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Future Scenarios and Trends of Energy Demand in Colombia using Long-range Energy Alternative Planning

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ABSTRACT

The prospective of Colombia's energy demand will be defined by economic, social, cultural and political phenomena. Modeling the factors that determine demand can be broadly divided into quantitative and qualitative. The quantitative phenomena, demography, energy efficiency and the direct consumption of fuels; qualitative effects are specific conditions, which are defined within each scenario as variables that will have effects on quantitative phenomena. In the baseline scenario, the transportation sector is expected to remain as the largest representative of Colombia's energy demand, although its participation in the year 2050 will be reduced by approximately 7%. The residential sector will have a reduced growth supported by the law 1715 that will increase distributed generation and implement more efficient lighting systems. A scenario focused on energy diversification shows a reduction in demand since the short term. Transport sector is maintained with similar behaviors in all scenarios as the goods transport networks keep the same.

Keywords: Energy Prospective, Energy Demand, Economic and Energy
JEL Classifications: Q47, Q41, Q50

1. INTRODUCTION

Energy demand is the consumption of all the different energy sources in a specific area of study. Usually the demand is divided by sectors of consumption, which in most cases coincide with the economic sectors of a country; being these mainly: Industrial, residential, tertiary and transport. In addition to these can be presented other sectors of consumption such as the Mining or Agricultural depending on the economy of each country (BP, 2016; EM, 2016; UPME, 2015a).

The energy demand prospective is the base for prospective plans and energetic planning. Considered from the model point of view, the demand is the basis for generating the supply (Grimaldo et al., 2017). This is because, in reality; the demand is an independent variable from the supply but, in most of cases, behaves according to the economic and social situations of a country (UPME, 2015b).

The economic conditions that shape the behavior of energy demand are quantifiable (Axsen and Kurani, 2012; Lutzenhiser, 1993). These variables, by the use of mathematical correlations; can be linked directly to the demand (Atalla and Hunt, 2016). However, the social and cultural variables that cause a great impact on the behavior of the demand, especially for sectors such as agriculture (Martinho, 2016) and residential, are variables of a qualitative nature and the presumption of their impact on the demand is nothing more than speculation (Najmi and Keramati, 2016; Steemers and Yun, 2009).

The methodology chosen for the realization of the prospective was based on long-range energy alternative planning (LEAP), so that according to the alignments of the software were defined the sectors of consumption, the largest of which were subdivided into subsectors with more homogeneous demands (Markovic et al., 2011). The growth of the demand in the sectors is affected by the added value; for the residential sector the principal variable is the population; for the transport sector, growth rates based on historical fuel consumption were used (Sadri et al., 2014).

This paper condenses the mathematical, statistical and modeling methodology used to develop the energy demand prospective as the considerations, obstacles and changes found in the way.

2. LEAP REVIEW

LEAP is a modeling software widely used in several countries as a main tool to analyze both demand management and supply scenarios focusing on the energy system, some works can be mentioned as Emodi et al. (2017) in Nigeria; Lind and Espegren (2017) in Oslo; Dayana et al. (2016) in Brunei Darussalam; Nojedehi et al. (2016) in Tehran; De et al. (2015) in Brazil; Ates (2015) in Turkey; McPherson and Karney (2014) in Panama; Bautista (2012) in Venezuela; Xu et al. (2012) in Henan Province; Liu et al. (2011) in Beijing; Wang and Zhang (2011) in China; Liu et al. (2011) in Jiangxi; Dagher and Ruble (2011) in Líbano; Huang et al. (2011) in Taiwan; Phdungsilp (2010) in Bangkok; Jun et al. (2010) in Korea and Shabbir and Ahmad (2010) in Rawalpindi e Islamabad. Despite the fact LEAP model has been widely used all over the world for prospective scenarios due it's very easy input data, internal black-box format and, assertive results; it appears to be limited for renewable energy solutions or for prospective based on the offer side, giving a general demand for all scenarios and fulfilling it with the solutions each author proposes. This paper looks up to create an accurate, valid and understandable methodology using LEAP which can lead to multiple demand scenarios focusing not in the energy solutions experts can imagine for their regions but the real behavior of the society under some specific conditions and how those behaviors will affect the energy sector.

The present application of the demand modeling is done through a tree structure in which the trunks (consumption sectors) and branches (consumption subsectors) are defined, each LEAP branch can be treated individually, having its own consumption values by energy source and growth at different periods; hence, LEAP allows the model to be as disaggregated or centralized as the user chooses (Markovic et al., 2011).

Each component included in the model must be congruent with the way in which LEAP models reality, whereby the consumer sectors; which in this model will be the variable components of demand, must be affected by one or several variables that modifies the domestic demand for each sector. LEAP proposes the use of added values as key variables (Heaps, 2012), which will directly affect the behavior of the demand for each sector.

Using added values (AV) it is possible to model the growth of demand on a macro and micro scale; which allows the prospective to have a greater accuracy in the data, minimizing the complexity of the model (Sadri et al., 2014; Lind and Espegren, 2017). The model will be simplified then to only one key variable between the growth of the demand and the different behaviors of the economy.

Added values may easily be linked to the macroeconomic variables of the country, which are modified for each proposed scenario, which is why a methodology based on the economy is considered (Rivera et al., 2016; Viola and Aceros, 2016).

Study times were defined as follows:
- Short term (ST): It corresponds to a period from the base year to the year 2020.
- Mid term (MD): Corresponds to the period 2020-2035.
- Long term (LT): Corresponds to the period 2035-2050.

The purpose of the division of the study in periods is to understand the dynamism of the economy and the world panorama of energy, based on these periods it is possible to define more complex and precise scenarios in the quantitative and qualitative situations that affect the Colombia's energy demand.

There are variables that are independent of these periods, as population; usually this variable continues the trend of growth characterized by an aging of the average population. However, for these behaviors to be affected would be necessary birth policies like in China (Zhang, 2017) or major natural disasters such as the spread of pandemics that can decimate the population of a country. Those independent variables will be used as key variables. Hence, the LEAP model is divided into five trunks with three key variables (AV, Population and Fuel consumption) that are modified for each period: Short, medium and long term.

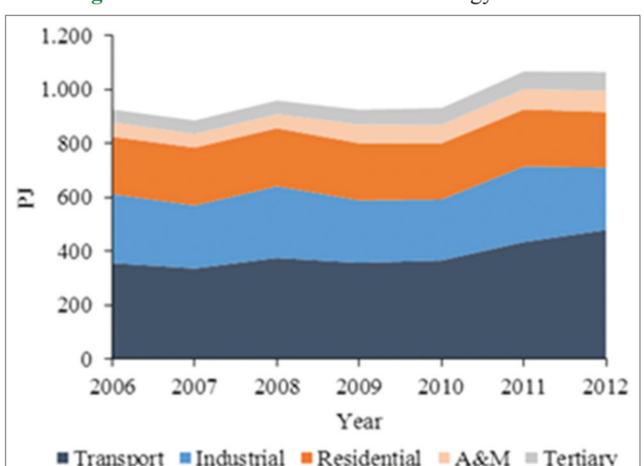
3. CONSUMPTION SECTORS

According to the consumption sectors proposed by the energy-mining planning unit (UPME), the most representative consumption sectors are: Residential, industrial, transport, tertiary and, agricultural and mining (UPME, 2015b). Figure 1 and Table 1 show, respectively, the demand trend since 2006 and the percentage distribution of the

Table 1: Consumption sectors

Sector	Total demand percentage
Residential	19.2
Tertiary	6.5
Transport	44.7
Industrial	21.6
Agricultural and mining (A and M)	7.3

Figure 1: Colombia's historical final energy demand



most representative sectors in Colombia (UPME, 2015a). Based on LEAP, it was chosen to use final energy consumptions to establish the demand; therefore, the generating sector is eliminated from the demand and simplifies the development of the prospective as shown in Figure 1, Colombia has historically based its demand on the use of fossil fuels in the transport sector. Due the lack of rail networks or naval routes within the country that allow an efficient handling of the transport of goods traditionally this sector is managed by trucks which represent 33.6% of the sector's domestic demand (UPME, 2010). As the transport sector is based on the transport of goods network the key variable for this sector will be the historical growth of its consumption with some modifications from the qualitative variables.

4. ECONOMIC MODEL

The model developed to generate the prospective is based on the behavior of the country's economy over time. The economic model has two main advantages. The first corresponds to the literature (Investig'Action, 2016; Yaffe, 2016; Mantilla, 2012); Colombia is a developing country; its history is marked by political, social and military events that have profoundly affected all sectors of society including aspects that compete with energy demand. A model based on economics allows a relatively simple quantification of qualitative variables thanks to the large study of the economics effects of those events (Sorrell, 2015).

On the other hand, demand is based on the behaviors of society; behaviors that are demonstrated can be directly related to different economic factors, which allows the economic model to be one of the closest models to the real understanding of society (Abreu et al., 2016; Lutzenhiser, 1993).

Due the large amount of economic variables, which can be used, it was necessary to carry out a previous study of the significance of the variables within the economic behavior of the country. The study resulted in the determination of the following economic variables for the development of the demand: Gross domestic product (GDP), population, representative exchange rate, trade balance, consumer price index (CPI), producer price index (PPI), unemployment and foreign direct investment (FDI).

Those variables will then be linked to the key variable through mathematics correlations. Transport and residential sectors are special cases inside the model as they are not affected by the macroeonomic but from their own keys variables. For the transport sector, the key variable was based on the projection of the historical fuels consumption to 2050 (SIPG, 2016).

The development of a special methodology for the transport sector made possible to simplify the model. The relationship between transport demand and the economy represents an academic challenge that would add mayor complexity to the model without achieving a notable grade of assertiveness in comparison with the simple model. The residential sector has been extensively studied at a global and national level, its behavior is parametrized and the variables that affect its demand have been summarized to a single one: Population (Atalla and Hunt, 2016, Najmi and Keramati, 2016; Xu et al, 2012).

For LEAP residential demand is treated also as an special case and is only required as input the historical data of population and the proyection of households; for Colombia this proyection is divided into urban and rural households as shonw on Figures 2 and 3 (UPME, 2015a; Banco Mundial, 2015).

1. Relationship between economics variables, added values and energy demand.

As shown in Figure 4, the model is based on the mathematical relation between economic variables and energy demand, being both linked by the key variable (added value). The added value is the specific GDP for each economic sector of a country, represents the growth or contraction of the sectors and is the most appropriate variable to be related to the demand of the sectors (Frei et al., 2013).

Figure 2: Historic data of households in Colombia

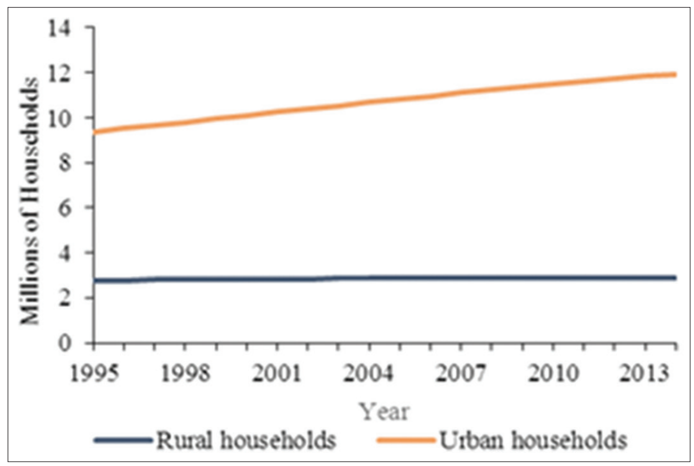


Figure 3: 2050 households prospective for Colombia

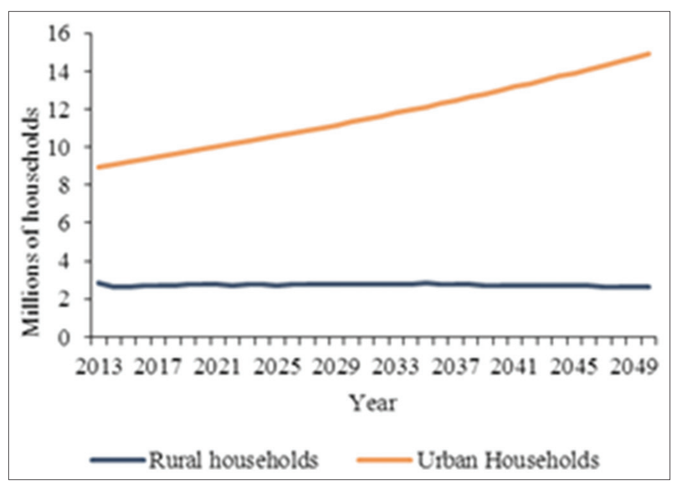


Figure 4: Relationship between the economic variables and the energy demand

For LEAP added values work as an independent variable within its black box system, adding some uncertainty to the whole but in exchange giving predetermined correlations between the added values and the energy demand. Therefore, a model based on added values is the easiest and best option for the prospective while using LEAP. However, these values are determined by equations proper to the developing regions that LEAP contemplates (Heaps, 2012.) and, although the user can modify these relations, it is not practical in most of the cases. Even when the relations between the added values and the demand is pre-stablished by LEAP, it is not the same case for the relation between the economics variables and added values.

2. Significance analysis between economic variables and added values.

A significance analysis pretends to correlate two or more variables in a way they can be defined one as function of the other and at the same time, if a large amount of different variables are in the same analysis; determined which variables are actually correlated and which ones doesn't. In order to run an accurate analysis there are need two different mathematical processes.

The first procedure corresponds to the development of a correlation study between the individual variables using the Pearson coefficient and the second corresponds to a multivariate regression in which several scenarios were studied in order to find the mathematical relationship between the added values and the economic variables.

Five different hypotheses of relationship were tested, where each one is fed with the information obtained in the previous evaluation, achieving a coefficient that is closer to one. This process is similar to the iteration processes used in mathematics and thermodynamics.

The general purpose of multiple regression is to learn more about the relationship between the predictor variables (macroeconomics) and a dependent or criterion variable (added value). The method looks up to reach the following equation (1), (Quinn and Keough, 2002).

$$y=b_0+b_1*x_1+b_2*x_2+\ldots+b_k*x_k+u$$

Where "y" is the criterion variable, "x" are the predictor variables, "b_0" is the interception point, "b" represents the growth in the criterion variable by the unitary growth of the corresponding predictor variable, and "u" represents the residual scores.

In order to achieve optimum estimations the Gauss-Markov theorem stablishes that the best method to approach the regression is the least-squares estimation. As in the linear regression R^2 is the principal coefficient which will determine the accuracy of the regression (Dowdy et al., 2011).

As basis for the multiple regression method there were taken data from the period 1992-2014 for the principal macroeconomic variables, which will be considered as the predictor variables and are described below.

- GDP.
- Population (POP).
- Representative exchange rate.
- Trade balance.
- CPI.
- PPI.
- Unemployment.
- FDI.

Each of the three sectors were treated independently. Hypothesis results are shown in the Table 2 while the multiple regression summaries are shown in Tables 3-5.

Table 2: Multivariable regression summary

Sector	Hypothesis
Tertiary	All of the variables
	Representative exchange rate
	Exchange rate, balance
	Exchange rate, balance, unemployment
Industrial	CPI discarded
	Exchange rate discarded balance, PPI
	PPI discarded, IED
	Balance, PPI discarded, FDI
	Balance, Pop, PPI discarded, FDI
A and M	All of the variables
	Balance discarded
	Pop, balance discarded

CPI: Consumer price index, PPI: Producer price index, FDI: Foreign direct investmen

Table 3: Multivariable regression results: Tertiary sector

Regression statistics	Regression statistics (%)
Multiple correlation coefficient	98.63%
Determination coefficient R^2	97.27%
Adjusted R^2	91.82%
Predictor variable	**Coefficient b**
Interception (b_0)	0.8800638
Trade balance	−0.00095911
FDI	−1.06E-06
POP	−6.3252E-09
PPI	0.5258144
CPI	−0.29466357
GDP	−0.03339498
Unemployment	−0.00716274
Representative exchange rate	0.04650805

GDP: Gross domestic product, CPI: Consumer price index, FDI: Foreign direct investment, PPI: Producer price index

Table 4: Multivariable regression results: Industrial sector

Regression statistics	Regression statistics (%)
Multiple correlation coefficient	98.233%
Determination coefficient R^2	96.498%
Adjusted R^2	92.995%
Predictor variable	**Coefficient b**
Interception (b_0)	0.588192636
GDP	−0.069834241
Representative exchange rate	−2.85222E-05
Trade balance	0.001292169
CPI	0.212380372
Unemployment	−0.36277885
POP	−10.10743975

GDP: Gross domestic product, CPI: Consumer price index

5. BASELINE SCENARIO

The baseline scenario will maintain the most expected growth for the different sectors, as well as the trend from the recent years. Mostly of this scenario is based on the baseline scenario proposed by the UPME in its energy ideas to 2050 (UPME, 2015b).

For the baseline scenario were taken into account the following expected considerations.

- Integrated international markets.
- Global economic contraction.
- Economic acceleration.
- Colombia as an emerging economy.
- Economic opening.
- Technological development.
- Population aging.

As well, the scenario is complemented with some qualitative considerations, which are focused on politics and social factors, being the most important the peace agreement with the subversive groups FARC-EP and ELN (Yaffe, 2016; Semana, 2016; Redacción Paz, 2014).

For the energy considerations, most of the aspects are related to the continuity of plans such as program for rational and efficient use of energy (PROURE) (Marulanda et al., 2017). Reduce of energy demand increases as the processes' efficiency does in the industry. Similar case for public lighting were is expected the massification of LED lights and photovoltaic lighting (Fajardo, 2016).

From the previous assumptions there was made the qualitative and quantitative analysis for the economic variables as shown in the Tables 6 and 7, respectively.

Based on the data from the Table 6 and the economic model, there was accomplished the AV projections for the baseline scenario as shown in Table 8.

Using the data from the Table 8, population and fuel consumption projections and through the software LEAP it was accomplished the prospective of the baseline scenario. Results are shown below.

Although transport sector occupies 44% of the final energy demand of the country (UPME, 2015a); industries in Colombia are characterized by high rates of energy inefficiency so, to 2014, 53.76% of primary energy demand of the country was consumed by the industries, and 46.3% will be to 2050 as shown in Figure 5. Industries consumption will be affected, mainly, by cogeneration processes and other mechanisms described in the PROURE program and continued in Law 1715 causing consumption to drop 7% for the studied period.

Residential sector will have a reduced growth on its participation, due to the entrance of induction stoves, LED lighting and others, this energy efficiency on mass consumption appliances will generate the sector to grow, on average, at a rate of 1.58% biannually.

Primary energy consumption will be characterized by a high demand of natural gas as shown in Figure 6, mainly for electricity generation, cogeneration processes and as a replacement to fuelwood in rural areas. However, the possible shortage of natural

Table 5: Multivariable regression results: A and M sector

Regression statistics (%)	
Multiple correlation coefficient	99.30
Determination coefficient R^2	98.60
Adjusted R^2	96.97
Predictor variable	**Coefficient b**
Interception (b_0)	−0.00446456
GDP	0.00370698
POP	−0.04445921
Representative exchange rate	1.5353E-05
CPI	0.19579477
Unemployment	0.30832588
FDI	1.5433E-06
PPI	0.13722509

GDP: Gross domestic product, CPI: Consumer price index, FDI: Foreign direct investment, PPI: Producer price index

Table 6: Qualitative matrix of the economy or the baseline scenario

Variable	ST	MT	LT
GDP	3.3-3.8	3.6-4.4	4-4.6
Unemployment	↓↓	↓↓↓	↓
CPI	↓	↓	↓
FDI	↑	↑↑	↑↑↑
Social inv.	→	→	→
Trade balance	↓↓	↓	↑
Oil price (USD)	40-80		
1st y 2nd sectors	↓	↓	↑
3rd sector	↑	↑↑	↑

GDP: Gross domestic product, CPI: Consumer price index, FDI: Foreign direct investment

Table 7: Quantitative matrix of the economy for the baseline scenario

Variable	Units	ST	MT	LT
GDP	%	3.3-3.8	3.6-4.4	4-4.6
Unemployment	%	8.3-8.8	8-8.6	8.3-8.6
CPI	%	4.6-5	4.4-4.8	4.2-4.5
FDI	%	−0.005-0.05	0-0.02	0.01-0.1
Trade balance	%	−4.7-−4.2	−4.3-3.7	−3.8-−3.2
1st y 2nd sectors growth	%	33-35	34-32	33-36
3rd sector growth	%	65-67	66-68	64-67

GDP: Gross domestic product, CPI: Consumer price index, FDI: Foreign direct investment

Table 8: Expected added values growth for the baseline scenario

Year	Units	Sector		
		A and M	Tertiary	Industrial
2015	2008 COP B	68.1	174.1	57.8
2020		77.5	221.3	63.7
2025		89.4	279.8	71.5
2030		102.5	351.6	79.8
2035		117	437.7	88.1
2040		132.2	538.3	96.7
2045		147.9	651.4	105.4

Figure 5: Primary energy consumption prospective. Sectors baseline scenario

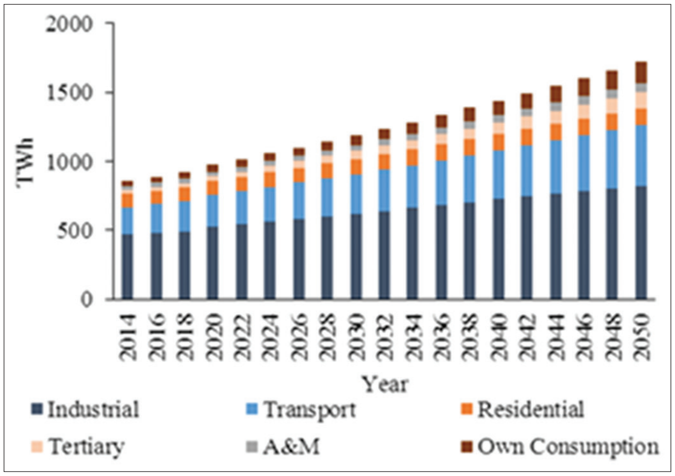
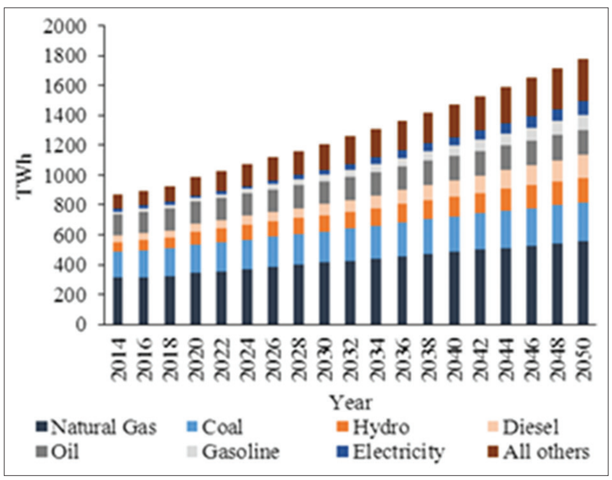


Figure 6: Primary energy consumption prospective. Energy sources. Baseline scenario



gas presented by the lack of reserves inside the country supposes its substitution in some of the cases to liquefied petroleum gas (LPG).

As shown in the Figure 7 residential sector will be mainly affected by the displacement from fuelwood to natural gas.

For the industries is expected to keep the consumption of natural gas and coal as primary energy source for the processes (Figure 8). With high rates of inefficiency it is not expected to reduce the inner consumption until the mid term when change in machinery and technological advances will start to improve the general efficiency.

As shown in Figure 9 transport sector will have a quick rate of growth, driven by the increase in the light-duty automotive fleet so gasoline will have an average growth of 10.44% biannually and, on the other hand, Biofuels will only grow by 4% biannually.

6. ENERGY SECURITY SCENARIO

This scenario focuses on one of the three pillars of the energy trilemma: Energy security (Wyman, 2015). In this sense, the most important aspects are to guarantee the continuity of energy services, paying more attention to the electricity sector, in which the dependence on water resources will be sought to safer and more reliable sources of energy.

Figure 7: Primary energy consumption prospective. Residential sector. Baseline scenario

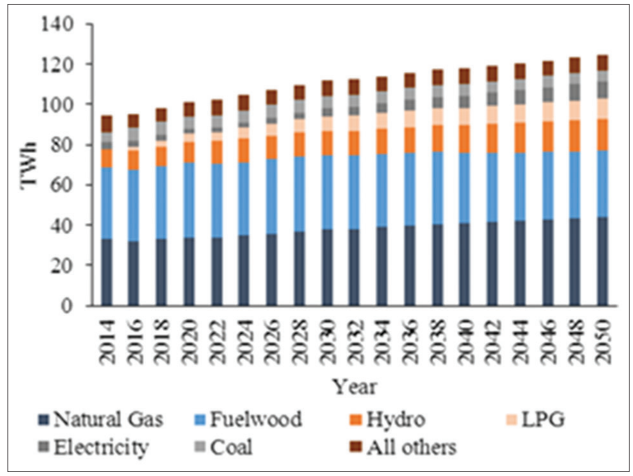


Figure 8: Primary energy consumption prospective. Industrial sector. Baseline scenario

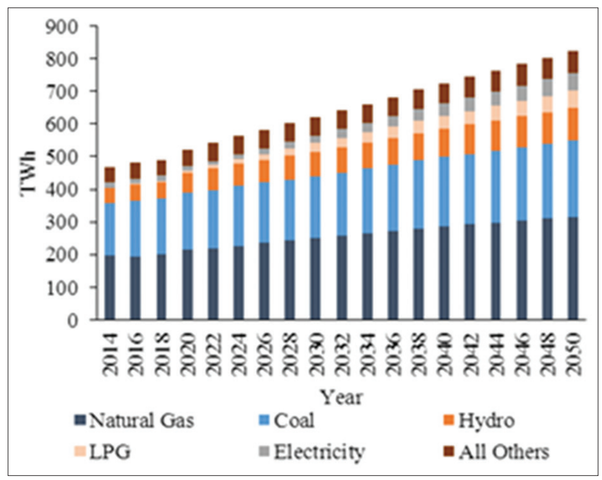
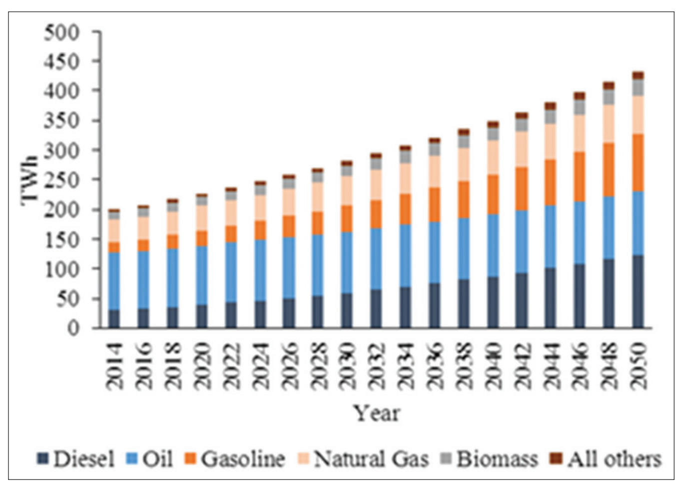


Figure 9: Primary energy consumption prospective. Transport sector. Baseline scenario



For this scenario is expected the growth of oil and natural gas reserves all over the country. Along with the high reserves, the scenario contemplates further assumptions as described below.

- High oil prices.
- Accelerated short-term economic growth due the oil industry impulse.
- Colombia as an economic power in Latin America.

Table 9 resumes the qualitative analysis for the economic scene of the scenario while Table 10 shows the quantitative analysis.

From the data of the Table 10 and the application of the economic model there were found the added values growth rates as shown in Table 11.

Driven by the foreign investment from the oil industry, the industrial sector will lead the energy demand over all the studied period as shown in Figure 10, its consumption will represent 46% of primary energy demand by 2050. On the other hand, the increase of incomes from oil, which is in the actuality the principal economic drive of the country, will lead to a high growth of the tertiary sector, increasing its participation on the demand over 3.31% during the period 2014-2050.

Residential sector is expected to grow in a very conservative rate of 1.58%, as the economic scene for the country will allow the fast implementation of efficiency technologies and expansion for the electric and natural gas network to rural areas.

Despite being a scenario based on fossil fuels as shown in Figure 11, it also contemplates the investment in energy efficiency for thermal generation and industrial processes as cogeneration, especially for natural gas, which is expected to be the principal energy source for the country.

LPG has a notable increase in its share of the total energy demand, driven by an increase in the country's oil resources and industry, which is the reason why LPG and refinery gases occupy 5.93% of the country's energy demand, a percentage increase of 5.83% over the base year.

Table 9: Qualitative matrix of the economy for the energy security scenario

Variable	ST	MT	LT
GDP	3.3-3.8	3.6-4.4	4-4.6
Unemployment	↓↓	↓↓↓	↓
CPI	↓	↓	↓
FDI	↑	↑↑	↑↑↑
Social inv.	→	→	→
Trade balance	↓↓	↓	↑
Oil price (USD)	40-80		
1st y 2nd sectors	↓	↓	↑
3rd sector	↑	↑↑	↑

GDP: Gross domestic product, CPI: Consumer price index, FDI: Foreign direct investment

Table 10: Qualitative matrix of the economy for the energy security scenario

Variable	Units	ST	MT	LT
GDP	%	3.6-4.6	4.5-5.2	4.8-6.5
Unemployment	%	8.3-8.8	8-8.6	8.2-8.4
CPI	%	4.6-5	4-4.6	3.8-4.4
FDI	%	−0.03-−0.01	−0.02-0.02	0.018-0.025
Trade balance	%	−4.7-−4	−4.1-−3.5	−3.6-−3
1st y 2nd sectors growth	%	33-34	33.5-32	33-30
3rd sector growth	%	66-67	66.5-68	67-70

GDP: Gross domestic product, CPI: Consumer price index, FDI: Foreign direct investment

Table 11: Expected added values growth for the energy security scenario

Year	Units	Sector		
		A and M	Tertiary	Industrial
2015	2008 COP B	68.34	174.71	58.00
2020		79.17	226.06	65.07
2025		92.91	290.80	74.31
2030		108.36	371.70	84.36
2035		125.86	470.86	94.77
2040		145.42	592.14	106.37
2045		166.39	732.83	118.58
2050		188.25	889.84	130.87

Figure 10: Primary energy consumption prospective. Sectors. Energy security scenario

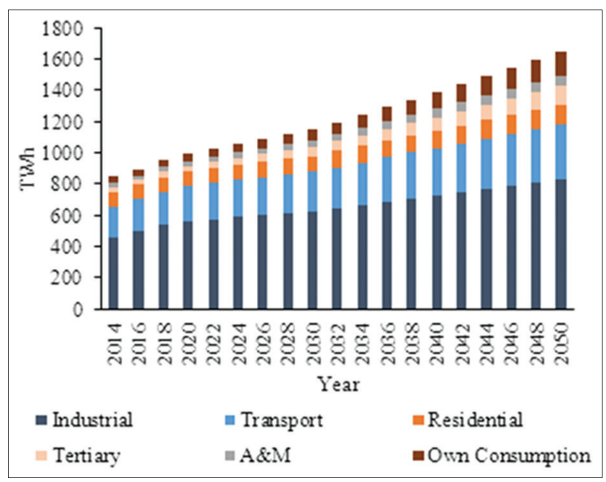
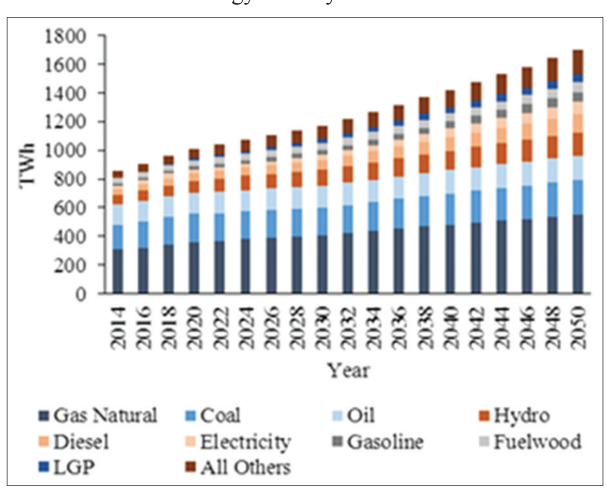


Figure 11: Primary energy consumption prospective. Energy sources. Energy security scenario



Modernization of oil industry will cause the use of oil (as direct energy source or for refinery processes) will be reduced 7% by 2050 in relation to the base year. By 2050, the use of natural gas in the residential sector will be reduced by 10.2% compared to the base year as shown in Figure 12, due to the technological change in natural gas combustion processes and the increase in the use of biomass.

Residential sector will continue to be characterized by the high use of biomass (fuelwood) in the rural cooking processes. Although plans for the expansion of natural gas networks will be implemented, the interest in induction cooking systems and electric systems will be few, as the legislation is not expected to be strict about these aspects for the not-interconnected areas. Thus, fuelwood use will increase from 37.2% of the total residential demand to 41.7% by 2050.

Industrial sector (Figure 13) will present the best performance in the energy security scenario. The discovery of new reserves in the short-term and the incentive to the economy from the hydrocarbons market will represent that in the mid-term industries will have access to better technological processes, which will allow a considerable increase in the efficiency of the thermal processes.

Figure 12: Primary energy consumption prospective. Residential sector. Energy security scenario

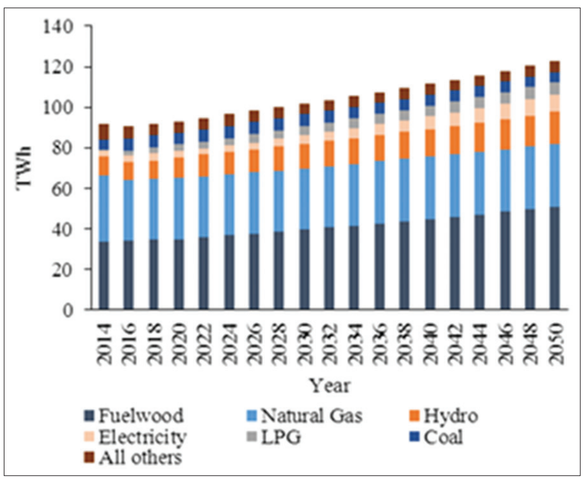
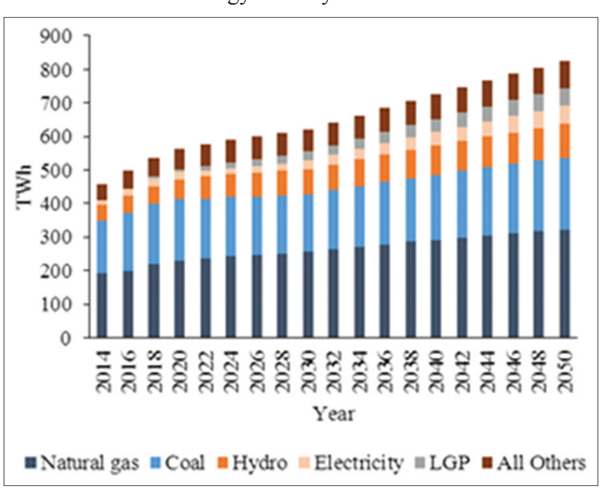


Figure 13: Primary energy consumption prospective. Industrial sector. Energy security scenario



As the efficiency in thermal processed is notable improved for the mid-term, industries will require less fuel for the same operations, meaning that natural gas consumption will have a reduced growth behavior (about 2% biannual for the mid-term). However, the greater improve for the sector will be for coal processes, where the efficiency is expected improve considerably with CO_2 capture techniques, and governmental investment for research and development as thermal generation expands over the country, so by 2050 coal demand will be reduced by 8.5% with respect to the base year.

For transport sector it is expected a very trend growth as there are no limitations for the fuel uses and is not expected to be any changes on the current goods transport network. Leading the oil (for jet fuel and others refinery fuels), diesel and gasoline as principal source of energy. Results are shown in the Figure 14.

7. ENERGY DIVERSIFICATION SCENARIO

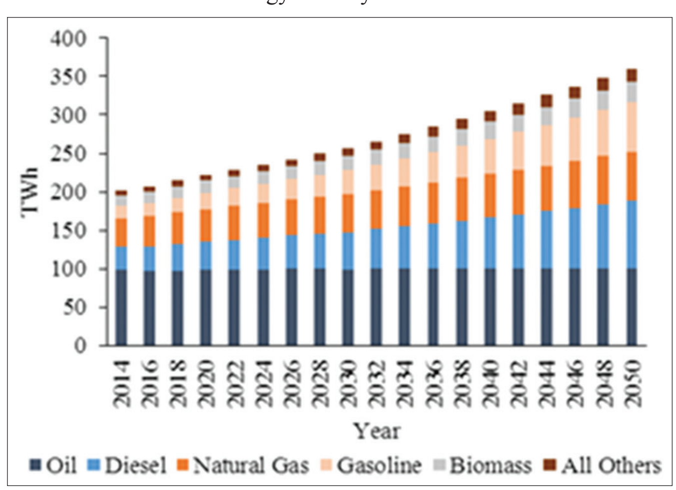
Energy diversification scenario considers lack of fossil resources that encourage the country to look up for new energy sources. Considering a political environment focused on energy independence to water resources, governmental policies and incentives will be granted to energy efficiency plans, distributed generation and large power plants with unconventional sources of energy as solar or wind (Blanco, 2016; Contreras and Rodríguez, 2016).

Several considerations for the scenario will affect the behavior of the energy demand as the ones listed below.

- Low oil prices.
- Shrinkage of the economy.
- Increased inflation.

As the economy scene does not seems to be friendly for the short-term, the scenario develops under the assumption of economy impulse to renewable energy and does not focuses on, for example, the increase of taxes due the low income from the oil industry. The qualitative and quantitative economic analyses are shown in Tables 12 and 13 respectively.

Figure 14: Primary energy consumption prospective. Transport sector. Energy security scenario



Based on the data from Table 13 it was possible to apply the economic model for the scenario giving the growth rates for the added values of each sector as shown in Table 14. For this scenario, which tends to the "smart grids" and distributed generation, it is expected that the sectors with the greatest investment will be the industrial and tertiary. Thus, profitability of companies under this scenario would drive not only technological advancements on this strategies but also the high demand of unconventional energy systems would boost the growth of the manufacturing sector, as much in supplements as in the generation systems themselves.

On the general energy demand shown in Figure 15 it is noticeable how the industrial sector will reduce its participation to 46.05% by 2050, 7.19% less than the base year. This will be partly due to the expansion of the commercial and public sector and partly due to the increased autogeneration and efficiency plans among the industries driven by the governmental support for these practices. On the other hand, tertiary sector will increase its demand by 4.62% by 2050.

Table 12: Qualitative matrix of the economy for the energy diversification scenario

Variable	ST	MT	LT
GDP	3.3-3.8	3.6-4.4	4-4.6
Unemployment	↓↓	↓↓↓	↓
CPI	↓	↓	↓
FDI	↑	↑↑	↑↑↑
Social inv.	→	→	→
Trade balance	↓↓	↓	↑
Oil price (USD)	40-80		
1st y 2nd sectors	↓	↓	↑
3rd sector	↑	↑↑	↑

GDP: Gross domestic product, CPI: Consumer price index, FDI: Foreign direct investment

Table 13: Quantitative matrix of the economy for the energy diversification scenario

Variable	Units	ST	MT	LT
GDP	%	3.2-3.6	3.8-4.7	4.3-5.8
Unemployment	%	8.7-9	8.9-9.3	9.2-9.4
CPI	%	5.2-5.4	5.3-5.5	5.4-5.7
FDI	%	−0.03-−0.01	−0.02-−0.06	−0.05-−0.08
Trade balance	%	−4.7-−5.1	−5-−5.5	−5.3-−5.6
1st y 2nd sectors growth	%	33-36	35-37	36-38
3rd sector growth	%	64-67	63-65	62-64

GDP: Gross domestic product, CPI: Consumer price index, FDI: Foreign direct investment

Table 14: Expected added values growth for the energy diversification scenario

Year	Units	Sector		
		A and M	Tertiary	Industrial
2015	2008 COP B	68.26	174.50	57.93
2020		78.61	224.46	64.61
2025		91.75	287.14	73.38
2030		106.41	365.00	82.84
2035		122.91	459.80	92.55
2040		141.01	574.18	103.14
2045		160.23	705.70	114.19
2050		180.07	851.18	125.18

The residential sector will significantly decrease its share of demand, mainly affected by the early application of LED lighting technologies and distributed generation decreasing its percentage demand 0.87% annually.

For energy sources demand, shown in Figure 16, principal sources will still be liquid fuels driven mainly by the growth of the automotive park and the decrease consume of fuels for the industries as natural gas.

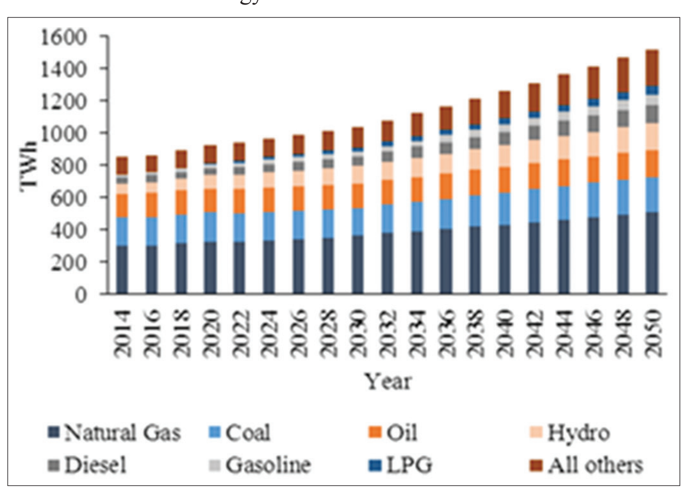
Oil and coal as primary energy source present the greatest reduction on its demand as expected. Thanks to stronger policies towards hydrocarbon and coal generation, low oil and gas reserves and a cultural phenomenon thrown to the renewable energies, oil use will grow 0.5% annually while coal will grow 1% annually.

Due to the technological change, the country will be directed to a process of electrification meaning electricity use will be the fastest growth in this scenario at a rate of 6.5% annually.

Residential sector is the most affected by environmental policies and environmental awareness, thanks to the early entry of electric

Figure 15: Primary energy consumption prospective. Sectors. Energy diversification scenario

Figure 16: Primary energy consumption prospective. Energy sources. Energy diversification scenario



induction stoves supported by subsidies and government financing, the consumption of fuelwood in rural sectors is significantly reduced, while LED lighting systems, demand management plans and structured policies towards distributed generation cause this sector to decrease its demand. By 2050, the residential sector of Colombia will demand 27.4% less primary energy compared to the base year as shown in the Figure 17.

Government's policies to encourage non-conventional energy, as well as environmental restrictions, oblige industries to make a technological change in the short-term, which means that by the mid-term, despite there will be growth in the industry, the most efficient processes and the best practices will cause the demand to remain static. During the long term, industries will be achieve world competitiveness generating a boom of the manufacturing sector, so demand will grow as the industry grows as shown in Figure 18.

Despite the technological change and vehicles with greater efficiency and better environmental yields, the effects in this sector are not of great consideration. The independence of the transport sector from the scenarios is a constant over the time. The highest consumption of the sectors is settled in the passenger transport systems and cargo transport within the country, while may be some changes with the inclusion of electric vehicles in the automotive part it's participation is minimum compared with the consumption from planes or trucks which are the two biggest fuels consumer of the country. So principal fuels consumption will be oil for jet fuel and others derivate, and diesel for trucks as shown in the Figure 19.

Figure 17: Primary energy consumption prospective. Residential sector. Energy diversification scenario

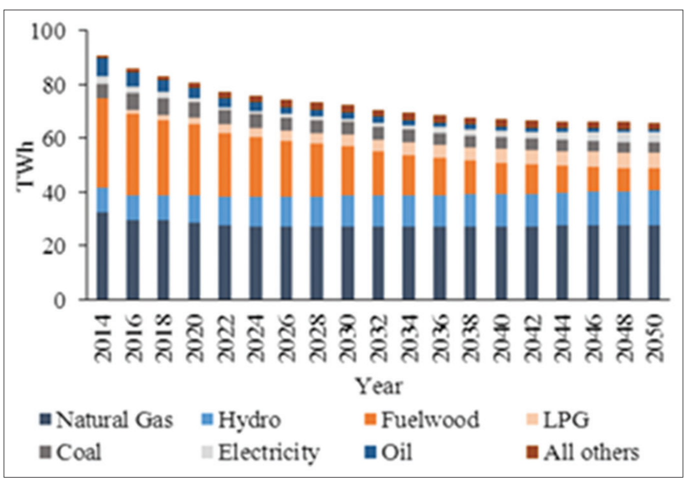
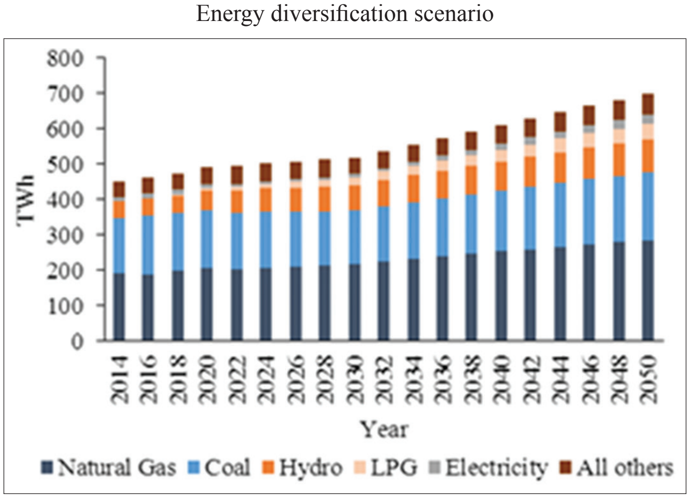


Figure 18: Primary energy consumption prospective. Industrial sector. Energy diversification scenario



8. RESULTS AND DISCUSSION

The prospective is a probability game; the serious development of prospects always considers scenarios that differentiates based on one or more determining factors, such as political relations, wars, social events, technological approaches, economic growth, etc.

The three scenarios chosen for this study are similar in their bases where the points to be varied are few and allowed a severe analysis of the results.

The baseline scenario behaved based on the trend, energy security focuses on the energy supply assuming the increase in hydrocarbon reserves and energy diversification involves strict environmental policies and shortages of conventional resources that oblige the country to adopt measures to meet the energy demand through cleaner technologies.

In spite of being three scenarios with different approaches, reality should not meet any of them and is, on the contrary a mixture of many factors presented in all three scenarios. The comparison of scenarios allows the predicting of economic, political and social situations which are the most convenient to establish a low demand, as well as the scenarios that should occur in order to become subject to shortages or surplus energy supply. That comparison is shown in the Figure 20.

In the short-term, energy security scenario presents the greatest demand, due to the fact that large volumes of fossil fuels enter the grid with highly inefficient systems, however the development of the oil industry will allow in the mid-term the technification and modernization of the obsolete systems, thereby reducing demand considerably.

Figure 19: Primary energy consumption prospective. Transport sector. Energy diversification scenario

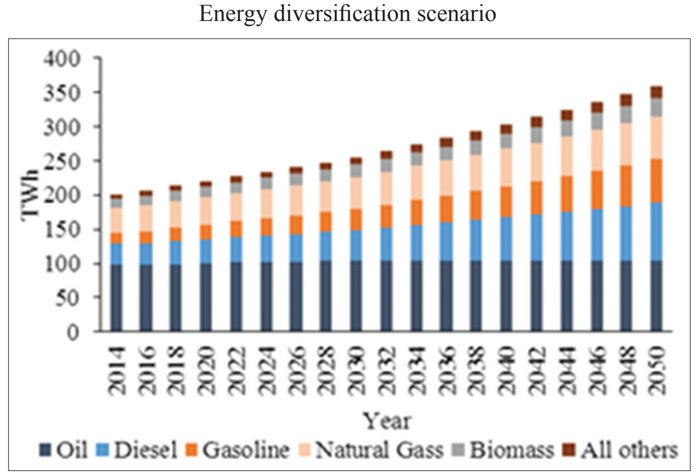
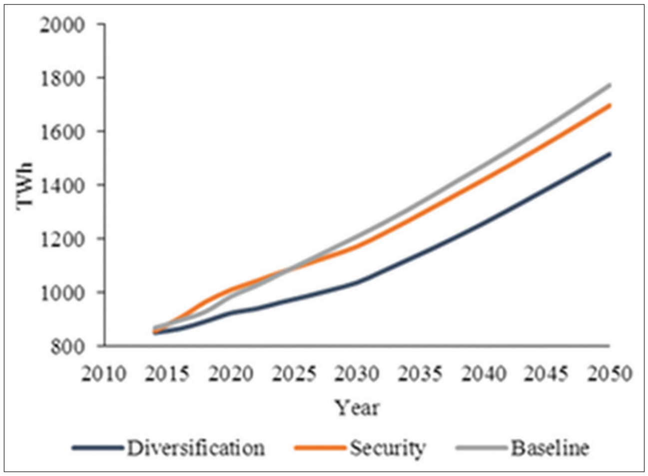


Figure 20: Scenarios total demand prospective comparison



The energy diversification scenario has the lower demand from all three, but it is also the less probable scenario, which is a consequence of the structural change that would undergo the country and the large investment needed in the short-term, both public and private funds to develop the more efficient systems.

9. CONCLUSION

The development of an economic model allows the centralization of the data to a reduced number of variables, which can assertively predict the behavior of demand in different scenarios.

There are no negative or positive scenarios in the study, but as in reality, the future sets itself towards a goal that is forced by the many situations.

In a scenario where new oil fields are found and the price of crude generates profitability in this industry, the demand for fuel will shift towards this type of resources, which in the first instance would cover a demand in highly inefficient sectors causing its demand in the short term to be greater. Although, the profitability of the oil industry will generate in the mid-term a technological change that will allow the country to become a competent and technified economy; thus, in the long term the demand in a scenario based on fossil fuels, efficiently presents a lower demand to what would be expected in a trend scenario.

A scenario focused on energy diversification characterized by a lack of conventional resources and oil prices that do not benefit the industry will generate, together with strong environmental policies, a scenario with technological change in the short-term, where the strong change in demand from the first few years due to the massive installation of on-site generation systems. However, this scenario is presented as the least probable, although it is true that the demand for new technologies would positively affect the country's economy, to enter this stage requires an initial investment that a country like Colombia, with one of the most devalued currencies of the continent; doubtfully can hold.

Thus, the scenarios of energy diversification and energy security are both likely and it is expected that the future will settle more towards one of them keeping traces of the other. Hence, the results for both of them show the similarity in most the consumption sectors, being the biggest difference the residential, which is enormously affected by "Smart grid" systems.

Even with different economic scenarios, there are sectors that are relatively independent of those, such as the transport sector, where, although engine efficiencies and therefore fuel consumption are varied, the only variables that could actually affect this sector would be the change in heavy transport networks, such as the creation of a national rail network.

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