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Energy foresight: Exploration of CO_2 reduction policy scenario for Ecuador during 2016–2030

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The energy sector is an important factor that influences life quality and economic prosperity. Differences in infrastructure, technology and even in culture of each country make it imperative to include their own characteristics into energy analyses, making it necessary to identify the different types of sources of CO_2 emissions and their magnitudes. The aim of this paper is to present a foresight analysis of the productive and energy matrices dynamics in Ecuador for the period 2016–2030 and to propose public policy that contributes to sustainable development. In a first stage, the research has an explanatory character, referring to construction of a model, which uses an extended variation of the Kaya Identity where the volume of CO_2 emissions may be examined quantifying contributions of productive sectors activity, sectorial energy intensity, energy matrix, and CO_2 emission features. Subsequently, the research acquires a predictive-experimental nature, using exploratory scenarios. That allows linking historic and present events with hypothetical futures. In consequence, driving forces of the scenario can be explained and analysed using quantitative modelling based on the Kaya Identity and qualitative narratives. Within this study two scenarios were built. The Business as Usual scenario, without modifying the structure of productive and energy matrices, and the Alternative scenario that seeks to reduce the consumption of oil derivatives in land transport, which consumes 50% of the country's energy demand. The Alternative scenario, which promotes the use of biofuels, projects to reduce the CO_2 emissions from 45.58 to 43.41 Mt of CO_2 equivalent for 2030. The policy on biofuels in Ecuador is at an early stage. So, biofuels offer important opportunities: i) diversification of the energy matrix, ii) contribution to energy security, iii) promotion of the growth of the industrial sector, and iv) substitution of fossil fuels and mitigation of the greenhouse gas effects.

Keywords: scenario analysis, Kaya Identity, CO_2 emissions, energy matrix

INTRODUCTION

The global economic model predominantly pursues continuous growth; in that sense, a progressive energy demand is required [1]. Consequently, numerous researches suggest a close nexus between economic development and energy consumption [2–7]. A higher economic development requires more energy consumption [4]. This implies that the energy sector of a country or region is an important factor which influences life quality and economic prosperity [1–2, 8]. Therefore, in addition to the association between economic growth and energy consumption, it is also important to include environmental pollutants as a fundamental part of the relationship, since the emissions are mainly caused by burning fossil fuels [9].

The most popular research streams show economic growth and environmental pollutants relationship. Therefore, the environmental Kuznets curve (EKC) hypothesis suggests an inverted U-shaped relationship between environmental degradation and income growth [6, 10–13]. The limitations of certain methods are tried to overcome with multivariate models that combine income, energy consumption, carbon emissions, labour force and others [9].

Climate change is one of the most important environmental problems, and carbon dioxide (CO_2) is the main contributor to the greenhouse effect [3, 6, 9]. As a result, CO_2 is the most studied pollutant due to the use of energy in human activities, which represents more than 75% of greenhouse gas emissions [8]. The main reasons for CO_2 emissions increase are: constant growth of energy consumption and the composition of energy and production matrix of the economies [14]. For this reason, the study of the increase in emissions due to economic growth is the most studied empirical relationship in ecological, energetic and social literature of different countries and regions [6, 15].

Differences in infrastructure, technology and even in culture of each country or region make imperative to include their own characteristics into energy analyses [16]. Developing regions have a style of development characterized by: low productive diversification, specialization in low value-added activities and natural resource dependence [17]. In addition, it is necessary to take into account aspects such as: i) phenomenal population growth, ii) urbanization dynamics [18], iii) a gap between the urban and rural areas [16], iv) energy matrix based mainly on fossil fuels, v) highly polluting and inefficient transport model [17], vi) importance of traditional biofuels use [16], vii) shortage of supplies, viii) low performance of electrical sector, ix) huge social subsidies, and others. These aspects show a structural situation in developing countries that result in environmental inefficiencies.

Historically, Ecuador has been a relatively low CO_2 emitter, recording 2.44 metric tons per capita in 2016 [19], compared to Qatar, which was the largest CO_2 emitter per capita in the same year, emitting 38.52 metric tons per capita. On the other hand, comparing Ecuador to the countries of its region, it has to be noted that this value is not low. Ecuador is positioned as the largest emitter of greenhouse gases compared to its neighbours Colombia and Peru that are larger, populated and industrialized countries in the region, which reached 1.59 and 1.81 metric tons, respectively, of CO_2 per capita in the same year [19].

Under this framework, the energy systems of developing countries differ from those in developed countries making it necessary to identify different types of CO_2 emission sources and their magnitudes; it is an essential information for socio-economic planning and for policy makers [3, 20–21].

Hence, it is necessary to formulate and implement public policies that allow the diversification of energy sources, making emphasis on increase of the participation of renewable energy sources (RES), and promote the increase of energy efficiency in the productive sectors [22]. Also, it is necessary to promote energy integration in the region [23], ensuring a stable and secure energy supply that improves competitiveness, as well as regional, national and local sustainable growth [24].

Therefore, the Economic Commission for Latin America and the Caribbean (ECLAC) recommends to include a notable environmental impulse as a strategic axis of the industrial and technological policy, in the creation of public goods and services to change the energy matrix, among others [17].

Accordingly, the protocols, models, scenarios and other tools derived from researches that allow the understanding of interactions as: i) supply and demand, ii) energy and environment, and iii) energy and economy that allow a medium- and long-term vision [25], and also consider the 'needs, capacities, available resources, and options for conservation of resources and the open use, appropriate and appropriable technologies' [23] are essential to have a positive impact on energy planning and public policies.

It is evident that energy planning and public policies are currently more complex because of the participation of multiple points of reference, such as: technical, social, economic and environmental [26].

This work is a contribution to reduce the gap in the literature about nexus studies between economic development and energy consumption in developing countries, particularly for Ecuador. Also, a case of study of a country help policy maker develop more comprehensive policies to manage environmental impact due to human activity.

In this paper a foresight analysis for both productive (Gross Domestic Product, GDP) and energy (Final Energy Consumption, Energy) matrices dynamics and their environmental impact (CO_2 emissions) in Ecuador for the time period 2016–2030 is presented. This was done to explore the effect of public policy application that could contribute to the socio-economic and environmental sustainability in the country. The transport is the sector with the highest demand of fossil energy, and it is the largest emitter of CO_2. Therefore, this study proposes an Alternative scenario: quantitative modelling and qualitative narratives. This dualism supports the formulation of public policies searching for initiatives that allow minimizing environmental impact derived from the growth of the land transport sector.

ECUADOR IN FIGURES

The Constitution of the Republic of Ecuador considers "energy in all its forms" a strategic sector; therefore, it has an economic, social, political and environmental influence. Article 314 states that the State is responsible for the provision, disposition of prices and tariffs, and establishes the control and regulation of public services such as: potable and irrigation water, electric power, hydrocarbons, telecommunications, and others that are determined by the Law. The mentioned above aspects demonstrate the predominance of statistical paradigm, which emphasizes the business role of the State. All the policies, programmes, projects and other skills are subjects of the current National Development Plan, being mandatory for the public sector and indicative for other sectors [27].

In the National Development Plan 2017–2021, it is emphasized that during the last decade (2007–2017) the axes of public policy have pursued the transformation of the productive and energy matrix, following the objective "to form an economy based on the provision of services and the generation of value-added goods, based on clean and sustainable production, under parameters of social and intergenerational justice" [28].

Thus, since 2009, Ecuador is immersed in a change process of the energy matrix under the several development plans [29]. The strategies for this change propose: i) to increase the participation of renewable energy sources (RES), prioritizing hydroelectric projects; ii) to foment the use of unconventional energy sources such as geothermal, biomass, wind and solar; iii) to reduce technical losses in energy transformation processes; iv) to increase transport efficiency; and v) to promote efficiency and saving programmes in the industrial and residential sectors [30].

As a result, Ecuador seeks to reduce the dependence of fossil fuels and to modify the pattern of production and accumulation, without neglecting the biophysical limits and natural cycles. Therefore, the goals set for 2021 are: i) to increase the electricity generation up to 90% through RES and ii) to increase fuel savings by optimizing electric generation and energy efficiency in the hydrocarbon sector, which would represent an increase from 9.09 to 26.6 million barrels of oil equivalent (Mboe) [28].

GDP, energy and CO_2 emissions are essential information for the energy analysis that pursues a positive impact on energy planning and public policies. Under this framework, it is important to see the variation of GDP, final energy consumption and CO_2 emissions in Ecuador.

Productive matrix

The productive structure of Ecuador is similar to several Latin American and developing countries. It is characterized by: i) high dependence on oil sector, ii) existence of an external gap that shows a delay in technological capabilities, and iii) an internal gap due to the differences in productivity that exist between productive sectors.

The productive economic activities are: i) agricultural (fisheries and mining), ii) industrial, iii) construction, iv) commercial (services and public administration), v) transport, and vi) residential sector [31]. Table 1 shows the participation percentage of economic sectors in the GDP during representative years of the study period (1995–2015), allowing to understand better the productive matrix of Ecuador.

Table 1 shows that the commercial (services and public administration) sector is the most important one in Ecuador. It showed a growth of around 4.4% during the time period 2007–2015 contributing with 36.8% to the total GDP in 2017 [32]. This important growth is explained through investments increase into the public sector; which aims to improve public services in Ecuador, such as technical and administrative activities, accommodation and food services, communications, education, health and others [33].

The agriculture (fisheries and mining) sector has a substantial participation into GDP during the time period of this study. The main reason for it is the aquaculture and shrimp-fishing segment, which directly affects the volume of exports. This segment has presented an annual average growth of approximately 12.1% (time period 2008–2017), reaching 18.96% of the total GDP in 2017 [32]. That rise is a consequence of the international price increase after the production fall in Asia [33].

The industrial sector is characterized by intensive presence of workforce and dependence on natural resources, as well as less presence of intensive engineering divisions. In 2013, natural resources intensive divisions provided almost a half of industrial employment, and a 73% of the value added of this sector; while, engineering intensive sectors gave less than 10% of employment and industrial value added [34]. Under these circumstances, the industrial sector had an average annual participation of approximately 15% of GDP (time period 2008–2016), reaching a value of 15.41% in 2017 [32]. According to the National Institute of Statistics and Census of Ecuador (INEC), this sector had the lowest growth in the time period 2007–2014, mainly as a result of oil refining production decrease [34].

The construction sector maintained a sustainable growth (time period 2000–2011), with a participation close to 8% per year of the total GDP [35]. In the time period 2012–2017, this sector has maintained the same dynamic, contributing with an annual average of 9.4% of the total GDP [32]. The stability of the construction sector over the last two decades can be explained by the important public sector investments in infrastructure, facilities to access mortgage loans, and in the increase of purchasing power (real wages) of the population.

Table 1. **Volume and shares of GDP in the productive sectors of Ecuador during 1995–2015**

Productive sector	1995	2001	2007	2015
Agricultural (fisheries and mining)	20.75%	19.51%	21.06%	18.49%
Industrial	14.45%	16.30%	14.88%	14.84%
Construction	6.23%	7.08%	7.87%	9.86%
Commercial (services and public administration)	34.82%	32.89%	34.27%	36.51%
Transport	6.95%	8.43%	8.77%	10.25%
Residential	10.64%	10.76%	8.25%	6.94%
Total GDP [KUSD]	$35,743,721.00	$39,241,363.00	$51,007,777.00	$70,353,852.00

Source: Central Bank of Ecuador [32].

Developed by: Authors.

The transport sector contributed with 10.52% to the GDP in 2017, presenting a growth of 5.45% (time period 2007–2015) [32]. The main factors for this growth were: a) infrastructure production promoted by the State, b) construction of hydroelectric and thermoelectric plants, c) and various extractive activities that were carried out in the Amazon region.

Energy matrix

Table 2 shows the volume and shares of final energy consumption by the productive sectors. As it is presented, the structure of the energy matrix has not presented any relevant changes during 1995–2015. However, final energy consumption increased by almost two times. The tendency is explained by the accelerated population increase of 54% [36] and by the development and progress activities implemented during 1995–2015.

Historically, the transport sector has been the largest energy consumer in Ecuador. During 2000–2015, this sector raised the energy demand for more than 50%. Industry and residential sectors are the second and the third largest energy consumers. They consumed close to 20% and 17% of final energy during the period, respectively. Finally, it is the commercial (services and public administration) sector, which refers to all government and public activities; it had a participation of 6.3% in final energy consumption in 2015. The construction, agricultural (fisheries and mining), and other minor sectors registered very low energy consumption, reaching less than 1.5% [37].

Table 3 shows the volume and shares of fuels and energy consumed in the productive sectors in 2015.

In 2015, fossil fuels (diesel oil, gasoline/naphtha, liquefied petroleum gases (LGP), fuel oil and

Table 2. **Volume and shares of final energy consumption in the productive sectors of Ecuador during 1995–2015**

Productive sector	1995	2001	2007	2015
Agricultural (fisheries and mining)	0.68%	0.49%	0.69%	1.14%
Industrial	22.56%	21.88%	17.65%	21.46%
Construction	0.00%	3.00%	1.06%	1.41%
Commercial (services and public administration)	3.19%	4.06%	4.57%	6.30%
Transport	49.63%	49.20%	55.96%	52.61%
Residential	21.78%	18.95%	18.11%	14.66%
Final energy consumption [Mboe]	41.98	50.18	65.77	82.64

Source: Coordinating Ministry of Strategic Sector [37].

Developed by: Authors.

Table 3. **Volume and shares of fuels and energy consumed in the productive sectors of Ecuador in 2015**

Productive sector	Firewood	Cane products	Electricity	LGP	Gasoline / naphtha	Kerosene	Diesel oil	Fuel oil
Agricultural, fisheries and mining				0.21%	0.93%			
Industrial	0.40%	2.79%	6.67%	0.88%	0.21%		8.29%	2.22%
Construction					0.02%		1.39%	
Commercial, services and public administration			3.80%				2.50%	
Transport			0.01%	0.07%	22.88%	3.12%	23.64%	2.90%
Residential	1.86%		5.19%	7.61%				
Final energy consumption [Mboe]	1.86	2.30	12.95	7.25	19.86	2.57	29.60	4.23
Final energy consumption [%]	2.26%	2.79%	15.67%	8.77%	24.04%	3.12%	35.82%	5.12%

Source: Coordinating Ministry of Strategic Sector [37].

Developed by: Authors.

kerosene) dominated in the structure of final energy consumption in Ecuador (76.87%). Diesel oil was the main fuel, reaching 35.82% of the final energy consumption and being mostly used by the transport and industrial sectors, while alternative and RES (firewood, cane products) and electricity represented 20.72%. The remaining 2.41% were attributed to a significant operating loss in the system. The structure of final energy consumption was constant during 1995–2015 and it did not have amendment while diesel price was the lowest of the region. In 2016, the price of diesel oil per litre in Ecuador was \$0.29 while in Colombia it reached \$0.64 and in Peru \$0.88; that is, 210% and 300% higher, respectively [38].

CO_2 emissions

The historical tendency of CO_2 emissions and the largest sectors emitters in Ecuador are shown in Table 4.

Transport is the most polluting sector, reaching an average of 69% of the total CO_2 emissions during 1995–2015. The existence of subsidies for petroleum products (LPG, gasoline and diesel) since 1974, which facilitate the growing use of fossil fuels for transportation and cooking, is the main factor of a high share of emissions [30]. Therefore, the transport sector is inefficient, even more if it only had contributed with an average of about 8.5% of the GDP. During 1995–2015 the industrial sector contributed with an average of 15.5% of total CO_2 emissions each year, and the residential sector with 8%. The other sectors are insignificant emitters.

METHODOLOGY

To elaborate a foresight analysis, it is required to collect and analyse quantitative and qualitative information, so a macro-characterization of the productive and energy matrices of Ecuador during 1995–2015 was made.

First, the research has an explanatory character, referring to a construction of the model. Following Robalino-López et al. (2014) the model uses a modification of the Kaya Identity [39], where the volume of CO_2 emissions may be estimated quantifying contributions of five factors: i) global industrial activity, ii) industrial activity mix, iii) sectorial energy intensity, iv) sectorial energy mix, and v) CO_2 emission factors [22].

Subsequently, the research acquires a predictive-experimental nature, since a prospective scenarios approach will be used. This study makes it possible to analyse sustainability and to provide guidelines for an agenda in order to obtain a friendlier development with all the stakeholders [40]. Figure 1 illustrates the methodological steps of the present work in three stages: i) collection of information, ii) explanatory character, and iii) predictive-experimental character.

Analysis of complex problems requires the use of complex scenarios. This implies combining both quantitative and qualitative approaches for the analysis of trends and underlying themes. This consideration avoids limiting the analysis to quantifiable aspects, allowing to incorporate institutional, cultural and non-quantifiable aspects of the system [40]. For these reasons, this study presents a dualism in the emission

Table 4. **Volume and shares of CO_2 emissions from the productive sectors of Ecuador during 1995–2015**

Productive sector	1995	2001	2007	2015
Agricultural (fisheries and mining)	0.58%	0.50%	0.67%	0.97%
Industrial	14.22%	15.76%	15.08%	17.02%
Construction	0.00%	6.79%	2.28%	2.72%
Commercial (services and public administration)	0.03%	0.84%	0.45%	4.88%
Transport	60.25%	71.24%	75.73%	68.47%
Residential	7.74%	9.35%	9.42%	5.94%
CO_2 emissions [Mt of CO_2 equivalent]	19.59	19.67	27.31	38.26

Source: Coordinating Ministry of Strategic Sector [37].

Developed by: Authors.

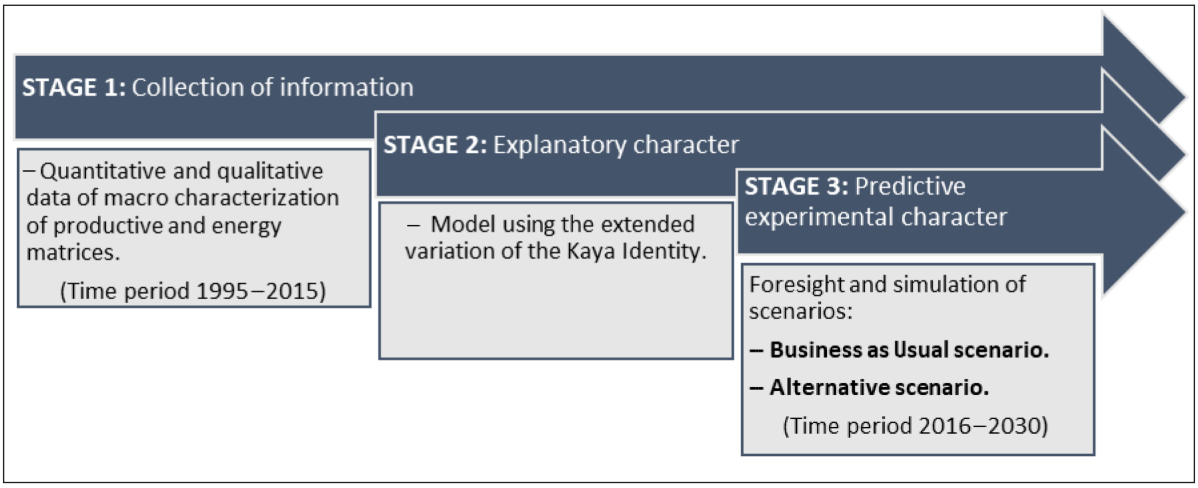

Fig. 1. Methodological steps

Developed by: Authors.

scenarios in two lines of research: quantitative modelling and qualitative narratives.

The exploratory scenarios allow linking historic and present events with hypothetical futures. In the scenarios, the driving forces are explained using the Kaya Identity. Trajectories of future energy carbon emissions resulting from energy consumption can be expressed as driving forces including demographics, resources, economics, technology and non-climate policies [40].

In consequence, the Kaya Identity gives the frame of reference to explore and analyse the driving forces of the scenario as the basic entities of scenario construction in quantitative modelling and qualitative narratives.

The simulation period of this study is from 1995 to 2030, where the time period 1995–2015 helps to tune the parameters of the model. The time period 2016–2030 is the simulated period, under assumptions of both scenarios concerning: population growth, an annual increase of the GDP, the evolution of the energy matrix and energy consumption and their impact on the growth rate of CO_2 emissions [22]. Moreover, the study period is splitted into three stages. The first stage covers 1995–2006. It is characterized by a political instability and economic crisis [41]. During the period the economy was based on agriculture; exports were based on commodities such as banana, flowers, shrimp, passion fruit, cocoa, coffee, and especially oil overall. During the second stage 2007–2015, a certain political stability was achieved, the State provided investments into the country's infrastructure development. The main roads were built and renovated, the electricity and telecommunication services were improved. Loans were leaded to the agricultural sector. In addition, the State promoted the provision of seeds, fertilizers, chemicals and subsidies on inputs to ensure higher productivity per hectare [41]. The third stage (2016–2030) corresponds to the projection of historical data of variables (driving forces) considered in the Kaya identity. It argues that the environmental impact caused by CO_2 emissions in terms of burning fossil fuels is the product of population variation, GDP per capita, energy intensity and carbon intensity [42].

Under this framework a list of strategies that promote the increase of non-conventional renewable energies in the country, is proposed in search of the diversification of the energy matrix, specifically in biofuels for the ground transportation subsector, contributing to the sustainable development of Ecuador.

Formulation of the model – Kaya Identify extended specification of *IPAT* identity

The *IPAT* (Impact, Population, Affluence, Technology) identity is a framework to describe environment impact, *I*, due to human activity. Therefore, these activities are divided into three anthropogenic forces: *P* refers to the total population in a country or region, *A* indicates affluence, and T indicates technology, which describes production techniques [43]. The *IPAT* identity allows to study quantitatively the participations of population, affluence and technology to resource consumption [44].

The IPAT analysis generally suggests that rapid economic growth (improved life quality and increasing income in a country) is the main driving force to increase final energy consumption, and consequently the growth of human activity impact on the environment [42–43]. The effect of population depends largely of the context, population growth, rapid industrialization processes and urbanization dynamics and consumption of resources. Technology is a driving force that can play a positive or negative role in the environmental impact. So, technology innovation offsets the increase of final energy use; in such a way, this performance is a balance factor [42–43]. Therefore, during economic growth, the affluence increases emissions being only partly compensated by decreasing energy intensity. For these reasons, public policies suggest that regions should "improve both their energy efficiency and energy structure; and optimize their economic by applying economic instruments and capacity building effort" [45]. Recently, much research has incorporated more extend factors to the original *IPAT* identity [45].

Within this study, the quantitative model for CO_2 emissions analysis uses the Kaya Identity, which is a specification of the *IPAT* [5–7, 45–46]. Kaya Identity allows to determine the driving forces in emission scenarios. This tool is mainly used to explore the main sources of CO_2 emissions.

According to Kaya Identity, CO_2 emissions are estimated through the product of four factors: i) demographic variable, population; ii) economic rent, which is defined as GDP per capita; iii) energy intensity, defined as energy consumed per unit of the GDP; iv) carbon intensity, which is defined as CO_2 emitted per unit of energy consumed [14].

The Kaya Identity:

$$\text{CO}_2 \text{ emissions} = P * \frac{QE}{P} * \frac{E}{Q} * \frac{\text{CO}_2}{E}. \quad (1)$$

For this case of study of Ecuador, the Kaya Identity variables are described, disaggregating the GDP values by the productive sector, energy and CO_2 emissions by fuel type [22]:

$$\text{CO}_2 \text{ emissions} = P * \frac{Q}{P} * \frac{Q_i}{Q} * \frac{E_i}{Q_i} * \frac{E_{ij}}{E_i} * \frac{U_{ij}}{E_{ij}}, \quad (2)$$

where:
P – population,
Q – total gross domestic product (GDP),
Q_i – gross domestic product by productive sector,
E_i – energy consumption by productive sector,
E_{ij} – energy consumption by type of fuel in a productive sector,
U_{ij} – CO_2 emissions by type of fuel in a productive sector.

In consequence, the Kaya Identity allows to analyse and discuss driving forces, such as demographics, economics, resources, technology and CO_2 emissions. Consistent with the built model, scenario analysis takes into consideration institutional, cultural and non-quantifiable characteristics of the system [40].

That helps decision-makers to face uncertainty by providing several possibilities for future development [47].

Scenarios are stories with the purpose about how the context could develop over the time [48–49]. Therefore, scenario analysis is the art of using scenarios for decision-making [50]. It is a form of exploration that can be taken to show a set of plausible future events, their causes and consequences [51], being a powerful tool that can be integrated into strategic planning.

Assumptions for the scenario's development

The energy system is a strategic sector of a country; therefore, public policies are priority to include guidelines, contents, instruments, mechanisms, definitions, modifications and the forecast of the expected results [52]. In such a way, article 413 of the Constitution of the Republic of Ecuador establishes the promotion of development and use of clean and healthy practices and technologies, energy efficiency and renewable, diversified and low impact energies [27].

In 2015, Ecuador signed the 2030 Agenda of the United Nations, which establishes guidelines to achieve the Sustainable Development Goals [53]. For this reason, the Organic Code of the Environment establishes articles that promote measures to mitigate climate change: i) numeral 1 of article 259 promotes patterns of production and consumption that reduce and stabilize greenhouse gas emissions; ii) numeral 9 of article 261 establishes the promotion of energy efficiency programmes, as well as the establishment of economic and non-economic incentives for conventional and non-conventional renewable energies; iii) numeral 10 of article 261 establishes the promotion of low emissions transports; and iv) numeral 12 of article 261 promotes the reuse of organic and inorganic waste, as well as the use of its energy potential [54].

Under this framework, on 7 February 2019, the Organic Energy Efficiency Law was signed, establishing transport as one of the priority sectors. In addition, the necessary policies for promoting the production and consumption of biofuels at the national level were recognized as priorities [53].

With respect to the transport sector, the Ecuadorian National Energy Efficiency Plan 2016–2035 stipulates the continuity and expansion of the project of partial replacement of fossil fuel by mixing with biofuel [55], the goal that can be achieved using the excess of African palm and sugar industry. Table 5 describes the assumptions

Table 5. **Assumptions of BAU and Alternative scenarios in relation to Kaya Identity**

Kaya Identity elements	BAU scenario	Alternative scenario
Population developments	Population presented a growth rate of 1.68% in the time period 1995–2006, and 1.43% during the period 2007–2015 [36]. Model estimates considerate an annual growth rate of 1.28% during the prediction period 2016–2030.	The same behaviour (growth rate of 1.28%) for population growth rate is considered.
GDP developments	GDP showed a growth rate of 2.82% during the time period 1995–2006, and 3.64% in the time period 2007–2015 [32]. The estimate growth rate for the time period 2016–2030 is based on a projected growth rate of 3.83% of total GDP. The commercial sector (services and public administration) will be the largest participation, with a growth rate of 5.11%. The industrial sector will not cause a change in the structure of the productive matrix, it will maintain an annual growth rate of 2.43%. Agricultural, construction, transport and residential sectors will have annual growth rates of 2.03%, 4.68%, 4.38% and 0.75%, respectively.	The annual growth rate will be of 3.83% during the time period 2016–2030. In the Alternative scenario, the industrial sector increases its share into GDP from 14.8% to 16.3% during this period. Therefore, this sector will have an annual growth rate of 4.01%. With this new structure the estimated new annual growth rate for the construction sector will be 3.10%.
Final energy consumption developments	The growth rate of final energy consumption is highest in the period 1995–2006, reached a value of 3.52%. While in the time period 2007–2015 it showed a growth rate of 2.57% [37]. The estimate trend for the time period 2016–2030 is based on a projected growth rate of 2.30% of the final energy consumption.	The same behaviour (growth rate of 2.30%) for final energy consumption is considered. In the case of transport sector consumptions for the time period 2018–2023 a B5 mixture (5% biodiesel and 95% diesel oil) is going to be added, and for the time period 2024–2030 a B10 mixture, which is 10% biodiesel, will be added to diesel oil.
CO_2 emissions developments	CO_2 emissions showed a growth rate of 1.91% during the time period 1995–2006, and 3.82% in the time period 2007–2015 [37]. Maintaining the same energy and production structure, the estimate growth rate of CO_2 emissions will be 2.2% due to the burning of fossil fuels during the time period 2016–2030.	With this new structure, it is expected to reduce the growth rate of CO_2 emissions due to the use of public policies to promote biofuels in Ecuador and to increase energy efficiency.

made for the two scenarios that has been considered: i) Business as Usual (BAU) scenario and ii) Alternative scenario.

The aspects that have been considered to simulate both BAU and Alternative scenarios are:

i) The qualitative and quantitative data collected for this study corresponds to the time period 1995–2015, divided into two parts. The first covers 1995–2006, and the second covers 2007–2015. For both scenarios the time period is 2016–2030 and the GDP growth annual rate is 3.83%. This assumption is a consequence of the fact that Ecuador's economic activity has registered about the same annual growth rate of its GDP in the last 10 years [28].

ii) For the BAU scenario, the structure of the productive matrix does not have changes (see Table 1). For the Alternative scenario, the industrial sector must have an annual growth of more than 4%. This growth can be achieved through the boost provided by the strengthening of both production and the distribution chain of biofuels in Ecuadorian economy.

iii) The proposal for the Alternative scenario is to generate an impulse in the use of biodiesel in the transport sector in Ecuador. Land transport consumes around 84% of the total energy demand [56] of the sector, being the gross consumer of oil derivatives and the largest emitter of CO_2, through the addition of biodiesel in conventional diesel oil. For the time period 2018–2023 a B5 mixture (5% biodiesel and 95% diesel oil) is going to be added, and for the time period 2024–2030 a B10 mixture, which is 10% biodiesel will be added to diesel oil.

RESULTS AND DISCUSSION

BAU scenario

In the BAU scenario, the structure of the productive matrix does not have significant changes. Figure 2 refers to the composition of sectorial energy consumption by fuel type in 2030 within the BAU scenario.

As it is presented, the final energy consumption will predominantly maintain the use of petroleum

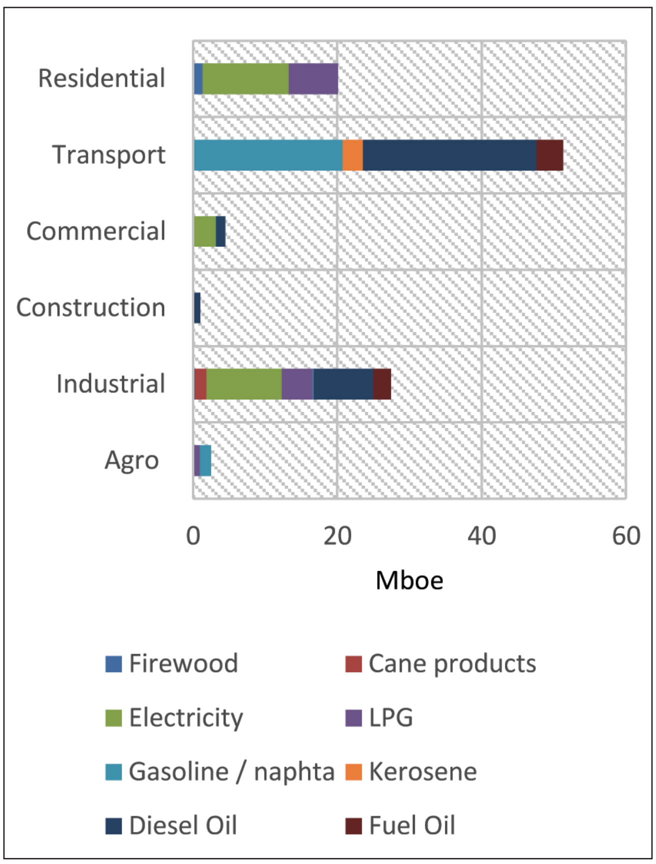

Fig. 2. Sectorial energy consumption by fuel type in Ecuador in 2030 under the BAU scenario
Developed by: Authors (Model estimations).

derivatives, and transport, industry and residential sectors will be the main energy consumers. By 2030, model estimations show that the transport sector will be the largest consumer of the final energy with 48.05%, industrial – 25.69%, residential – 18.80%, commercial – 4.19%, agricultural – 2.34% and construction – 0.94%. The energy mix consumed in the transport sector will mainly consist of diesel and gasoline/naphtha. Totally, 51.32 Mboe will be consumed by the sector in 2030. The industrial sector will present a consumption dependent on the characteristics of the production processes. Therefore, it will consume the energy mix dominated by electricity, diesel oil and LPG. Totally, 27.44 Mboe will be consumed by the sector in 2030. The residential sector will present a higher consumption of electricity and LPG than other sectors. Lighting purposes, equipment or appliances functioning and other devices with lower energy consumption for electricity, and food cooking and water heating sub-sectors will remain the final users of LPG. Totally, 20.08 Mboe will be consumed by the residential sector in 2030.

Diesel and gasoline/naphtha will be the dominant fuels in the energy matrix. Totally, 34.54 Mboe of diesel and 22.39 Mboe of gasoline/naphtha will be consumed in Ecuador in 2030. Both diesel and gasoline fuels will represent 53.3% of the final energy consumption in the country. By 2030, it is estimated that 25.54 Mboe of electricity (23.9%) and 12.14 Mboe of LPG (11.4%) will be consumed in Ecuador. The final consumption of other fuels, such us firewood, cane products, kerosene and fuel oil, will represent 12.20 Mboe (11.4%) by the same year.

Figure 3 presents the trends of GDP and CO_2 emissions under the BAU scenario during 2016–2030.

The BAU scenario estimates that CO_2 emissions will increase by 1.16% a year since Ecuador economy will function based on burning of fossil fuels. Therefore, Ecuador will increase emissions by 119% in 2030. That is more than the double of its current level. During 2016–2030, 631.15 Mt of CO_2 equivalent will have been emitted to the atmosphere. For 2030, the transport sector will continue being the main CO_2 emitter, making up to 68% of the total CO_2 emissions (31.06 Mt of CO_2 equivalent), followed by the industrial sector with 20% of the total CO_2 emissions (9.05 Mt of CO_2 equivalent).

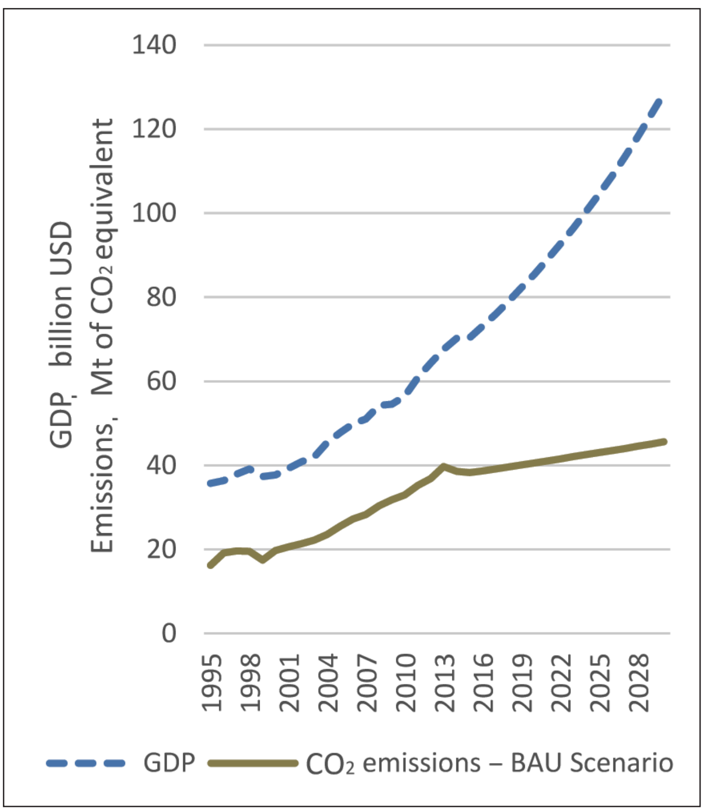

Fig. 3. Developments of GDP and CO_2 emissions in Ecuador during 1995–2030 under the BAU scenario

Developed by: Authors (Model estimations).

Alterative scenario

This work proposes an Alternative scenario that is quantitative modelling and qualitative narratives. This dualism supports the formulation of public policies in search of initiatives that would allow minimizing environmental impact derived from the growth of the land transport sector [57].

The trend of the global energy sector is the transition from fossil fuels to RES. The main sources of renewable energy exploited for energy production during the last decade were the following: wind, solar, traditional hydroelectric power and biomass [58]. The search for alternatives that would minimize the environmental impact of land transport is a challenge for all countries and regions, biomass is an attractive input to improve energy efficiency in this sector.

Biofuels are alcohols, esters or different chemical compounds that are obtained from biomass, agricultural residues, forestry, industrial waste and food industry waste. Bioethanol and biodiesel are the most developed biofuels. Bioethanol is obtained mainly from abundant crops of sugarcane or starch. Biodiesel is usually obtained from oil plants. The use of these is considered neutral in carbon emissions, due to consumption of this during the growth of biomass through photosynthesis [59].

Therefore, according to data from the National Information System of Agriculture, Livestock, Aquaculture and Fisheries (SINAGAP), the production of sugarcane for external uses of sugar processing is 16,000 Ha [60]; to this data can be added the waste from the process of sugar elaboration and other components for the generation of biomass.

The experience with bioethanol in Ecuador goes back to the "Ecopaís" project, which started in January 2011. The objective was to commercialize a fuel, 95% gasoline and 5% ethanol. Currently, 80,000 gallons of "Ecopaís" are supplied in the country every day [57].

In Ecuador, biodiesel can be produced from the African palm, which registers 369,406 Ha planted in 2015; 21.4% (79,063 Ha) of this total were not harvested [61]. The experience with biodiesel in Ecuador is incipient. A research project from an Ecuadorian university has a pilot plant that produces 100 litres of biodiesel every six hours, using raw material oils from oleaginous plants such as Jatropha [57].

In 2014 in Ecuador, the transport sector had approximately 1,752,712 vehicles, of which 529,521 were buses, trucks, vans, tankers, trailers and others; those represent 30% of the total [62]. The advantage of biodiesel is that it can be used directly in diesel engines without a necessity to modify them, the most common mixture is B20, 20% biodiesel and 80% diesel oil [59].

Biodiesel is currently not being refined from African palms in Ecuador, despite the fact that 41% of the production of palm oil, about 140,000 tons, were exported abroad in 2006, much of it in the countries of destination was destined for the refining of biodiesel [63].

Nowadays, there is a possibility of developing biodiesel based on sugarcane products, through a process of genetic modification. In this process molecules are hydrogenated into farnesane and can be used as a biodiesel component by being mixed directly into diesel fuel up to approximately 30% [64]. After adding 5% of biodiesel to conventional fuel, approximately 240 million litres of biodiesel are required per year. Currently, 30% of this production could be covered by African palm oil [65].

Under this framework, the proposal is to use a B5 mixture (which consists of 5% of biodiesel) in the time period 2018–2023, and a B10 mixture (which consists of 10% of biodiesel) in the time period 2024–2030.

In the Alternative scenario, the industrial sector increases its contribution to the GDP from 14.8% to 16.3% in the time period 2016–2030. In order to achieve the growth, the industrial sector will have to grow by 4% a year during the next 15 years. Precisely, producing biofuels will be a driving factor for the industrial sector.

Figure 4 shows the composition of final energy consumption by fuel type in 2030 under the Alternative scenario.

Figure 4 illustrates that in the Alternative scenario, composition of energy consumption will not change substantially by 2030 in comparison to the BAU scenario. The transport sector will continue being the largest consumer of diesel oil and gasoline/naphtha. It will consume 48.92 Mboe in 2030. However, the use of biofuels has already been appreciated. It will reach 2.4 Mboe in 2030 (2.25%). This modification in the composition of final energy consumption in the transport sector causes a decrease in CO_2

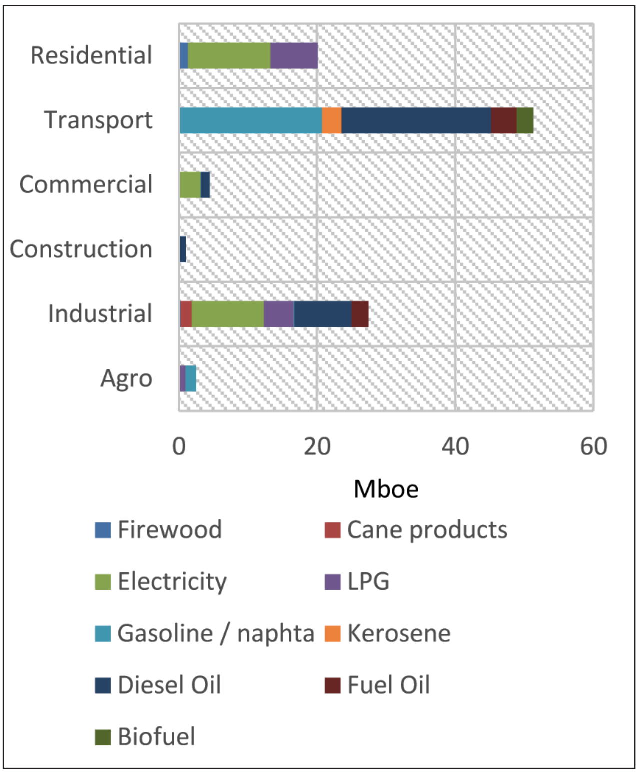

Fig. 4. Sectorial energy consumption by fuel type in Ecuador in 2030 under the Alternative scenario
Developed by: Authors (Model estimations).

emissions from 45.58 to 43.41 Mt of CO_2 equivalent by 2030 (4.76% of decrease). The industrial sector will continue consuming electricity, diesel oil and LPG. Totally, 27.44 Mboe will be consumed. The residential sector will use electricity and LGP predominantly. Totally, 20.08 Mboe will be consumed by the sector in 2030.

Figure 5 presents the trends of GDP and CO_2 emissions under the Alternative scenario during 2016–2030.

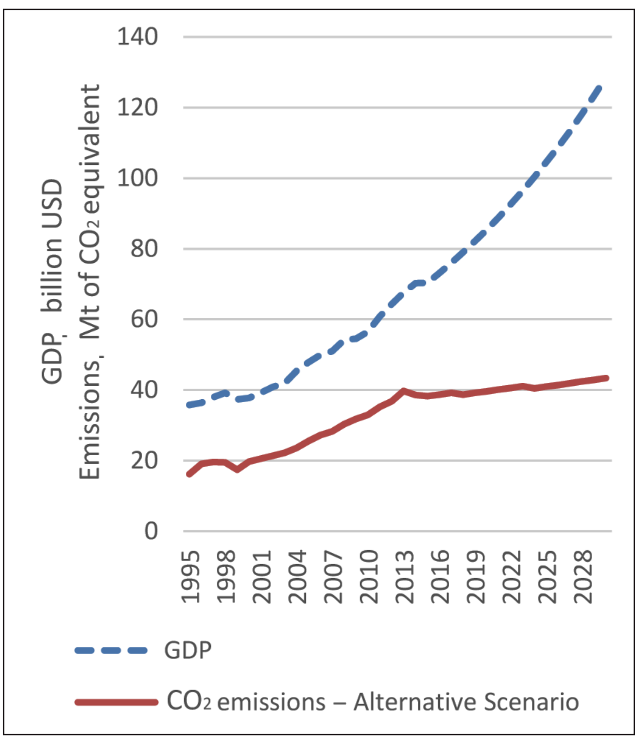

Fig. 5. Developments of GDP and CO_2 emissions in Ecuador during 1995–2030 under the Alternative scenario
Developed by: Authors (Model estimations).

The Alternative scenario reports that CO_2 emissions will increase by 0.84%. Therefore, during 2016–2030, 610.66 Mt of CO_2 equivalent will have been emitted to the atmosphere. For 2030, the transport sector will produce 28.9 Mt of CO_2 equivalent, followed by the industrial sector with 9.05 Mt of CO_2 equivalent.

Comparison of CO_2 emissions under BAU and Alternative scenarios

Figure 6 shows comparison of CO_2 emissions under BAU and Alternative scenarios.

The model estimations during the time period 2016–2030 show that under the BAU scenario, approximately 631.15 Mt of CO_2 equivalent will be emitted, while under the Alternative scenario projected emissions are 610.66 Mt of CO_2 equivalent. Therefore, CO_2 emission reduction will be 20.49 Mt of CO_2 equivalent. For the time period 2018–2023 a B5 mixture (5% biodiesel and 95% diesel oil) is going to be added, this first stage will represent 5.79 Mt of CO_2 equivalent of reduction. For the time period 2024–2030 a B10 mixture, which is 10% biodiesel will be added to diesel oil, this second stage will represent 14.69 Mt of CO_2 equivalent of reduction. The reason for this is an assumption of the Alternative scenario that the transport sector will continue being the largest consumer of fossil energy. However, in this scenario the use of biofuels and their impact in the reduction in CO_2 emissions has already been appreciated. A decrease of 0.30% in the emission growth rate will be obtained considering the use of biofuels to reduce CO_2 emissions in the Alternative scenario. Therefore, in the BAU scenario, an annual growth rate of 3.83% in the GDP will cause an increase of 1.16% in the CO_2 emissions. While in the Alternative scenario, the same continuous growth rate in the GDP will cause an annual increase of 0.84% in the CO_2 emissions for the time period 2016–2030.

Public policies to promote biofuels in Ecuador

Governments around the world have been given plentiful attention to biofuels, because they are an environmentally friendly and adaptable substitute for fossil fuels. Many countries have supported regulations and laws to promote the sustainable development of biofuels [66]. The significant drivers to promote biofuels are: i) combat climate change and reduce emissions, ii) increase employment in the agricultural sector and create an additional agricultural market, and iii) energy

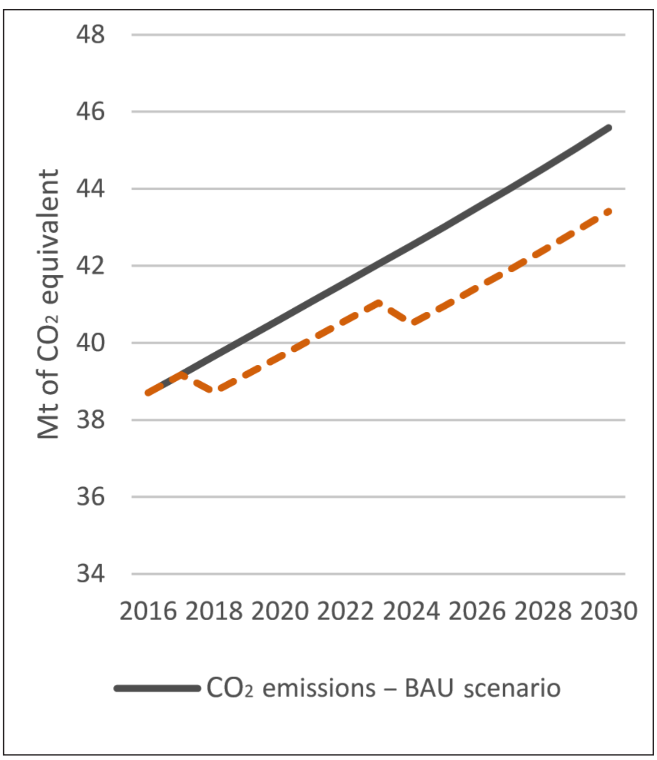

Fig. 6. Developments of CO_2 emissions under BAU and Alternative scenarios

Developed by: Authors (Model estimations).

security and resource potentials [67]. Therefore, public policies are a priority to include guidelines, contents, instruments, mechanisms, definitions, and moreover, they are crucial in influencing the direction of socio-economic and technical change [52]. Policy support must be the driven force for developing the phase of biofuels industry, because it is less competitive than traditional energy in terms of "high production cost, immature technology and poor supporting infrastructure" [66].

Now, more than ever, responsible public policies must take into consideration the transport systems and the fuels that power them into long-term sustainability strategies. The biofuels promotion has become more attractive; it takes advantage of existing supply chains and distribution infrastructure [68]. Biofuels constitute the most immediate sources of alternative energy for vehicular use. So, they might provide a partial solution to environmental problems, displacing conventional fuels in transport and reducing emissions of fossil fuels consumed [67].

Under this framework, biofuels offer important opportunities for Ecuador, allowing: i) diversify the energy matrix, ii) contributing to energy security, iii) promoting industrial sector growth, iv) pursuing the substitution of fossil fuels, v) mitigating of greenhouse effect gases, vi) creating of jobs [69–70], vii) vehicle park updating with better performance and safety, viii) purchasing product in the domestic market avoiding capital outflow, and ix) promotion of agricultural and biofuels research and development [55], among other benefits.

Any bioenergy project must comply with sustainability criteria, avoiding competing with other land uses or affecting biodiversity and food security [70]. For this reason, article 15 of the Constitution of the Republic of Ecuador specifies that "energy sovereignty will not be reached at the expense of food sovereignty" [27].

Under this framework, Figure 7 summarizes a list of strategies that promote the increase of non-conventional renewable energies in the country, focused on land transport and biofuels.

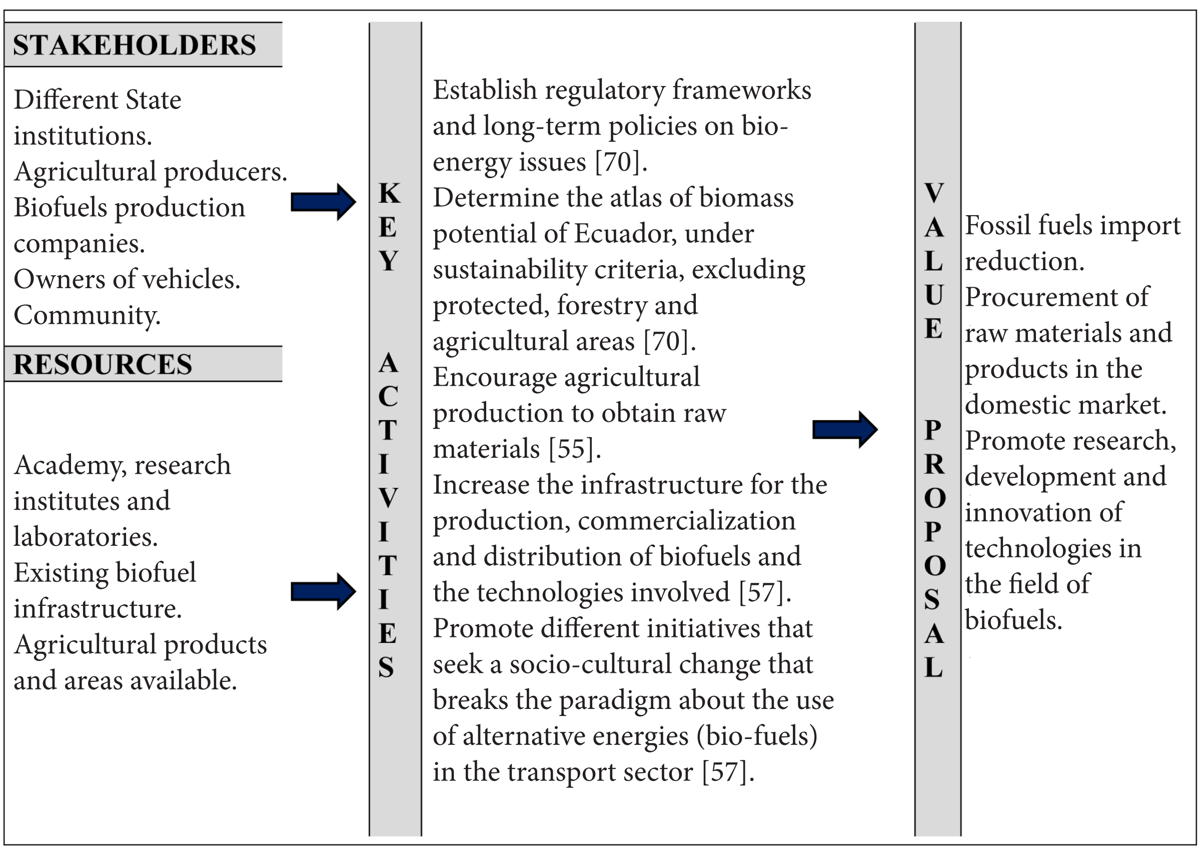

Fig. 7. Strategies to promote the increase of biofuels in Ecuador
Developed by: Authors.

The policy of biofuels in Ecuador is at an early stage of development and experiences have been incipient. Therefore, it is important to consider referential costs: implementation of biofuel refining infrastructure, marketing and distribution network, socialization campaigns and agricultural development [55, 71]. But nevertheless, the beneficiaries are agricultural producers, companies that produce biofuels, fuel trading companies, service stations of fuels, network of professionals, owners of vehicles and community in general.

CONCLUSIONS

In order to implement appropriate sustainable development strategies and public policies, it is crucial for energy long-term planning studies that include mathematical models to be complemented by qualitative approach. This combination allows to incorporate aspects that are beyond the scope of quantitative approaches. Therefore, the evaluation of mixed scenarios is an effective tool for decision-makers as it broadens thinking and overcomes the false certainty of a static forecast. Under such a circumstance, this study combines both a mathematical model using the extended variation of the Kaya Identity, construction of narrative scenarios and simulation of these scenarios.

The results show that the transport and industrial sectors are causing 85% of CO_2 emissions, due to the consumption of fossil fuels. The BAU scenario shows that under the current conditions, emissions will have a growth rate of 1.16%, that is, 45.58 Mt of CO_2 equivalent in 2030. The Alternative scenario estimates to reduce CO_2 emissions down to 43.41 Mt of CO_2 equivalent. So, for the Alternative scenario, a continuous growth rate of 3.83% in the GDP will cause an annual increase of 0.84% in the CO_2 emissions for the time period 2016–2030.

The main purposes to promote biofuels in Ecuador are to reduce the consumption and import of fossil fuels and reduce CO_2 emissions. Moreover, the reference to impulse an additional market for agricultural products and supply the national demand of biofuels is notable. Then, public policies support is essential to include guidelines and mechanisms to influence the direction of socio-technical change. The sustainability of the transport system and the fuels that power them are a main topic for medium- and long-term considerations. Therefore, the proposal to impulse the use of biodiesel in the transport sector in Ecuador through the addition of biodiesel in conventional diesel oil is an interesting alternative.

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References

1. Bariss U., Laicane I., Blumberga D. Analysis of factors influencing energy efficiency in a Smart Metering Pilot. *Energetika*. 2014. Vol. 60. Iss. 2. P. 125–135.
2. Alcántara V., Padilla E. Análisis de las emisiones de CO_2 y sus factores explicativos en las diferentes áreas del mundo. *Revista Económica Crítica*. 2005. Vol. 4. P. 17–37.
3. IPCC. Intergovernmental Panel on Climate Change. *Chapter 6. Reference Approach. IPCC Guidelines for National Greenhouse Gas Inventories*. 2006.
4. Halicioglu F. An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey. *31st. IAEE Annual International Conference*. 2008. Vol. 1. P. 17. Available: https://pdfs.semanticscholar.org/c2ec/0ea11c33f5cedfb02cf93d7fb09084a9e23b.pdf.
5. Robalino-López A., Mena-Nieto A., García-Ramos J. E., Golpe A. System dynamics modelling and the environmental Kuznets curve in Ecuador (1980–2025). *Energy Policy*. 2014. Vol. 67. Issue 1. P. 923–931.
6. Robalino-López A., Mena-Nieto A., García-Ramos J. E., Golpe A. Studying the relationship between economic growth, CO_2 emissions, and the environmental Kuznets curve in Venezuela (1980–2025). *Renewable and Sustainable Energy Reviews*. 2015. Vol. 41. P. 602–614.

7. Aniscenko Z., Robalino-López A., Escobar T., Escobar Pérez B. Regional cooperation in dealing with environmental protection. E-government and sustainable development in Andean countries. *Proceedings of the International Scientific Practical Conference*. 2017. Vol. 1. P. 13. Available: http://journals.ru.lv/index.php/ETR/article/download/2578/2484.

8. IPCC. Intergovernmental Panel on Climate Change. *Cambio climático 2014. Impactos, adaptación y vulnerabilidad. Resumen para responsables de políticas.* 2014.

9. Zhang X. P., Cheng X. M. Energy consumption, carbon emissions, and economic growth in China. *Ecological Economics.* 2009. Vol. 68. Iss. 10. P. 2706–2712.

10. Kuznets S. Economic growth and income inequality. *The American Economic Review.* 1955. Vol. 45. Iss. 1. P. 1–28.

11. Shafik N., Bandyopadhyay S. Economic growth and environmental quality: time series and cross-country evidence. *Policy Research Working Paper Series*. 1992. Vol. 18. Iss. 5. P. 55.

12. Correa F., Vasco A. F., Pérez C. La Curva Medioambiental De Kuznets: Evidencia Empírica para Colombia. *Semestre Económico.* 2005. Vol. 8. Iss. 15. P. 13–30.

13. Acaravci A., Ozturk I. On the relationship between energy consumption, CO_2 emissions and economic growth in Europe. *Energy*. 2010. Vol. 35. Iss. 12. P. 5412–5420.

14. Robalino-López A., García-Ramos J. E., Golpe A., Mena-Nieto A. CO_2 emissions convergence among 10 South American countries. A study of Kaya components (1980–2010). *Carbon Management*. 2016. Vol. 7. Iss. 1–2. P. 1–12.

15. Mohelska H., Sokolova M. The creation of the qualitative scenarios in the virtual three-dimensional environment Second Life. *Procedia Computer Science. World Congress on Information Technology 2010*. 2011. Vol. 3. P. 312–315.

16. Urban F. Sustainable energy for developing countries: modelling transitions to renewable and clean energy in rapidly developing countries. *UMCG Research Database*. 2009. P. 1–28.

17. CEPAL – Comisión Económica para América Latina y el Caribe. *La ineficiencia de la desigualdad*. 2018.

18. Jebaraj S., Iniyan S. A review of energy models. *Renewable and Sustainable Energy Reviews.* 2006. Vol. 10. Iss. 4. P. 281–311.

19. Datosmacro. Emisiones de CO_2 2016. 2016. Available: https://datosmacro.expansion.com/energia-y-medio-ambiente/emisiones-co2.

20. Burgwal G., Cuéllar J. C. *Planificación Estratégica y Operativa. Aplicada a Gobiernos Locales. Manual De Facilitación.* Quito, Ecuador: Abya Yala. 1999.

21. Alizadeh R., Lund P. D., Beynaghi A., Abolghasemi M., Maknoon R. An integrated scenario-based robust planning approach for foresight and strategic management with application to energy industry. *Technological Forecasting and Social Change.* 2015. Vol. 104. P. 162–171.

22. Robalino-López A., Mena-Nieto A., García-Ramos J. E. System dynamics modeling for renewable energy and CO_2 emissions: A case study of Ecuador. *Energy for Sustainable Development*. 2014. Vol. 20. Iss. 1. P. 11–20.

23. Dafermos G., Kotsampopoulos K., Latoufis K., Margaris I., Rivela B., Washima F., Ariza-Montobbio P., López J. Energía: conocimientos libres, energía distribuida y empoderamiento social para un cambio de matriz energética. *Buen Conocer – FLOK SOCIETY. Modelos sostenibles y políticas públicas para una economía social del conocimiento común y abierto en Ecuador.* 2015. Vol. 1. P. 431–476.

24. Ruiz-Caro A. *Cooperación e integración energética en América Latina y el Caribe. SERIE recursos naturales e infraestructura.* Santiago de Chile: CEPAL, 2006. P. 1–79.

25. Bhattacharyya S. *Energy Economics: Concepts, Issues, Markets and Governance.* London, UK: Springer, 2011.

26. Osmani F., Kochov A. Definition of indicators for decision-making to contribute to sustainable development through Cleaner Production and Resource Efficiency by using the AHP method. *Energetika*. 2018. Vol. 64. Iss. 3. P. 155–166.

27. Asamblea Nacional Constituyente. *Constitución de la República del Ecuador*. Quito, Ecuador. 2008. P. 1–140.

28. SENPLADES. Secretaria Nacional de Planificación y Desarrollo. *Plan Nacional de Desarrollo 2017–2021. TODA UNA VIDA*. Quito, Ecuador. 2017. P. 1–148.

29. SENPLADES. Secretaria Nacional de Planificación y Desarrollo. *Plan Nacional para el Buen Vivir 2009–2013*. Quito, Ecuador. 2009. P. 1–120.

30. Castro M. *Hacia una matriz energética diversificada en Ecuador.* Quito, Ecuador. 2011.

31. INEC. Instituto Nacional de Estadísticas y Censos. *Clasificación nacional de actividades económicas.* 2012. Available: http://aplicaciones2.ecuadorencifras.gob.ec/SIN/metodologias/CIIU%204.0.pdf.

32. BCE. Banco Central del Ecuador. *Información Estadística Mensual, Producto Interno Bruto IEM-432-e*. 2018. Available: https://contenido.bce.fin.ec/documentos/PublicacionesNotas/Catalogo/IEMensual/m1993/IEM-432-e.xlsx.

33. Oficina Económica y Comercial de España en Pekín. *Informe Económico y Comercial de Corea del Norte*. 2005.

34. INEC. Instituto Nacional de Estadísticas y Censos. *Evolución del sector manufacturero ecuatoriano 2010–2013*. Quito, Ecuador. 2016. Available: http://www.ecuadorencifras.gob.ec/documentos/web-inec/Bibliotecas/Libros/SECTOR%20MANUFACTURERO.pdf.

35. INEC. Instituto Nacional de Estadísticas y Censos. Análisis sectorial: La Industria de la Construcción. *Infoeconomía*. 2012. Vol. 10. P. 1–8. Available: http://www.ecuadorencifras.gob.ec/wpcontent/descargas/Infoconomia/info10.pdf.

36. INEC. Instituto Nacional de Estadísticas y Censos. Proyecciones Poblacionales 2010–2020. 2010. Available: http://www.ecuadorencifras.gob.ec/proyecciones-poblacionales/.

37. MiCSE. Ministerio Coordinador de Sectores Estratégicos. *Balance Energético Nacional 2016*. Quito, Ecuador. 2016.

38. World Bank. Data de Precios Internacionales de Derivados de Petróleo: Gasolina y Diésel. 2016.

39. Kaya Y., Yokobori K. Environment, energy, and economy: strategies for sustainability. *Conference on Global Environment, Energy, and Economic Development, 1993*.

40. O' Mahony T. Integrated scenarios for energy: A methodology for the short term. *Futures*. 2014. Vol. 55. P. 41–57.

41. Delgado F. *La transformación de la matriz productiva: Análisis e interpretación de la percepción del discurso oficial en los pequeños y medianos productores del sector agropecuario ecuatoriano*. FLACSO. 2015.

42. Sandoval García E. R. Proyección sobre energía eléctrica en México mediante la Identidad de Kaya. *Economía Informa*. 2013. Vol. 380. P. 41–53.

43. Aguir Bargaoui S., Liouane N., Nouri F. Z. Environmental impact determinants: An empirical analysis based on the STIRPAT model. *Procedia. Social Behavior Sciences. Second World Conference Business, Economics and Management*. 2014. Vol. 109. P. 449–458.

44. Yu X., Geng Y., Dong H., Ulgiati S., Liu Z., Ma Z., Tian X., Sun L. Sustainability assessment of one industrial region: A combined method of emergy analysis and IPAT (Human Impact Population Affluence Technology). *Energy*. 2016. Vol. 107. P. 818–830.

45. Brizga J., Feng K., Hubacek K. Drivers of CO_2 emissions in the former Soviet Union: A country level IPAT analysis from 1990 to 2010. *Energy*. 2013. Vol. 59. P. 743–753.

46. Robalino-López A., Aniscenko Z. Ecological, Economic and technological aspects of development. Decomposition analysis of energy consumption related to CO_2 emissions in Ecuador. *Proceedings of the 11th International Scientific and Practical Conference*. 2017. Vol. 1. P. 229–234. Available: http://journals.rta.lv/index.php/ETR/article/download/2645/2527.

47. Roxburgh C. The use and abuse of scenarios. *McKinsey Quarterly*. 2009. P. 1–10.

48. Porter M. E. *Competitive Strategy. Techniques for Analyzing Industries and Competitors*. New York, 1990.

49. Burt G., Wright G., Bradfield R., Cairns G., Van der Heijden K. The role of scenario planning in exploring the environment in view of the limitations of PEST and its derivatives. *International Studies of Management and Organization*. 2006. Vol. 36. Iss. 3. P. 50–76.

50. Ringland G. *Introduction to Scenario Planning*. Scenarios in Marketing, 2006. 18 p.

51. Quiceno G., Álvarez C., Ávila R., Fernández Ó., Franco C., Kunc M., Dyner I. Scenario analysis for strategy design: A case study of the Colombian electricity industry. *Energy Strategy Reviews*. 2019. Vol. 23. P. 57–68.

52. Lahera E., *Política y políticas públicas*. Santiago de Chile: CEPAL. 2004. P. 1–32.

53. Asamblea Nacional Constituyente. *Proyecto de Ley Orgánica de Eficiencia Energética*. 2019. P. 1–31.

54. Asamblea Nacional Constituyente. *Código Orgánico del Ambiente*. 2017. P. 1–92.

55. MEER – Ministerio de Electricidad y Energía Renovable. *Plan Nacional de Eficiencia Energética 2016–2035*. 2016.

56. INER. Instituto Nacional de Eficiencia Energética y Energías Renovables. *Eficiencia Energética en Transporte*. Quito, Ecuador. 2012. Available: http://ctpp.org.ec/wp-content/uploads/2018/06/presentacion_iner_transporte.pdf.

57. Barreiro C., Soria R., Hidalgo V. H. *Estudio Prospectivo del Sector Transporte de Ecuador y su Incidencia en la Matriz Energética en el Periodo 2017 – 2040*. Escuela Politécnica Nacional. 2018. Available: http://bibdigital.epn.edu.ec/handle/15000/19816.

58. Adomavičius V., Kaminickas M. Analysis of PV power future development possibilities. *Energetika*. 2014. Vol. 60. Iss. 4. P. 233–248.

59. Stratta J. *BIOCOMBUSTIBLES: los aceites vegetales como constituyentes principales del biodiesel*. Bolsa de Comercio de Rosario. 2000. P. 1–15.

60. MAGAP – Ministerio de Agricultura y Ganadería. SINAGAP. Sistemas de Información Nacional de Agricultura, Ganadería, Acuacultura y Pesca. [Online]. Available: https://www.agricultura.gob.ec/sinagap/.

61. INEC. Instituto Nacional de Estadísticas y Censos. *ESPAC 2015 – Encuesta de Superficie y Producción Agropecuaria Continua*. Quito, Ecuador. 2016.

62. INEC. Instituto Nacional de Estadísticas y Censos. *Anuario de Estadísticas de Transporte*. Quito, Ecuador. 2014.

63. Castro M. Reflexiones en torno al desarrollo de los biocombustibles en Ecuador. *CEDA. Centro Ecuatoriano Desarrollo Ambiental. Temas de análisis*. 2012. Vol. 25. P. 1–6.

64. Total Ecosolutions. Total Amyris biodiesel. Available: https://www.ecosolutions.total.com/en/products-services/total-amyris-biodiesel. [Accessed: 2 January 2019].

65. Grupo Spurrier: ProEcuador – Instituto de Promoción de Exportaciones e Inversiones, *Biocombustibles*. 2013.

66. Su Y., Zhang P., Su Y. An overview of biofuels policies and industrialization in the major biofuel producing countries. *Renewable and Sustainable Energy Review*. 2015. Vol. 50. P. 991–1003.

67. Charles M. B., Ryan R., Ryan N., Oloruntoba R. Public policy and biofuels: The way forward?. *Energy Policy*. 2007. Vol. 35. Iss. 11. P. 5737–5746.

68. Lim M. K., Ouyang Y. Biofuel supply chain network design and operations. In: Atasu A. (ed.). *Environmentally Responsible Supply Chains. Springer Series in Supply Chain Management, 3*. 2016. P. 143–162.

69. Dale V. H., Efroymson R. A., Kline K. L., Davitt M. S. A framework for selecting indicators of bioenergy sustainability. *Biofuels, Bioproducts and Biorefining*. 2015. Vol. 9. Iss. 4. P. 435–446.

70. García C., Masera O. *Estado del Arte de la Bioenergía en México*. Conacyt. México D. F., 2016. P. 1–105. Available: http://rtbioenergia.org.mx/wp-content/uploads/2016/12/Divulgacion_Estado-del-arte-de-la-bioenerg%C3%ADa-en-M%C3%A9xico.pdf.

71. Dufey A., Stange D., CEPAL, GIZ. *Estudio regional sobre la economía de los biocombustibles en 2010: temas claves para los países de América Latina y el Caribe. 2010*. P. 1–94.

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KURO IR ENERGIJOS NAUDOJIMO PERSPEKTYVOS: CO_2 EMISIJŲ MAŽINIMO POLITIKOS SCENARIJŲ EKVADORUI 2016–2030 M. TYRIMAS

Santrauka

Energetikos sektorius yra svarbus gyvenimo kokybę ir ekonominę gerovę lemiantis veiksnys. Kiekvienos šalies infrastruktūros, technologijų ir net kultūros skirtumus būtina įtraukti į tos šalies energetikos analizę, kuri reikalinga nustatant skirtingus CO_2 išmetimo šaltinių tipus ir jų dydžius. Straipsnio tikslas – pateikti atliktą Ekvadoro energijos ir kuro bei gamybos matricų perspektyvinę analizę 2016–2030 m., pasiūlyti prie šalies darnaus vystymosi prisidedančią visuomeninę politiką.

Pirmajame etape tyrimas yra aiškinamojo pobūdžio – pateikiamas modelio, besiremiančio „Kaya Identity" išplėstiniu variantu, kur CO_2 išmetimai tiriami kiekybiškai įvertinus pasaulio pramonės veiklą, jos įvairovę, sektorinį energijos naudojimo intensyvumą, sektorinį sunaudojamo kuro ir energijos rūšių derinį ir CO_2 emisijų veiksnius, aprašymas.

Antrajame etape, naudojant tiriamuosius (žvalgomuosius) scenarijus, tyrimas įgyja nuspėjamąjį-eksperimentinį pobūdį. Tai leidžia susieti istorinius ir dabarties įvykius su hipotetine (menamąja) ateitimi. Todėl „Kaya Indentity" pateikia gaires (struktūrą), kaip tirti ir aptarti scenarijaus varomąsias jėgas, kurios yra kiekybinio modeliavimo ir kokybinio faktų dėstymo pagrindiniai subjektai.

Tyrimo metu parengti du scenarijai: „Įprastų veiksmų" (angl. *Business as Usual*), kuriuo nekeičiama energijos ir kuro bei gamybos matricų struktūra; „Alternatyvusis" (angl. *Alternative*), kuriuo siekiama sumažinti sausumos transporto naftos produktų sunaudojimą. Alternatyviojo scenarijaus, numatančio biokuro naudojimą, atveju planuojama, kad CO_2 išmetimų apimtys sumažės nuo 45,58 iki 43,41 Mt CO_2 ekvivalentų 2030 metais. Ekvadore biokuro politika yra ankstyvajame raidos etape. Tačiau biokuras atveria svarbias galimybes: (1) leidžia diversifikuoti kuro ir energijos matricą; (2) prisideda prie energetinio saugumo; (3) skatina pramonės sektoriaus augimą; (4) siekia iškastinio kuro pakeitimo ir šiltnamio efektą sukeliančių dujų poveikio mažinimo.

Raktažodžiai: scenarijų analizė, „Kaya Identity", CO_2 išmetimai, kuro ir energijos matrica