0.0978\left[\left(P_{LOAD} + min\left(f_{max_{SE}}.P_{SE}.f_{maxp_{load}}.P_{LOAD}\right)\right)\Big/ n_{HUMAN}\right] - 0.319 f_{max_{SE}} \tag{7}$$

Where;

$f_{max_{SE}}$: Element of maximum consumption of surplus electrical energy and can be used for additional AC charging.
$P_{LY}/_{C}$: Energy yearly electricity consumption per capita in kWh/yr/person
P_{SE}: Annual system surplus energy in kWh/year
$f_{maxp_{load}}$: Element that allows increasing the annual AC load and that the maximum surplus energy can be used.
n_{HUMAN}:Number of people consuming power generated from the hybrid system.

3. Results and discussion

The results are divided into the study of global socio-economic viability of the system by 2050, the marginal viability considering hydro production constant and going to a transition of polluting energies by viable renewable energies for exploitation in Ecuador. The starting scenario presents an installed power of 11248 MW and by 2050 with 20027 MW.

It should be noted that the scenario is based on a recommended realistic status. However, the possibility of exploiting various renewable energy sources is more significant, geothermal energy currently does not figure within the energy mix, but it can very well be exploited massively given that it has the resource [179]. However, in our scenario, it is consider it with an exploitation level that does not exceed 15%. Similarly, the same solar and wind energy can be massively exploited, but we maintain their exploitation ranges at measured levels. See Fig. 24.

In Fig. 25 and Table 6, the total primary energy supply in 2020 and 2050 can be seen. In 2050, all energy supply is 100% renewable, based mainly on hydro, wind and PV energy. There are small contributions from other energies, but they will not be enough to get some of the mentioned ones out of operation.

Fig. 26 shows the 100% renewable energy generation mix by 2050.

With these results, the transfer from high dependence on fossil fuels to complete self-sufficiency through renewable energies is the main challenge of each future government, but above all a sustained agenda is required to carry out these actions, for this reason They need long-term policies to encourage the development of new technologies focused on unconventional clean energy sources such as solar energy, wind energy, geothermal energy, biomass and maintain the current infrastructure based on hydropower. It is necessary to have effective guidelines that allow infrastructure projects according to a change of time in Ecuador within the South American context that is also marching at an accelerated pace as has been observed in the literature described here, guaranteeing the electric power service with the highest quality standards. Renewable energy in Ecuador begins to develop and promises in the coming years to play an important role in reducing the generation and consumption of energy sources with high carbon content. An orderly transition with an economy of renewable energies and low carbon emissions is key to mitigating climate change in Ecuador, where pollution levels are outside of those allowed. Climate policies adhering to CO_2 emissions nowadays no longer

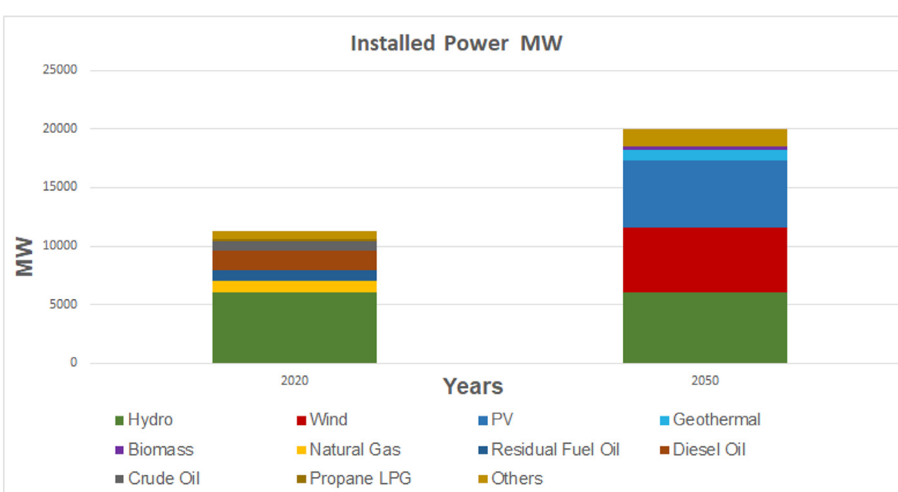

Fig. 24. Installed power capacity by sources en the scenario from 2020 to 2050 in Ecuador.

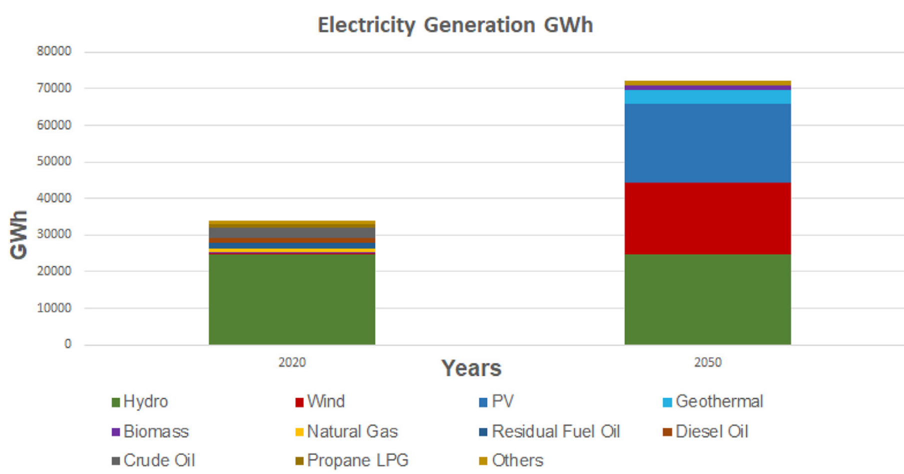

Fig. 25. Primary energy supply in the year 2020 and 2050 in Ecuador.

Table 6
Current status vs. projected scenario to 2050,100% renewable.

Source	2020 (GWh)	2050 (GWh)
Hydro	24887.3	24887.3
Wind	82.54	19554.3
PV	37.25	21331.9
Geothermal	15	3733
Biomass	464.85	1244.3
Natural Gas	877.73	
Residual Fuel Oil	1500	
Diesel Oil	1300	
Crude Oil	2895.85	
Propane LPG	1000	
Others	700	1493.2

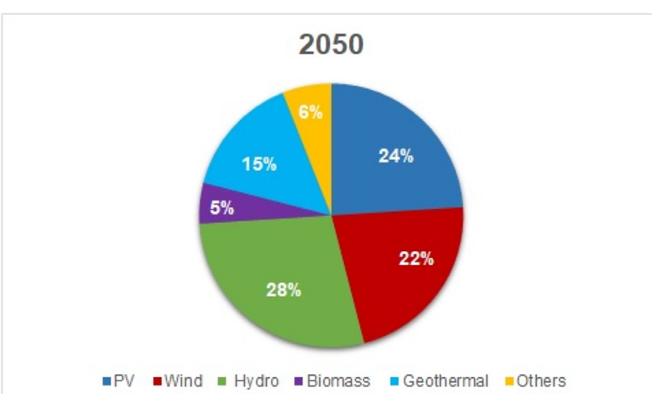

Fig. 26. Mix of renewable electricity generation in the year 2050 [GWh].

have cavities and cause rejection in the population due to the adverse effects on human health. Increasing the use of renewable energy would discourage those who resist change and stay current from using fossil fuel consumption and thus mitigate carbon. This study finds a long-term positive equilibrium relationship between renewable energy consumption and economic growth. This research already shows that the energy system in Ecuador will grow close to double by 2050, from 33760 GWh to 72244 GWh. This implies taking forceful actions by the central government and maintaining that same line in future mandates with the firm intention of radicalizing the change in the Ecuadorian energy matrix. The promotion of renewable energies invigorates and stimulates the economic and sustainable growth of the nations and Ecuador with all the energy wealth available and that is not currently being used effectively, it can become an avant-garde and very prosperous country.

3.1. Economic analysis

In Ecuador, subsidies for electricity and oil derivatives have been part of state policy since 1974, it emerged as a compensation system when the sucre currency was in force, particularly at times when the international price of oil was booming, which increased the exploitation of oil for export. In this situation, a substantial increase in tax collection and an economic surplus were also achieved in the country. In the first instance, this allowed to meet the requirements of military transport in the following years, it applied to public transport and finally to private transport. The purpose of expanding the subsidy policy was to reactivate the economy of the poorest social groups, in addition to also applying the subsidy to liquefied petroleum gas (LPG), maintaining it over time. However, when the economic situation began to falter due to the currency exchange from sucres to dollars, that is when the state stopped investing in electricity generation projects. Additionally, the price of imported gas was higher than the price of hydrocarbons domestically.

Since the time of President Rafael Correa, as of 2007 the Ecuadorian electricity sector began to renew itself, especially because the energy mix began to include higher percentages of renewable and diversified energy with clearer policies and concrete actions with the implementation of different hydroelectric, wind and photovoltaic generation plants mainly. Energy efficiency policies were also promoted, among the most important being the acquisition of electric stoves that allow citizens to use electricity instead of LPG [181], in order to eliminate the subsidy for gas for domestic use, and obtain savings in the Fiscal cash of almost 2000 million dollars annually, in this way its collection was aimed at increasing public investment in new electrification projects. After this Correista period there have been no major advances, however, from the Constitution to the development plans, they are providing the tools for the energy sector to take advantage of renewable energy sources as a pillar of the country's economic development.

The Central Bank of Ecuador in its report issued according to Ref. [182], states that between 2007 and 2015 Ecuador has spent around 22 billion dollars on fossil fuel subsidies. The main subsidized fuel has been diesel, then extra gasoline, LPG and premium

Table 7
Plotting scenarios to determine the average cost of production.

Description	Scenarios		
	S1	S2	S3
Average growth in net electricity demand up to 2050 (%)	20	30	40
Total costs up to 2050 (millions of dollars)	60000	50000	40000
Average growth of electricity available service until 2050 (%)	15	20	25
Losses of electricity in transmission and distribution systems until 2050 (12.42% in 2017) (%)	12	15	18
Electric vehicle sales growth up to 2050 (%)	20	15	15
Change of LPG for the consumption of electricity to heat water in the domestic sector (%)	7	17	27
Penetration level of electric stoves.	8	12	18

gasoline.

Consequently, the policy based on subsidies has been the mechanism for the governments of the moment to keep calm the population that became accustomed to this economic dynamic of apparent contribution to the lower social class, this has transformed into a fiscal burden and entails not being able to promote with greater determination some other electrical projects. At present even these sources are considered as sources of access to produce contamination, they are a virus within the economy, sources that must be progressively withdrawn, or in their reason, if the interest is to support the population, the subsidy must be transferred to those who do. use of electric power systems. In this way, it is possible to motivate citizens to use and take advantage of non-polluting electrical systems and accelerate the change of the energy matrix with values equal to or less than $ 0.10 per kWh [131].

In relation to the economic analysis, three scenarios are drawn as shown in Table 7: conservative (S1), expected (S2) and optimistic (S3). The value that most affects the scenarios outlined is the cost of the technology, which is between 40000 and 60000 million dollars. Values that are undoubtedly considerable and put in check future governments that should promote these projects, possibly in alliances with other countries, but that stopping doing so may be more expensive when European and Asian countries have been modifying the electricity market for a long time [184–187]. Based on high contribution rates from renewable energies, including countries within South America, it has been difficult for them to replace these large volumes of polluting energy with clean energy and today they are in clear development. This article outlines a roadmap that will surely influence decision-making and on this basis, more discussion will be generated by researchers, professionals and people linked to the electricity sector.

Next, Fig. 27 shows the proposed scenarios regarding the forecast of the cost of electricity production. It is identified that the

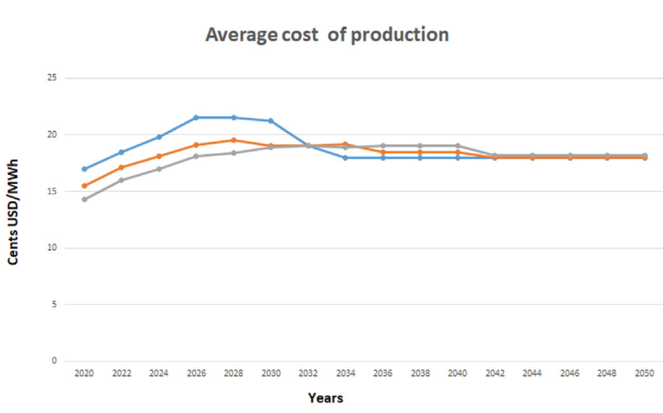

Fig. 27. Average cost of production.

impact according to the required costs S1 is the highest, causing a high rate until 2032 due to the highest investment made, which ends up falling on the electricity rate. However, in S1 it becomes interesting when in years close to 2050 the prices in the three scenarios S1, S2, S3 tend to be constant in 18 cents USD/MWh. It implies that a real rate as specified in this analysis is free of subsidies and above all it requires a 100% renewable technology change and having the operating system supported by O&M available. From the point of view of the transformation of the electricity sector, it has great positive repercussions on society, such as having healthy people, generating employment in a cleaner industry, the possibility of conserving the unique species on the planet, among other benefits. This transformation opens up a range of growth possibilities in different productive areas, boosting the country's economy.

3.2. Policies on Ecuadorian 100% renewable electricity generation system by 2050

Ecuador's development has been based on the sustainable development goals that were raised in the national development plan known as National Plan for Good Living 2013–2017 (PNBV), then this plan was renewed by the National Plan for a Lifetime 2017–2021 (PNTV) that is currently in force.

In reality, the objectives in relation to the energy transition are maintained and aligned with what is related to:

- Ensure the sovereignty and efficiency of strategic sectors for industrial and technological transformation.
- Promote the transformation of the productive matrix.
- Guarantee the rights of nature and promote environmental, territorial and global sustainability.
- Improve the quality of life of the population.
- Promote equality, cohesion and social and territorial integration in diversity.

In the country, energy planning and the gathering of statistical information have not been part of the strategic lines of development for several years, much worse to make projections and plan the electricity system in the long term as if they carried out much more developed countries. The change in the structure of the Ecuadorian electricity sector is generated as a result of the new Montecristi constitution of 2008 promoted by former President Rafael Correa, which includes rights to nature, energy sovereignty, economic boost with the contribution of renewable energies, in other aspects. From now on, the changes have been very positive and, above all, the construction of diversified generation plants was given impetus, including hydroelectric, wind, solar photovoltaic, etc.

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Currently, the Ministry of Energy and Non-Renewable Natural Resources is the state portfolio in charge of directing, planning and legislating electricity, hydrocarbon and mining energy.

Among his duties regarding the electricity sector are:

1. Increase efficiency, institutional capacities and productivity in harvesting of energy and mining resources.
2. Increase the efficient use of electricity demand at the national level.
3. Increase the quality, continuity, resilience, security and coverage of the public service of electric power.
4. Increase the supply of electricity generation and transmission in the country.
5. Increase the spaces for dialogue, follow-up and coordination between the actors of the territory for compliance with sustainability mechanisms in environmental management and of the energy and mining sector in the areas of influence of its projects.

Ecuador has enormous unused potential in renewable energy, due to factors such as its location on the equator, which allows it to receive the maximum solar energy per unit of surface area, its high rainfall and the Andes mountain range, which provide it with considerable resources hydroelectric and geothermal. As a result of the relative abundance of oil since 1972 and the debt crisis that began in 1982, the development of renewable energies in the country has been discontinuous, insufficient, and has concentrated on large hydroelectric projects, which in some cases have suffered serious shortcomings.

The energy transition towards the adoption of renewable energy sources has already become not an option but a strategic necessity in Ecuador, mainly due to the progressive depletion of oil reserves, which it will be difficult to maintain exports for more than 20 years. The development of energies renewable sources is also justified by the negative impacts of oil extraction on both the biodiversity, which constitutes the country's main enduring wealth, such as on climate change, which is the main threat to global sustainability in the present century.

The availability of oil has limited the development of alternative sources of energy, Ecuador's specialization as an exporter of hydrocarbons has contributed little to a sustainable social and economic development, and the progressive depletion of reserves demand a rapid energy transition to renewable sources, widely available in Ecuador.

With the perspective that oil is depleting its reserves, the path to sustainable energy development is set in renewable energies, investments must be made in these coming years, the MERNNR must be the entity that articulates this transition.

A strategy to promote the ecological transition in Ecuador was presented on June 05, 2021 by President Guillermo Lasso in his executive decree No. 59. The strategy will include having the so-called green funds for this purpose [188].

Within article 6 of the decree it states: Public policies and public and private initiatives be developed and fulfilled with priority, in public, private and community alliances that promote the transition towards sustainable production and consumption systems that lead Ecuador towards net zero emissions until the year 2050.

3.3. Discussion

According to the results obtained when drawing the scenarios S1, S2, S3 corresponding to the economic part, it should be specified that since it is a study that corresponds to Ecuador as a country, it is important that the central government be called to promote this transition but with economic resources, which in this case are essential to more than the accompanying plans and projects to make it a reality. It is insisted that studies in this sense exist in other European countries, especially Asiatics, at first they considered it as very difficult goals to achieve, but in the literature presented in this study we see that the efforts that are being made in the matter of transition are giving Its fruits, in this sense, Ecuador has very good opportunities because there is already a path, however short it has been, now that much-needed impulse is needed that must occur at the country level. This transition may not take place immediately, however the price of not doing it at the right time can be a very high price and time is unforgiving.

Another opportunity is created together with a coordinated work with local governments, together it is very possible to create alliances with the national government and the investments are shared under the same development and cooperation scheme.

The so-called energy transition brings renewal of the Ecuadorian electricity system within the South American context, this implies that also as a group of sister countries it is possible to include issues of common interest regarding the electricity market in which, under a comprehensive scheme, commitments are expressed with the firm purpose of collectively transform the electrical system of each member country.

The possibilities of making changes in the Ecuadorian electricity system a reality can be made in the interest of a country, the regrettable thing would be that a generational change in technology is the one that forces a restructuring which is more difficult to develop on the fly.

In the first instance, the changes that are required in the different countries are discussed a lot, in fact that happens often and is positive as long as that discussion reaches a real path of energy transformation, after that it is convenient to avoid that there are many paths towards achievement of a 100% sustainable energy future in Ecuador. If this occurs, it would imply a lack of coordination and it has repercussions in delays and undoubtedly economic losses, it triggers a certain level of urgencies if it is very close to 2050 when a large number of countries are enjoying sustainability. The legal system at the country level is underway, however the new National Assembly of Ecuador must review and make feasible the change of the energy matrix and allow the government of the day to carry out the operational work. In reality, significant issues such as the new era of electric vehicles, should be considered within the Assembly and encourage the use of renewable energy.

Although the planning carried out in this article is directed to South America and Ecuador, it is possible to serve as a reference for other countries that have the same purposes of accelerating the energy transition processes and have medium and long-term goals. However, it must be pointed out that for Ecuador one of the limitations is the economic aspect, so it was tried to be as cautious as possible when drawing the scenarios, however other countries may have higher tax revenues and can facilitate their investments, it is in this aspect that the energy transition can be much more viable and accelerated.

Next, in Fig. 28, the multisectoral roadmap is presented, which comprises from a national, provincial and municipal integrated

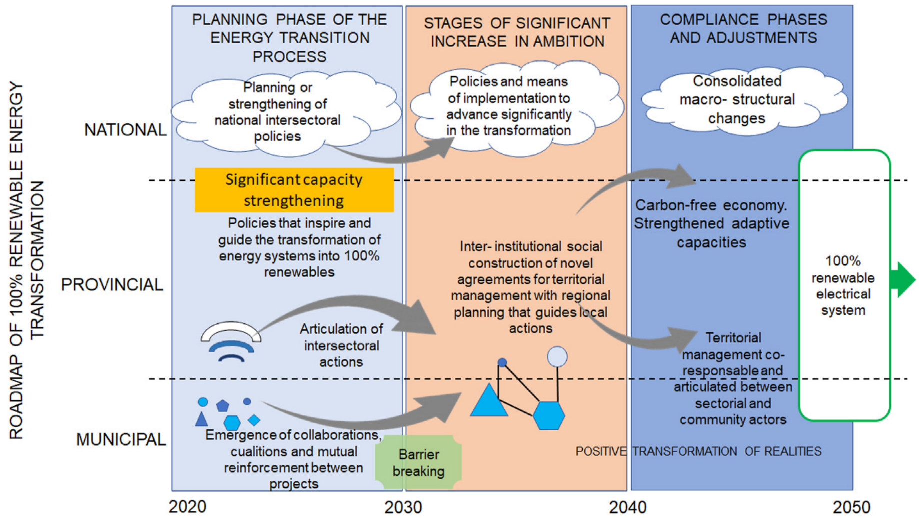

Fig. 28. Roadmap of 100% renewable energy transformation.

order so that in a unified way the purpose of an orderly energy transformation is achieved in which the different sectors complement each other and achieve the complete energy transition.

A flow chart of the energy transition process to be carried out is presented in Fig. 29. It is important to note that the actions to be undertaken must be pigeonholed according to the national development plan. The current national plan is “All a Life” and surely in the future the plan will be updated but it is necessary to comply with the process year by year.

Increasing a greater share of renewable energies will make it possible to reduce the share of fossil fuels for electricity production. In these processes of change in the energy matrix, undoubtedly actions are required to promote research and innovation that must be in tune with the reality of each country, in that sense it is important that researchers are always an integral part of these processes renewal of the electricity market.

The participation of high percentages of renewable energies in the electricity mix is very important, however this process must be adequately planned. It is not a question of nipping the participation of fossil fuels in the electricity system in the bud, since it would imply having other impacts that are not desirable, such as affecting the jobs of those who are part of the thermoelectric sector. Here social responsibility plays a relevant role, it is fair that these workers are reintegrated into the new 100% renewable energy model.

4. Conclusions and recommendations

This research analyzed how renewable energy systems are affecting the world and, in turn, highlights the transition that South American countries are focusing on to move from a fossil fuel-based electricity production system to a 100% extractable system. The literature analyzed the strategies taken by the South American countries and from this the case of Ecuador was deepened, which has reorganized its energy systems based on the bad experiences lived by pollution and the reduction in oil production. A flexible and adaptable transformation route for the energy matrix to 2050 is presented in this article, considering in time a gradual but visionary change based on the organizational structure currently underway. The software called EnergyPlan is a very useful tool for this analysis and a clear horizon is established to lead to a 100% renewable energy production system.

A fairly complete analysis is established corresponding to the structure of the Ecuadorian electricity system as a link within South America, according to the rate of development of the region. Take advantage of the fact that the Ecuadorian regulatory framework offers possibilities to accelerate this transition, it also implies taking advantage of the available resources based on renewable energies with concrete results, in which it is highlighted that several projects are already being implemented at the national level. The scenario to be built in 2050 guarantees a higher quality of life for citizens, boosts the economy and the energy system as a whole will no longer be supplied by oil derivatives, since it is already a 100% extractable and achievable energy model, it is flexible given the favorable conditions that it meets and that it can be exploited without great difficulties from the technical point of view. Political aspects are not included in this article, so it is assumed that the provisions of laws and development plans will be fulfilled over time. From a methodological point of view, we can conclude that the design of future 100% renewable energy systems is a fairly complex process in the socio-economic sphere. For one thing, there are a variety of steps that need to be taken to achieve this. On the other hand, each measure taken must be well determined and not radically affect the lifestyle of the population. The 2050 scenario proposed for Ecuador is based on three primary sources of renewable energy such as existing hydropower, useable energies such as solar and wind, which have now aroused the interest of national government institutions in exploiting them. There will also be other sources of energy such as biogas and geothermal energy that, although in the final scenario, we do not consider them to be of direct influence due to the high costs they entail, however, at a certain point they will take off and allow a greater diversification of the energy system.

In short, Ecuador and all of South America are moving to a relatively good position due to the mix of generation technologies. However, it is important to consider enough incentives to locate enough generation plants in suitable territories. If this does not happen, the risk that South America will not be able to contribute effectively to the Paris Agreement would increase. New research could address this situation in depth and gain a better understanding of the effects of regional energy climate policy.

Moving to a 100% renewable energy system requires stronger policies that drive South America towards decarbonization, particularly the economic issue for many countries becomes quite complicated when historically it has depended on oil and Ecuador is in that line. However, achieving an orderly transition with clear

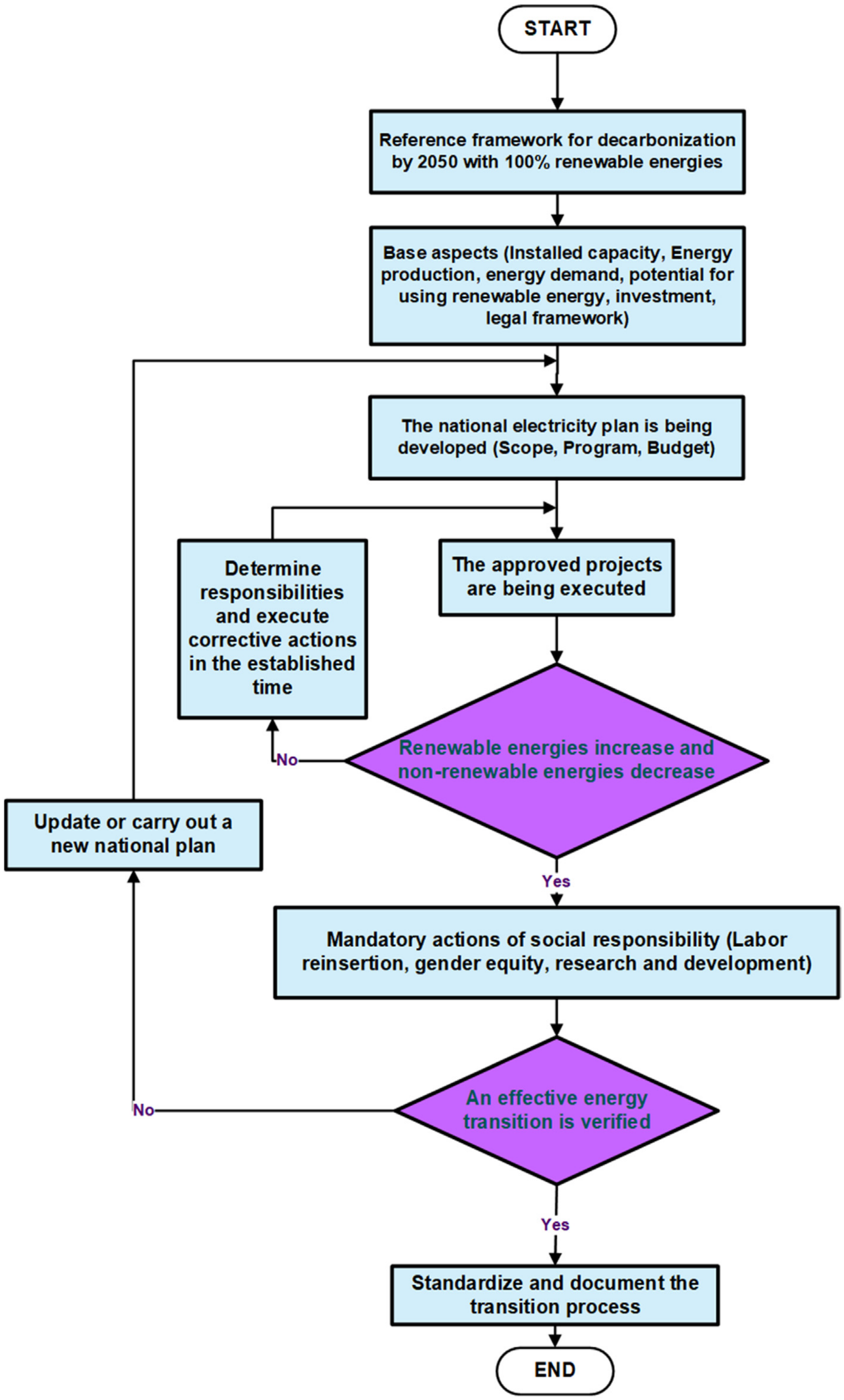

Fig. 29. Process flow diagram.

actions will bring important benefits such as the creation of direct and indirect sources of employment, promoting tourism and improving air quality in urban and rural areas, among others.

In addition to the fact that cities have clean electrical energy systems, it opens the possibility of planning the territory in a better way and becoming aware that it is possible to transform them into smart cities according to the proposal of the White Paper on Digital Territories in Ecuador, which opens a range of opportunities in the sector not only electricity but also communications. One more motivation to transform polluting systems for ones that are friendlier to the environment and citizens, electrical systems even have a greater possibility of control and integration with communication systems compared to systems based on fossil fuels.

Although from the point of energy generation it is possible to achieve a 100% renewable system, it is also imperative to implement energy efficiency strategies since it would not help much if we have a clean generation and a demand that pollutes, which is why a true transformation is necessary. of the energy system is attached to the national development plans that do contemplate efficiency actions, particularly in the Ecuadorian National Plan All a Life.

It is recommended as future work to evaluate the economic impacts of the scenario simulated in this study and, in contrast, its economic implications that it would have if the proposed energy transition is not fulfilled. Another future work would be of great interest to create labor reintegration models for workers who, due to situations inherent to the energy transition, have to leave thermal power plants and are included in the electricity market made up of renewable generation plants.

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CRediT authorship contribution statement

Daniel Icaza: Conceptualization, Methodology, Software, Writing – original draft, Data curation. **David Borge-Diez:** Conceptualization, Methodology, Writing – original draft. **Santiago Pulla Galindo:** Conceptualization, Writing – original draft, All the authors have contributed equally for the development of the paper, the contributions are listed below.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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