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Article

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International Journal of Energy Economics and Policy

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2018, 8(4), 42-54.

Energy Efficiency Plan Benefits in Ecuador: Long-range Energy Alternative Planning Model

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ABSTRACT

The aim of this study was to analyze the energy demand in a scenario considering the national policy for energy efficiency of Ecuador. For this purpose, the effects on energy supply and demand by taking into account an economic scenario were studied. The economic scenario considered historical gross domestic product (GDP). The main contribution is this scenario was considered the development plan and current information. The data selected included the fall in GDP in 2015 as a result of the crisis caused by the fall in oil prices. The energy scenarios were designed using long-range energy alternative planning (LEAP) model. Two scenarios were development, business as usual without policies and projects. The results show that energy efficiency measures implicate cumulative energy savings that could reach 216,700 kBOE between 2015 and 2035.

Keywords: Energy Scenarios, Energy Efficiency, Long-range Energy Alternative Planning
JEL Classification: Q4

1. INTRODUCTION

Ecuador is a country located in northwestern South America, with a population of about 16.14 million people in 2015 (INEC, 2010). It is one of the petroleum producer and net exporter countries in the region. Oil prices have contributed to the economic and population growth, as well as a better quality of life during the past eight years; these have had direct consequences over the energy demand. From 2007 to 2015, gross domestic product (GDP) increased at a CAGR of 4.1%. Energy demand by sector is shown in Figure 1. In 2015, transport (46%), industry (19%) and households (13%) had the highest share in total energy consumption; which reached 95 million BOE (MICSE, 2016). Out of these three sectors, households have increased its energy intake at an AAGR of 7.2%, followed by transport (5.6%) and industry (3.6%). Despite its energy consumption, transport sector share in GDP in 2015 was only 12.5%; whereas Industry reached 21.6%.

Energy demand by source is shown in Figure 2. The main petroleum products consumed from 2007 to 2015 were diesel (30.9%), gasoline (24.3%), and LPG (9.5%) (MICSE, 2016). The first two fuels are mainly used in the transport sector whereas the latter is mostly used in households for cooking.

Historically, imports of these fuels have surpassed national production in order to satisfy an increasing demand, as seen in Table 1 high imports, along with high subsidies to these fuels have become a major issue for Ecuadorian energy system. Energy efficiency plays a key role in competitiveness, climate change mitigation, energy security and social aspects. However, there are important barriers such as high investments, low involvement of stakeholders, scarce information, limited access to efficient technologies, and difficult to quantify and measure of the benefits associated to energy efficiency that need to be overtaken in order to reach the existing energy savings potential that supply and demand sectors have in Ecuador. It is then a priority for the government to include energy efficiency as a public policy. In order to establish it as long-term state policy, it must be supported on a strong legal and institutional framework. The existing legal framework starts with The constitution of Ecuador. It establishes in Article 413: "The state will promote energy efficiency, development, and use of clean

Figure 1: Energy demand by sector and gross domestic product (2007–2015)

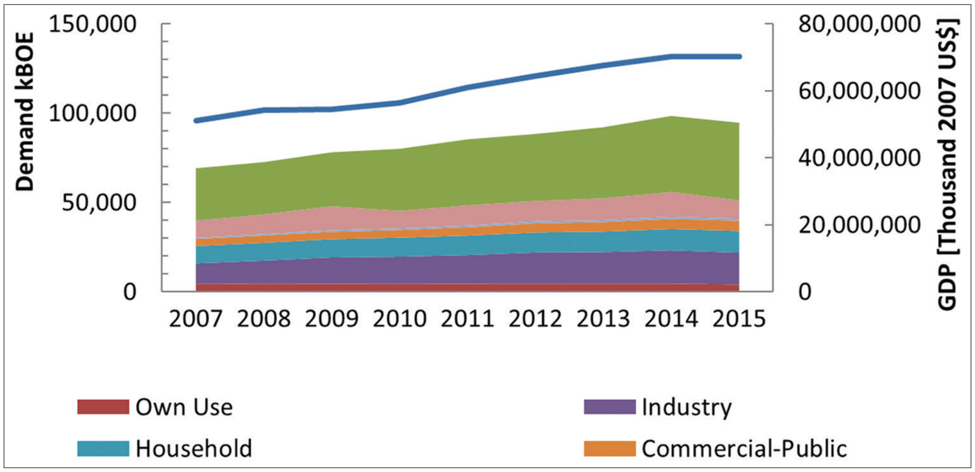


Figure 2: Energy demand by fossil fuel (2007–2015)

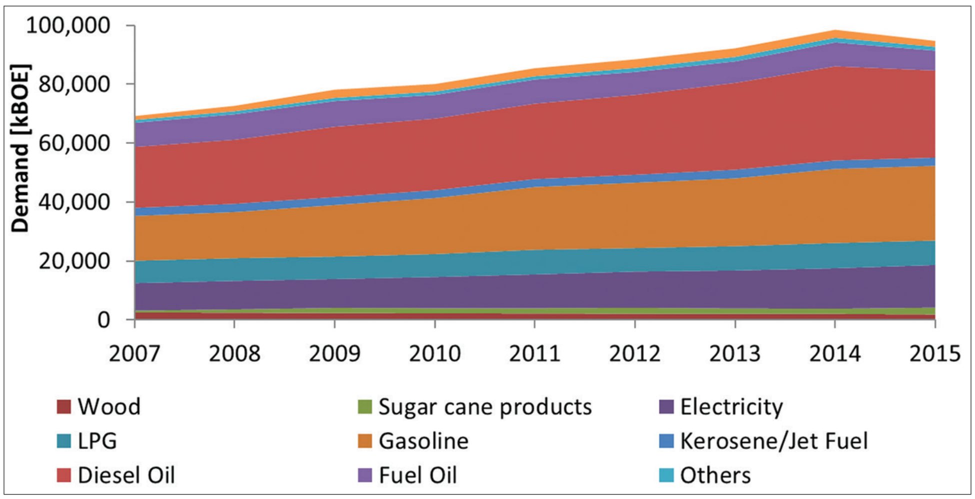


Table 1: Production and imports of diesel, gasoline, and LPG (2007–2015) (Ministerio de Electricidad y Energía Renovable, 2015)

kBOE	Diesel		Gasoline		LPG	
Year	Production	Imports	Production	Imports	Production	Imports
2007	12,594	11,862	9,486	6,955	1,214	6,500
2008	13,547	11,176	10,806	6,668	1,603	6,223
2009	14,355	14,481	10,633	8,387	1,644	6,084
2010	12,226	19,960	8,916	10,879	1,566	6,295
2011	14,087	15,112	10,992	11,293	1,947	6,523
2012	13,212	17,048	10,847	12,739	2,032	6,039
2013	11,831	20,872	9,743	14,329	1,912	6,410
2014	10,981	25,008	8,600	17,804	1,508	7,192
2015	10,812	23,720	7,440	17,389	1,146	7,247

and environmentally technologies and practices; as well as renewable energy, diversified and low-impact renewable energy technologies" (CONSTITUCION DEL ECUADOR, 2008). The national development plan (plan Nacional del Buen Vivir, 2013; 2017) establishes two objectives focused on energy efficiency and environmental conservation: Objective 7: To guarantee the rights of nature and promote environmental, territorial and global sustainability; Objective 11: To ensure the sovereignty and efficiency of the strategic sectors for an industrial and technological transformation (SENPLADES, 2013). In 2015, The Electric Power Public Services Law (LOSPEE) was enacted; in Article. 74 the Law describes the objectives regarding energy efficiency: "(i) to foment efficiency in the economy and general society; (ii) to promote values and conducts oriented at the rational use of energy resource; (iii) to propitiate the rational use of energy; (iv) To encourage the reduction of production costs, (v) to reduce the consumption of fossil fuels; (vi) To guide and defend the rights of consumers; and (vii) to reduce environmental impacts"(Ministerio de Electricidad y Energía Renovable, 2015).

Some strategies to address this situation have been undertaken among economic sectors; the most relevant is the plan for efficient cooking (PEC), whose aim is to replace LPG for electricity cooktops in 3 million households by 2022. Concomitantly, electricity supply has been addressed through the construction of 8 hydropower plants, which will add 2,822 MW of installed capacity.

PEC is promoting technology as well as energy source substitution in households, which is the third largest consumer. In industry and transport sectors, the second and first consumer, respectively, machinery and fleet replacement plans were developed. However, these strategies have not been widely implemented and their impact in energy consumption of these sectors was not noticeable. Thus, supply and demand sectors still need further measures to promote energy savings. In this sense, the ministry of electricity and renewable energy, supported on its duties established in Article 12, Chapter. II, Title III of LOSPEE has developed the national plan for energy efficiency (PLANEE). The aim of this plan is to increase the efficient use of energy sources through the execution of programs and projects in energy supply and demand in order to reduce the imports of oil products, and contribute to climate change mitigation. Furthermore, the Plan seeks the establishment of an energy efficiency culture among the population, which will be supported by a solid legal and institutional framework (MEER, 2017b). It is expected that PLANEE will become an instrument of public policy that will articulate stakeholders and will identify actions, programs, and projects in the aforementioned sectors. Its implementation will secure energy supply, reduce investments in infrastructure, reduce energy imports, and mitigate climate change.

PLANEE is structured in sectorial axes considering energy supply, energy demand, legal aspects, institutional aspects and information aspects as follows: (1) Legal, institutional framework and information access; (2) households, commercial and public; (3) industry; (4) transport, and (5) own use. Every axe has a general objective, specific objectives, goals and action lines.

The aim of this study is to analyze the effects on energy supply, energy demand, and greenhouse gas (GHG) emissions that implementing the National PLANEE might have by taking into account one economic scenario and two energy scenarios, one of them considering strategies addressed to accomplish the objectives stated in PLANEE. For this purpose, the Long-range energy alternatives planning system (LEAP) was used. This is a bottom-up-type accounting energy modeling platform developed by the Stockholm Environment Institute. It has been widely used to project energy demand, supply, and CO_2 emissions considering different scenarios (Heaps, 2013; Lazarus et al., 1995). LEAP has been used to assess the effect of energy policies related to introduction of new technologies or energy sources, energy efficiency measures, and its effects on GHG emissions on national energy systems (Cai et al., 2008; Emodi et al., 2017; He et al., 2010; Huang et al., 2011; Islas et al., 2007; Kim et al., 2011; Kuldna et al., 2015; Zhao et al., 2011). It has also been implemented in the analysis of specific sectors such as transportation (Azam et al., 2016; Hong et al., 2016; Manzini, 2006; Sadri et al., 2014; Shabbir and Ahmad, 2010), industry (Ates, 2015; Wang et al., 2007), households (Davoudpour and Ahadi, 2006), and electricity generation (Bautista, 2012; Cai et al., 2007; Islas et al., 2002; McPherson and Karney, 2014a; Shin et al., 2005).

This research is organized as follows: Section 2 describes the scenario design, policy considerations and assumptions for each scenario. Section 3 then presents the main results regarding demand, supply, emissions, costs, and comparisons between scenarios. Section 4 present the discussion of the main results and implication of the research. Finally, Section 5 contains conclusions.

2. SCENARIO DESIGN

2.1. The Model

LEAP is a widely-used tool for energy policy analyst and climate change mitigation assessment (Heaps, 2013). The software can be used to created models in countries or regions. The structure of LEAP is flexible; the user will design energy, economic and environmental models. The energy supply required depends on how energy is demanded, transformed and generated in each specific case using economic variables that address the energy consumption. Figure 3 describes how LEAP works. Demographic data, energy scenario (assumptions) and macroeconomic data are the variables which conducted the energy demand. Energy transformation and supply energy depends on demand necessities. Finally, an environmental and cost-benefit analyst could be achieved in the process.

2.2. Structure

The prospective analysis is meant to be an operation which allows performing an exploration of the future. Thus, this idea relate the formulation a variety of scenarios which introduce different alternatives (OLADE, 2017). In this context, two economic assumptions were considered to design the scenarios.

Figure 4 shows the structure of scenarios. The historical GDP scenario was used to determine the alternative scenario. Business as usual (BAU) scenario is derived from alternative economic scenario but no energy efficiency measures apart from current initiatives were included. Efficient alternatives and energy programs based on PLANEE were included in "energy efficiency scenario (ES)."

2.3. Economic Scenarios

Historical GDP scenario is a reference to the economic growth that Ecuador has experimented up to date. Characteristics such as population rationality, development capabilities, and public and private management have been taken into account. The historical scenario considered historical GDP taken from the World Bank for the period 1961–2007 (World Bank, 2016) and from the official information of Central Bank of Ecuador for the period 2008–2016 (Banco Central del Ecuador, 2016). A second order polynomial fit was performed obtaining a correlation coefficient of 98%. The GDP projections with the model resulted in CAGR from 2017 to 2035 of 2.4% (Figure 5).

For the alternative GDP scenario, the national development plan "plan nacional para el Buen Vivir 2013–2017" has been used as a reference. In this document, population and GDP per

Figure 3: Long-range energy alternative planning framework diagram

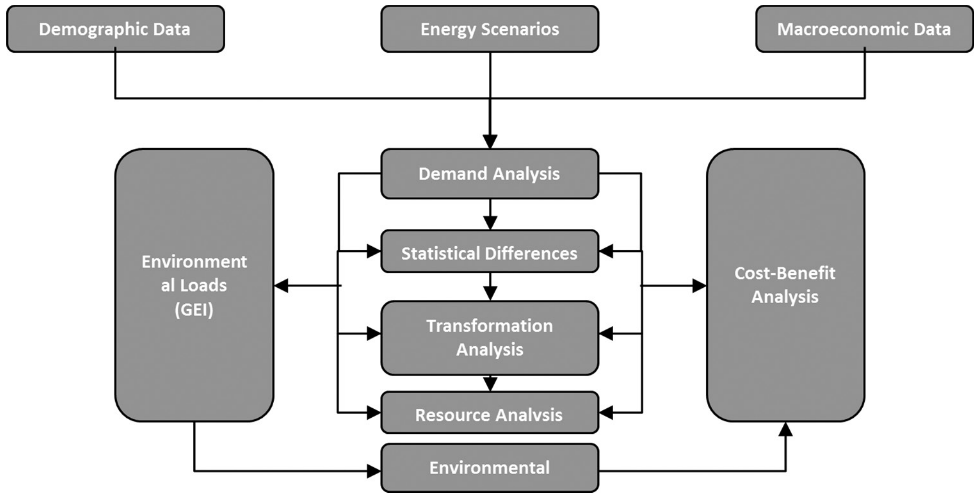
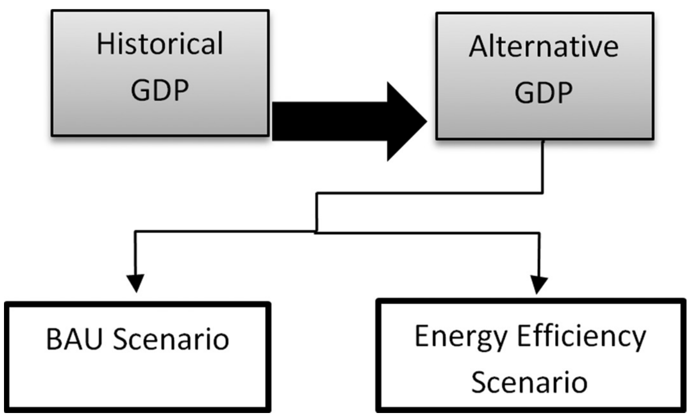


Figure 4: Scenario design



capita have been estimated to grow at a CAGR of 1.3 and 3.5, respectively from 2013 to 2030 (SENPLADES, 2013). The rates were calculated using GDP and energy consumption data from 1990 to 2011. Given the inertia of the Historical GDP scenario, it has been considered that the growth rates might be plausible after 2020. Thus, both scenarios will have the same GDP up to the aforementioned year. The CAGR of GDP for the period 2020–2030 was estimated to reach 4.4%. For the time period subsequent to the one considered in the national development plan (2031–2035), the same growth rate for GDP per capita. CAGR of GDP for this period was estimated to reach 4.1%. Considering the time frame 2016–2040, GDP reached a cumulative growth rate of 3%. This projection determines a viable alternative scenario that will require considerable efforts regarding public management and public policy. Furthermore, it has been considered that strategic industries such as aluminum, steel, copper, and petrochemicals would be implemented in the country.

2.4. BAU Scenario

In order to model the scenarios, Ecuador's 2016 national energy balance (base year 2015) was reproduced in LEAP and the aforementioned year was considered as a reference. This scenario will use as first input the macroeconomic scenario "alternative" developed. Energy demand by the economic sectors will grow at the same rate of its GDP (OECD, 2004). It was assumed that energy intensity of every sector will remain constant in the analyzed period.

2.4.1. Residential sector

Residential sector demanded 9421 kBOE in 2006, and increased to 12,123 kBOE in 2015 with a CAGR of 2.8%. LPG is the most used energy source for cooking (around 60.2%) (MICSE, 2016). Energy consumption by residential sector was projected based on the private consumption of household per capita, population, and energy intensity. The final use of energy in the sector was divided in cooking, water heating, lighting, refrigeration and other uses.

The demand for the residential final users was estimated using total consumption per source by the residential sector and the share of each use in the aforementioned consumption. As an example, the energy used for cooking by households from LPG was obtained by multiplying the consumption of LPG reported in the national energy balance for the residential sector by the participation (in percentage) of cooking in LPG consumption.

2.4.2. Industry

Energy consumption in the industry sector was 38% diesel, 31% electricity, 13% bioagasse and the rest (18%) were others fuels in 2015. Thus, industrial sector consumption share reached 26% of the energy in the country.

The industrial energy consumption was projected based on the gross value added as activity level, and base year energy intensity that was considered to remain constant for the entire period under analysis. Using international standard industrial classification of all economic activities the industry sector was divided in food and beverages, textile, wood and paper, coke and refined products, minerals and metals and small industry subsectors.

The percentage of energy consumption on the industrial subsector was considered the same as in the National Energy Balance 2013 (Figure 6). The Energy demand from National Energy Balance 2015 was multiplied by the percentage of final energy.

Figure 5: Gross domestic product to alternative and historical scenarios

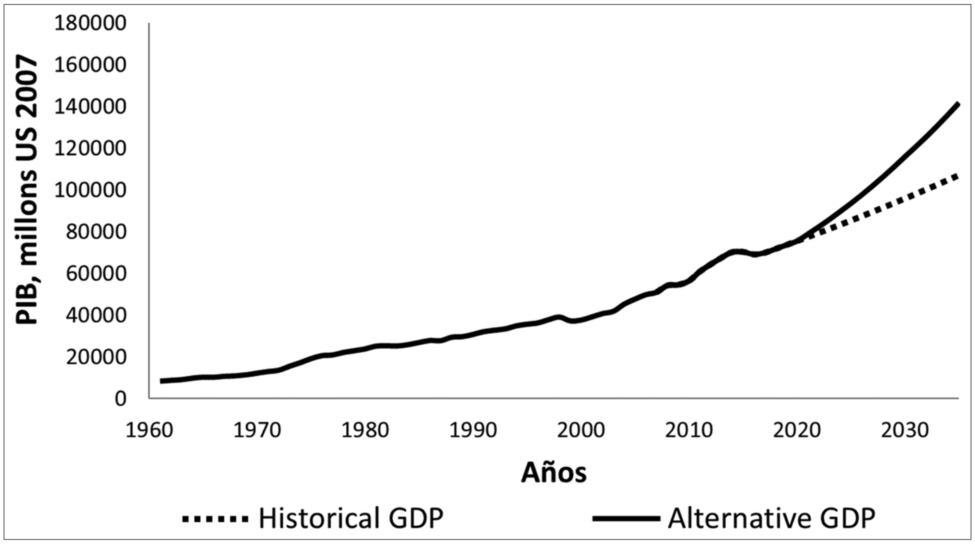
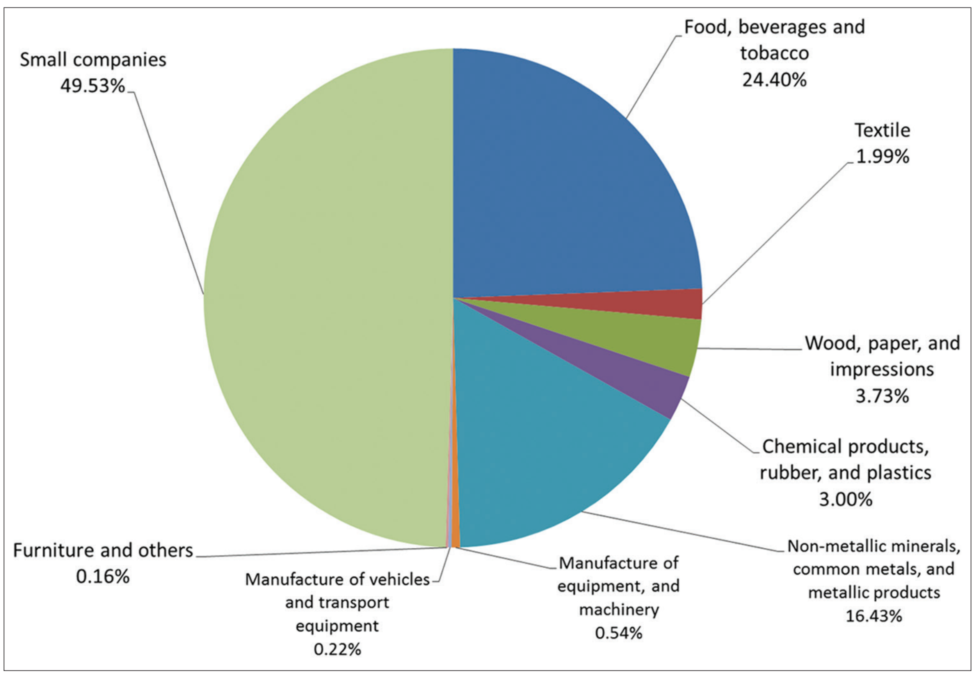


Figure 6: Energy consumption in the industry sectors of ecuador



Source: MICSE, 2013

The manufacturing energy and carbon footprints study was used to estimate the percentage of final energy used. The final uses considered in the study are steam, direct heat, mechanical force, and others

2.4.3. Transport sector

National energy balance 2015 estimated that 46% of the demand energy is consumed by transport sector (MICSE, 2016). The highest demand within the sector corresponds to freight transport. The majority of the energy consumed is diesel (45%) followed by gasoline (43%). Transport sector was divided in road transport (passenger and freight), maritime and air transport. According to National Transport Statistics, the fleet of passenger transport was breakout into cars, taxis, SUVs, buses, and motorcycles. Low and medium duty trucks and heavy duty trucks were included in freight transport fleet.

Figure 7 represents the Gompertz function was used to analyze the fleet projection, is a model based on the evolution of per capita income and the rate of motorization. Thus, the growth of the number of vehicles per 1000 inhabitants was estimated as a function of per capita GDP (Dargay et al., 2007). For Ecuador, the number of vehicles per 1000 inhabitants as a function of per capita income in base year was around 88 vehicles per inhabitant in 2015. Gompertz growth rate has been engaged to estimate the fleet.

Share fuel of vehicles will grow as the blue map scenario developed by international energy agency (OECD/IEA, 2016). In the case of Ecuador, blue map scenario was developed according to the market behavior worldwide. The sales of cars and technology development were used to design the scenario according with the historical record by type of vehicle. Figure 8 shows the Blue map scenario for Ecuador, which fits national and international market evolution.

2.4.4. Energy supply

Installed power capacity increased at an average rate of 3.8% from 2000 to 2007. After 2007, the AAGR of installed capacity reached 4.1%. Hydropower plants with no inclusion of "Emblematic" projects along with gas turbine and steam turbine thermal plants are the technologies that will increase its share in the mix. In 2015 total installed capacity was 6192 MW (49.5% was hydroelectricity) (MICSE, 2016) and it will reach 18,500 MW in 2035. The electrical generation will increase with the construction of the Santiago hydropower project. Around 15,790 GWh/year will be generated using 3600 MW of installed capacity, and the plant is expected to demand an investment of 3500 MMUSD (MICSE, 2015).

Transmission and distribution (T and D) losses will decrease at an average annual rate of 4.5%. It will reach 10% in 2022 following a more conservative projection than the electricity master plan 2013–2022 (CONELEC, 2014). These projections of T and D losses will be kept constant after 2022 for all scenarios.

Regarding oil production, data based on a study developed by Wood was provided by the Ministry of Hydrocarbons. This study considered a low investment and high investment scenarios for projecting oil production. For the base scenario, low investment was used as input. According to this study, oil production for the scenario considered will decline at an average annual rate of 5.5%. In 2013, production reached 197,908 kBOE, and this value is expected to be reduced to 99,433 kBOE by 2035. Associated natural gas will follow crude oil production scenario, considering an average fraction of gas of 5.4% of total output. Non associated gas production reached its peak in 2014 (3,477 kBOE) and started to decrease in 2015. From 2016 to 2018 it was considered that production would remain constant (3,085 kBOE/year) before a new decrease in 2019. After this year and until 2022 production would be constant (1543 kBOE) and reserves would be completely extracted (Wood, 2013).

Refining capacity is assumed to be maintained 63,933 (kBOE/year) given that the three existing refineries (La Libertad, Esmeraldas and Shushufindi) will continue operating until 2035.

2.5. Energy ES

The energy ES involves implementing energy efficiency measures such as improvements in energy intensity, fuel substitution, and technology substitution on the demand side. Table 2 presents the strategies presented in PLANEE policy.

2.5.1. Residential sector

According to the 2015, National Energy Balance (MICSE, 2016) 86% of the total LPG supply was based on imports. Furthermore, 82% of LPG consumption is attributed to the residential sector.

Figure 7: Vehicle distribution with gross domestic product

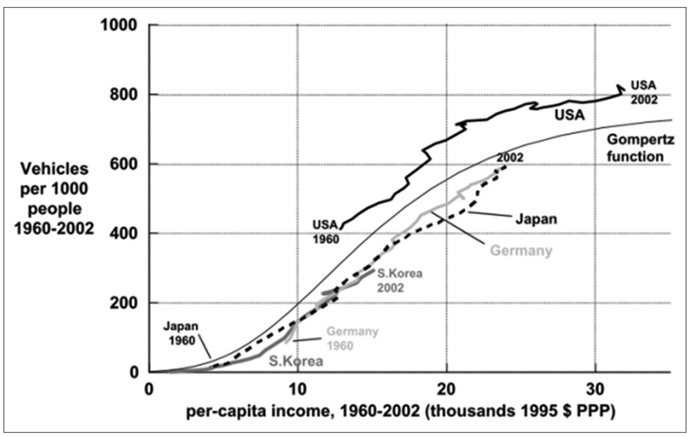
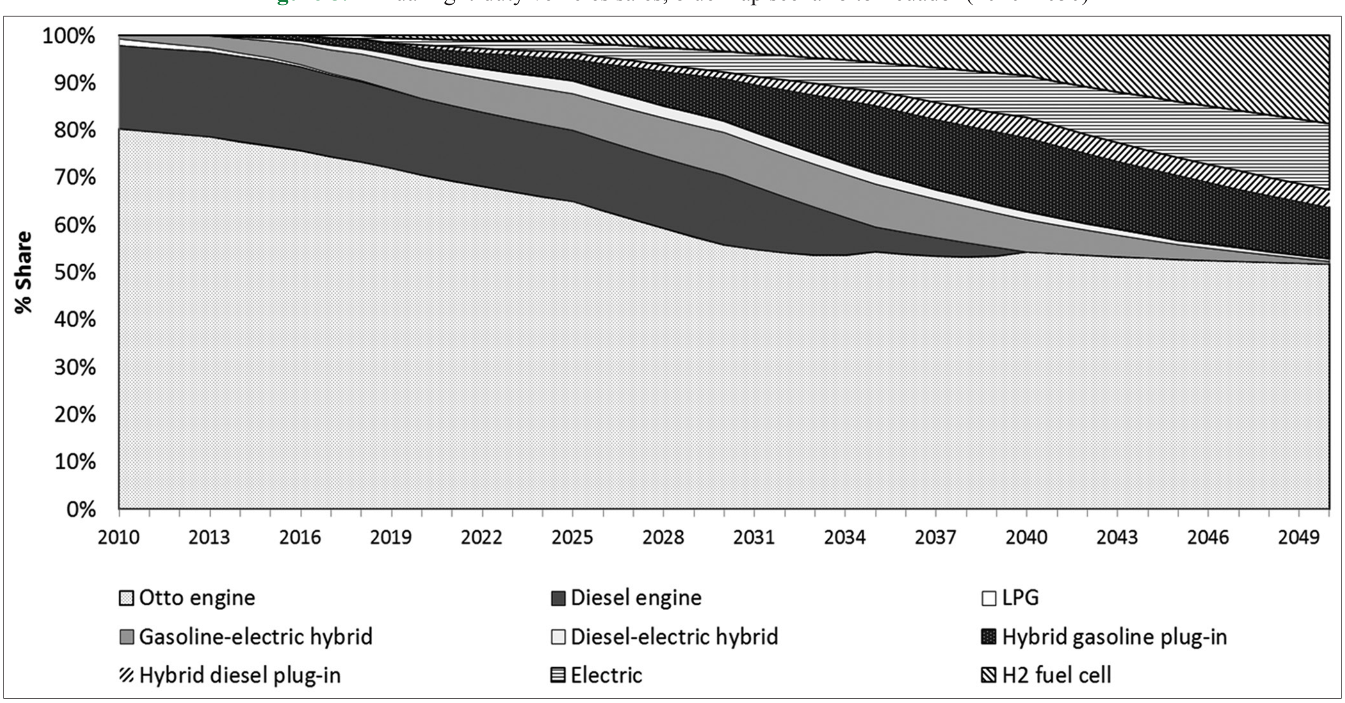


Figure 8: Annual light-duty vehicles sales, blue map scenario to Ecuador (2010–2050)



To reduce LPG use in this sector, the Ministry of Electricity and Renewable energy launched in 2014 the "National PEC." This is an initiative with the aim of replacing LPG cooktops with induction cooktops (Martínez-Gómez et al., 2016). The electricity necessary for the development of this plan will be generated by the new hydropower projects as it will be described in the electricity section. The goal was to reach 3 million induction cooktops by 2017 (Martínez-Gómez et al., 2017). However, considering the present situation it was assumed in this scenario that the goal of induction cooktops will be reached in 2022. After this year, and once PEC is completed, the number of households with induction cooktops will increase at an AAGR of 2.1% from 2020 to 2035. This means that 64% of households would have switched to induction by 2035. Figure 9 shows the projected share of technologies used for cooking.

Regarding water heating, replacement of LPG water heaters with electric heaters was assumed. The aim of the government is to replace 750,000 gas heaters with electrical heaters (Kastillo et al., 2017; Martínez-Gómez et al., 2016; Martínez et al., 2017; MEER, 2017a). Electric water heaters would be used in 80% of households by 2030.

In 2012, a plan to replace low efficiency refrigerators was launched by the government. Up to 2015, 82,772 refrigerators were replaced. In this case, it was considered that the substitution of all low efficiency refrigerators would be completed by 2030.

Assumptions regarding lightning considered the government plan for replacing incandescent light bulbs with fluorescent light bulbs that started in 2008. As of 2015, 14.9 million incandescent bulbs were replaced. Using the goals established in PLANEE, the share of lightning technologies was represented in Figure 10.

Table 2: Strategies for energy ES

Sectors	Strategies
Residential, commercial and lightning	Water heating
	National PEC
	Labeling
	Replacement of refrigerators
	Efficient lighting
	Improved the public lighting
Industry	ISO 50001 standard
	Cogeneration
	ESCO market
	Replacement of Equipment
Transport	RENOVA plan (replacement of vehicles)
	Labeling
	Biofuels
	Performance improvement
	Electric vehicles
	Massive urban transport
	Eco driving
	Fuel quality improvement
Hydrocarbons supply	OGE project
	Replacement of equipment
National interconnected system	Renewable energy

OGE: Optimization to generate electricity, PEC: Plan for efficient cooking, ES: Efficiency scenario

Appliance labeling will seek the replacement of inefficient appliances by equipment of better performance based on the labeling that built-in appliances should have.

2.5.2. Transport sector

Studies regarding strategies and opportunities in energy efficiency i.e., PLANEE and Base Line Study developed by INER highlighted the importance of reducing energy consumption in this sector using new technology and alternative sources. For this scenario, efficiency measures, as well as technology substitution, and penetration of renewable sources have been taken from PLANEE and Base Line Study in transport sector in Ecuador.

In 2010, ECOPAIS pilot plan started in the city of Guayaquil. The aim of the plan was to replace regular gasoline with a blend of 5% ethanol and 95% gasoline (E5). By the end of 2013, ECOPAIS gasoline was commercialized in 41 out of the 125 gas stations within the city. In May 2015, executive decree 675 states that E5 must be commercialized nationwide. Moreover, the blend could progressively reach E10 (Ecuador, 2015).

Other hypothesis included technology penetration in vehicles. Replacing conventional engines with hybrid cars will reach 30% of the fleet by 2030. In the case of electric vehicles, 6% of the vehicles share of the fleet by 2030. Thus, fleet Renovation. The Ecuadorian RENOVA Plan for the transport sector started in 2008, and its purpose was to take out of circulation obsolete vehicles

Figure 9: Share of technologies used for cooking in households (2015–2035)

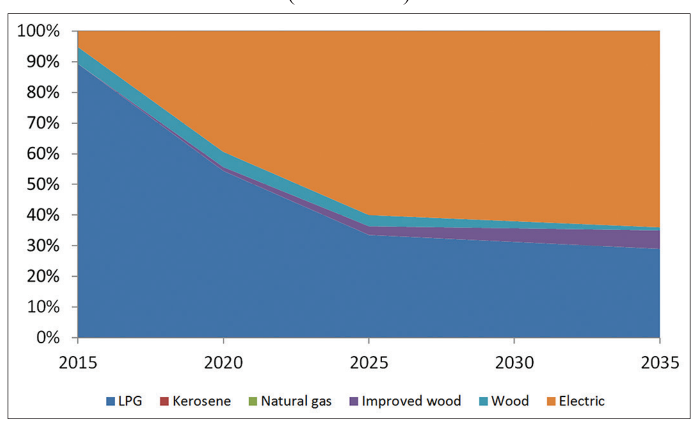
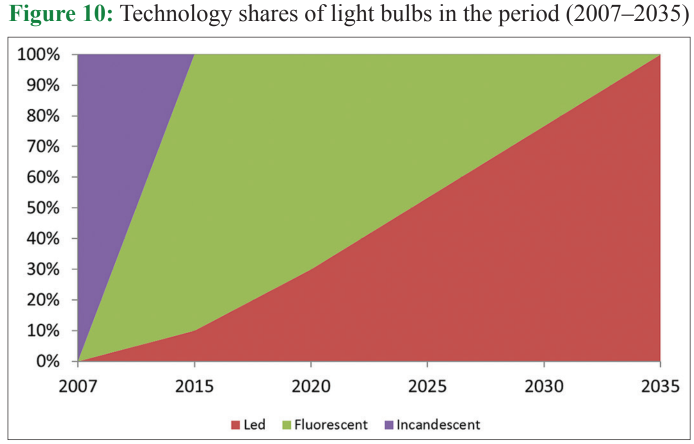


Figure 10: Technology shares of light bulbs in the period (2007–2035)



and replace them with new ones. The result of this initiative was a reduction of 0.89% in gasoline consumption for light-duty transport (ANT, 2013). This scenario estimates the same reductions by 2030. Improvements in fuel economy for different engines were considered. In reference to studies of transportation, the useful energy intensity in road transport is expected to be reduced in 10.35% by 2030 (INER, 2013). Furthermore, improved quality of fuels was simulated. This action promotes the formulation in refineries of fuels for the automotive sector with a Euro 5 standard.

Consumer behavior was also taken as a hypothesis in transport sector. It was considered that eco driving, and the correct vehicle maintenance would improve energy intensity in 24% (Barkenbus, 2010).

Labeling is an alternative that gives the customer the possibility to choose the most efficient technology (Wang et al., 2011). A 5% reduction of useful energy intensity was estimated base on European studies (Raimund et al., 1998).

Regarding massive transportation, the operation of the bus rapid transit, metro and trolley were considered to be aligned with Strategies Mobility plans. In this case supply energy provided by hydropower plans.

2.5.3. Industry sector

Following "plan RENOVA"(MIPRO, 2012), a government program launched in 2012 to replace obsolete and inefficient machinery and equipment in industries, energy efficiency measures, and increase of electricity´s participation in the fuel share used for heat and prime movers have been considered. The number of replaced machines will reach 10% in 2035 including medium and big industries.

The first assumption was that the energy intensity of all industries in the period under analysis would be reduced 10% by the implementation of ISO 50001 Standard. Furthermore, 9.2% of minerals and metals industries will implement ISO Stands since 2035 on base at actual behavior. The rest of industries like chemical and plastics, textiles, food and beverages and tobacco will reach 2% to 2035 (at least100 industries with high production).

Additionally, cogeneration was considered in ES. The aim is to optimize the processes to produce both electricity and heat in industry. Energy efficiency in steel production will increase from 80% in 2016 to 90% in 2035.

Finally, in the industry sector, the introduction of energy services companies (ESCO's) was considered. ESCO´s companies have the aim of developing, installing and financing projects for improving the energy efficiency of facilities owned or operated by customers (Larsen et al., 2012). Useful energy intensity should decrease 0.02%.

2.5.4. Electricity generation

Installed power capacity in this scenario was assumed to follow the Ecuadorian electricity master plan 2013–2022 (PME 2013–2022). Hydropower plants, including "emblematic" projects along with gas turbine and steam turbine thermal plants are the technologies that will increase its share in the mix. Table 3 shows the cost and installed capacity for hydropower plants, which could be included in the EE scenario if the government would find the required investment. In order to cover the demand generated by the assumptions in each economic sector, it has been considered that combined cycle power plants will be introduced in addition to the projects included in the PME 2013–2022 (CONELEC, 2014). In 2015 total installed capacity was 6,192 [MW].

2.5.1.1. Gas, crude oil - fossil fuel production

Along with a higher investment, this scenario considers the exploitation of existing reserves in protected areas (ITT fields). In 2015, indigenous production reached 204,220.63 kBOE, and this value is expected to be reduced to 138,877.15 kBOE by 2030. Associated natural gas will follow crude oil production profile, considering an average fraction of gas of 5.4% of total output. Non associated natural gas production was assumed to follow the same assumptions as BAU scenario.

Regarding refining capacity, the construction of a new refinery complex, "Refinería del Pacífico" has been considered. This new complex will have a capacity of 300,000 barrels per day and its operation is linked to the closure of "La Libertad" Refinery. The total refining capacity will increase from 63,933 kBOE/year in the base year to 150,486 kBOE/year in 2022. This capacity was assumed to be maintained until 2035. Furthermore, an upgrade in Esmeraldas Refinery was considered that would change the output share as seen in Figure 9 in order to prioritize the production of gasoline and diesel.

3. RESULTS

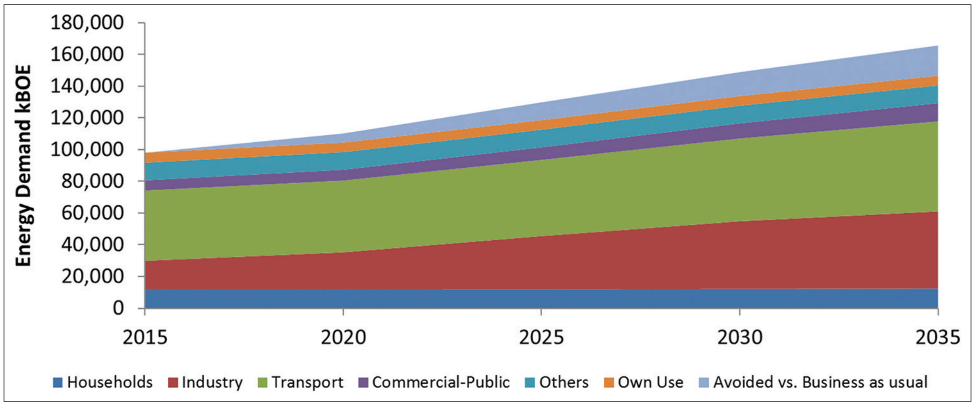
The following results have been obtained from the simulations using LEAP software. Annual energy demand in energy ES to 2035 is depicted in Figure 9 with transport as the main consumer. Despite the actions considered and a cumulative reduction of 77,485 kBOE compared to BAU scenario, energy demand in transport continues to grow. Its share in total demand in 2035 would reach around 39%, and would still remain as the main contributor in terms of GHG emissions as seen in Figure 11.

Among all the strategies, the introduction of hybrid and electric vehicles is the most representative in terms of energy savings. Freight transport would be the subsector with the highest share in energy savings (around 76%). If transport sector would apply all the strategies described in section 3.2, the cumulative reduction in total energy demand would reach 216,700 kBOE for the period

Table 3: Hydroelectric projects in Ecuador

Projects	Installed capacity, MW	Investment costs, billions dollars
Rio Santiago	3,600	3,500
Cardenillo	595.6	1,135
Chontal	194	595
Angamarca sinde	32.1	52
La merced jondachi	19	52
Infiernillos	19.6	40

Figure 11: Energy demand in energy efficiency scenario



2016–2035 as shown in Table 3. Despite the strategies considered, vehicle fleet size has a correlation with economic growth. In this sense, complementary measures such as fostering public transportation multimodal mobility, and freight train would reduce the use of private and freight vehicles. It is worth mentioning that the government developed a pre-feasibility study for the construction of an electric freight train that would connect the largest cities in the country (Quito and Guayaquil). Furthermore, projects such as the construction of a subway in the city of Quito, and a trolley in the city of Cuenca have the aim of reducing the use of private cars. However, public transportation still needs to be improved in order to cause a deep change in consumer behavior.

Industry is another sector to highlight regarding the effects of implementing energy efficiency policies. Energy demand in industry has an important increment in 2018 as a consequence of the introduction of strategic industries, which will represent 18% of the energy demand in the sector by 2035. Nevertheless, the cumulative reduction in energy demand for all industries compared to BAU scenario would reach 53,713 kBOE as seen in Table 3. Most of this energy savings are attributed to the reduction in diesel oil consumption for steam as a result of equipment replacement and implementation of energy management systems (EMS) and ISO 50,001. This sector will still remain as the second consumer, reaching a share of 33% by 2035, only six points below transport 39% furthermore, diesel oil will still have the largest share in industry energy mix by 2035, with 41%. The introduction of energy intensive industries and economic growth is the main reason for these shares increase. More aggressive strategies focused on energy source substitution should be taken into account such as using electricity or natural gas instead of diesel. However, in order support them an important barrier needs to be overcome, which is the persistence of subsidies for oil liquids. The current and future massive deployment of electricity supply should be focused on achieving a reduction on the share of hydrocarbons in the industry sector considering that it is one of the sectors that contribute the most to the total GDP.

Technology and fuel substitution in the residential sector for cooking and water heating would have a significant impact on energy demand of households. Cumulative energy savings would reach 52,152 kBOE compared to BAU scenario. Electricity share would go from 35% in 2015 to 63% in 2035. The introduction of induction cooktops is a critical aspect to be considered in households given the impact that this strategy might have in energy demand and fuel share in this sector. Furthermore, the substitution of LPG for electricity would reduce drastically the imports of the first fuel, which in 2015 reached 86% of total supply and is highly subsidized.

Energy indicators in Table 4 show the effects of the implementation of PLANEE. A reduction in energy intensity of 26% from 2015 to 2035 would be feasible in Energy ES compared to 16% in BAU. regarding per capita energy demand, a reduction of 11% can be achieved by 2035 in Energy ES compared to BAU, despite the introduction of strategic industries which are energy intensive. The Energy Demand in Energy ES is shown in Figure 11, an increase of the Energy Demand of Ecuador is observed. Industry is going to present a sustained increase in energy demand. Furthermore, transport will maintain a predominant participation in energy demand above all sectors.

LEAP uses the IPCC factors to estimate the GHG emissions. Figure 12 shows the GHG emissions for Energy ES, included those avoided versus BAU. The cumulative reduction of CO_2 EQ emissions for Energy ES, compared to BAU is 104 Mton. The main drivers for this reduction are fuel and technology substitution in energy demand side (electricity for fossil fuels), and changing the electricity mix to a high share of hydropower.

Figure 13 depicts fuel share in electricity generation within the interconnected national system (INS) in energy ES with a predominance of hydro. Santiago hydropower project installed capacity would be 5.000 MW in 2035 (30% of total installed capacity and 35% of electricity generated). The construction of Santiago power plant will start in 2024 with an installed capacity of 2.500 MW. Emblematic hydroelectric plants will produce in 2035, 24% of electricity supply and current hydroelectric projects will produce 33%. In total 92% the electricity generated will come from hydropower within the INS by 2035.

Per capita energy demand and final energy intensity are presented in Table 5. Per capita energy demand from 2015 to 2035 increases 31.7% in BAU scenario. Meanwhile in energy ES it increases 16.6%, which corresponds to an increase of almost half compared to BAU scenario. The final energy intensity, from 2015 to 2035, decreases in 15.8% in BAU scenario. Whereas energy ES shows a decrease of 25.9%.

Figure 12: Output share of oil products energy efficiency scenario

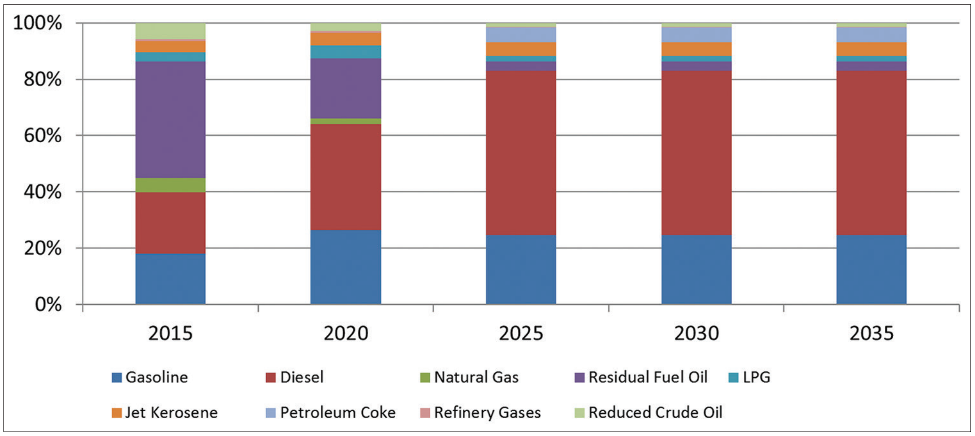


Figure 13: Greenhouse gas emissions energy efficiency scenario

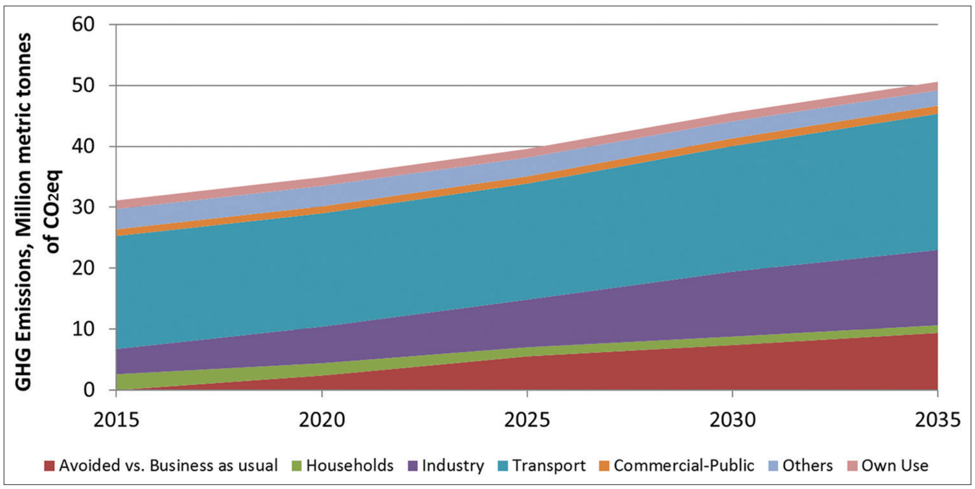


Table 4: Cumulative energy savings in energy ES

Sector	Cumulative energy savings (kBOE)				
	2015	2020	2025	2030	2035
Households	0	3,918	15,876	32,304	52,152
Transport	0	7,567	24,002	47,693	77,485
Industry	0	2,894	11,751	28,599	53,713
Commercial-public	0	469	3,098	7,691	14,174
Others	0	2,339	7,627	13,050	18,474
Own use	0	13	124	355	702
Total	0	17,200	62,478	129,692	216,700

ES: Efficiency scenario

The expansion and improvements in refining capacity are a critical aspect for energy supply in Energy ES, most of all for reducing imports as depicted in Table 6. The Fuel share in electricity generation Energy ES and Fuel share in Energy Imports Energy ES are show in Figure 14. The implementation of energy efficiency strategies along with a new and upgraded refining infrastructure would reduce imports (mainly oil products) by nearly 40% by 2035 compared to BAU scenario. A larger refining capacity will reduce crude oil exports in order to satisfy domestic requirements based on national oil reserves. As seen in Figure 14 exports before 2025 are mainly oil products; after this year national crude oil reserves will not be enough to satisfy domestic demand and imports will have an important share in oil supply.

Using international prices perspective to 2040 of fossil fuels by the U.S. Energy Information Administration (EIA, 2015), the social cost was estimated to all subsector (Table 7). The prices of oil, gasoline, diesel, aviation gasoline, LPG, electricity were related to energy use in every sector. The energy costs were updated to dollars in 2016. Prices from the country's investment catalog were used in the case of the transformation processes of both the generation of electricity and refining process. The refining cost for the Pacific Refinery was taken from the CAPEX and OPEX costs for a lower capacity refinery (200bbl/day). The most important result is observed for the saving of secondary fuels. Having a Refinery is an investment that brings significant savings due to the reduction of derivatives imports. According to Table 7, there is a saving of about 70 billion dollars for the application of energy efficiency measures and considering an investment in hydraulic energy and the refinery.

4. DISCUSSION AND POLICY IMPLICATIONS

The search for equality and equity, as well as the constant struggle against poverty through the promotion of the country's sustainable development, is an unavoidable task of the State. In this sense, and considering that energy is the motor that allows the world

Figure 14: (a) Fuel share in electricity generation energy efficiency scenario, and (b) fuel share in energy imports energy efficiency scenario

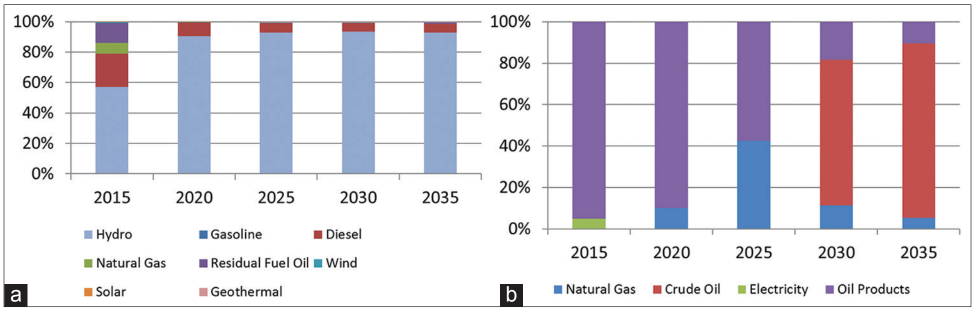


Table 5: Energy efficiency indicators

Scenario	Per capita energy demand (BOE/Inhab.)					Final energy intensity (BOE/2007 USD)				
	2015	2020	2025	2030	2035	2015	2020	2025	2030	2035
BAU	6.03	6.3	6.95	7.51	7.94	1.39	1.46	1.39	1.28	1.17
Energy efficiency	6.03	5.97	6.35	6.75	7.03	1.39	1.38	1.27	1.15	1.03

BAU: Business as usual

Table 6: Energy imports per scenario

Scenario	Energy imports (kBOE)				
	2015	2020	2025	2030	2035
BAU	60,326	73,489	95,472	113,779	129,150
Energy efficiency	60,326	31,338	9,848	37,529	78,024

BAU: Business as usual

Table 7: Energy cost by sectors in millions 2016 US dollars

Sector/Branch	BAU scenario	Energy efficient scenario	Savings
Demand	-	231	231
Residential	-	43	43
Industry	-	4	4
Transport	-	133	133
Commercial and public	-	51	51
Transformation	63,841	79,678	15,837
OGE generation	6,577	16,851	10,275
Oil transport	14	26	12
Refinery	3,897	9,449	5,552
Oil production	53,353	53,351	(2)
Recourses	59,819	−10,528	−70,346
Primary	−57,362	−40,851	16,511
Secondary	117,180	30,323	−86,857
Total	123,660	69,381	−54,278

BAU: Business as usual

development, Ecuador ratifies the commitment assumed before the United Nations to achieve the fulfillment of the Sustainable Development Goals in energy matters, as these are the general framework that will guide the development of this sector and its implications for sustainability. Ecuador initiated a process based on energy planning, with political decision and under the commitment to achieve Buen Vivir. This now translates into projects and mega constructions that improve the quality of life of the citizens, allowing the sustainable use of natural resources, under precepts of responsibility, justice, social equity and energy efficiency.

In order to evaluate Energy Efficiency Plan Benefits in Ecuador through the implementation of PLANEE, this research developed and applied LEAP model. LEAP model allows to analyze the effects on energy supply and demand by taking into account an economic scenario, which considered historical GDP. The study contributes with new added credibility of the use of expert validation the existing literature about LEAP-based in different sectors as households, transport, industry, commercial-public and others, similar than (Cai et al., 2008). To undertake this, two scenarios were development, BAU without policies and projects, and Energy Efficiency, which includes energy efficient actions in demand using technology, policy, education, research and production. This is the first Ecuadorian research to specifically evaluate he energy demand in a scenario considering the national policy for energy efficiency (PLANEE) of Ecuador. The results support future decision making to the government of Ecuador, which represents the reduction in energy demand, supply needs and emissions.

Among the different policy measures that PLANEE develops, the introduction of hybrid and electric vehicles, improvements in fuel economy and biofuels, are important strategies that place transport as the sector with the largest reduction in energy demand compared to BAU scenario, followed by industry and households. Similar results were observed by Azam et al.in (Azam et al., 2016), Sadri et al. in (Sadri et al., 2014) or Hong et al. in (Wang et al., 2014) where the LEAP model allows to calculate the reductions of energy consumption and emission projection for the road transport sector. These studies found that the development of hybrid, electric vehicles and biofuels implicates an important reduction in energy demand and GHG emissions. However, in case of Ecuador, transport would still be the main consumer among all economic sectors. More ambitious measures such as a higher penetration of electric vehicles, and the introduction of an electric freight train should be considered in future studies.

Industry sector would have from 2020 a considerable increase in its energy intake due to the operation of energy intensive strategic industries. It would remain as the second main consumer in BAU and Energy ES. Equipment replacement and implementation of EMS and ISO 50001 are the strategies that contribute the most to reach a cumulative reduction of 6% in EE scenario compared to BAU. Similar results have been found by Ates (Ates, 2015) and

Wang et al. in (Wang et al., 2007) where the use of LEAP helps to calculate Energy efficiency and CO_2 mitigation potential in the industry of Turkish and China. In these studies it is observed than equipment replacement and implementation of EMS and ISO 50001 are the strategies that contribute at the energy efficiency of the sector.

Among all energy efficiency strategies in households, replacement of LPG cooktops with induction is the most representative given the impact that it will have in reducing energy demand compared to BAU as well as LPG imports.

The expansion in electricity generation by renewable energies and refining capacity are also crucial in order to satisfy a domestic demand of electricity and oil products, and reduce energy imports 40% by 2035. Similar ideas were exposed by McPherson and Karney in (McPherson and Karney, 2014b) or Islas et al. in (Islas et al., 2002), where the use of LEAP, the generaion by renewable energies hepls new oportunuty to develop estrategies for application electricity sector in emerging countries.

5. CONCLUSIONS

This research analyzes the effects on energy supply, energy demand, and GHG emissions that implementing the PLANEE in Ecuador by using the LEAP model. It had been taking into account one economic scenario and two energy scenarios, one of them considering strategies addressed to accomplish the objectives stated in PLANEE.

Cumulative energy savings were estimated to reach 216,700 kBOE for the period studied. Despite the actions considered and a cumulative reduction of 77,485 kBOE compared to BAU scenario, energy demand in transport continues to grow. The introduction of hybrid and electric vehicles, improvements in fuel economy and biofuels, were observed as important strategies that place transport as the sector with the largest reduction in energy demand compared to BAU scenario. The cumulative reduction in energy demand for all industries compared to BAU scenario would reach 53,713 kBOE. Most of this energy savings are attributed to the reduction in Diesel Oil consumption for steam as a result of equipment replacement and implementation of EMS and ISO 50001 standard. Technology and fuel substitution in the residential sector for cooking and water heating would have a significant impact on energy demand of households. Cumulative energy savings would reach 52,152 kBOE compared to BAU scenario. In addition, there is a saving of about 70 billion dollars for the application of energy efficiency measures and considering an investment in hydro power plants and a new oil refining.facility Furthermore, a reduction in energy intensity of 26% from 2015 to 2035 would be feasible in Energy ES compared to 16% in BAU. Regarding per capita energy demand, a reduction of 11% can be achieved by 2035 in Energy ES compared to BAU, despite the introduction of strategic industries which are energy intensive.

In this research, the use of LEAP assesses the effect of energy policies related to the introduction of new technologies, energy sources, energy efficiency measures, and its effects on GHG emissions on national energy systems. However, analysis of specific sectors such as transportation could be developed in further detail. In the case of Ecuador, transport would still be the main consumer among all economic sectors. More ambitious measures such as a higher penetration of electric vehicles, electric massive passenger transportation, and the introduction of an electric freight train could be considered for future studies.

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