DESARROLLO DE UN MODELO ECONÓMICO DE ENERGÍA PARA PRONOSTICAR LA DEMANDA ENERGÉTICA POR SECTORES DE CONSUMO EN COLOMBIA

LAURA CATALINA JARAMILLO VILLARREAL

UNIVERSIDAD AUTÓNOMA DE BUCARAMANGA
FACULTAD DE INGENIERIAS
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LAURA CATALINA JARAMILLO VILLARREAL

TRABAJO DE GRADO DE INGENIERÍA EN ENERGÍA

DIRECTOR
LEONARDO E. PACHECO SANDOVAL

UNIVERSIDAD AUTÓNOMA DE BUCARAMANGA
FACULTAD DE INGENIERIAS
INGENIERÍA EN ENERGÍA
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Resumen

El siguiente trabajo de grado se realizó con base al semillero de investigación "Prospectiva Energética" y el programa '4+1' entre la Universidad Autónoma de Bucaramanga (Unab) y Oregon Institute of Technology (OIT) para cumplir con el requisito de grado en Ingeniría en Energía en la Unab y establecer una ruta de continuidad hacia estudios de maestría en el exterior con el programa de Master of Science in Renewable Energy Engineering – MSREE de OIT.

En cumplimiento parcial del programa '4+1', este trabajo de grado propone el desarrollo de una planificación energética en Colombia mediante un modelo económico de energía para pronosticar la demanda de energía por sectores de consumo, ademas, promueve la implementación de análisis prospectivos para estudiar la demanda energética del país. Utilizando el análisis de regresión múltiple, técnicas de prospectiva y "multi-criteria decision-making (MCDM)", este proyecto proporciona una metodología sistemática para identificar variables económicas que impactan la demanda de energía. Los sectores de transporte, comercial, industrial, residencial, agricultura, minería y construcción se consideran dentro de este estudio para ejecutar la metodología. Los resultados muestran que el sector de minería y construcción no refleja un alto consumo en la demanda total de energía de Colombia y esos sectores están dictados no solo por variables económicas. Además, la demanda de energía residencial, de transporte y comercial está altamente correlacionada con el factor económico.

Development of an economic energy model to forecast the energy demand in Colombia by sectors of consumption

A Thesis
Presented to the Faculty
of Oregon Institute of Technology
in Partial Fulfillment For Requirements of the Degree
Master of Science in Renewable Energy Engineering

by
Laura C. Jaramillo
2020

Dedicated to Unab-Oregon Tech Transnational Energy Forecasting Research Group.

I will always treasure our friendship.

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05/12/2020

Abstract

In partial fulfillment of ‘4+1’ program at Unab and Oregon Tech, this thesis attempts to provide an energy planning practice for Colombia through the development of an economic energy model to forecast the energy demand by sectors of consumption and promote the implementation of forecasting systems to study the energy demand in the country. Using multi-regression analysis, forecasting, La Prospective techniques, and multi-criteria decision-making approach, this project provides a systematic methodology to identify economic variables that impact energy demand. Transport, commercial, industrial, residential, agriculture, mining, and construction sectors are considered within this study to execute the methodology. The results show that mining and construction sector do not reflects high consumption in the total energy demand of Colombia and those sector are dictated not only by economic variables. In addition, residential, transport and commercial energy demand are highly correlated with economic factor.

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CHAPTER 1 Introduction

1.1 Introduction & Background

The development of a country depends on economic, social, environmental, and energy factors. In order to accomplish development of goods and services in a nation, energy sector provides the main input, including fuel for manufacturing processes, transportation services, and agriculture production. Energy supply requires high-quality standards to ensure service continuity that meets energy needs of the country. As a response action, many nations have designed energy policies so the government can decide to address energy production, distribution, and consumption matters to maintain production of goods and services, allowing economic growth [1].

In Colombia, the energy demand is divided by consumption sectors. In fact, the entity in charged of development, planning, and use of energy and mining resources, *Unidad de Planeación Minero Energética UPME* (Mineral and Energy Planning Unit), showed that the energy used in 2017 was distributed as follows: 34.99% in the transport sector, 33.19% in the industrial sector, 17.48% in the residential sector, 5.21% in the commercial sector, 3.44% in the agricultural, mining, and construction sectors, 1.51% in the non-energetic sector, and 4.18% is Non-Identified [2].

Currently, energy generation in Colombia is provided by the use of different technologies: 67.3% hydropower plants, 27.1% gas and thermal coal plants, while 5.7% comprises smaller sources including wind and solar as renewable technologies making part of the energy portfolio. Colombia leads its energy portfolio by hydropower generation. However, hydropower plants are highly impacted by climatic conditions, including El Niño Phenomenon that decreases the level of impounding reservoir, limiting the main resource of hydropower generation. Due to gradual growth of energy demand, Colombia's national energy system needs to guarantee energy supply to maintain all economic sectors of the country while facing external conditions [3].

The quantity of energy and energy generation resources required to meet energy demand is established once historical data of energy used and variables of different disciplines are analyzed. The behavior of several disciplines that impact energy demand is useful to plan an energy policy projecting energy needs of any country and expanding power generation technologies to fulfill energy production despite external problems such as financial and environmental aspects [4].

Many nations developed specific tools and methods to forecast energy demand and supply. As an example, China developed the highest number of Energy planning models (EPMs). EPMs help providing a policy formulation for energy sector development, where different forecasting methods, from statistical models to machine learning methods have been applied [5]. In fact, selection of a particular forecasting method is mostly based on data availability, model objectives, and planning exercises carried out by researchers and professionals. While developed countries have implemented those accurate methods, developing countries have not conducted planning exercises that enable them to select appropriate energy resources to meet their needs.

Some entities in Colombia are in charged of the energy demand study. Those are XM, UPME, and MINMINAS. XM is the subsidiary of ISA, which is a public-private multi-Latin company group with more than 52 years of experience in Electric Energy, Roads, Telecomunications and ICT businesses. XM analyzes daily energy demand in Colombia in short, medium, and long term. In addition, UPME studies the regional energy demand including a relationship with an economic variable, such as GDP. It also encompasses population growth and geographic temperature of the National interconnected system (SIN) [6] [7] [8].

Moreover, Colombia's Oil Company ('Empresa Colombiana de Petroleos S.A. - ECOPETROL') together with UPME developed a long-term energy scenario in 2019 in Colombia. This plan included economic variables to project the behavior of energy demand within country in 2050. This study involved research groups of three universities of the region: Universidad Autonoma de Bucaramanga (UNAB), Universidad Industrial de Santander (UIS), and Universidad Pontificia Bolivariana (UPB). This research proposed an integrated energy planning model for Colombia [9]. However, the study only analyzed the main economic indicators to project the energy consumption of the country without a detailed view of all financial aspects to identify variables within the model [10] [11] [12] [13].

Colombia accomplish energy demand forecast applying methods based on historical data including annual energy consumption and financial indicators. However, having few economic variables is not enough to have a general study of how deeply other different factors impact energy consumption. Integral methods found in the literature review used EPMs and systematic methodologies to achieve the energy forecast of a country. It is essential to thoroughly analyze how the behavior of each variable is in relation to energy consumption to provide long-term scenarios of the country's energy demand.

This MS thesis proposes a systematic methodology to forecast the energy demand in Colombia, focusing on macroeconomic variables behavior. The research uses multiple regression analysis and two disciplines of strategy and forecast to establish a systematic and integrated methodology to analyze energy demand behavior in the long-term for different sectors of energy consumption in Colombia.

1.2 Problem Definition

The primary objective of this project is designing, developing, and implementing a systematic methodology to identify economic variables that impact energy demand using statistical approaches. Transport, commercial, industrial, residential, agriculture, mining, and construction sectors are considered within this study to execute the methodology.

Additionally, macroeconomic variables of the energy model are analyzed to forecast Colombia's energy demand in the future by consumption sectors, which allows for determining country's total energy demand only considering economic variables behavior.

1.3 Significance

Energy is one of the most critical factors in the development of a country and human life because it provides the primary input to maintain financial activities for any country. In order to supply energy for human needs, it is necessary to have an essential component in electricity planning which is the development of a demand forecast management plan. As a result, many stakeholders decisions are based on historical and predictive data that use probabilistic forecast methods to determine energy demand. The role of forecasting is essential in the different stages including commercialization, energy generation, and demand-side management [14] [15].

A large variety of mathematical methods have been used for energy demand forecasting. Some of them use auto regressive models such the Autoregressive (AUTOREG), Autoregressive Moving Average (ARMA), Autoregressive Integrated Moving Average (ARIMA), Seasonal ARIMA, Seasonal Exponential Smoothing Method (ESM). Artificial neural network (ANN) and multiple regression are considered under the machine learning algorithms [16] [17]. Some forecast models for energy demand rely only on historical data of energy consumption and not on parameters that influence energy consumption. The forecast problem for energy management systems is based on many influence factors to generate an accurate model for energy demand [18]. Energy data process and the selection of suitable forecast methods have been an important need to predict energy demand in a process or a country.

The entity in charge of energy demand of Colombia is XM. It projects energy consumption to align and meet the long-term energy demand, including the participation of renewable energy sources. In addition, to encompass the prospective tool in the country, this research attempts to analyze and project long-term behavior of Colombia's energy demand, considering the macroeconomic variables. Its objective is design and generation of possible energy demand scenarios in long-term for all the economic sectors in Colombia following a systematic methodology to identify the variables of the model, which is supported by statistical techniques, Multi-criteria decision making (MCDM), strategic approaches, and La prospective technique .

This MS thesis represents the second stage of the development of an energy-based model for forecasting energy demand of Colombia, a graduate thesis by the Author Jose A. Suarez D. and a transnational research project, 'Renewable Energy in National Electric Resource Forecasting', that Oregon Institute of Technology (OT) and UNAB conducted.

1.4 R&D Objectives & Thesis Contributions

1.4.1 Objectives

The study was divided into four primary objectives to accomplish the development of an economical energy model to forecast the energy demand in Colombia.

- Generating long-term scenarios for energy demand by consumption sectors in Colombia based on the macroeconomic variables.
- Determining macroeconomic variables that impact Colombia's energy demand in dif-

ferent sectors including residential, industrial, commercial, transportation, agriculture, mining and construction through literature review.

- Developing a systematic methodology to assess and validate macroeconomic variables impact energy demand in different sectors including residential, industrial, commercial, transportation, agriculture, mining and construction.

- Generating an energy-based model in different sectors including residential, industrial, commercial, transportation, agriculture, mining and construction though a systematic methodology that comprises macroeconomic variables

1.4.2 Thesis Contributions

This study has three goals to assess future energy demand in Colombia. The first goal is to identify the economic variables that impact and have a relationship with energy consumption. In order to accomplish this goal, it is necessary to provide a fundamental analysis highlighting identified variables and their characteristics.

The second goal is implementing an integrated methodology to validate the selection of an economic variable set that is proposed in the fundamental analysis using an automatic program that helps to gather accurate results of the best variables to forecast the energy demand in Colombia.

The third goal is modeling the final economic variable set in each sector of consumption and then providing an energy-based model to forecast the total energy demand of Colombia. This research aims to support the decision-making and criteria of stakeholders to meet the ever-growing energy demand demonstrating the future behavior of energy use in Colombia.

1.5 R&D Orientation, Methods & Materials

This MS thesis conducts a research to address the main economic variables impacting the most in energy demand. Following a systematic approach, this study includes three stages, as follows:

- Stage 1 comprises the literature review of energy planning methods to forecast the energy demand in a country.
- Stage 2 designs a systematic methodology implementing Microsoft Excel Software allowing feedback by experts and stakeholder for future work.

- Stage 3 develops the energy based model of the energy consume in Colombia. Once the energy based model comprising the economic variables to quantify energy consume of each sector is completed, total energy demand of Colombia can be projected.

The systematic and integrated methodology of this research is based on multiple regression analysis, including two disciplines known as Multi-criteria decision making (MCDM) and 'La prospective' technique. Those methods lead to analyze future behavior of energy demand in consumption sectors of in Colombia. Transport, commercial, industrial, residential, agriculture, mining and construction sectors were used to forecast the total energy demand of the country.

Datasets regarding economic indicators and annual energy demand are required to accomplish the systematic methodology establishing the relationship between variables based on statistical approaches. This dataset must be divided and organized in two groups, the economic factor and the energy factor. Additionally, the dataset is organized historically within defined time frames for each energy consumption sector, and each economic indicator in Colombia.

CHAPTER 2 Background & Literature Review

2.1 Background

The interest of stakeholders around the world about energy planning in a country has been focused on the multi-criteria method, which can provide solutions and address complex energy management problems. This method stressed the main objective for the traditional decision-making of maximizing benefits by minimizing costs citePoliciesEnergydemand15 [15]. In addition, the energy demand is analyzed from models based on statistical, econometric, and engineering techniques, being the last one the most complex and sophisticated of all. In statistical models, simple extrapolations or multivariate statistical techniques determine the value of energy demand using discriminatory analysis and taxonomy analysis, whereas, in econometric methods, these values are calculated based on macroeconomic theories [16].

The most common energy planning tools implement economic parameters to make reference projections about likely long-term energy demand; those tools allows higher impact and more disaggregated level to develop flexible approaches. One of those tools is the model of demand of Energy for Europe (MEDEE), which was developed by french energy companies leading to the development of MEDEE 2 and MEDEE 3 models. MEDEE 2 provides a simplified approach to the long-term energy demand model, where the energy demand is considered a demand induced by economic activities and by the satisfaction of social needs. MEDEE 3 uses a dynamic process to accomplish long-term energy demand. Furthermore, model for analysis of the Energy Demand (MAED & MADE-II) established a medium to long-term assumptions of socioeconomic, technological and demographic developments in a country or region [5] [32] [33] [34]. Among the methods mentioned, MEDEE and MAED are techno-economic models, and MADE-II has a more integral model, which comprises a distribution model for the energy demand in household groups, an engineering model, and the intermediate model for the transport sector [35]. Finally, the third model is the Low Emissions Analysis Platform (LEAP) developed at the Stockholm Environment Institute. It is a software tool for energy policy analysis and climate change mitigation assessment. LEAP supports a wide range of different modeling methodologies from bottom-up, end-use accounting techniques to top-down macroeconomic modeling regarding the demand side. Due to a very flexible structure, LEAP allows its users to perform a detailed analysis of social, economic, and technological scenarios on end-use energy consumption tracking energy consumption, energy production, and energy resource extraction in all sectors of an economy. Besides, it can be used to take into account sources and sinks of greenhouse gases (GHGs) in the energy and non-energy sectors. [36] [37].

In Colombia, the analysis of energy demand is based on forecast models. Using historical and predictive data, stakeholders determine the demand required in their processes and establish the best electricity generation resource that suits their energy needs. Currently, the sector that consumes the highest amount of energy in Colombia is the transport sector. It was driven by 34.99% in 2015 [2]. Due to climate and technical factors in energy production, Colombia has faced electricity rationing. This led the country to establish the need for solid energy policy and energy planning to achieve continuity in energy supply for each sector of consumption [30].

2.1.1 Overview of the Colombian economy

The economy of Colombia is established by the main economic activities proposed by the 'Departamento Administrativo Nacional de Estadistica' - DANE and the International

Standard Industrial Classification of All Economic Activities (ISIC), which was aligned to the Resolution 066 of 31 January 2012 [38].

The financial activities that maintain economic growth in Colombia are distributed in 4 big sectors, as follows: (i) transport sector, (ii) industrial sector, (iii) residential sector, and (iv) commercial sector. However, studies and analyses conducted by UPME towards energy consumption suggest that the energy demand need to be divided into 7 sectors of final consumption, whose categories are: (i) transport sector, (ii) industrial sector, (iii) residential sector, (iv) commercial sector, (v) agriculture sector, (vi) mining sector, and (viii) construction sector [39].

The energy sector in Colombia presented a slow recovery in oil prices and a low production of coal and gold [40]. In addition, exports in 2018 of the industrial sector grew 9.30%, in the mining sector increased 20.40% and regarding the agricultural sector, it reached rates of 2.60% compared to 2017 [42].

The official report of DANE and *Asociación Nacional de Empresarios de Colombia* showed that the economic growth in Colombia in 2019 had a recovery allocating its value in 3.3% in the GDP of the country. The economic activity that contributed the most to the growth of 2019 was commerce, transport, and food services that grow 4.9%. Also, there was an increase in Foreign Direct Investment of significant capital above 20% in the energy sector and other sectors, such as transport, construction, and industry [41] [43].

The energy sector's economic activity contributes to the annual variation allocating the energy, gas, and water supply activity in 2.8%, oil and mining activity in 2.1%, and manufacturing industry activities in 1.6%. See Figure 2.1.

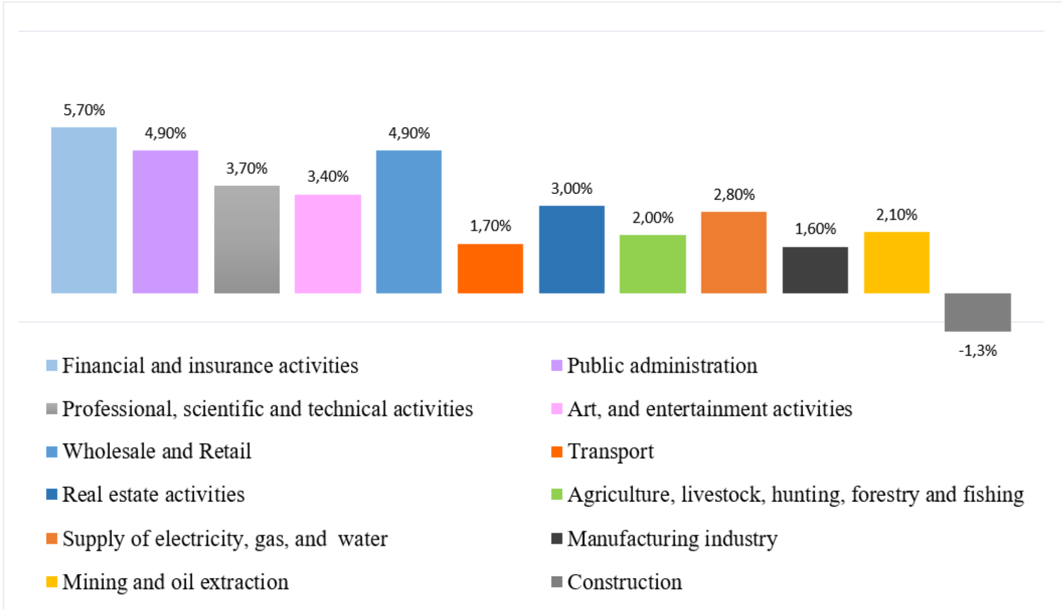


Figure 2.1: Annual variation of the economic activities of GDP in 2019.

2.1.2 Overview of energy consumption in Colombia

The internal supply of primary energy resources has a high percentage transformed to derivatives from oil and electricity, as well as inputs and outputs of imports, exports, and storage. The energy balance of Colombia in 2015 showed a net energy consumption (exchange and transformation) of 29,655 kTEP/year for the big sectors of the economy. The transport sector allocated 39.8% of the total energy consumption, where oil derivatives supplied 93.6% of total energy consumption in this sector. The industrial sector consumed 26.39% of the country's energy, which was led by coal (29.09%), natural gas (25.05%), bagasse (17.09%), and electricity (13.40%). The residential sector consumed 16.28% of the net energy consumption, and the commercial sector consumed 5.18% of the total energy of Colombia [44] [39].

On the other hand, based on the UPME classification of the consumption sectors, the transport, industrial and residential sectors consumed a high percentage of Colombian energy in 2017. The sectors that consume less energy quantity were: agriculture sector, construction sector, mining sector, and commercial sector. Figure 2.2 shows the energy consumption for final consumption sectors in 2017.

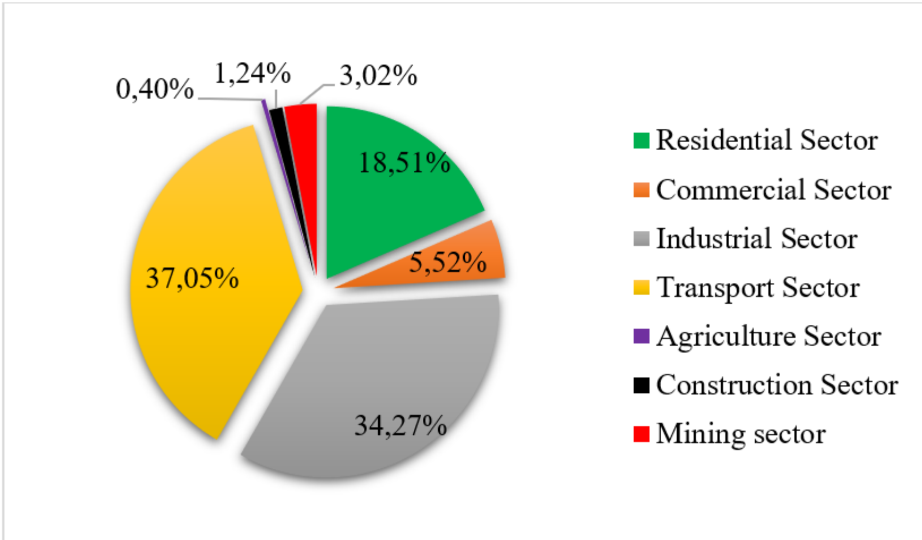


Figure 2.2: Energy demand based on the UPME classification, 2017.

2.2 Patent Landscape

A state-of-art patent search was conducted to determine current developments regarding energy planning models for forecasts. This analysis was performed only for patent applications and granted patents from the US throughout an open platform for Innovation Cartography called Lens. Forecast tools predict energy demand for operation and planning of power systems, and they comprise a large number of influence factors to predict this energy demand.

The preliminary search was conducted by keywords on titles, abstracts and claims, including: Electric power, demand, and forecast. The preliminary search was not limited to a time frame. This search produced 405 results published since 1974, there were 150 granted patents and 255 patent applications 2.3 The search indicated a higher number of results within the last 16 years from 2019.

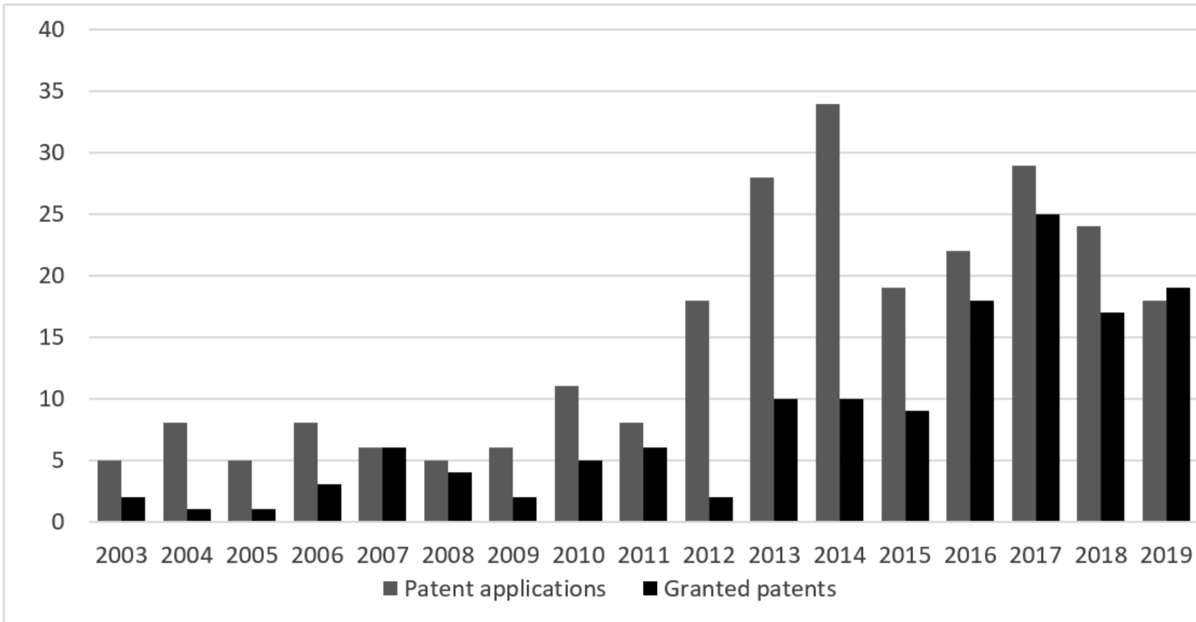


Figure 2.3: Search results filtered by only keywords for granted patents and patent applications from 2003 to October, 2019.

Due to the time frame, the results were obtained under several Cooperative Patent Classification - CPC, the most common class searches were H02 (Generation; Conversion Or Distribution Of Electric Power) and G06 (Computing; Calculating; Counting). Furthermore, the sub classes were H02J2003/003 (load forecast, e.g. method and systems for forecasting future load demand), Y02A30/12 (weather forecasting for energy supply management), and G06Q50/06 (electricity, gas or water supply).

Reducing the search criteria to only granted patents and patent applications issued within the last 16 years using the search strategy of the form *(title:(electric power demand) OR abstract:(electric power demand) OR claims:(electric power demand)) AND (title:(forecast) OR abstract:(forecast) OR claims:(forecast)) AND classification˙cpc:(H02J2003/003)* resulted in 82 documents published since 2006, there were 29 granted patent and 53 patent applications.

Adding the Y02A30/12 CPC patent classification code to the previous search criteria, the results produced 6 documents published since 2007, there were 2 granted patents and 4 patent applications.

Finally, using only the G06Q50/06 and H02J2003/003 CPC patent classification codes, the results produced 41 documents published since 2004, there were 15 granted patents and 26 patent applications.

The progress of patents regarding energy demand forecasts are related with conversion or distribution of electric power, besides computing, calculating, and counting methods. The first patent reviewed, US Patent number US 9852483 B2,'Forecast system and method of electric Power Demand' describes a forecasting method of predicting the electric power demand using weather data due the electric power demand is considered to correlate with changes in weather. It is based on the weather record and the electric power demand data in the past with forecast weather groups in a period (including a forecast target day) for forecasting the electric power demand [24].

Patent number US 10250034 B2, 'Distributed Utility Resource Planning And Forecast', is disclosed for managing and forecasting energy usage. It comprises systems, apparatus, and methods. The distributed forecast device (Hardware and Software component) is located remotely from a central server where it receives energy usage data from energy meters related to one or more accounts via a connection network in order to predict an energy usage forecast for each of the accounts based on the energy data. The central server stores weather forecast, historical weather information, and historical energy usage [25].

Patent number US 9672304 B2, 'Dynamic Online Energy Forecasting' shows a dynamic online energy forecasting. An accurate energy forecast request is received, and an initial energy forecast is calculated in response to the request. Energy forecasting used mathematical models that describe the behavior and development of historical time series. Forecast models include auto regressive models such as the multi-equation EGRV model and exponential smoothing models (Taylor's triple seasonal exponential smoothing model) [26].

Other Patent number reviewed, US 9588145 B2, 'Electric Power Management Apparatus And Electric Power Management Method' presents an electric power management apparatus including an electric power measurement block and an electric power comparison block to make a comparison between an electric power consumption amount measured by the electric power measurement block and an electric power demand forecast amount from a forecast amount of an electric power demand of the electric power consumer. The patent includes a HEMS (Home Energy Management System) configuration in the Electric Management Apparatus to realize energy saving by enhancing the efficiency of energy usage in typical households by use of IT technologies [27].

Patent number, US 8406935 B2,'Load Forecasting Analysis System For Calculating Customer Baseline Load' shows a load forecasting analysis system for calculating a customer baseline load (CBL). It receives a load profile and provides a CBL forecast method, a period selector for conditions used to calculate the CBL using the load profile, a CBL processor for calculating forecasting based on the forecasting method and conditions. It also provides a CBL determiner for calculating an error value by comparing the load profile with the forecasting value [28].

Patent number, US 7085660 B2, 'Energy Management System In A Power And Distribution System' optimizes the performance of the generation and distribution of a power system. It calculates statistical information, uses historical performance data and economic factors to analyze and control power production. It predicts load demands by utilizing short term load forecasts that are based on historical data, demand patterns, and short-term load forecasts [29].

H02J2003/003 — G06Q50/06	Y02A30/12
US 8,406,935 B2	US 9,852,483 B2
US 9,588,145 B2	US 10250034 B2
US 7,085,660 B2	US 2019/0067946 A1
US 9,672,304 B2	
US 2019/0251580 A1	

Table 2.1: Distribution of granted patents and patent applications by CPC sub classes

The patents reviewed thus far 2.1 determine the energy demand forecast based on system and methods for managing the energy data from power consumption meters, and there is not a significant advance in terms of quantity referring to methods that include weather factors. However, some current developments are starting to include those factors as they correlate with energy demand. The patent application, US 2019/0067946 A1, shows a method for short term load forecasting in a power grid, including historical data of power consumption, load, and weather factors corresponding to time index data recorded from a location in a power distribution network of the power grid. The method uses statistical techniques to modified historical data to avoid errors and estimate one or more power values at a future time instant based on the modified historical data and the power grid data.

On the other hand, the patent application US 2019/0251580 A1, develops a system and method of forecasting power consumption from one consumer to accomplish advance in household consumption and energy efficiency. It determines the power consumption patterns and forecasts future behavior based on the historical data, and the power consumption patterns. The method also generates energy-saving recommendations to at least one consumer based on the forecasting.

There are not several patents that include external factors apart from the historical energy data to provide a forecast response to manage the energy demand system. Besides, the patents study the forecast of energy consume in an specific process and not within a whole country.

2.3 Scientific Literature Review

The first work of energy planning corresponds to Kumar Biswajit Debnath and Monjur Mourshed, who conducted the study of *methods of forecasting models of energy planning* in 2018. The authors managed the models of energy planning (EPMs), which redeem an indispensable role in the formulation of policies and the development of the energy sector. A systematic and critical review was presented to 483 EPMs, where 50 forecast methods were identified, being artificial neural network (ANN) the method that is applied in 40% of the EPMs analyzed. Other methods that stood out were, in descending order: support vector machine (SVM), self-regressive integrated moving average (ARIMA), fuzzy logic (FL), linear regression (LR), genetic algorithm (GA), particle swarm optimization (PSO), Gray (GM) and Self-Regressive Moving Average (ARMA) prediction. The EPMs focus on energy demand and load forecasting. In terms of geographical coverage, the most significant number of EPMs are developed in China since more models were established for the developed country than for the developing countries (Colombia case) [5].

Also, in February 2019, a study of *forecasting energy needs with the logistical function* by Theodore Modis was presented in the Journal Technological Forecasting and Social Change. This investigation was based on using the logistic substitution model (LSM) to predict the energy consumed in the whole world and the oil production in the U.S. for 2050. This logistics function proposes a model of replacement of technological change based on a simple set of assumptions in the dynamics of the long-term competition like a way to represent growth processes, in this case, the energy market [19]. From this study, the author suggested that coal has a greater proportion over the oil and profits of hydropower plants, then is followed by the natural gas, renewable energy (wind, geothermal, solar, biomass and residues) grow exclusively due nuclear energy, and are prepared to overcome them at the end of the decade of 2030. In the middle of century XXI, coal, oil, and natural gas remain the main actors of comparable size, and hydropower has almost doubled in size. Finally, fracking-produced oil in the United States is projected to cease in the mid-21st century, while oil produced by traditional methods should continue its slowly declining trend [20].

Another investigation, in September 2017, was presented by Fernando Dellano-Paz, Anxo Calvo-Silvosaa, Susana Iglesias Antelo and Isabel Soares with the title of *Energy planning and modern portfolio theory: A review.* This work provides a comprehensive review of the literature on the implementation of the methodology, 'Modern portfolio theory (MPT)' in the field of energy planning and the production of electricity. The MPT methodology attempts to solve the problem of long-term investment selection by defining the participation of each one of the real assets of power generation. The technological alternatives are analyzed from the perspective of two parts, whether cost-risk or risk of return for each technology and set of technologies. The study drives to the works analyzed in terms of renewable technologies and the political implications derived from them showing preference to the inclusion of renewable technologies on efficient portfolios [12].

From a national view, in the same approach was found the research work entitled *Colombian energy planning - Neither for energy, nor for Colombia* presented in 2019, by Martínez Viviana and O.L. Castillo. Through its national energy plans and the energy transitions that the country has experienced in the last forty years. The study shows that the central objective of the Colombian case in energy planning and its institutional framework has been to advance and maximize the exploitation of energy resources for export purposes, rather than guiding reorganizing the system towards reducing energy consumption and the progressive replacement to renewable sources [21].

In addition, the study conducted by the *UPME* in 2015, *Plan energético nacional Colombia: ideario energético 2050* attempts to project the development of Colombian energy sector in the future like a possible base for creating and implementation of energy policy by this entity. This study analyzes aspects such as: (i) achieve domestic supply and external energy and minerals efficiently, with criteria of safety, reliability and low impact generating value for the regions and populations,(ii) to diversify the energy mix and minerals of Colombia, and (iii) to promote the access and affordability of service and the formality in mining [22].

The book entitled *'Prospectiva energética'* studies the behavior of the Colombian energy demand to 2050. This study was made in agreement with three universities: Universidad Autonoma de Bucaramanga (UNAB), Universidad Industrial de Santander (UIS), and Universidad Pontificia Bolivariana (UPB), and Ecopetrol. This study shows the projection of alternative scenarios for reducing energy resource emissions taking base scenarios for the construction of the new energy scenarios, modeling in the software long-range Energy Alternatives Planning System, LEAP [9].

Finally, this MS thesis is a second stage of the work developed in Jose A. Suarez's thesis, which is used as a basis for research. In his study of *Development of an Energy-Based model for forecasting the Energy Demand of Colombia*, the research project establishes a methodology to identify the socio-economic and climatic variables that express the energy consumption of the residential sector in Colombia using the multiple regression analysis, forecasts. Besides, techniques as La Prospective, and multi-criteria decision-making [23].

CHAPTER 3 Methodology

The development of this study comprises two disciplines known as Multi-criteria decision making (MCDM), strategic approaches, and La prospective technique. MCDM analysis is applied in mathematics, decision analysis, economics, computer technology, or information systems. This analysis is known as the selection criteria of the 'best' alternative from a set of available alternatives, choosing a small set of suitable alternatives, or grouping alternatives into different sets of preferences. It is in charge of structuring, planning, and solving decision problems that involve multiple criteria. There is no single solution to find the best alternative for a decision-maker (DM), as well as finding a set of reasonable alternatives. Therefore, it is necessary to take into account the preferences of the DM or stakeholder to differentiate between solutions, and to use statistical tools that help the stakeholder to focus on the preferred alternatives [45].

On the other hand, the strategic foresight is an analysis developed by Michel Godet that implies the tools of two sciences (prospective and strategy) in the selection criteria of alternatives to determine a new path to current development policies [46] [47]. The strategic prospective presents six tools for planning, which are: (i) MicMac, ii) Mactor, iii) Scenaring, iv) Smic Prob-expert, v) prospective workshops and (vi) Multipol [46].

This research methodology integrates both disciplines. Part of the analysis of the input of historical data represents the key parameter to obtain accurate results, as well as the implementation of quantitative and qualitative techniques that drive the implementation of MCDM analysis to obtain the best alternatives to develop scenarios, and the implementation of a multiple regression analysis of the macroeconomic variables that are used to plan the energy demand in Colombia.

To accomplish this study, the Microsoft Excel application is used to select the best alternatives for the projection of energy demand in Colombia. This application provides the option of being reviewed by experts in the field, validating the results and providing improvements or feedback to the model.

3.1 Fundamental Analysis

An exhaustive analysis in literature of the methods used for planning and forecast energy demand is established. In addition, the research focuses on the variables that attempt to project, this study aims to analyze the panorama of the economy in Colombia, and sectors that demand energy in the country was analyzed. Indeed, literature review provides the first step to identify variables that could comprise the energy-based model. Moreover, following the principles of the MCDM technique, experts' opinion must be taken into account to validate possible variables to implement the systematic methodology.

Once possible variables of energy-based model are determined from previous step, the fundamental analysis examines related macroeconomic variables that impact on energy demand of Colombia is carried out. In the same way, sectors that demand energy for its production are included in the fundamental analysis. This step establishes how independent variables (economic indicators) affect dependent variables of the model (energy demand by sectors). Characterization of the variables is carried out analyzing its behavior with the model (endogenous — exogenous), and the measurement of variables included in the model (quantifiable — not quantifiable).

3.2 Dataset

After identifying the related variables of the study's objective, it is necessary to gather quantitative information that describes the variables. In general, from a statistical point of view, the model needs large amount of data to provide accurate results [48]. A time-series technique is used to construct the data set to have a sequence of n data equidistant chronologically. Historical data sets are mathematically represented in the form (x_t, x_{t-k}), t is the current year, and k the oldest year in the data set. The difference must be equal to the amount of data that the model wants to forecast. Several prospective studies such as the book of *Prospectiva energética Colombia 2050*, and "Future scenarios and trends in energy demand in Colombia using LEAP" follow this statistical principle as inputs to project energy scenarios [9] [49] [50].

3.3 Correlation analysis

A descriptive and correlation analysis of the independent variables is added as part of the methodology's sequential reasoning. The correlation study's implementation is performed to find the correlation coefficient between the independent variables and the dependent variable, that is, to know the general behavior of the independent variables with which you want to express the study variables.

Pearson's correlation coefficient is used because the model comprises quantitative variables with a bivariate distribution. In other words, when the values of one variable increase, the values of the other variable can increase or decrease proportionally. Pearson's correlation values range are from -1 to 1. Extreme values indicate the greatest correlation between variables implying that a linear equation describes the relationship between x and y. On the other hand, values of 0 indicate that there is no linear correlation between the variables.

$$r = \frac{S_{xy}}{S_x S_y} = \frac{Covariance}{Product\,of\,standard\,deviations} \tag{3.1}$$

Where,

$$S_{xy} = \sum_{i=1}^{n} \frac{x_i y_i}{n} - \bar{x}\bar{y} \tag{3.2}$$

$$S_x S_y = \sqrt{\frac{\sum(x-\bar{x})^2}{n}} \times \sqrt{\frac{\sum(y-\bar{y})^2}{n}} \tag{3.3}$$

x_i	Each value of x variable
y_i	Each value of y variable
n	Data quantity
$\bar{x}$	Average of x variable
$\bar{y}$	Average of y variable

Table 3.1: Variables criteria of Pearson's correlation coefficient

Pearson's correlation coefficient establishes the relationship range of a variable as follows: If the correlation coefficient shown is between 0 and 0.2, then the correlation is minimal. If it is between 0.2 and 0.4, it is a low correlation. If it is between 0.4 and 0.6, then it is a moderate correlation, since between 0.6 and 0.8 it is a good correlation. Finally, between 0.8 and 1, it is a very good correlation. The same applies in negative values, where its relationship is indirect [51] [52].

3.4 Statistical analysis

3.4.1 Variation of variables

Correlation analysis shows the strength and direction of the linear relationship between variables. But, Relationships between variables are not always linear. For this, a variation of the expression of the independent variables is performed since there are other specifications to mathematically express this relationship between variables [53] [55] [56] [57] [58].

- Linear model

  Represents changes linearly, depend linearly on their unknown parameters. If X varies 1 unit, y varies 1 unit.

$$y = \beta_0 + \beta_1 X \tag{3.4}$$

- Semi-logarithmic models

  It is used to model the variations of percentage terms in X produce constant variations in absolute terms in y.

$$y = \beta_0 + \beta_1 ln(X) \tag{3.5}$$

- Model with quadratic terms

  Quadratic independent variables are used to analyze marginal effects (increasing or decreasing) in relation to the dependent variable. For instance, one variable could determine whether energy consumption increases as people's income increases (linear regression) or inquire whether consumption increases but not constantly. On the contrary, it increases depending on the income range more and more or less and less, as income increases (quadratic function).

$$y = \beta_0 + \beta_1 X + \beta_2 X^2 \tag{3.6}$$

  Depending on the sign, the marginal effects increases ($\beta_2 > 0$) or decreases ($\beta_2 < 0$).

- Model with cubic terms

  It is used when the linear, quadratic or semi-log models do not present variance in the study variable (dependent variable).

To determine the behavior of the independent variables that is implemented on the study, a second correlation analysis is performed to express the direct or indirect relationship of the variables based on their variations (Linear, Semi-logarithmic, quadratic or cubic).

3.5.2 Combinatorics

After determining the specifications or variations of the independent variables, the statistical combinatorial tool is implemented. It allows to obtain all possible events of the independent variables with the dependent variable. The mathematical expression is expressed by the form:

$$nC_r = \frac{n!}{(n-r)!\,r!}; n \text{ elements organized in } r \text{ sets} \tag{3.7}$$

To accomplish the combinatoric tool, there are iterative combinations that start from models that include all the variables to models that have a single independent variable. Each variation of the variables is taken independently, it means that in the same model is not possible to implement more than one variation of an independent variable. For instance, It is not allowed to have two independent variables of type X and X^2.

3.4.3 Multiple regression analysis

Once all the possible events between the independent variables and the dependent variables are accomplished, the multiple regression analysis is performed. This technique allows establishing the relationship that occurs between a dependent variable y and a set of independent variables $(X_1, X_2, ...X_n)$. Multiple linear regression analysis, unlike the simple one, is closer to real analysis situations since social phenomena, facts and processes are complex and, consequently, should be explained as far as possible by the series of variables that, directly and indirectly, participate in its behavior allowing the applicability of the MCDM analysis.

The result allows to understand the behavior of the independent variables by analyzing the expression of y, when X assumes certain changes during the iteration process.

Variation in y is related to k explanatory variables $X_1, , ..., X_k$, (independent variables).

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \epsilon \tag{3.8}$$

y is the variable to be predicted, $\beta_0, \beta_1, \beta_2, \ldots \beta_k$, are unknown parameters to estimate (coefficients of the variables in the equation), and is the error in the prediction of the parameters. In addition, to know the coefficients for each independent variable, it is necessary to compile the results of the regressions results: Multiple correlation coefficient, Multiple determination coefficient R^2, and Adjusted R^2.

The multiple correlation coefficient measures the association between several independent and one dependent variables. In the case of simple linear regression, it coincides with the correlation coefficient of simple. It expresses the correlation between the real values of the dependent variable in multiple regression and the values given by the regression equation.

The multiple determination coefficient R^2 represents the % of variation of y explained by the regression.

$$R^2 = \frac{SCR_{eg}}{SCT} = 1 - \frac{SCRE}{SCT}; 0^2 \geq 1 \tag{3.9}$$

$$R^2 = 1 - \frac{\text{Variation not explained in Y}}{\text{Total variation in Y}} = \frac{\text{Variation explained in Y}}{\text{Total variation in Y}} \tag{3.10}$$

- If $R^2 = 0 \rightarrow SCR_{eg} = 0 \therefore$ The model does not explain anything about the variation of y from its linear relationship with $X_1, \ldots, X_K$.

- If $R^2 = 1 \rightarrow SCR_{eg} = SCT \therefore$ All the variation of y is explained by the terms present in the model.

- If R^2 is close to $1 \therefore$ All the variation of y is explained by the terms present in the model.

The adjusted R^2 (or adjusted determination coefficient) is used in the multiple regression to see the degree of intensity or effectiveness that the independent variables have in explaining the dependent variable, that is, it represents what percentage of variation of the dependent variable is collectively explained by all independent variables.

$$R_a^2 = 1 - [(\frac{n-1}{n-k-1})] * (1 - R^2) \tag{3.11}$$

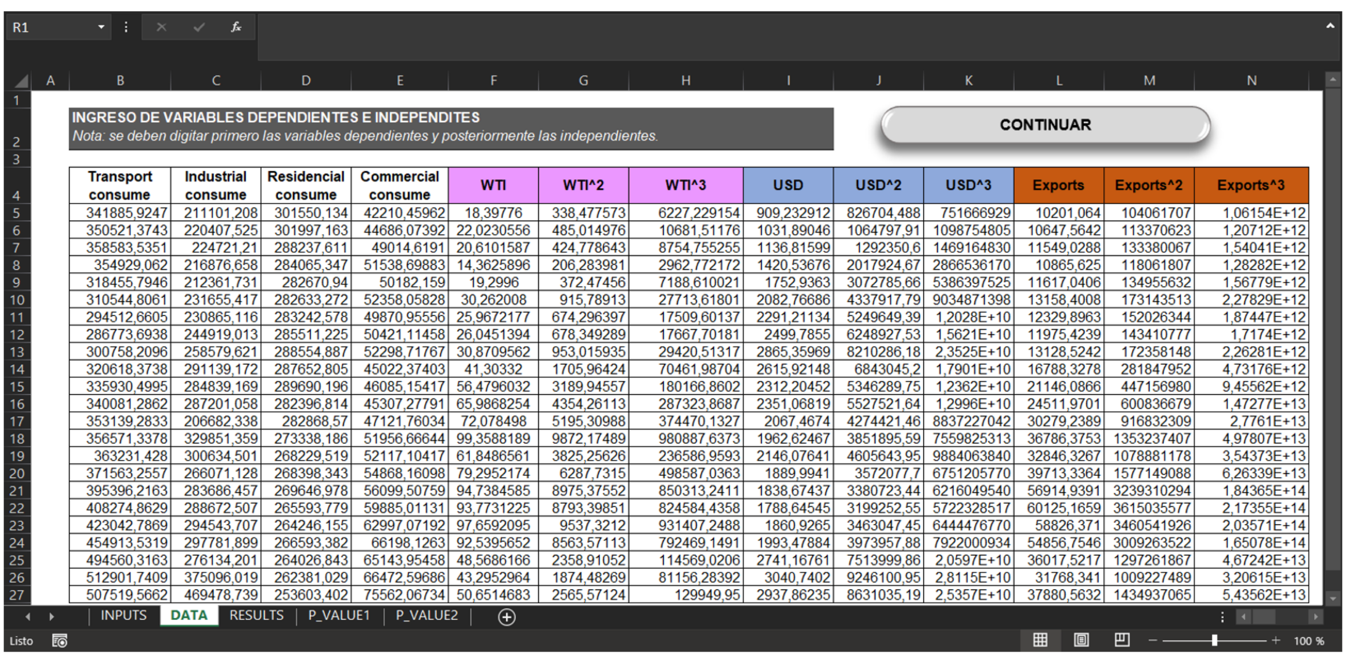
R_a^2 represents the adjusted R^2, R^2 is the R squared or coefficient of determination, n is the number of observations in the sample, and k represents the number of independent variables.

The combinatorics and multiple regression analysis procedure is programmed in the Microsoft Excel application through macros in order to reduce working time and automate data input for the significance analysis. The code is designed in a standard way, the user can input up to 16 independent variables with three variations for each one.

The program interface is shown in figure 3.1. It has 4 steps. Step 1 is responsible for requesting the number of dependent variables, the number of independent variables and the number of variations applied to the independent variables within the model.

Figure 3.1: Main interface of the Excel program for multiple regression analysis.

Once the input data info is registered, the program requests the dataset to start, dataset must be located according to program's instructions (See Figure 3.1). After filling data for each variable and its variations, the program generates a combinatorial matrix taking into account what is mentioned in point 3.4.2

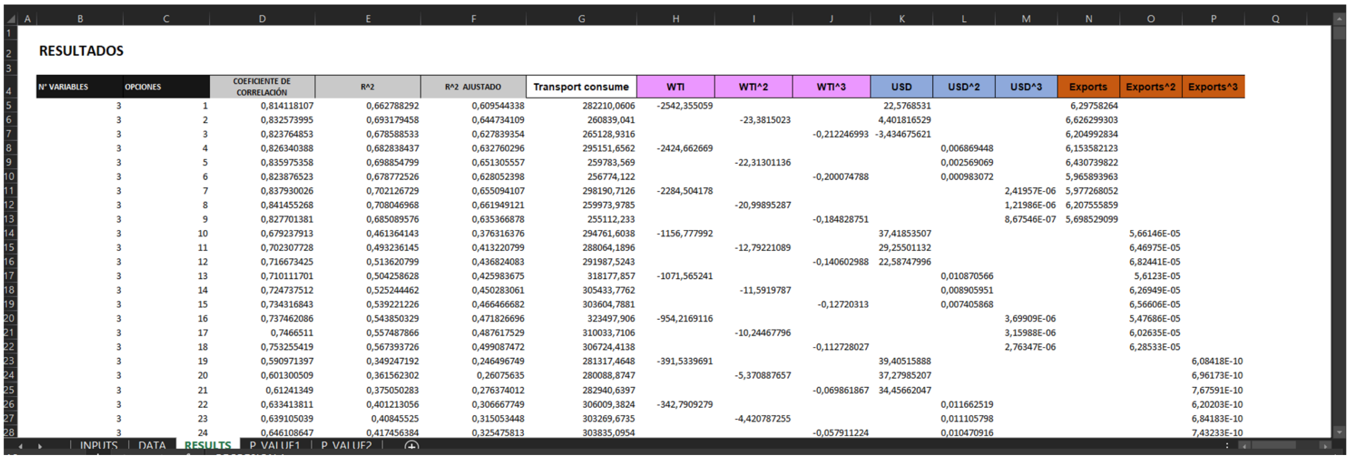


Transport consume	Industrial consume	Residencial consume	Commercial consume	WTI	WTI^2	WTI^3	USD	USD^2	USD^3	Exports	Exports^2	Exports^3
341885,9247	211101,208	301550,134	42210,45962	18,39776	338,477573	6227,229154	909,232912	826704,488	751666929	10201,064	104061707	1,06154E+12
350521,3743	220407,525	301997,163	44686,07392	22,0230556	485,014976	10681,51176	1031,89046	1064797,91	1098754805	10647,5642	113370623	1,20712E+12
358583,5351	224721,21	288237,611	49014,6191	20,6101587	424,778643	8754,755255	1136,81599	1292350,6	1469164830	11549,0288	133380067	1,54041E+12
354929,062	216876,658	284065,347	51538,69883	14,3625896	206,283981	2962,772172	1420,53676	2017924,67	2866536170	10865,625	118061807	1,28282E+12
318455,7946	212361,731	282670,94	50182,159	19,2996	372,47456	7188,610021	1752,9363	3072785,66	5386397525	11617,0406	134955632	1,56779E+12
310544,8061	231655,417	282633,272	52358,05828	30,262008	915,78913	27713,61801	2082,76686	4337917,79	9034871398	13158,4008	173143513	2,27829E+12
294512,6605	230865,116	283242,578	49870,95556	25,9672177	674,296397	17509,60137	2291,21134	5249649,39	1,2028E+10	12329,8963	152026344	1,87447E+12
286773,6938	244919,013	285511,225	50421,11458	26,0451394	678,349289	17667,70181	2499,7855	6248927,53	1,5621E+10	11975,4239	143410777	1,7174E+12
300758,2096	258579,621	288554,887	52298,71767	30,8709562	953,015935	29420,51317	2865,35969	8210286,18	2,3525E+10	13128,5242	172358148	2,26281E+12
320618,3738	291139,172	287652,805	45022,37403	41,30332	1705,96424	70461,98704	2615,92148	6843045,2	1,7901E+10	16788,3278	281847952	4,73176E+12
335930,4995	284839,169	289690,196	46085,15417	56,4796032	3189,94557	180166,8602	2312,20452	5346289,75	1,2362E+10	21146,0866	447156980	9,45562E+12
340081,2862	287201,058	282396,814	45307,27791	65,9868254	4354,26113	287323,8687	2351,06819	5527521,64	1,2996E+10	24511,9701	600836679	1,47277E+13
353139,2833	206682,338	282868,57	47121,76034	72,078498	5195,30988	374470,1327	2067,4674	4274421,46	8837227042	30279,2389	916832309	2,7761E+13
356571,3378	329851,359	273338,186	51956,66644	99,3588189	9872,17489	980887,6373	1962,62467	3851895,59	7559825313	36786,3753	1353237407	4,97807E+13
363231,428	300634,501	268229,519	52117,10417	61,8486561	3825,25626	236586,9593	2146,07641	4605643,95	9884063840	32846,3267	1078881178	3,54373E+13
371563,2557	266071,128	268398,343	54868,16098	79,2952174	6287,7315	498587,0363	1889,9941	3572077,7	6751205770	39713,3364	1577149088	6,26339E+13
395396,2163	283686,457	269646,978	56099,50759	94,7384585	8975,37552	850313,2411	1838,67437	3380723,44	6216049540	56914,9391	3239310294	1,84365E+14
408274,8629	288672,507	265593,779	59885,01131	93,7731225	8793,39851	824584,4358	1788,64545	3199252,55	5722328517	60125,1659	3615035577	2,17355E+14
423042,7869	294543,707	264246,155	62997,07192	97,6592095	9537,3212	931407,2488	1860,9265	3463047,45	6444476770	58826,371	3460541926	2,03571E+14
454913,5319	297781,899	266593,382	66198,1263	92,5395652	8563,57113	792469,1491	1993,47884	3973957,88	7922000934	54856,7546	3009263522	1,65078E+14
494560,3163	276134,201	264026,843	65143,95458	48,5686166	2358,91052	114569,0206	2741,16761	7513999,86	2,0597E+10	36017,5217	1297261867	4,67242E+13
512901,7409	375096,019	262381,029	66472,59686	43,2952964	1874,48269	81156,28392	3040,7402	9246100,95	2,8115E+10	31768,341	1009227489	3,20615E+13
507519,5662	469478,739	253603,402	75562,06734	50,6514683	2565,57124	129949,95	2937,86235	8631035,19	2,5357E+10	37880,5632	1434937065	5,43562E+13

Figure 3.2: Data input for multiple regression analysis

Finally, the number of the dependent variable, which the program will start the multiple regression analysis must be filled, and the results will be generated in three new Excel data sheets.

The first data sheet comprises the most relevant data as the coefficients of the variables in the equation, the multiple correlation coefficient, multiple determination coefficient R^2, and Adjusted R^2 (See figure 3.3).



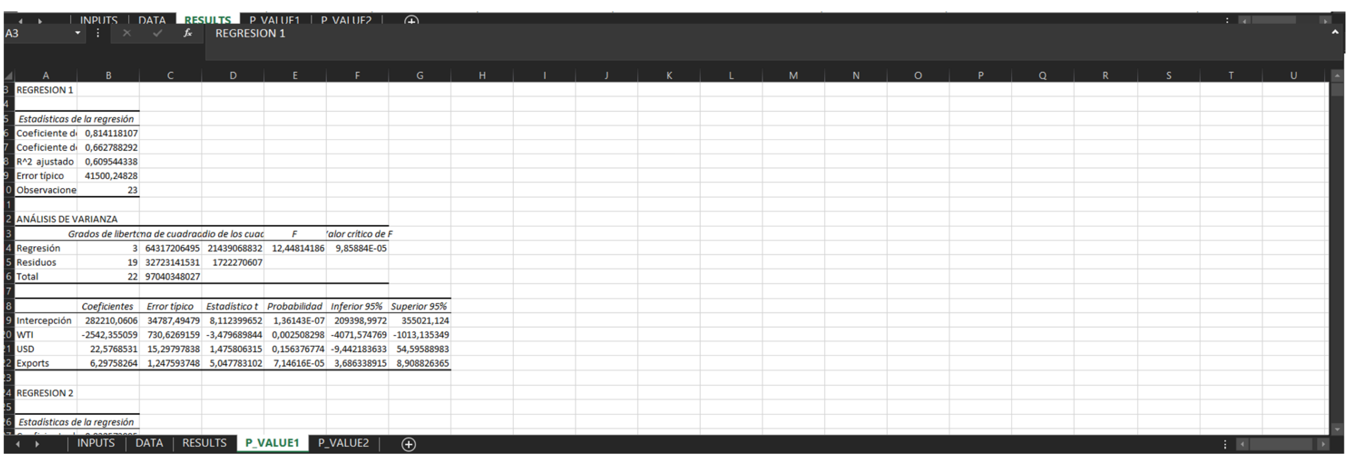
RESULTADOS

N° VARIABLES	OPCIONES	COEFICIENTE DE CORRELACIÓN	R^2	R^2 AJUSTADO	Transport consume	WTI	WTI^2	WTI^3	USD	USD^2	USD^3	Exports	Exports^2	Exports^3
3	1	0,814118107	0,662788292	0,609544338	282210,0606	-2542,355059			22,5768531			6,29758264		
3	2	0,832573995	0,693179458	0,644734109	260839,041		-23,3815023		4,401816529			6,626299303		
3	3	0,823764853	0,678588533	0,627839354	265128,9316			-0,212246993	-3,434675621			6,204992834		
3	4	0,826340388	0,682838437	0,632760296	295151,6562	-2424,662669				0,006869448		6,153582123		
3	5	0,835975358	0,698854799	0,651305557	259783,569		-22,31301136			0,002569069		6,430739822		
3	6	0,823876523	0,678772526	0,628052398	256774,122			-0,200074788		0,000983072		5,965893963		
3	7	0,837930026	0,702126729	0,655094107	298190,7126	-2284,504178					2,41957E-06	5,977268052		
3	8	0,841455268	0,708046968	0,661949121	259973,9785		-20,99895287				1,21986E-06	6,207555859		
3	9	0,827701381	0,685089576	0,635366878	255112,233			-0,184828751			8,67546E-07	5,698529099		
3	10	0,679237913	0,461364143	0,376316376	294761,6038	-1156,777992			37,41853507				5,66146E-05	
3	11	0,702307728	0,493236145	0,413220799	288064,1896		-12,79221089		29,25501132				6,46975E-05	
3	12	0,716673425	0,513620799	0,436824083	291987,5243			-0,140602988	22,58747996				6,82441E-05	
3	13	0,710111701	0,504258628	0,425983675	318177,857	-1071,565241				0,010870566			5,6123E-05	
3	14	0,724737512	0,525244462	0,450283061	305433,7762		-11,5919787			0,008905951			6,26949E-05	
3	15	0,734316843	0,539221226	0,466466682	303604,7881			-0,12720313		0,007405868			6,56606E-05	
3	16	0,737462086	0,543850329	0,471826696	323497,906	-954,2169116					3,69909E-06		5,47686E-05	
3	17	0,7466511	0,557487866	0,487617529	310033,7106		-10,24467796				3,15988E-06		6,02635E-05	
3	18	0,753255419	0,567393726	0,499087472	306724,4138			-0,112728027			2,76347E-06		6,28533E-05	
3	19	0,590971397	0,349247192	0,246496749	281317,4648	-391,5339691			39,40515888					6,08418E-10
3	20	0,601300509	0,361562302	0,26075635	280088,8747		-5,370887657		37,27985207					6,96173E-10
3	21	0,61241349	0,375050283	0,276374012	282940,6397			-0,069861867	34,45662047					7,67591E-10
3	22	0,633413811	0,401213056	0,306667749	306009,3824	-342,7909279				0,011662519				6,20203E-10
3	23	0,639105039	0,40845525	0,315053448	303269,6735		-4,420787255			0,011105798				6,84183E-10
3	24	0,646108647	0,417456384	0,325475813	303835,0954			-0,057911224		0,010470916				7,43233E-10

INPUTS | DATA | RESULTS | P_VALUE1 | P_VALUE2

Figure 3.3: Multiple Regression Analysis Results Format 1

The last two data sheets comprises more data info obtained by the Excel regression tool (See figure 3.4).



INPUTS | DATA | RESULTS | P_VALUE1 | P_VALUE2

A3 REGRESION 1

REGRESION 1

Estadísticas de la regresión	
Coeficiente d	0,814118107
Coeficiente d	0,662788292
R^2 ajustado	0,609544338
Error típico	41500,24828
Observacione	23

ANÁLISIS DE VARIANZA

	Grados de libert	ma de cuadrad	dio de los cuac	F	'alor crítico de F
Regresión	3	64317206495	21439068832	12,44814186	9,85884E-05
Residuos	19	32723141531	1722270607		
Total	22	97040348027			

	Coeficientes	Error típico	Estadístico t	Probabilidad	Inferior 95%	Superior 95%
Intercepción	282210,0606	34787,49479	8,112399652	1,36143E-07	209398,9972	355021,124
WTI	-2542,355059	730,6269159	-3,479689844	0,002508298	-4071,574769	-1013,135349
USD	22,5768531	15,29797838	1,475806315	0,156376774	-9,442183633	54,59588983
Exports	6,29758264	1,247593748	5,047783102	7,14616E-05	3,686338915	8,908826365

REGRESION 2

Estadísticas de la regresión

INPUTS | DATA | RESULTS | P_VALUE1 | P_VALUE2

Figure 3.4: Multiple Regression Analysis Results Format 2

3.5 Significance analysis

Once the results of the multiple regression analysis are obtaining, a significance analysis should be performed following the systematic process of the model.

It starts with statistical averages of the multiple correlation coefficient, multiple determination coefficient R^2, and the adjusted determination coefficient for each independent variable according to the number of variables in the regression. This pre-analysis is done to determine the independent variables that create low performance of the coefficients compared to its population.

After the general assessment of the behavior of each independent variable in the energy-based model, the methodology proceeds to calculate the maximums and minimums for each group, identifying the statistical parameters mentioned above. The objective is to assets the model with its maximum regressive parameters to determine the set of variables that the regressive analysis focuses on.

Once the variables that presented the maximum values in their regressive parameters have been identified, the population group (set of variables) is filtered by using the MCDM analysis, comparing these results with the statistical pre-analysis and fundamental analysis.

3.5.1 Variable preselection

The last step of the significance analysis is to apply P-value in Hypothesis testing identifying the P-value (probability) for each set of variables. The analysis of P-value comes from Ronald Fisher, Egon Pearson and Jerzy Neymande study. The null hypothesis significance test explains that if P-value is less than the significance level (which tells a researcher how extreme results must be in order to reject the null hypothesis), null hypothesis is rejected and an alternative hypothesis is accepted. In addition, it affirms that when the lower level of p-value is, the more significant the result will be [59] [60] [61] [62].

The null hypothesis, H_o is the statement that two or more parameters are not related to each other. It is a starting point for research that does not reject H_o unless the sample data seems to show that it is false. The objective is to assume in a first point, the opposite of what you want to prove until the conclusions obtained show that the starting point was false, in order to reject and conclude the opposite, that is, what you wanted to prove (alternative hypothesis) [59] [63].

The significance level for a given hypothesis test is a value for which a P-value less than or equal to is considered statistically significant. Another interpretation of the significance level, based in decision theory, is that corresponds to the value for which one chooses to reject or accept the null hypothesis H_o.

Furthermore, significance level presents a probability that must be defined by the researcher during the design test. Common significance levels are 0.05, 0.01, and 0.001. When the P-value is less than the level of significance, the null hypothesis is rejected, being that result. This significance level conversely translates to a 95% confidence interval (CI) *statistically significant* [59] [63]. See equation 3.12 and 3.13.

$$Significance = 1 - CI \tag{3.12}$$

$$CI = Sample\,mean\ +/- Z\,score\,(Standard\,error\,of\,the\,mean) \tag{3.13}$$

The P-value results are generated by the Excel program. The last filter is based on whether the set of variables has a p-value less than 5% to be accepted, otherwise the second best model must be studied until the entire set of variables accepts the P-value.

Following the MCDM discipline, the analysis is performed and the independent variables that meet the parameters of significance are selected in the best models that describe the dependent variable.

The obtained p value provides a degree of significance. Fisher proposes that p values below 0.05 should be interpreted as evidence criteria against the null hypothesis, but not absolutely. In other words, a p value of around 0.05 could not lead to the rejection or acceptance of the null hypothesis, but rather to the decision to carry out another experiment that would allow the decision on the study to be made [64] [65].

As a complement to the proposed methodology, the MicMac analysis is implemented to re-affirm the behavior of the independent variables with the dependent variables.

3.6 MicMac analysis

Following the two disciplines that implement this methodology, a MicMac analysis proposed by Michel Gogdet is carried out based on foresight and strategic planning. The purpose of the MicMac method is to identify the most influential and dependent variables (key variables), constructing a typology of the variables through direct and indirect classifications. In this step, the analysis must be constructed from a macro vision to a micro evaluation, taking into account the fundamental analysis, the set of variables and its variation of these with the regressive models.

Analyzing all the direct influences, a series of information is obtained: (i) the sum of the line, which represents the number of times where variable i implies an action on the system, that is, influence of variable i, and (ii) the sum of the column, which represents the number of times that j makes a change on the other variables, that is, dependence on variable j. Thus, an influence indicator and a dependency indicator are obtained for each variable, which allows classifying the variables according to these two criteria.

The identification of the key variables for the study is represented from an influence-dependency plane, which is classified into 4 zones, figure 3.5.

- Driving factors

  Highly influential and lower dependent variables. They are the explanatory variables that condition the rest of the system.

- Linkage factors

  Highly influential and dependent variables. They are unstable link variables by nature. In effect, any action on these variables will affect the others and will have a "boomerang" effect on themselves that will amplify or deactivate the initial impulse.

- Autonomous factors

  Lower influential and highly dependent variables. They are the resulting variables, whose evolution is explained by the variables of the Driving and linkage factors.

- Dependence factors Lower influential and dependent variables. These variables constitute strong trends or relatively autonomous factors. They are not used, and may be excluded from the analysis.

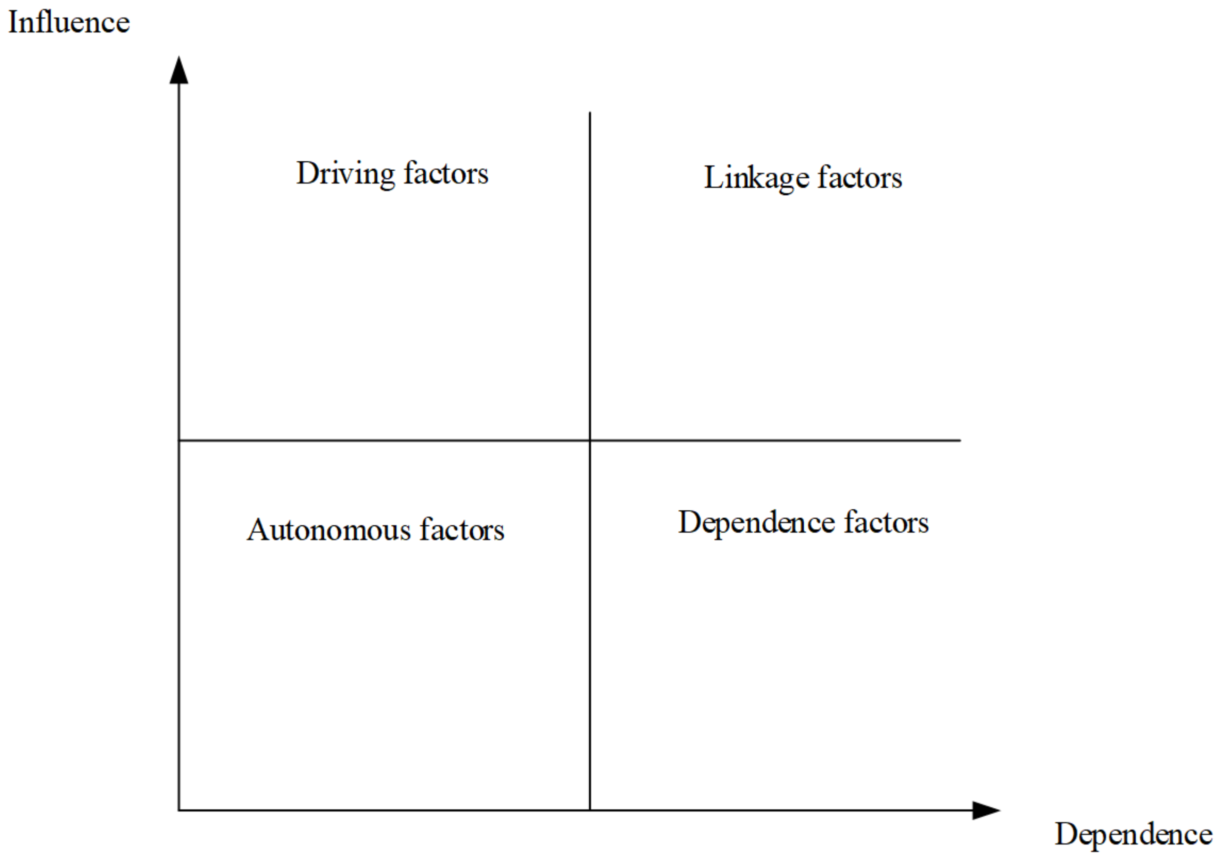


Figure 3.5: MicMac matrix: influence-dependency

The selection of the key variables are taken from a stable system where a dichotomy must be introduced between the influencing variables, and the linking variables that depend on the previous ones [66].

3.7 Variables confirmation

A confirmation of the key variables is performed through a correlation analysis, significance analysis, and MicMac analysis is implemented, integrating the two disciplines proposed for the methodology. The set of independent variables that will represent the behavior of the dependent variables is evaluated.

The researcher must integrate all the analyzes previously carried out. First, it is identified which variables have a high relationship with the study variables from the correlation analysis. Then, the best set of variables in the significance analysis is determined. This analysis implies the acceptance of the p-value, a high multiple correlation coefficient, multiple determination coefficient R^2 and Adjusted R^2.

Finally, the MicMac analysis of the preselected variables is implemented to corroborate their behavior with the dependent variables, focusing on a qualitative and quantitative analysis (fundamental analysis, R^2, and correlation coefficient) to locate the variables on the influence-dependent diagram.

As a result of the systematic methodology, once the key variables have been selected in the model, the behavior of the dependent variables with the independent variables is mathematically expressed. Each equation is proposed based on the selected regression of the significance analysis in order to project the behavior of the object of study (energy demand by sectors of consumption).

CHAPTER 4 Results and Performance Assessment

4.1 Fundamental Analysis of the Macroeconomic Variables

The energy demand is determined as the objective of study, and seven dependent variables are defined since it attempts to study the phenomenon in a sectoral path: (i) Energy demand of the transport sector, (ii) Energy demand of the commercial sector, (iii) Energy demand of the industrial sector, (iv) Energy demand of the residential sector, (v) Energy demand of the agriculture sector, (vi) Energy demand of the mining sector, and (vii) Energy demand of the construction sector. At the same time, eight independent variables regarding economy are identified to accomplish the study proposed in the systematic methodology. The fundamental analysis of each variable focuses on the behavior of the variable isolated to the model, which is why each variable is characterized as endogenous/exogenous and independent/dependent.

Model's variables	
Independent variables	**Dependent variables**
GDP_Variable	Industrial_Sector
PPI_Variable	Transport_Sector
CPI_Variable	Commercial_Sector
WTI_Variable	Residential_Sector
USD_Variable	Agriculture_Sector
FDI_Variable	Mining_Sector
Imports_Variable	Construction_Sector
Exports_Variable	

Table 4.1: Variables of the energy based model

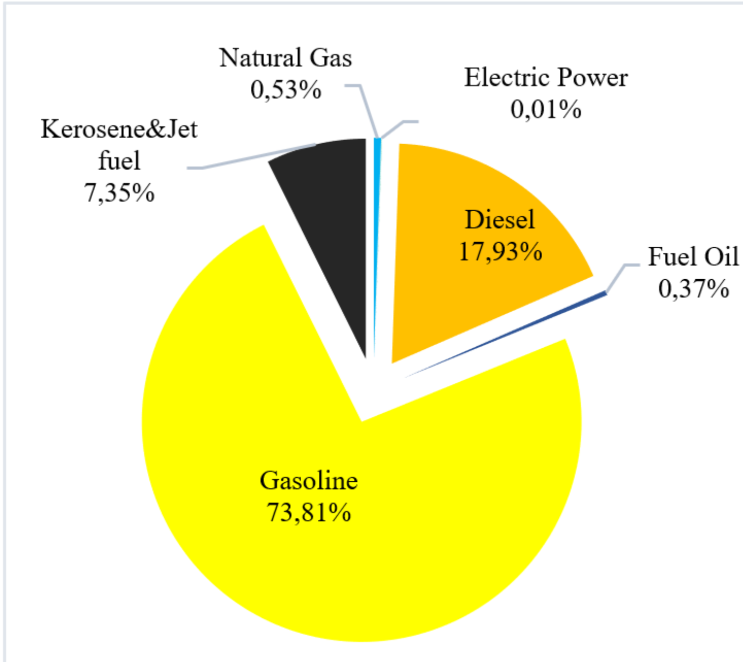
4.1.1 Dependent variables

Transport Sector

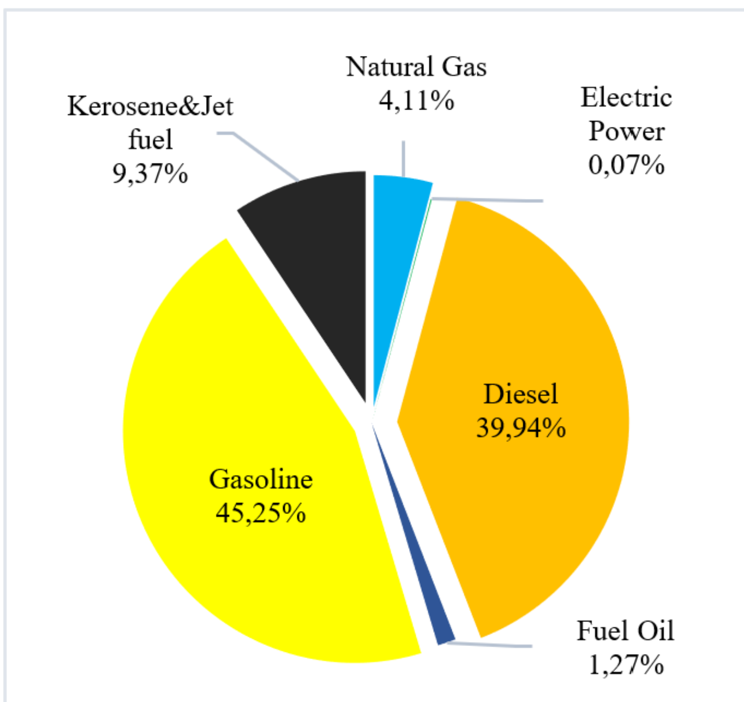
According to the study of the Colombian energy balance carried out by UPME, the transport sector demands the highest amount of energy compared to the other sectors of consumption. The sector comprises five sub-sectors: air, maritime, fluvial, railway and highway. The latter being the one with the highest energy consumption within the sector [40].

Diesel and gasoline are the mainly energy resources used in the transport sector allocating its percentage of the sector's energy consumption around 37% and 40% respectively. Electric power has a participation of less than 1%. Additionally, natural gas, fuel oil, kerosene and jet fuel are used, these energy resources allocate its participation around 4%, 1% and 9%, respectively [39].

Graph 4.1 shows the change in energy demand of the transport sector.



(a) 1995



(b) 2017

Figure 4.1: Consumption of the transport sector by primary and secondary energy resource in 1995 and 2017.

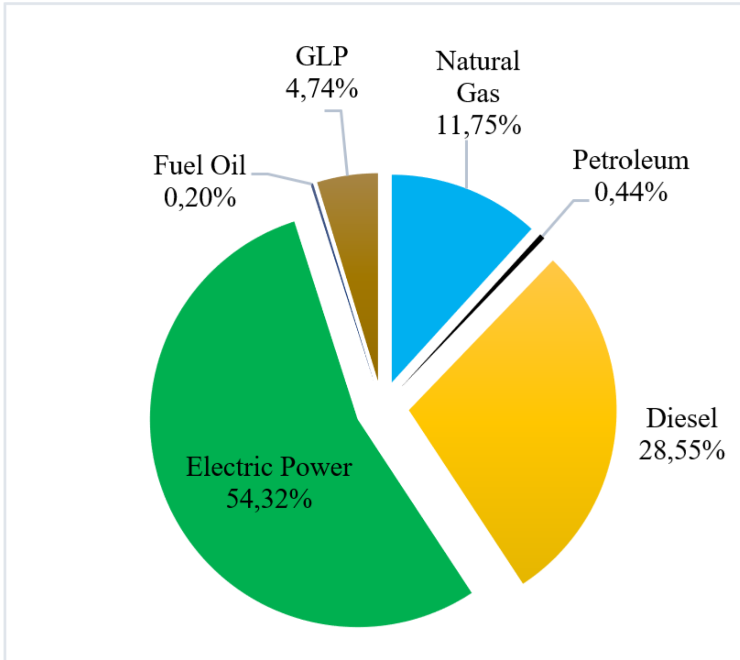
Commercial Sector

According to national data from the economy entity of Colombia (DANE), commercial sector participates in the Colombian economy with a value of approximately 60% of the national GDP. This sector includes the activities classified according to International Standard Industrial Classification of All Economic Activities (ISIC) Rev.3 A.C.4.2

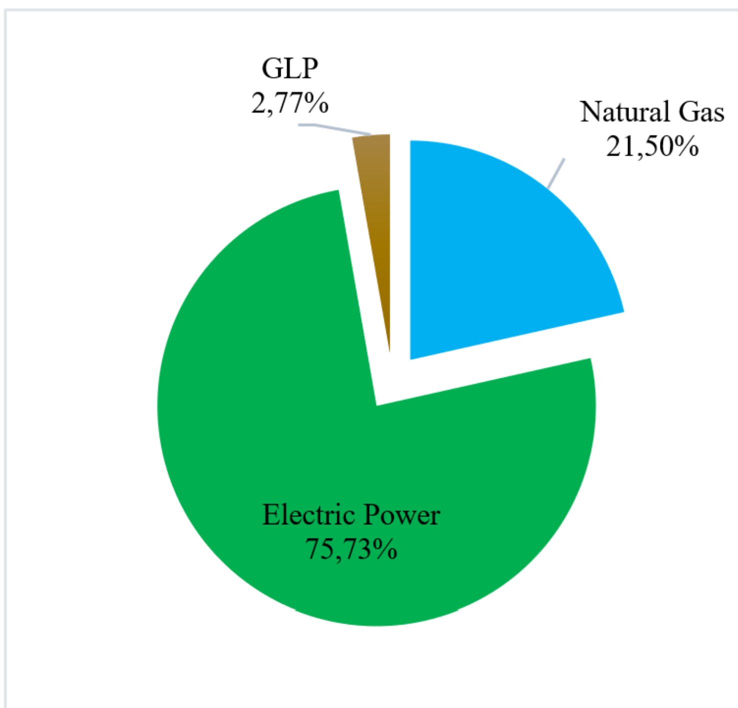
ISIC	Economic activities
50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel
51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
52	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods
55	Hotels and restaurants
63	Supporting and auxiliary transport activities; activities of travel agencies
64	Post and telecommunications
65	Financial intermediation, except insurance and pension funding
66	Insurance and pension funding, except compulsory social security
67	Activities auxiliary to financial intermediation
70	Real estate activities
71	Renting of machinery and equipment without operator and of personal and household goods
72	Computer and related activities
73	Research and development
75	Public administration and defence; compulsory social security
80	Education
85	Health and social work
91	Activities of membership organizations n.e.c.
92	Recreational, cultural and sporting activities
93	Other service activities

Table 4.2: International Standard Industrial Classification of All Economic Activities (ISIC) Rev.3

Based on the economic activities of the commercial sector and the study accomplished by the UPME entity, the main energy resources that meet the commercial energy demand are electric power (57223.34 TJ / year), natural gas (16245.95 TJ / year) and LPG (2092.76 TJ / year) in 2017. The distribution of these energy sources are shown in graph 4.2, as well as a comparison in 1995.



(a) 1995



(b) 2017

Figure 4.2: Consumption of the commercial sector by primary and secondary energy resource in 1995 and 2017.

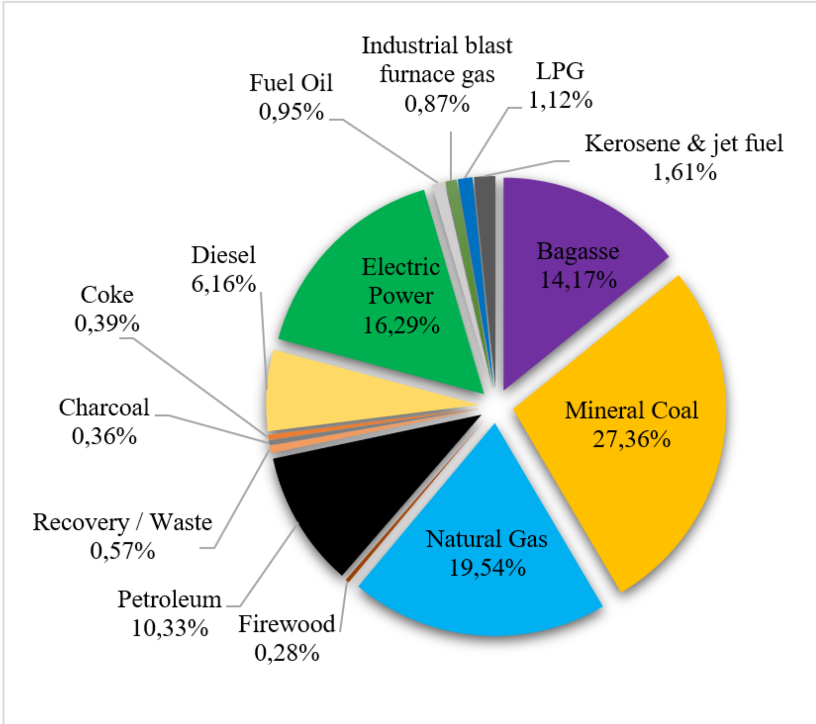
Industrial Sector

The information and business report system (SIREM) in Colombia states that 4,100 companies comprise the industrial sector, economic activities that take place in this sector are classified by the ISIC codes 4.3.

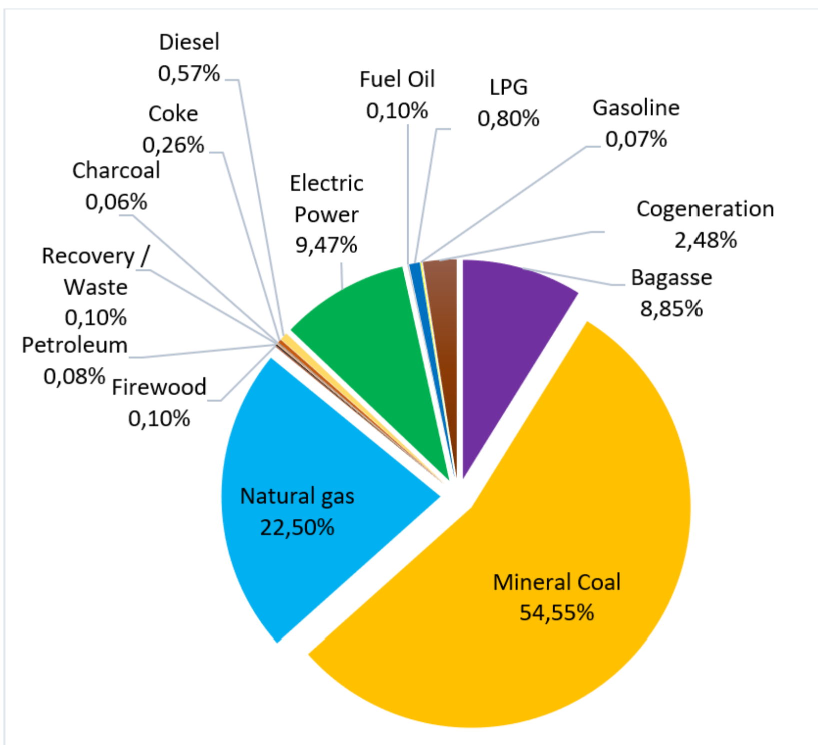
ISIC	Economic activities
15	Manufacture of food products and beverages
16	Manufacture of tobacco products
17	Manufacture of textiles
18	Manufacture of wearing apparel; dressing and dyeing of fur
19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
21	Manufacture of paper and paper products
22	Publishing, printing and reproduction of recorded media
23	Manufacture of coke, refined petroleum products and nuclear fuel
24	Manufacture of chemicals and chemical products
25	Manufacture of rubber and plastics products
26	Manufacture of other non-metallic mineral products
27	Manufacture of basic metals
23	Manufacture of coke, refined petroleum products and nuclear fuel
28	Manufacture of fabricated metal products, except machinery and equipment
29	Manufacture of machinery and equipment n.e.c.
30	Manufacture of office, accounting and computing machinery
31	Manufacture of electrical machinery and apparatus n.e.c.
32	Manufacture of radio, television and communication equipment and apparatus
34	Manufacture of motor vehicles, trailers and semi-trailers
35	Manufacture of other transport equipment
36	Manufacture of furniture; manufacturing n.e.c.

Table 4.3: International Standard Industrial Classification (ISIC) of the industrial sector. Rev.3

The industrial energy consumption allocate its highest participation in mineral coal, natural gas and bagasse for thermal uses. On the other hand, electric power is either energy purchased from the grid or energy generated through auto and cogeneration systems. The energy demand for this sector are shown in graph 4.3 as well as a contrast with the use of energy resources in 1995.



(a) 1995



(b) 2017

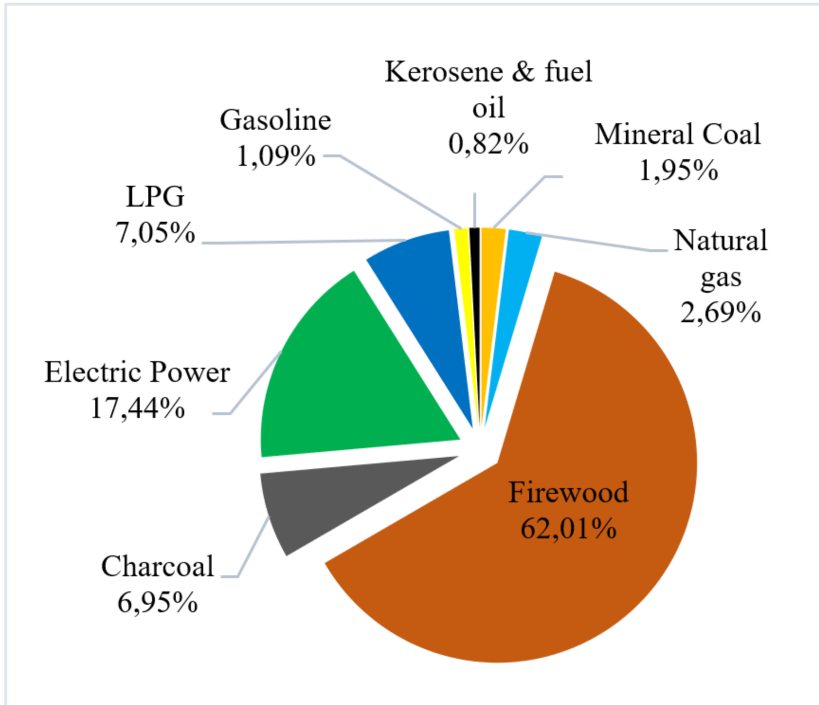
Figure 4.3: Consumption of the industrial sector by primary and secondary energy resource in 1995 and 2017.

Residential Sector

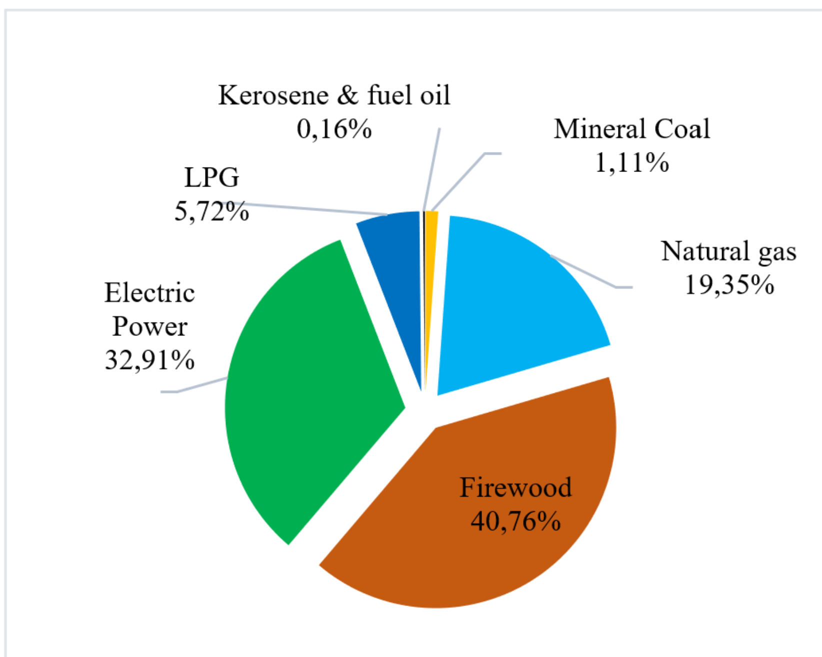
Residential consumption is comprised by households classified in socioeconomic stratum from 1 to 6 according to their location, city, access roads, and services received [67]. The energy need in this sector is distributed by cooking processes, refrigeration, and lighting. Cooking is the one with the highest percentage in relation to all the factors identified (air conditioning, water heating, and lighting) [68]

In 2017, the energy consumption of the sector by primary energy resources are allocated as: Firewood (66%), Natural gas (32%), and mineral coal (2%). In contrast, the energy resource in 1995 of firewood had a value of 93%, Natural Gas had a consumption of 4%, and the use of mineral coal had a value of 3%. Graph 4.4 shows the change in energy demand of the residential sector.

The previous change in the percentage of use of the energy resources was generated by the initiatives of the government entities, such as Law 142 of 1994, which indicated that the distribution of Natural gas and its complementary activities was part of the domiciliary public services to guarantee the quality of life of the users [69]. On the other hand, in 2011, the Ministry of Mines and Energy (MME) implied a mechanism to promote the assurance of the national supply of natural gas. the entity issued the 2100 decree, which stated in its Article 17 that *the MME will adopt an indicative plan for the supply of natural gas for a period of ten (10) years [. . .] by the UPME* [70].



(a) 1995



(b) 2017

Figure 4.4: Consumption of the residential sector by primary and secondary energy resource in 1995 and 2017.

Agriculture Sector

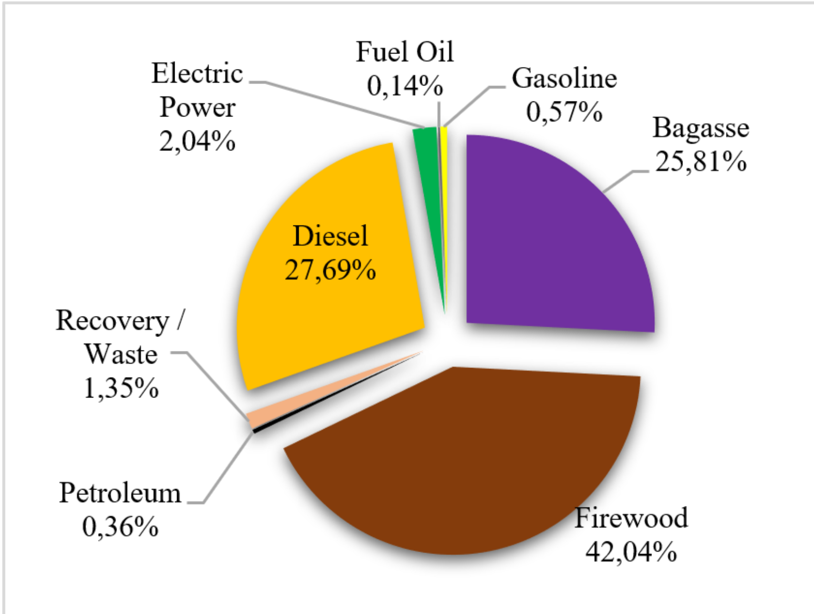
The activities of agriculture, livestock, hunting and fishing demand energy in order to generate products for the industry, some factors such as agricultural production, mechanical energy, agricultural infrastructure, and energy prices impact the preference of the energy resource to meet the energy needs [71] [72] [73].

The preference in the energy resources was based on Firewood, Diesel and Bagasse in 1995. As a contrast, the electric power occupied a higher percentage as an energy resource for agriculture sector in 2017. Diesel, gasoline and natural gas are used as well. Graph 4.5 shows the change in the energy resources in this sector.

Mining Sector

The economic activities that comprise the mining sector are: the exploitation or extraction of minerals in the soil and subsoil such as coal, metals and precious stones such as gold, silver, platinum and emeralds, metallic minerals such as nickel, copper, iron, among others, and non-metallic minerals such as salt, sulfur, clay, among others [74] [75] [76].

According to the Ministry of Mines and Energy, Colombia has several minerals in its soil, the country allocates 70% of underground geological cartographic information, 12% of geochemical information and 46% of geophysical study, all those at an exploration level. To accomplish the production of products in the mining sector, the energy demand is categorized by Diesel, Electric Power, and Natural gas. Graph 4.6 shows the preference in each energy resource to meet the energy needs in the mining sector in 2017.



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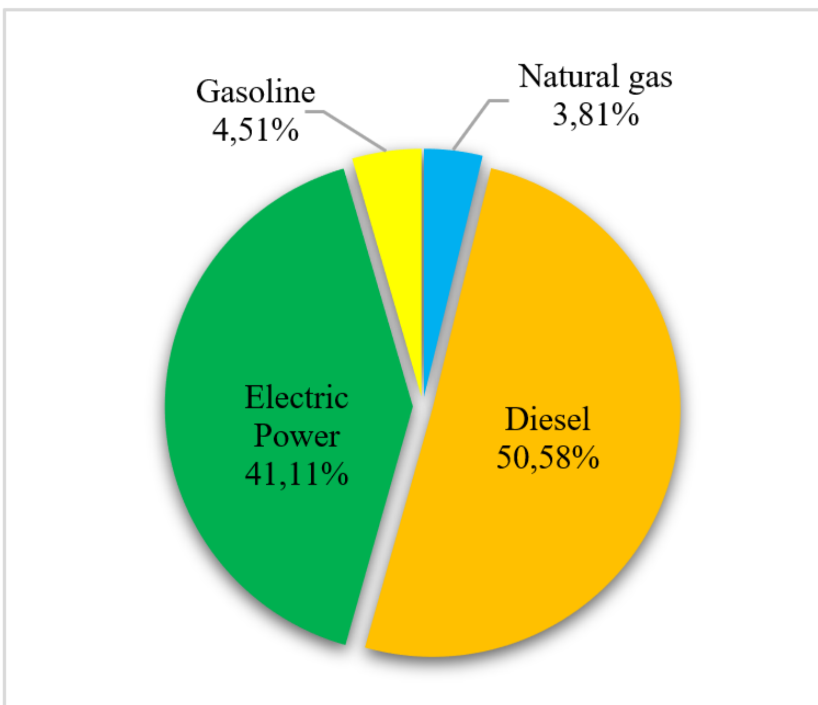


(b) 2017

Figure 4.5: Consumption of the agricultural sector by primary and secondary energy resource in 1995 and 2017.

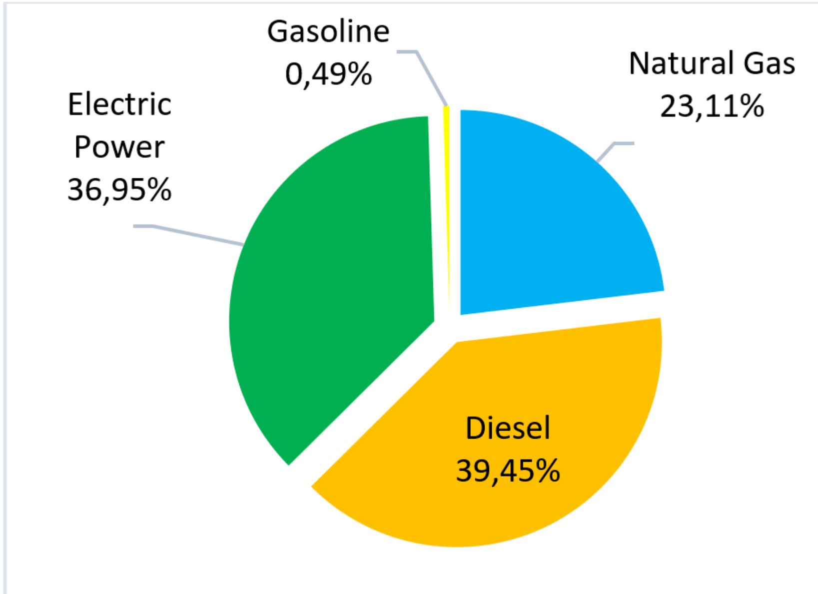
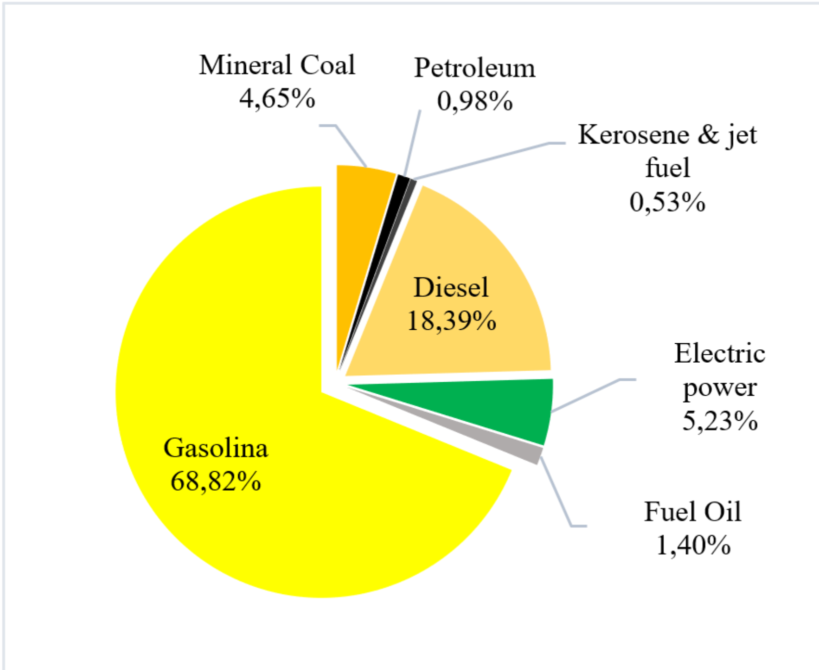


Figure 4.6: Consumption of the mining sector by primary and secondary energy resource in 2017.

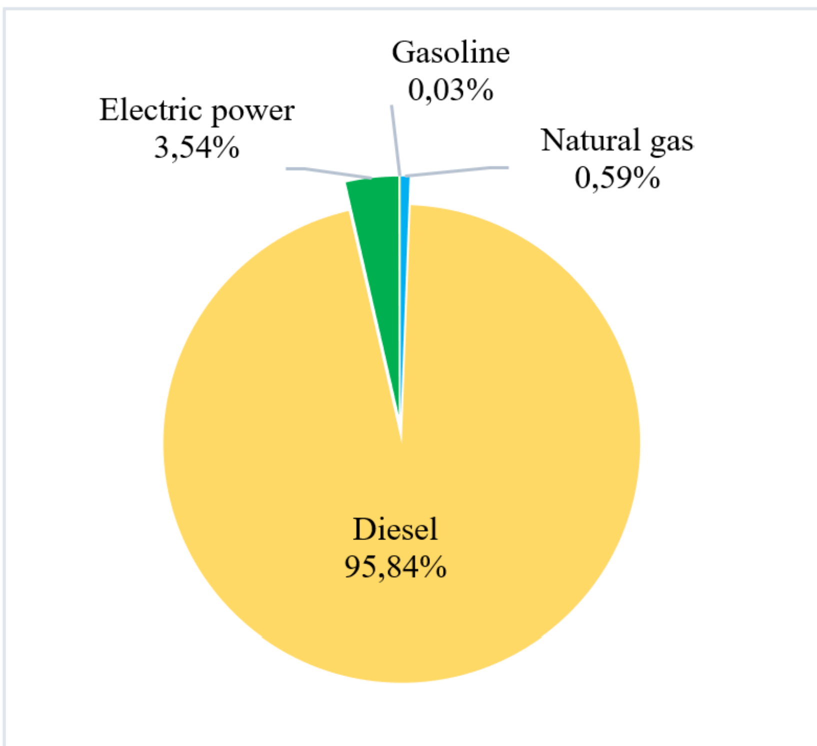
Construction Sector

The construction sector affects the economy at three levels: family, business and the State. This sector demands land, capital, workforce, machinery, materials, goods and services, technology, and financial resources. This sector carries out civil and building works, which generate wages, income, profits, taxes, and employment. The development of infrastructure and buildings in this sector requires the consumption of a high amount of non-renewable energy [77] [78].

The most used energy resource in 1995 was gasoline, then diesel, electric power, and mineral coal. As a contrast, in 2017, energy demand was based on diesel, electric power and natural gas. Graph 4.7 shows the change in energy resources of the construction sector.



(a) 1995



(b) 2017

Figure 4.7: Consumption of the construction sector by primary and secondary energy resource in 1995 and 2017.

4.1.2 Independent variables

Gross Domestic Product, GDP

Several hypotheses of the economy and energy sector imply that there is a relationship between the GDP and the energy demand, one of them is the hypothesis of *energy-guided growth* (Energy-GDP Granger causality) [79]. Granger's causality states that there is one-way causality starting from economic growth to energy consumption [80]. At the same time, in a meta-regression analysis of a large sample of the literature on the Energy-GDP relationship, Bruns et al. Discovered that (total) energy consumption has some causal connection with GDP [81]. This finding also corresponds to other recent contribution of Gross, 2012, and Stern-Enflo, 2013) [82].

Other studies such as Bowden and Payne (2009), and Zachariadis (2007) investigated the causality between energy consumption and economic growth at the macro and micro levels. The relationship between energy and economic growth seems to be neutral at the macro level, and both studies attempted to present evidence of the "Granger Causality" at the micro level [83] [84].

The GDP was classified into nine branches or groups until 2017. Economic activities that comprised each category in the GDP index were: (i) agriculture, livestock, hunting, forestry and fishing, (ii) exploitation of mines and quarries, (iii) manufacturing industry, (iv)electricity, gas and water supply, (v) construction, (vi) commerce, repair, restaurants and hotels, (vii) transportation, storage and communications, (viii) financial establishments, insurance, real estate activities and business services, and (ix) social, community and personal service activities [85].

The categories that included activities related to the energy sector were: (i) exploitation of mines and quarries, (ii) manufacturing industry, and (iii) electricity, gas and water supply. Those branches generate a direct relationship with energy demand since the other economic activities need to be supplied by the three branches that comprise the energy sector in Colombia's GDP.

Table 4.4 shows the economic activities to accomplish the development of each of the three energy branches in the GDP.

Energy branches of the GDP	**Economic activities**
Exploitation of mines and quarries	Extraction of mineral coal, crude oil, natural gas, metallic minerals, and non-metallic minerals
Manufacturing industry	ISIC codes 16-36. Rev 3 4.3
Electricity, gas and water supply	1. Generation, collection and distribution of electrical energy. 2. Household gas. 3. Purification and distribution of water and elimination of waste and residual water, sanitation and similar activities.

Table 4.4: International Standard Industrial Classification (ISIC) of the industrial sector. Rev.3

The study of Paul J. Burke and Zsuzsanna Csereklyei about the energy-GDP elasticity with the economic sectors (the percentage of change in energy use associated with a 1% change in GDP), defines that the energy consumption in the residential sector is highly inelastic to national GDP due to the high dependence of many developing economies on traditional fuels. However, the study states that the residential use of electric power has a higher elasticity with GDP. Economic growth induces the shift of residential fuels to higher quality types of energy resources [86]. In addition, the study implies that the energy use of the agriculture sector has a lower GDP elasticity and the transport, industry, and services sectors have greater energy-GDP elasticity. This explains that countries with higher gasoline prices tend to use less energy, countries with winter seasons tend to use more energy, more populated countries use less energy for transportation, and more spacious countries use more energy for agriculture [86].

Based on the theory previously defined and supported, the behavior of the GDP isolated to the model implies an endogenous and dependent relationship with the energy consumption. This is explain because the GDP is a variable that is affected by other parameters, such as the nine branches of the economic activity, besides, its value is linked to changes in other factors.

As the GDP is defined as an endogenous variable to the energy consumption, the branches of economic activity are the exogenous variables and independent of energy consumption. For this study, GDP is taken as the study variable, taking into account that it intrinsically contains nine exogenous and independent factors, which are represented by the nine branches of economic activity in Colombia established by DANE.

Producer Price Index, PPI

This index is related to energy consumption through its influence for setting prices in Fuels and Electric power according to the rates established in Colombia. The Commission for the Regulation of Energy and Gas (CREG), is the entity in charge of establishing the equations for setting the financial rates for the public electric energy service, the Unit Cost of Service Provision (CU), is an economic cost that results from adding the costs of some components, such as, Generation, Transmission, Distribution and Commercialization, defined by CREG Resolution 119 of 2007. The value of the rate established in the resolution is monthly and its changes from one period to another depend on the variations the components, which are linked to the behavior of the PPI, the supply and demand of energy [87].

The Transmission and Distribution cost components in the CU, depend on variations in the IPP. According to CREG, the transport component represents the cost of using the National Transmission System (STN) (energy transmission network through which electric power is brought from production sites to consumption centers) as well as the distribution component that represents the cost for delivery the energy from the consumption centers of

STN to the end user [87].

The residential sector is impacted with the PPI because this economic indicator is taken into account for calculating the unit cost to provide the electric energy service. It is the value that each residential user must pay per kWh consumed. On the other hand, the industrial, transport, agricultural and commercial sectors have an implicit relationship with the IPP since they are in charge of issuing construction material tariffs, reactivation of civil works, fuel prices driven by the recovery in oil prices, and prices of goods that are part of the first stage of commercialization in the agricultural sector [**?**] [89].

Therefore, the PPI shows an exogenous and independent relationship with the energy consumption because its value is not affected by other factors or variables, on the contrary, it directly affects factors such as the transmission and distribution cost components of the CU.

Consumer Price Index, CPI

The relationship of this macroeconomic variable with the energy consumption is evidenced in the CU defined by CREG Resolution 119 of 2007, as well as the PPI variable. The commercialization component presents variations that are subject to the CPI, since the update of prices occurs with this economic index. This cost component of the CU refers to costs related to energy meters, issuance and delivery of invoices, attention to requests, and claims [87].

In addition, the generation cost component, which corresponds to the cost of energy purchase either on the energy stock market, or by contracts with generators or other marketers. It is also affected by the CPI since long-term energy contracts are mainly indexed with this indicator [87].

On the other hand, it directly affects the price of *'reconciliación positiva'* of thermal generators in the balance of the national dispatch center. According to XM, *Compañía Expertos en Mercados S.A. E.S.P.*, the term of *'reconciliación'* is understood as the difference between the real generation and the ideal generation of a energy plant or resource in the national dispatch center when the real generation is greater than the ideal generation, the skateholder sell *'reconciliación'* (receive), and when the real generation is less than the ideal generation, the stakeholder buys *'reconciliación'* (pays).

In order to establish the price of *'reconciliación positiva'* in thermal generators, based on the CREG-063 resolution of 2000, the following concepts are taken into account: (i) cost of fuel supply (CSC), (ii) fuel transportation cost (CTC), (iii) cost of operation and maintenance (COM), (iv) start-stop cost (CAP), (v) fluctuating costs (OCV), where the COM is updated monthly with the last CPI available at the time of the settlement [90].

Based on the definition of the CPI set out above, residential energy consumption is impacted by the CPI due the financial rates of the energy service and its production are highly linked with this economic index [89]. On the other hand, the industrial and commercial sectors has a low relationship compared to the residential sector because although the CPI affects the prices of contracts or tariffs, it is not the main variable to take into account to settle the price[22]. The agricultural sector is impacted by the food inflation, and the transport sector by public transport rates and fuel prices [Try adding as the first line of the fileor specify an encoding such as [latin1]inputencin the document preamble.Alternatively, save the file in UTF-8 using your editor or another tool**?**, Try adding as the first line of the fileor specify an encoding such as [latin1]inputencin the document preamble.Alternatively, save the file in UTF-8 using your editor or another tool].

This variable has an exogenous and independent relationship with the energy consumption because its value is not affected by external variables, but it affects factors such as the generation and commercialization component of the unit cost electric power service provision (CU).

West texas intermediate, WTI

Despite Colombia was considered as a new member of the Organization for Economic Cooperation and Development (OECD) in May 2018, the country continues to be highly dependent to the behavior of WTI [92] [93]. Many manufacturing processes consume oil and fuel as raw material for its production. In some non-OECD countries oil remains as an important fuel for power generation. Due to these uses, oil prices tend to rise when economic activity and oil demand is growing strongly.

According to the EIA, Energy Information Administration, the structural conditions in the economy of each country influence the relationship between oil prices and economic growth. Developing countries tend to invest a high part of the economy in manufacturing industries, which are more energy intensive than service industries. In the transport sector, the oil use is usually a smaller proportion of the total oil consumption in non-OECD countries. However, this use tends to increase since vehicle ownership per capita is highly correlated with rising incomes and has a growth opportunity in non-OECD countries. Therefore, non-OECD economic growth rates tend to be an important factor affecting oil prices. The EIA projects that oil consumption in the next 25 years will come from non-OECD countries [94].

An increase in the economic overview would tend to allocated the oil markets with higher prices. The manufacturing sector has a direct consumption of oil and its derivatives, which drives the production cost to a high value when electricity tariffs increase due to rising oil prices [95].

High oil prices affect the energy sector more due to the highly energy intensity and the negative impact of oil price fluctuations. Those changes negatively affect the manufacturing, agriculture and electricity area in the short and long term, while it provides a positively impact in transport and communication since it is not vulnerable to oil price fluctuations [96].

According to the previous definition, an exogenous and independent relationship with the country's energy consumption is presented, because its value is not affected by the other variables within the model. WTI affects factors such as oil consumption which is related to fuel use as raw material for power generation.

USD

The US dollar is the official currency of the United States of America, this variable is related to energy demand through energy commodities. Energy raw materials are products that stand out in the commercial market allocating oil and gold prices as the main economic variables to lead the evolution of the economy [97] [98] [99]. Also, changes in the value of the US dollar will have collateral impacts on fluctuations in commodity prices for importing and exporting countries [100].

Some models as the MGARCH (Multivariate generalized autoregressive conditional heteroskedasticity) analyze the relationship between financial variables since their change is not constant [101], other studies developed by Julien Chevallier (2019) and Stéphane Goutte (2018) used the GJR-GARCH model to explore the dependence structure between oil, gold and USD exchange rate during normal and crisis periods. The results showed that the dependence rate for periods of crisis is stronger compared to dependence during normal periods [99].

Based on the USD definition above, this variable has an exogenous and independent relationship with the country's energy consumption. This variable is related to energy consumption through the price of energy commodities as a raw material for the transformation phase of energy generation.

Foreign direct investment in Colombia, FDI

The status of International Investments (Decree 2080 of 2000) explain this indicator as the investment of capital from abroad in the Colombian territory, including Colombian free zones, by nonresidents in Colombia [102]. Increasing foreign capital investment in a country leads to a change in the industrial structure and improvement in the technological level, which increase the energy consumption in the industrial sector [102]. In 2018, Foreign Direct Investment had its highest contribution in the energy mining sector with a value of 37%, followed by the financial and transport sectors [103].

The renewable energy industry in developing countries is one of the industries that attracts the investment of FDI, and it depends on regulatory policies [104]. Renewable energy field had more than 11% of total FDI in 2015, which led it to one of the top 5 industries in terms of the amount of FDI allocated. In Colombia, the development of oil and mining projects requires the participation of foreign companies to afford the capital and technology used. In the period 2000-2010, 96% of oil companies received investment to accomplish all the projects, it was distributed by 41% in mining and quarrying and 47% in electricity, gas and water companies [105].

FDI variable has an exogenous and independent relationship with the country's energy consumption. This variable allocates its relationship with energy demand through capital investment in oil companies, and provision of electricity, gas or water service for energy consumption.

Trade balance: Imports and Exports

The trade balance indicator summarizes all transactions for exports and imports of goods and services in the country [106]. The hypothesis that imports drives energy consumption, and that energy demand also drives imports has been one of the objects of investigation, for instance, foreign energy dependent countries experience persistent trade deficits over the years due to high import levels. If energy consumption is determined to be a catalyst for exports or imports, any reduction in energy consumption due to energy conservation policies will reduce exports or imports and therefore the benefits of trade, this will show a lower economic growth rate. Despite, exports and imports are catalysts for energy, energy conservation policies do not negatively affect the benefits of trade, resulting in increased economic growth. The unit price of energy products, exchange rate and income are important factors for energy import demand [107] [108].

Energy efficiency and innovation is highly interlinked with the access to the foreign market [109] [110] [111], and a decline in energy consumption could also impede international competitiveness and negatively affect the portfolio of products for export purposes [112]. The trade balance is an endogenous variable in the model due its value depend on the import and export variables. Exports and Imports of Colombia were considered separated variables to execute the systematic methodology since the Trade balance depends on the values of those variables.

4.2 Data Selection

As a study reference following the systematic methodology, the research gathered data from 1995 to 2017. The information was taken from Colombia's energy balance by the UPME (BECO), and financial entities focused on economic indicators, such as DANE and the Republic bank in Colombia. See figure 4.8.

Year	Transport consume	Industrial consume	Residential consume	Commercial consume	Agricultural consume	Mining consume	Construction consume	GDP	CPI	PPI	WTI	USD	FDI	Exports	Imports
1995	341.885,9TJ	211.101,2TJ	301.550,1TJ	42.210,5TJ	61.507,0TJ	3.045,0TJ	3.785,0TJ	5,2%	20,2%	18,1%	$18,4	$ 909,23	$ 968,37	$10.201,06	$12.952,34
1996	350.521,4TJ	220.407,5TJ	301.997,2TJ	44.686,1TJ	60.350,0TJ	3.289,0TJ	3.878,0TJ	0,8%	20,6%	15,0%	$22,0	$1.031,89	$ 3.111,68	$10.647,56	$12.791,87
1997	358.583,5TJ	224.721,2TJ	288.237,6TJ	49.014,6TJ	62.061,0TJ	3.110,0TJ	4.059,0TJ	4,9%	17,8%	15,4%	$20,6	$1.136,82	$ 5.562,22	$11.549,03	$14.369,19
1998	354.929,1TJ	216.876,7TJ	284.065,3TJ	51.538,7TJ	62.002,0TJ	2.994,0TJ	4.105,0TJ	-4,4%	17,2%	17,3%	$14,4	$1.420,54	$ 2.828,83	$10.865,63	$13.768,06
1999	318.455,8TJ	212.361,7TJ	282.670,9TJ	50.182,2TJ	58.669,0TJ	3.012,0TJ	3.703,0TJ	-0,7%	8,3%	9,8%	$19,3	$1.752,94	$ 1.507,91	$11.617,04	$ 9.991,05
2000	310.544,8TJ	231.655,4TJ	282.633,3TJ	52.358,1TJ	57.945,0TJ	3.256,0TJ	2.917,0TJ	3,3%	8,5%	11,0%	$30,3	$2.082,77	$ 2.436,46	$13.158,40	$10.997,92
2001	294.512,7TJ	230.865,1TJ	283.242,6TJ	49.871,0TJ	58.082,0TJ	3.706,0TJ	2.467,0TJ	1,7%	7,4%	6,9%	$26,0	$2.291,21	$ 2.541,94	$12.329,90	$11.996,61
2002	286.773,7TJ	244.919,0TJ	285.511,2TJ	50.421,1TJ	41.924,0TJ	3.608,0TJ	2.878,0TJ	2,5%	7,4%	9,3%	$26,0	$2.499,79	$ 2.133,70	$11.975,42	$11.897,23
2003	300.758,2TJ	258.579,6TJ	288.554,9TJ	52.298,7TJ	62.595,0TJ	4.419,0TJ	2.908,0TJ	3,9%	6,2%	5,7%	$30,9	$2.865,36	$ 1.720,49	$13.128,52	$13.025,68
2004	320.618,4TJ	291.139,2TJ	287.652,8TJ	45.022,4TJ	66.325,0TJ	4.612,0TJ	2.509,0TJ	5,3%	5,4%	4,6%	$41,3	$2.615,92	$ 3.115,80	$16.788,33	$15.648,65
2005	335.930,5TJ	284.839,2TJ	289.690,2TJ	46.085,2TJ	57.163,0TJ	5.029,0TJ	2.864,0TJ	4,7%	4,6%	2,1%	$56,5	$2.312,20	$10.235,42	$21.146,09	$19.798,91
2006	340.081,3TJ	287.201,1TJ	282.396,8TJ	45.307,3TJ	19.677,0TJ	8.721,0TJ	68,0TJ	6,8%	4,7%	5,5%	$66,0	$2.351,07	$ 6.750,62	$24.511,97	$24.534,00
2007	353.139,3TJ	206.682,3TJ	282.868,6TJ	47.121,8TJ	19.269,0TJ	8.745,0TJ	112,0TJ	7,5%	6,0%	1,3%	$72,1	$2.067,47	$ 8.885,77	$30.279,24	$30.807,39
2008	356.571,3TJ	329.851,4TJ	273.338,2TJ	51.956,7TJ	18.916,0TJ	10.061,0TJ	213,0TJ	3,5%	7,2%	9,0%	$99,4	$1.962,62	$10.564,15	$36.786,38	$37.152,39
2009	363.231,4TJ	300.634,5TJ	268.229,5TJ	52.117,1TJ	18.615,0TJ	10.705,0TJ	239,0TJ	1,5%	2,1%	-2,2%	$61,8	$2.146,08	$ 8.034,57	$32.846,33	$31.181,28
2010	371.563,3TJ	266.071,1TJ	268.398,3TJ	54.868,2TJ	18.151,0TJ	11.678,0TJ	194,0TJ	4,3%	3,4%	4,4%	$79,3	$1.889,99	$ 6.429,94	$39.713,34	$38.153,97
2011	395.396,2TJ	283.686,5TJ	269.647,0TJ	56.099,5TJ	17.704,0TJ	11.115,0TJ	159,0TJ	6,6%	3,5%	5,5%	$94,7	$1.838,67	$14.646,78	$56.914,94	$51.556,49
2012	408.274,9TJ	288.672,5TJ	265.593,8TJ	59.885,0TJ	17.441,0TJ	13.473,0TJ	209,0TJ	4,0%	2,0%	-3,0%	$93,8	$1.788,65	$15.039,37	$60.125,17	$56.102,15
2013	423.042,8TJ	294.543,7TJ	264.246,2TJ	62.997,1TJ	17.143,0TJ	13.824,0TJ	238,0TJ	4,3%	2,1%	-0,5%	$97,7	$1.860,93	$16.209,39	$58.826,37	$56.620,33
2014	454.913,5TJ	297.781,9TJ	266.593,4TJ	66.198,1TJ	16.839,0TJ	19.943,0TJ	435,0TJ	4,6%	3,8%	6,3%	$92,5	$1.993,48	$16.167,02	$54.856,75	$61.087,82
2015	494.560,3TJ	276.134,2TJ	264.026,8TJ	65.144,0TJ	16.390,0TJ	14.951,0TJ	336,0TJ	3,1%	6,8%	5,5%	$48,6	$2.741,17	$11.723,22	$36.017,52	$51.598,04
2016	512.901,7TJ	375.096,0TJ	262.381,0TJ	66.472,6TJ	15.975,0TJ	15.108,0TJ	377,0TJ	2,0%	5,8%	2,2%	$43,3	$3.040,74	$13.850,06	$31.768,34	$42.849,44
2017	507.519,6TJ	469.478,7TJ	253.603,4TJ	75.562,1TJ	5.437,0TJ	41.309,0TJ	17.004,0TJ	1,8%	4,1%	3,3%	$50,7	$2.937,86	$13.836,16	$37.880,56	$43.972,26

Figure 4.8: Dataset

4.2.1 Descriptive statistical analysis

In order to analyze the general behaviour of the quantitative data of the model, three basic aspects were studied, such as the mid-point of all the data (median), measures of Spread (Range, Variance and Standard Deviation), and distribution form (kurtosis). Table 4.5.

Based on the 3.4.1 point of the methodology proposed, the variability of the independent variables is determined due those factors are going to explain the behaviour of the dependent variables. As a result, each independent variable in the model uses the quadratic and cubic expressions with an exception of the CPI since it uses the quadratic and semi-logarithmic expression. Its measurement unit is the percentage and it did not present negative values that could altered the semi-logarithmic model for the multiple regression analysis. Table 4.6.

Independent Variables						
Energy sectors	Mean	Standard Error	Range	Variance	Standard Deviation	kurtosis
Transport	371,943.9 TJ	13,848.4 TJ	286,773.7 - 512.901.7TJ	4410924910	66.414.8 TJ	0.112 Leptokurtic
Industrial	274.056,5 TJ	12,558.06 TJ	206.682,3 - 469.478,7 TJ	3627213896	60.226,4 TJ	4,065 Leptokurtic
Residential	278.136,1 TJ	2,656.1 TJ	253.603,4 - 301.997,2 TJ	162266290,4	12.738,4 TJ	-0,627 Platykurtic
Commercial	53.800,8 TJ	1,774.77 TJ	42.210,5- 75.562,1 TJ	72446119,5	8.511,5 TJ	0,430 Leptokurtic
Agriculture	36.964,3 TJ	4,609.44 TJ	5.437,0- 66.325,0 TJ	488681012,6	22.106,1 TJ	-1,9805 Platykurtic
Mining	9.552,7 TJ	1,783.3 TJ	2.994,0- 41.309,0 TJ	73146157,11	8.552,6 TJ	8,216 Leptokurtic
construction	2.419,9 TJ	740.4 TJ	68,0- 17.004,0 TJ	12609827,85	3.551,0 TJ	13,645 Leptokurtic
Dependent Variables						
GDP	3.36%	0.54%	-4.38% - 7.52%	0.000678095	2.6%	2.415 Leptokurtic
CPI	7.61%	1.19%	2.00% - 20.62%	0.00322982	5.68%	0.973 Leptokurtic
PPI	3.36%	1.22%	-2.96% - 18.13%	0.003416691	5.85%	-0.340 Platykurtic
WTI	$52.4	$6.12	$14.4 - $99.4	862.3965384	$29.37	-1.330 Platykurtic
USD	$2,066.84	$121.73	$909.23 - $3,040.74	340820.0778	$583.80	-0.312 Platykurtic
FDI	$7,7520.17	$1,117.20	$968.37 - $16,209.39	28707245.97	$5,357.91	-1.47 Platykurtic
Imports	$29,254.48	$3,594.56	$9,991.05 - $61,087.82	297181369.6	$17,238.95	-0.8246 Platykurtic
Exports	$27,997.13	$3,690.24	$10,201.06 - $60,125.17	862.3965384	$29.37	-1.330 Platykurtic

Table 4.5: Statistical analysis

Gross Domestic Product	GDP
	GDP^2
	GDP^3
Cosumer price index	CPI
	CPI^2
	Ln(CPI)
Producer price index	PPI
	PPI^2
	PPI^3
West Texas Intermediate	WTI
	WTI^2
	WTI^3
United States Dollar	USD
	USD^2
	USD^3
Foreign Direct Investment	FDI
	FDI^2
	FDI^3
Colombian Exports	Exports
	Exports^2
	Exports^3
Colombian Imports	Imports
	Imports^2
	Imports^3

Table 4.6: Variations of the independent variables of the model

4.3 Correlation Analysis by Sectors of Consumption

In order to quantify the direction and strength of the association between the two variables, a correlation analysis between the independent variables and the seven sectors of study was performed, whether it is positive (higher levels of one variable are associated with higher levels of the other) or negative (higher levels of one variable are associated with lower levels of the other), and quantify the relationship level of the variables (High, medium, low).

	Transport consume	Industrial consume	Commercial consume	Residencial consume	Agricultural consume	Mining consume	Construction consume
GDP	-0,34%	3,98%	-13,16%	0,29%	-28,00%	5,66%	-32,00%
GDP^2	-11,45%	-21,86%	-31,47%	15,59%	-13,39%	-11,77%	-31,54%
GDP^3	-9,32%	-14,49%	-28,85%	11,47%	-23,47%	-4,35%	-30,63%
PCI	-26,98%	-52,04%	-47,17%	70,89%	64,44%	-46,48%	21,65%
PCI^2	-20,95%	-48,15%	-44,46%	67,18%	57,58%	-40,77%	20,38%
Ln(PCI)	-32,85%	-51,09%	-47,82%	72,14%	68,74%	-49,20%	23,27%
PPI	-35,09%	-50,56%	-42,94%	65,04%	64,34%	-45,87%	22,25%
PPI^2	-29,23%	-52,21%	-43,63%	63,41%	60,84%	-45,22%	19,69%
PPI^3	-23,48%	-48,76%	-41,57%	60,75%	56,94%	-41,04%	19,99%
WTI	38,81%	40,41%	38,14%	-61,84%	-77,55%	44,46%	-39,64%
WTI^2	34,32%	32,51%	35,10%	-56,70%	-71,34%	37,92%	-40,97%
WTI^3	30,65%	27,41%	33,06%	-52,24%	-65,14%	32,74%	-40,71%
USD	28,84%	60,31%	46,65%	-48,96%	-34,43%	43,19%	12,00%
USD^2	33,14%	62,40%	47,34%	-44,26%	-29,83%	44,52%	19,64%
USD^3	37,11%	63,46%	48,18%	-40,68%	-26,10%	45,42%	25,68%
FDI	79,58%	64,10%	73,13%	-79,09%	-81,59%	70,50%	-11,14%
FDI^2	78,42%	60,84%	76,39%	-76,67%	-75,40%	69,24%	-8,21%
FDI^3	74,67%	55,95%	75,98%	-72,82%	-68,99%	65,84%	-7,19%
Exports	63,74%	49,31%	64,64%	-78,42%	-82,89%	61,32%	-25,51%
Exports^2	56,52%	38,85%	60,25%	-70,18%	-72,24%	52,78%	-25,86%
Exports^3	48,85%	29,97%	54,48%	-61,72%	-62,01%	44,26%	-26,19%
Imports	79,80%	56,01%	75,83%	-83,28%	-86,46%	69,79%	-20,17%
Imports^2	76,89%	48,92%	76,33%	-79,07%	-78,75%	65,43%	-20,18%
Imports^3	72,00%	41,50%	73,72%	-72,86%	-70,40%	59,79%	-20,72%

Figure 4.9: Correlation analysis of the model's variables

The variables that had a positive and high relationship with the energy consumption of the transport and mining sector were Import and FDI. The energy consumption of the industrial sector has a high relationship with the CPI, PPI, USD, FDI and Imports. Besides, the commercial energy demand had a high relationship with Imports, FDI and exports. On the other hand, the residential and agriculture sectors had a positive and high relationship with CPI, PPI, WTI, FDI and imports. Finally, the energy consumption of the construction sector showed only an medium relationship with the WTI. See figure 4.9.

4.3.1 Transport Sector

As a result of the correlation analysis, the behaviour of the transport sector's energy consumption with the GDP is negative and there is a low relationship between them. This is evident in the fundamental analysis because the economic growth of Colombia does not rely on the development of the transport energy activities even though it is one of the sectors with the highest demand for energy resources.

On the other hand, the correlation analysis showed a negative and medium relationship with the CPI and the PPI because CPI impacts the rates of the transport service, and IPP issues the fuel rates for the provision of the service.

The WTI price and USD showed a positive and medium relationship with the energy consumption of the transport sector because WTI represents the cost of the main input for vehicle fuel, and the USD accomplished the financial activities of energy commodities as outstanding products in the international trade market.

FDI, exports and imports are the variables that showed a high and positive relationship with the energy consumption of the transport sector because FDI has the greatest percentage of contribution within the sector, besides energy consumption is considered as a catalyst for exports or imports, it means that if any decrease in energy demand by conservation policies, the exports of the country will decrease too.

4.3.2 Industrial Sector

The behavior of the energy consumption in the industrial sector with GDP is negative and has a medium-level relationship. Fundamental analysis showed that the GDP is impacted the most by the economic activities that companies provides in the commercial field. The relationship with the CPI and PPI is negative and medium because the energy demand for this sector is purchased by contracts where those economic indexes impact on the rates that energy suppliers can propose to companies.

WTI has a positive and a medium relationship with the industrial energy consumption because it is the price of the resource to produce energy in the country. On the other hand, USD and FDI have a positive and high relationship due to USD is the international currency that impacts the energy commodities, and FDI is the principal investment to develop and conduct projects on the industry.

Imports and Exports have a positive and a medium relationship with the energy demand in the industrial sector because it covers the international competitiveness of some industries based on theirs portfolio of products, for instance, if there is a decrease in the energy consumption, the import and export factors will be impacted in the same way. There will not be production and therefore there will not be capital to import products or technology for the supply chain of the industry.

4.3.3 Commercial Sector

The relationship between the energy consumption of the commercial sector with GDP is medium and negative because this economic index is focused mainly in the profits that commercial activities provide to the country. Moreover, the CPI and PPI have the same relationship as the GDP since the higher values of the indexes are, the lower demand for products by people will be.

The WTI has a positive and medium relationship with the energy demand of the commercial sector since based on the fundamental analysis, the oil price impacts the bargaining power of clients that want to acquire products for energy plants or to acquire fuel for the daily use of a vehicle.

The correlation analysis and the fundamental analysis suggest that the USD has a positive and medium relationship with the consumption of energy due the same reason as the industrial sector implied, it is the international currency and in terms of energy supply, the energy resources are traded by the USD. Furthermore, the FDI has a positive and high relationship with the energy demand of the commercial sector since its funds are allocated to the main sectors that drives the economic growth. The investment in the sectors that consumes higher amount of energy was above 20% in 2019.

In addition, the imports and exports showed a positive and high relationship with the energy demand of the commercial sector. The fundamental analysis proposed that those independent variables are important factors to achieve economic growth because when there is a higher demand of international materials or products in the commercial sector, the companies will need higher energy resources to accomplish the total process of the supply chain with the new entrance of products. At the same time, when the companies attempt to expand the geographic portfolio since it has a organizational structure with a high global integration due to its products, the company will required more energy to accomplish the high-quality production to achieve international attention.

4.3.4 Residential Sector

The GDP has a positive and low relationship with the energy demand of the residential sector. The fundamental analysis implies that GDP is impacted the most by the sectors that provides goods and services to the country such as commerce, transport, and manufacturing industry sectors. It focuses on the earn of revenue rather that the consumption of the resources used to accomplish the economic activities, this explain the negative correlation with all the sectors of consumption because the GDP aligns with the earn of profits and not the energy consumption by those sectors. In addition, the energy consumption in the residential sector is highly inelastic to national GDP due to the high dependence of many developing economies on traditional fuels. Due this, the sectors which its main objective is to consume, such as the residential sector, consumes goods and services that other sectors of the country provides, this can align the main objective of increase profit to the economy of the country. Therefore, the energy consumed by the residential sector has a positive correlation with the GDP.

Additionally, the CPI has a high and positive relationship with the energy demand of the residential sector. This economic index impacts the price of the energy (kWh) that is consumed per house during a month, as it was mentioned in the fundamental analysis, the CPI impacts the CU price related to energy meters, issuance and delivery of invoices, attention to requests, and claims in the residential sector.

Furthermore, the PPI has a high and positive relationship with the residential energy demand due to the monthly cost of the electric energy service that each residential user must pay per kWh consumed. The value of the rate changes from one period to another based on the behavior of the PPI, which impact some cost components of equation to establish the CU price.

The WTI has a negative and high relationship with the energy demand of the residential sector since its values highly impact the sectors that directly provides the energy resources for the financial activities of the country, which lead to economic growth. In addition, the USD has a negative and medium relationship with the energy demand of the residential users since the commercialization of electricity is not established by the international currency, it directly impacts the sector in charge of those energy resources. Finally, the FDI, imports, and exports have a negative and high relationship with the energy demand of the residential sector. The fundamental analysis showed that due to the financial help, the demand of international energy products and the geographic expansion of energy portfolio only impacts the production sectors and not the ones aligned to consume goods and services.

4.3.5 Agriculture Sector

The GDP has a negative and medium relationship with the energy demand of the agriculture sector since the GDP relies on the revenue that the food products provide to the country. In fact, the fundamental analysis showed that the agriculture sector does not consume high percentage of the total energy of the country, it consumes around 0.40% of the total energy demand of Colombia in 2017. Therefore, the correlation of the energy demand with the GDP is not high.

The CPI and the PPI have a positive and high relationship with the energy consumption of the agriculture sector. Based on the fundamental analysis, the CPI show the variation of the price to trade food products in the country and small business of food, and the PPI establishes the price rate of the end product once all the supply chain is taking into account. Furthermore, the demand of those end products need energy resources to maintain the production areas which lead to achieve profits in the sector, this is why those financial indicators are correlated with the energy demand of the sector.

On the other hand, the WTI has a negative and high relationship with the energy demand of the agriculture sector since oil price variations highly impact the agriculture production in the short and long term. The inputs costs in production areas will increase with higher energy prices.

The USD has a negative and medium relationship with the energy resources used by agriculture production. The fundamental analysis implies that high ratios in the international currency lead to decrease the investment in energy inputs such as fuels to maintain the technology in the supply chain of food products to expand those is small business.

The FDI, imports and exports have a negative and high relationship with the energy demand in the agricultural sector since the foreign investment allocates its fund to oil and mining sector, transport, commercial and manufacturing process to achieve higher revenues. In addition, studies of the impact of imports and exports on agricultural productivity in the journal of economic and sustainable development showed that exports and agricultural productivity has a bi-directional Granger causality, this refers that both variables cause the development of the other. In contrast, imports and agriculture production have no causality and it does not impacts the productivity including the energy resources used to maintain high-quality standard in the supply chain of the end-products.

4.3.6 Mining Sector

The GDP has a negative and low relationship with the energy demand of the mining sector. Based on the fundamental analysis, the mining sector provides the main energy input to other sectors of the country, whose economic activities directly impact the GDP. Although there is a negative correlation the level of this relationship is qualified as low since it has a value of 11.77%.

The CPI and PPI has a negative and medium relationship with the energy consumption of the mining sector because those economic indicators impacts the sectors that consume a high percentage of the goods and services in the country and the sectors that provide those services. Mining sector focuses on the extraction of those energy resources to maintain the economic growth but this sector does not align with the manufacturing process.

The WTI and USD has a positive and medium relationship with the energy demand in the mining sector. The fundamental analysis implies that the higher oil prices can lead to the increase in exploration, extraction and production of the main energy resource for electricity generation in the country, as well as the international currency that establishes the trade of energy commodities.

In addition, FDI has a positive and high relationship with the energy demand of the mining sector since the high percentage of the foreign investment is allocated to the energy sector, the one in charge to produce the fuels for the development of the economic growth. FDI in 2019 was established around 20% for the energy sector. Finally, the imports and exports have a positive and high correlation since the energy sector expands the geographic portfolio to achieve profits to the country, as well as the imports of technologies for oil and mining activities.

4.3.7 Construction Sector

The GDP has a negative and medium relationship with the energy demand of the construction sector due the main objective of this financial indicator as it was mentioned before, to measures the profits of the sector. Although the economic activities of the construction sector has a positive correlation, the energy demand showed the contrary. On the other hand, the CPI and PPI have a positive and medium.

The WTI has a negative and medium relationship with the energy demand of the construction sector. The fundamental analysis suggest that when there are high oil prices, the manufacture process decrease the acquirement of energy input for the production of goods and services. Therefore, the construction sector is not able to achieve all the products through the suppliers to accomplish civil projects.

Furthermore, the USD has a positive and medium relationship with the energy consumption in the construction sector since the energy resources and products, such as fuel or oil derivatives, are traded with the international currency. As a contrast, the FDI has a negative and low relationship with the energy consumed in the construction sector due to high part of the international investors allocate funds to the energy sector. A official report by the Central bank in 2020 showed that around 5% of the FDI in Colombia is invested in the construction sector, whereas the oil sector, mining sector, finance sector, commercial sector and manufacturing sector have the higher percentage of FDI in the country.

Finally, imports and exports have a negative and medium relationship with the energy demand in the construction sector since the only products to achieve global integration in this sectors are Steel and Iron, which showed 1.6% of Colombia's exports, and 34.1% of

Colombia's imports in 2018. This implies a connection which the materials for construction industries and not the energy used to accomplish the projects.

4.4 Multi-regression analysis & Macroeconomic Variables Selection

The Excel tool developed in the systematic methodology provided 458,745 regressions, which were obtained by applying multiple regression analysis along with combinatorial analysis. Each study variable (transport, industrial, commercial, residential, agriculture, mining, and construction sector) had 65,535 regressions results in order to be analyzed.

4.3.1 Transport Sector

Applying the significance analysis in the transport sector, the variable that had the highest statistical noise in the set of variables was the *GDP*. The set of variables without this variable showed a better performance in the general behaviour of the statistical coefficients, as follows: 89,78% in R^2, 85% in adjusted R^2 and 94,71% in the multiple correlation coefficient.

The maximum values for each statistical coefficient are shown (table 4.7) as follows:

- The highest coefficients in the 8 variables set, where showed in *Option 1921*. The model comprised $GDP, CPI^2, PPI, WTI^3, USD^3, FDI^2, Exports^3, Imports$.
- The highest coefficients in the 7 variables set, where showed in *Option 18139*. The model comprised $GDP, CPI^2, WTI^3, USD^3, FDI^2, Exports^3, Imports$.
- The highest coefficients in the 6 variables set, where showed in *Option 33736*. The model comprised $GDP, CPI^2, WTI^2, FDI^2, Exports^3, Imports$.
- The highest coefficients in the 5 variables set, where showed in *Option 56201*. The model comprised $CPI^2, WTI^2, FDI^3, Exports^3, Imports$.

- The highest coefficients in the 4 variables set, where showed in *Option 63604*. The model comprised $WTI, FDI, Exports^3, Imports$.

- The highest coefficients in the 3 variables set, where showed in *Option 65131*. The model comprised $WTI, Exports^3, Imports$.

- The highest coefficients in the 2 variables set, where showed in *Option 65450*. The model comprised $WTI^2, Imports$.

- The highest coefficients in the 1 variable set, where showed in *Option 65533*. The model comprised: $Imports$.

Variables Set	**Statistical Coefficients of the Multiple Regression analysis**		
	Multiple Correlation Coefficient	R^2	**Adjusted** R^2
8 – Opt. 1921	98,56%	97,14%	95,50%
7 – Opt. 18139	98,52%	97,07%	95,70%
6 - Opt. 33736	98,48%	96,99%	95,86%
5 – Opt. 56201	98,16%	96,37%	95,30%
4 – Opt. 63604	97,84%	95,72%	94,77%
3 – Opt. 65131	96,41%	92,95%	91,83%
2 – Opt. 65450	94,50%	89,31%	88,24%
1 – Opt. 65533	79,80%	63,67%	61,94%

Table 4.7: Maximum coefficients of multiple regression analysis for the transport sector.

The set of 5 variables was the model with the best coefficients evaluated and the first one to accept the P-value in each variable, as shown in figure A.1. The p-value in this model were showed as: CPI^2 - 0.371%, WTI^2 - 0.014%, FDI^3 - 0.284%, $Exports^3$ - 0.008%, and Imports - 0.00001%.

4.3.2 Industrial Sector

Applying the significance analysis in the industrial sector, the variable that had the highest statistical noise in the set of variables was the *CPI*. The set of variables without this variable showed a positive change in the general behaviour of the statistical coefficients, as follows: 89,78% in R^2, 85% in adjusted R^2 and 94,71% in the multiple correlation coefficient.

The maximum values for each statistical coefficient are shown (table 4.8) as follows:

- The highest coefficients in the 8 variables set, where showed in *Option 2411*. The model comprised $GDP^2, Ln(CPI), PPI, WTI^3, USD^3, FDI, Exports, Imports^2$.
- The highest coefficients in the 7 variables set, where showed in *Option 16829*. The model comprised $GDP^2, Ln(CPI), PPI, USD^3, FDI, Exports, Imports^3$.
- The highest coefficients in the 6 variables set, where showed in *Option 29708*. The model comprised $GDP^2, Ln(CPI), PPI, USD^3, FDI, Imports^3$.
- The highest coefficients in the 5 variables set, where showed in *Option 54852*. The model comprised $Ln(CPI), PPI, USD^3, FDI, Imports^3$.
- The highest coefficients in the 4 variables set, where showed in *Option 60732*. The model comprised $GDP^3, USD^3, FDI, Imports^3$.
- The highest coefficients in the 3 variables set, where showed in *Option 65202*. The model comprised $USD^3, FDI^2, Imports^3$.
- The highest coefficients in the 2 variables set, where showed in *Option 65460*. The model comprised USD^3, FDI.
- The highest coefficients in the 1 variable set, where showed in *Option 65527*. The model comprised: FDI

Following the methodology developed, the P-value needs to be analyzed. The set of 6 variables was the model with the best coefficients evaluated. The first regression result did not accept the p-value (Opt. 29708), therefore it was excluded A.2. As a result, the fifth best regression result (Opt. 38441) in this set of variables was the first one in accept the P-value, as shown in figure A.3. The p-value of the Opt. 38441 were showed as: GDP^2 -

Variables Set	Statistical Coefficients of the Multiple Regression analysis		
	Multiple Correlation Coefficient	R^2	Adjusted R^2
8 – Opt. 2411	93,82%	88,03%	81,19%
7 – Opt. 16829	93,26%	86,98%	80,91%
6 - Opt. 29708	92,87%	86,25%	81,09%
5 – Opt. 54852	89,71%	80,47%	74,73%
4 – Opt. 60732	87,63%	76,79%	71,64%
3 – Opt. 65202	84,99%	72,24%	67,85%
2 – Opt. 65460	82,80%	68,55%	65,41%
1 – Opt. 65527	64,10%	41,09%	38,28%

Table 4.8: Maximum coefficients of multiple regression analysis for the industrial sector.

1.42%, PPI - 2.01%, USD^3 - 0.01%, FDI^2 - 0.89%, $Exports$ - 0.43%, and $Imports^3$ - 0.07%.

4.3.3 Commercial Sector

Applying the significance analysis in the commercial sector, the variable that had the highest statistical noise in the set of variables was the GDP. The set of variables without this variable showed a better performance in the general behaviour of the statistical coefficients, as follows: 87,14% in R^2, 81,14% in adjusted R^2 and 93,34% in the multiple correlation coefficient.

The maximum values for each statistical coefficient are shown (table 4.9) as follows:

- The highest coefficients in the 8 variables set, where showed in *Option 167*. The model comprised $GDP^2, CPI^2, PPI, WTI, USD^3, FDI, Exports, Imports$.

- The highest coefficients in the 7 variables set, where showed in *Option 6755*. The model comprised $GDP^2, CPI^2, PPI, WTI^2, USD^3, FDI, Exports$.

- The highest coefficients in the 6 variables set, where showed in *Option 34994*. The model comprised $GDP^2, PPI, WTI, USD, FDI, Exports$.

- The highest coefficients in the 5 variables set, where showed in *Option 49583*. The model comprised $GDP^2, PPI, WTI^2, USD, Exports$.

- The highest coefficients in the 4 variables set, where showed in *Option 60267*. The model comprised $GDP^3, WTI, USD, Imports$.

- The highest coefficients in the 3 variables set, where showed in *Option 64222*. The model comprised $GDP, USD^3, Imports^2$.

- The highest coefficients in the 2 variables set, where showed in *Option 65450*. The model comprised $WTI^2, Imports$.

- The highest coefficients in the 1 variable set, where showed in *Option 65528*. The model comprised: FDI^2.

Variables Set	**Statistical Coefficients of the Multiple Regression analysis**		
	Multiple Correlation Coefficient	R^2	**Adjusted** R^2
8 – Opt. 167	96,26%	92,66%	88,46%
7 – Opt. 6755	96,20%	92,55%	89,08%
6 - Opt. 34994	95,94%	92,05%	89,07%
5 – Opt. 49583	95,18%	90,59%	87,82%
4 – Opt. 60267	94%	88,36%	85,78%
3 – Opt. 64222	92,95%	86,39%	84,25%
2 – Opt. 65450	87,63%	76,79%	74,47%
1 – Opt. 65528	76,39%	58,36%	56,38%

Table 4.9: Maximum coefficients of multiple regression analysis for the commercial sector.

The set of 5 variables was the model with the best coefficients assessment and the first one in accept the P-value in each variable, as shown in figure A.4. The p-value in this model is shown, as follows: GDP^2 - 0,44%, PPI - 0,10%, WTI^2 - 0,09%, USD - 0,02%, and Exports - 0,000017%.

4.3.4 Residential Sector

Applying the significance analysis in the residential sector, the variable that had the highest statistical noise in the set of variables was the *GDP*. The set of variables without this variable showed a better performance in the general behaviour of the statistical coefficients, as follows: 91,79% in R^2, 84,30% in adjusted R^2 and 76,97% in the multiple correlation coefficient.

The maximum values for each statistical coefficient are shown (table 4.10) as follows:

- The highest coefficients in the 8 variables set, where showed in *Option 4442*. The model comprised $GDP^2, CPI^2, PPI^2, WTI^3, USD, FDI, Exports, Imports^3$.
- The highest coefficients in the 7 variables set, where showed in *Option 14640*. The model comprised $GDP^3, CPI^2, PPI, WTI^3, FDI, Exports, Imports^3$.
- The highest coefficients in the 6 variables set, where showed in *Option 27874*. The model comprised $GDP, CPI, PPI^2, WTI, Exports^3, Imports$.
- The highest coefficients in the 5 variables set, where showed in *Option 45265*. The model comprised $GDP^3, CPI, PPI^2, WTI^3, Imports$.
- The highest coefficients in the 4 variables set, where showed in *Option 58747*. The model comprised $GDP, CPI^2, WTI^3, Imports$.
- The highest coefficients in the 3 variables set, where showed in *Option 63886*. The model comprised $GDP, CPI^2, Imports$.
- The highest coefficients in the 2 variables set, where showed in *Option 65476*. The model comprised $USD, Imports$.
- The highest coefficients in the 1 variable set, where showed in *Option 65533*. The model comprised: $Imports$.

Variables Set	**Statistical Coefficients of the Multiple Regression analysis**		
	Multiple Correlation Coefficient	R^2	**Adjusted** R^2
8 – Opt. 4442	96,10%	92,35%	87,98%
7 – Opt. 14640	96,03%	92,22%	88,59%
6 - Opt. 27874	95,59%	91,37%	88,14%
5 – Opt. 45265	95,17%	90,58%	87,81%
4 – Opt. 58747	94,69%	89,66%	87,36%
3 – Opt. 63886	93,62%	87,66%	85,71%
2 – Opt. 65476	89,21%	79,58%	77,53%
1 – Opt. 65533	83,28%	69,36%	67,90%

Table 4.10: Maximum coefficients of multiple regression analysis for the residential sector.

Following the methodology developed, the P-value needs to be analyzed. The set of 7 variables was the model with the best coefficients evaluated. However, the first regression result did not accept the p-value (Opt. 14640), therefore it was excluded A.5. As a result, Figure A.6 shows the best second regression result (Opt. 14613) in this set of variables that accepted the P-value, as follows: GDP^3 - 0,727%, CPI^2 - 0,051%, PPI - 1,374%, WTI^2 - 0,138%, FDI - 4,744%, , $Exports$ - 0,084%, and $Imports^3$ - 1,644%.

4.3.5 Agriculture Sector

Applying the significance analysis in the transport sector, the variable that had the highest statistical noise in the set of variables was *Imports*. The set of variables without this variable showed a better performance in the general behaviour of the statistical coefficients, as follows: 89,78% in R^2, 85% in adjusted R^2 and 94,71% in the multiple correlation coefficient.

The maximum values for each statistical coefficient are shown (table 4.11) as follows:

- The highest coefficients in the 8 variables set, where showed in *Option 2178*. The model comprised $GDP^3, Ln(CPI), PPI^2, WTI^3, USD^3, FDI^3, Exports^3, Imports$.
- The highest coefficients in the 7 variables set, where showed in *Option 13842*. The model comprised $GDP^3, Ln(CPI), PPI^2, WTI^3, FDI^3, Exports^3, Imports$.
- The highest coefficients in the 6 variables set, where showed in *Option 27936*. The model comprised $GDP^3, Ln(CPI), PPI^2, WTI^3, Exports^3, Imports$.
- The highest coefficients in the 5 variables set, where showed in *Option 46728*. The model comprised $GDP^3, Ln(CPI), PPI^2, Exports^3, Imports$.
- The highest coefficients in the 4 variables set, where showed in *Option 62151*. The model comprised $Ln(CPI), WTI^2, Exports^3, Imports$.
- The highest coefficients in the 3 variables set, where showed in *Option 65131*. The model comprised $WTI, Exports^3, Imports$.
- The highest coefficients in the 2 variables set, where showed in *Option 65505*. The model comprised $Exports^3, Imports$.

- The highest coefficients in the 1 variable set, where showed in *Option 65533*. The model comprised: *Imports*.

Variables Set	Statistical Coefficients of the Multiple Regression analysis		
	Multiple Correlation Coefficient	R^2	**Adjusted** R^2
8 – Opt. 2178	93,35%	87,15%	79,80%
7 – Opt. 13842	93,33%	87,11%	81,10%
6 - Opt. 27936	93,28%	87,02%	82,15%
5 – Opt. 46728	92,85%	86,22%	82,16%
4 – Opt. 62151	92,58%	85,71%	82,54%
3 – Opt. 65131	91,76%	84,19%	81,70%
2 – Opt. 65505	89,68%	80,42%	78,46%
1 – Opt. 65533	86,46%	74,75%	73,55%

Table 4.11: Maximum coefficients of multiple regression analysis for the agriculture sector.

The set of 3 variables was first model that has the best coefficients assessment and the one to accept the P-value in each variable, as it is shown in figure A.7. The p-value in this model were showed, as follows: WTI - 4,66%, $Exports^3$ - 0.52%, and Imports - 0.0034%.

4.3.6 Mining & Construction Sectors

Applying the significance analysis in the transport and construction sectors, the models with maximum coefficients assessment for each set of variables were identified. However, none of the models accepted the P-value in both sectors, this result is explain due to the lower energy consume based on the UPME report from 1995 to 2017, as follows: Mining sector (3.02%), and Construction sector (1,24%). In addition, the systematic methodology uses MCDM and 'La prospective" disciplines to accomplish the economic energy based model in transport and construction sector, this implies that several criteria must be applied to thoroughly analyze the behaviour of the variables that attempt to project the energy demand in those sector. Since only economic factor was used in the applied research, it is not enough that those variables produce or reflect variations in the energy consumption of transport and construction sector.

Mining sector

Following the significance analysis, the set of variables without USD showed a better performance in the general behaviour of the statistical coefficients, as follows: 63,95% in R^2, 47,12% in adjusted R^2 and 79,94% in the multiple correlation coefficient.

The maximum values for each statistical coefficient are shown (table 4.12) as follows:

- The highest coefficients in the 8 variables set, where showed in *Option 4598*. The model comprised $GDP^2, Ln(CPI), PPI, WTI^3, USD^3, FDI, Exports, Imports$.
- The highest coefficients in the 7 variables set, where showed in *Option 21188*. The model comprised $GDP^2, PPI, WTI^3, USD^2, FDI, Exports, Imports$.
- The highest coefficients in the 6 variables set, where showed in *Option 44269*. The model comprised $PPI, WTI^3, USD^2, FDI^2, Exports, Imports^3$.
- The highest coefficients in the 5 variables set, where showed in *Option 57292*. The model comprised $PPI, WTI^3, USD^3, Exports, Imports^3$.
- The highest coefficients in the 4 variables set, where showed in *Option 62638*. The model comprised $PPI, WTI^3, USD^3, Exports$.
- The highest coefficients in the 3 variables set, where showed in *Option 65052*. The model comprised $WTI^3, USD^3, Imports$.
- The highest coefficients in the 2 variables set, where showed in *Option 65478*. The model comprised $USD^3, Imports$.
- The highest coefficients in the 1 variable set, where showed in *Option 65527*. The model comprised: FDI.

Variables Set	Statistical Coefficients of the Multiple Regression analysis		
	Multiple Correlation Coefficient	R^2	**Adjusted** R^2
8 – Opt. 4598	86,42%	74,69%	60,23%
7 – Opt. 21188	86,15%	74,22%	62,19%
6 - Opt. 44269	84,97%	72,20%	61,77%
5 – Opt. 57292	83,56%	69,82%	60,95%
4 – Opt. 62638	81,96%	67,18%	59,88%
3 – Opt. 65052	80,01%	64,02%	58,34%
2 – Opt. 65478	78,37%	61,41%	57,56%
1 – Opt. 65527	70,50%	49,70%	47,30%

Table 4.12: Maximum coefficients of multiple regression analysis for the Mining sector.

Construction Sector

The set of variables without Imports showed a better performance in the general behaviour of the statistical coefficients, as follows: 35,90% in R^2, 5,98% in adjusted R^2 and 59,81% in the multiple correlation coefficient.

The maximum values for each statistical coefficient are shown (table 4.13) as follows:

- The highest coefficients in the 8 variables set, where showed in *Option 2816*. The model comprised $GDP^2, Ln(CPI), PPI, WTI^3, USD^2, FDI^3, Exports, Imports^2$.
- The highest coefficients in the 7 variables set, where showed in *Option 20621*. The model comprised $GDP^2, PPI, WTI^3, USD^2, FDI^3, Exports, Imports^2$.
- The highest coefficients in the 6 variables set, where showed in *Option 37739*. The model comprised $GDP^2, PPI, WTI^3, FDI^3, Exports, Imports^3$.
- The highest coefficients in the 5 variables set, where showed in *Option 54156*. The model comprised $Ln(CPI), PPI, WTI^3, FDI^2, Imports^3$.
- The highest coefficients in the 4 variables set, where showed in *Option 63643*. The model comprised $WTI, FDI^2, Exports, Imports^3$.

- The highest coefficients in the 3 variables set, where showed in *Option 65123*. The model comprised $WTI^2, FDI^3, Imports$.

- The highest coefficients in the 2 variables set, where showed in *Option 65435*. The model comprised WTI^2, FDI^2.

- The highest coefficients in the 1 variable set, where showed in *Option 65522*. The model comprised: WTI^2.

Variables Set	**Statistical Coefficients of the Multiple Regression analysis**		
	Multiple Correlation Coefficient	R^2	**Adjusted** R^2
8 – Opt. 2816	73,75%	54,39%	28,32%
7 – Opt. 20621	73,65%	54,24%	32,88%
6 - Opt. 37739	70,10%	49,14%	30,07%
5 – Opt. 54156	66,90%	44,75%	28,51%
4 – Opt. 63643	61,37%	37,67%	23,81%
3 – Opt. 65123	59,03%	34,85%	24,56%
2 – Opt. 65435	53,23%	28,33%	21,16%
1 – Opt. 6552	40,97%	16,78%	12,82%

Table 4.13: Maximum coefficients of multiple regression analysis for the Construction sector.

4.5 Micmac analysis assessment

MICMAC is used to examine the strength of the relationship of economic variables of the model selected in the P-value assessment. The economic variables have been categorized into four groups based on their driving and dependence power, as shown in Table 4.14.

Assessment Criteria		
High	3	76% - 100%
Moderate	2	21% - 75%
Low	1	11% - 20%
Null	0	0% - 10%

Table 4.14: Assessment criteria to MICMAC analysis

4.5.2 Transport Sector

Economic set variables of Transport sector selected in the P-value assessment occupied the "Linkage Factors" group. $Exports^3$, FDI^3, $Imports$ were allocated at the top level of influence axis and had a high dependence. WTI^2 had a lower influence and dependence than the three previous variables, and PCI^2 had a medium dependence and high influence after WTI^2, as shown in Figure B.1 in Appendix B).

4.5.2 Commercial Sector

Economic set variables of Commercial sector selected in the P-value assessment occupied all the four groups in the MICMAC matrix. $Exports^3$ and PPI occupied the "Linkage Factors" group having a high influence and dependence, whereas WTI^2 occupied the cut line between the "Linkage Factors" and "Dependence Factors" having a medium influence and high dependence. In addition, GDP^2 occupied the cut line between the "Driving Factors" and "Autonomous Factors" having a medium influence and low dependence. Finally, USD occupied the cut line between the "Autonomous Factors" and "Dependence Factors" having had a medium influence and dependence, as shown in Figure B.2 in Appendix B).

4.5.3 Industrial Sector

Economic set variables of Industrial sector selected in the P-value assessment occupied all the three groups in the MICMAC matrix. $Exports^3$, FDI^2,and PPI occupied the "Linkage Factors" group having a high influence and dependence, whereas $Imports^3$ had a medium influence and high dependence. In addition, GDP^2 occupied the "Autonomous Factors"group having a low influence and dependence. Finally, USD^3 occupied the "Dependence Factors" group having had a low influence and medium dependence, as shown in Figure B.3 in Appendix B).

4.5.4 Residential Sector

Economic set variables of Residential sector selected in the P-value assessment occupied two groups in the MICMAC matrix. $Exports$, FDI, $Imports^3$, PPI, CPI^2, WTI^2 were allocated in the "Linkage Factors" group having a low influence and high dependence despite the medium dependence of CPI^2. Finally, GDP^3 occupied the "Driving Factors" group having a medium influence and low dependence, as shown in Figure B.4 in Appendix B).

4.5.5 Agriculture Sector

Economic set variables of Agriculture sector selected in the P-value assessment occupied the "Linkage Factors" group. $Exports^3$, WTI, and $Imports$ had a high influence and dependence, as shown in Figure B.5 in Appendix B).

4.6 Energy Based Model by Sectors of Consumption

4.5.5 Total Energy Demand

The total energy demand of Colombia is projected using economic variables. GDP, CPI, PPI, WTI, USD, FDI, Export, and Import were considered within this study to accomplish the total energy demand with its own variations, as shown in table 4.15, which is the sum of all the equations of the sectors.

The overall error between theory energy and energy projected is 2.49%. Mining and Construction sectors were not included in the total energy demand as any model did not accept the P-value reflecting that only economic variables cannot explain the energy demand in those sectors. See Figure C.1 and C.2 in Appendix C.

Sectors	Equations
Transport	$246795,9437 + 940212,8344$ CPI^2 $- 9,5809$ WTI^2 $+ 2,20x10^{-8}$ FDI^3 $-6,3967x10^{-10}$ Exports^3 $+ 5,3701$ Imports
Industrial	$92454,5873 - 11442106,7786$ GDP^2+$482347,4172$ PPI+$5,1442x10^{-6}$USD^3 $+5,75x10^{-4}$ FDI^2 $+ +4,5597$ Exports$-1,1865x10^{-9}$ Imports^3
Commercial	$19884,9110 - 1523229,4345$ GDP^2 $+ 77404,0850$ PPI$-1,9394$ WTI^2 $+ 7,3124$ USD $+0,8321$ Exports^3
Residential	$305627,5584 + 28115093,6374$ GDP^3 $+ 601640,9775$ CPI^2 $- 108770,6713$ PPI $+3,2458$ WTI^2 $- 0,9839$ FDI$-1,3839$ Exports$+1,2565x10^{-10}$ Imports^3
Agriculture	$81496,2127 - 275,4241$ WTI$+1,8567x10^{-10}$ Exports^3 $- 1,3386$ Imports
Mining	Model did not accept the P-value
Construction	Model did not accept the P-value

Table 4.15: Energy consumption equations for each economic sector in Colombia

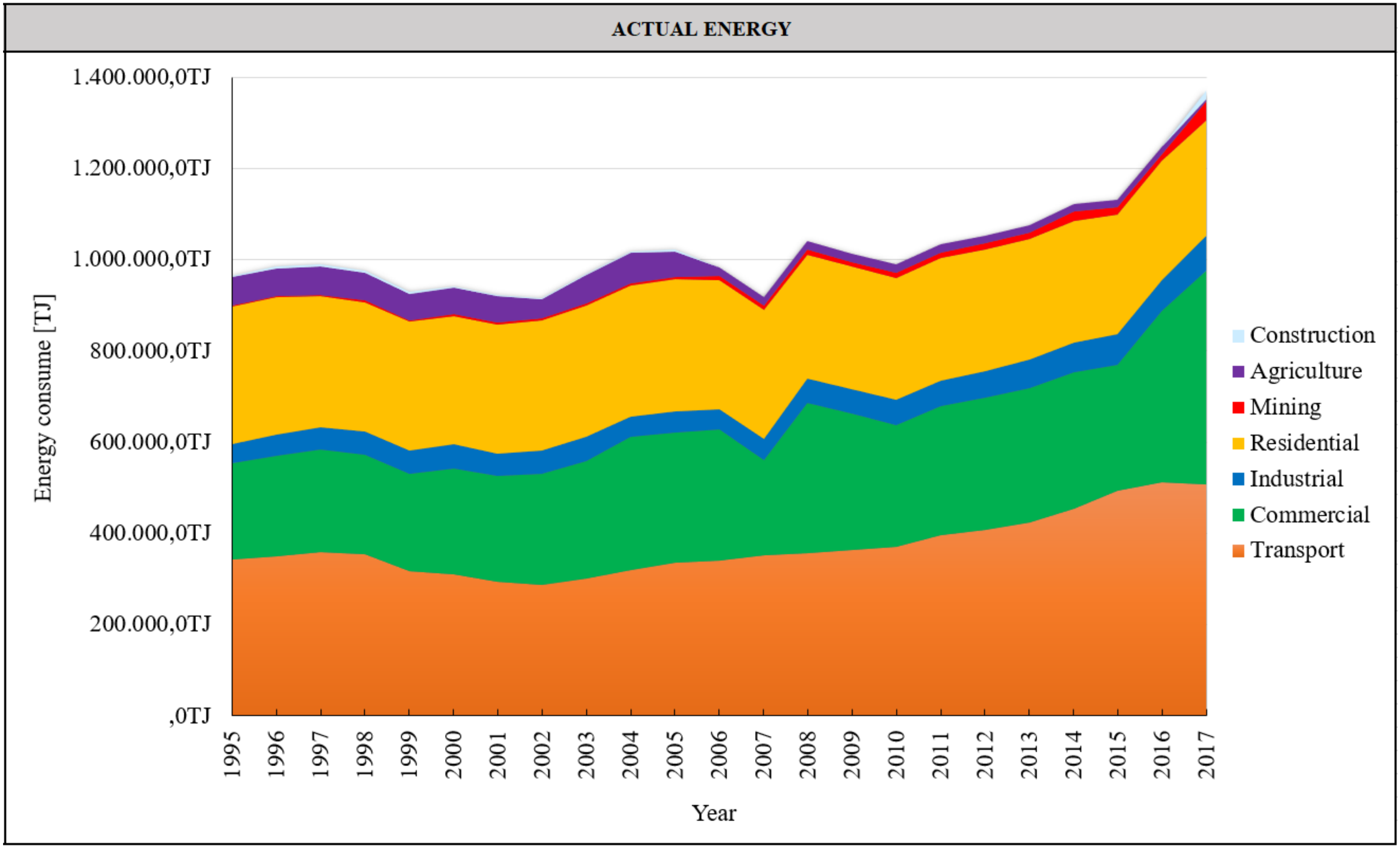


Figure 4.10: Actual energy

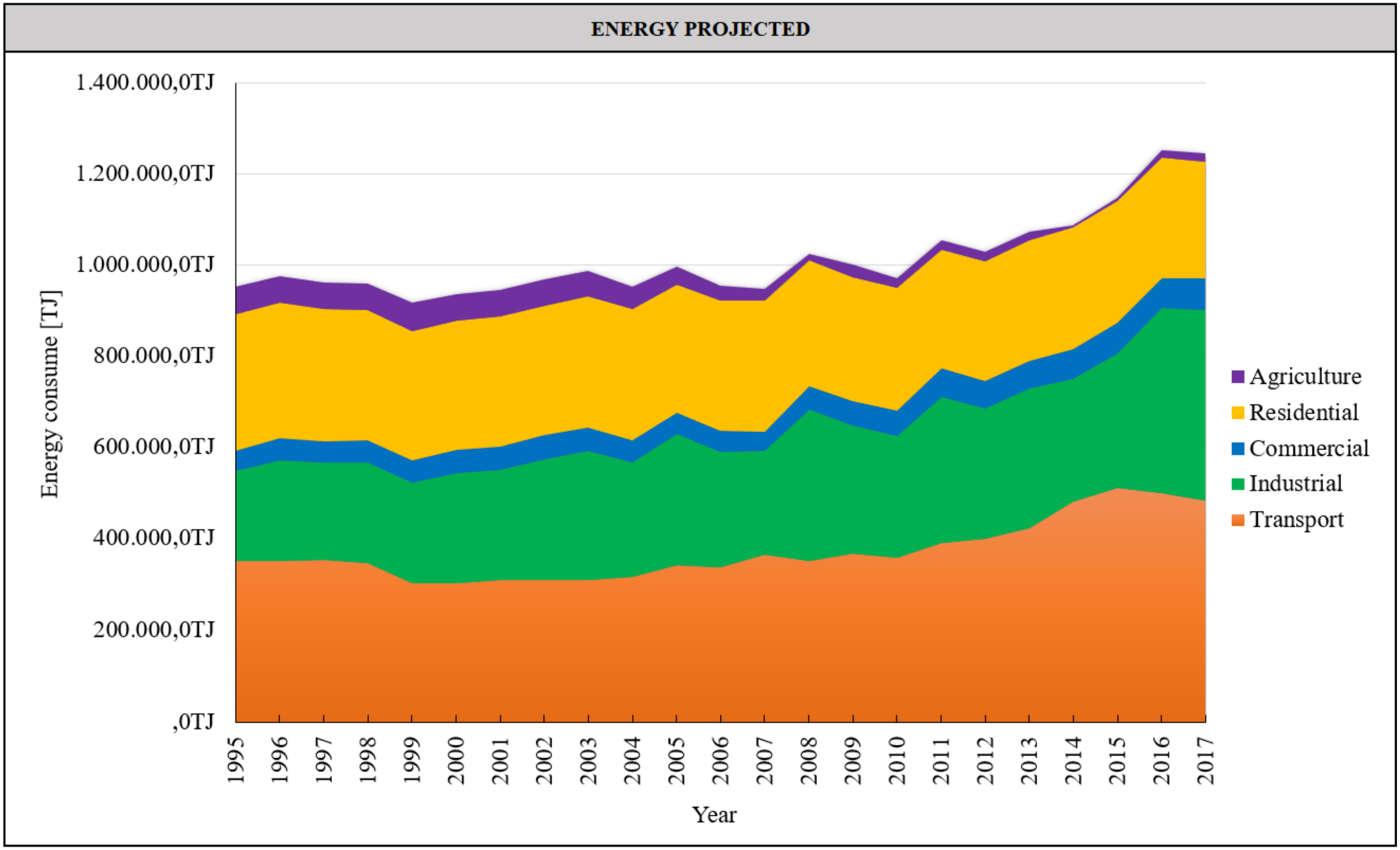


Figure 4.11: Energy projected

4.5.5 Transport Sector

Transport energy demand of Colombia is projected using economic variables. The overall error between theory energy and energy projected within this sector is 2.77%, as shown in figure 4.12 and 4.13. CPI^2, WTI^2, FDI^3, $Export^3$, and $Import$ were the variables considered within this study to accomplish the energy-based model of transport energy demand of Colombia, as shown in equation 4.1. The regression used to project the energy demand was Opt. 56201.

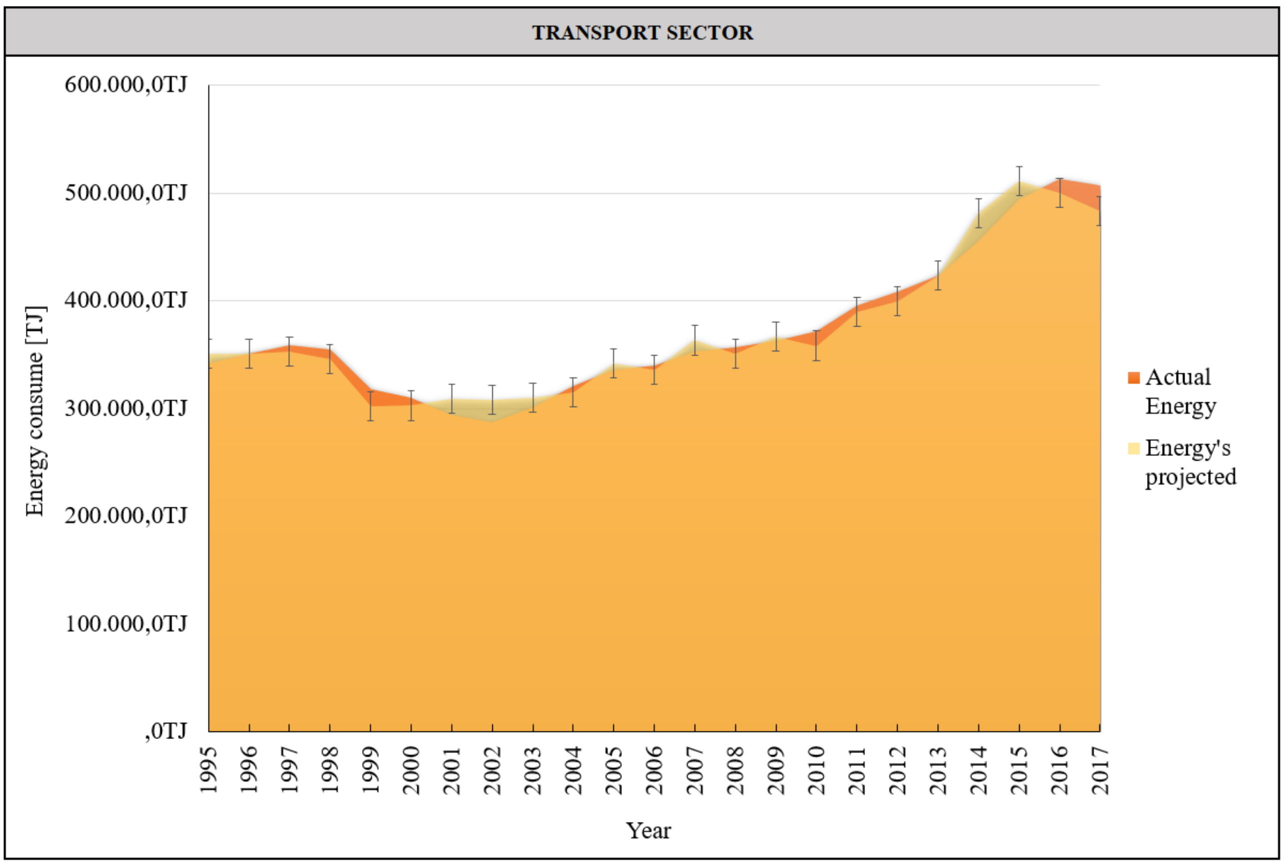


Figure 4.12: Energy demand of Transport sector

Opt. 56201															
Year	β_0	β_1	PCI^2	β_2	WTI^2	β_3	FDI^3	β_4	Exports^3	β_5	Imports	Energy Projected	Theory Energy	Differ	Error
1995			20,2%		$ 18,4		$ 968,37		$ 10.201,06		$ 12.952,34	350.966,3TJ	341.885,9TJ	9.080,4TJ	2,66%
1996			20,6%		$ 22,0		$ 3.111,68		$ 10.647,56		$ 12.791,87	350.710,0TJ	350.521,4TJ	188,6TJ	0,05%
1997			17,8%		$ 20,6		$ 5.562,22		$ 11.549,03		$ 14.369,19	352.613,6TJ	358.583,5TJ	5.969,9TJ	1,66%
1998			17,2%		$ 14,4		$ 2.828,83		$ 10.865,63		$ 13.768,06	346.183,8TJ	354.929,1TJ	8.745,3TJ	2,46%
1999			8,3%		$ 19,3		$ 1.507,91		$ 11.617,04		$ 9.991,05	302.352,5TJ	318.455,8TJ	16.103,3TJ	5,06%
2000			8,5%		$ 30,3		$ 2.436,46		$ 13.158,40		$ 10.997,92	302.720,0TJ	310.544,8TJ	7.824,8TJ	2,52%
2001			7,4%		$ 26,0		$ 2.541,94		$ 12.329,90		$ 11.996,61	309.028,1TJ	294.512,7TJ	14.515,5TJ	4,93%
2002			7,4%		$ 26,0		$ 2.133,70		$ 11.975,42		$ 11.897,23	308.436,3TJ	286.773,7TJ	21.662,6TJ	7,55%
2003			6,2%		$ 30,9		$ 1.720,49		$ 13.128,52		$ 13.025,68	309.882,0TJ	300.758,2TJ	9.123,8TJ	3,03%
2004			5,4%		$ 41,3		$ 3.115,80		$ 16.788,33		$ 15.648,65	314.897,4TJ	320.618,4TJ	5.721,0TJ	1,78%
2005			4,6%		$ 56,5		$ 10.235,42		$ 21.146,09		$ 19.798,91	342.044,6TJ	335.930,5TJ	6.114,1TJ	1,82%
2006	246795,944	940212,834	4,7%	-9,5809071	$ 66,0	2,1992E-08	$ 6.750,62	-6,40E-10	$ 24.511,97	5,370139	$ 24.534,00	336.259,5TJ	340.081,3TJ	3.821,8TJ	1,12%
2007			6,0%		$ 72,1		$ 8.885,77		$ 30.279,24		$ 30.807,39	363.516,3TJ	353.139,3TJ	10.377,1TJ	2,94%
2008			7,2%		$ 99,4		$ 10.564,15		$ 36.786,38		$ 37.152,39	350.656,7TJ	356.571,3TJ	5.914,6TJ	1,66%
2009			2,1%		$ 61,8		$ 8.034,57		$ 32.846,33		$ 31.181,28	366.747,3TJ	363.231,4TJ	3.515,8TJ	0,97%
2010			3,4%		$ 79,3		$ 6.429,94		$ 39.713,34		$ 38.153,97	358.314,3TJ	371.563,3TJ	13.249,0TJ	3,57%
2011			3,5%		$ 94,7		$ 14.646,78		$ 56.914,94		$ 51.556,49	390.016,5TJ	395.396,2TJ	5.379,8TJ	1,36%
2012			2,0%		$ 93,8		$ 15.039,37		$ 60.125,17		$ 56.102,15	399.973,2TJ	408.274,9TJ	8.301,7TJ	2,03%
2013			2,1%		$ 97,7		$ 16.209,39		$ 58.826,37		$ 56.620,33	423.348,8TJ	423.042,8TJ	306,0TJ	0,07%
2014			3,8%		$ 92,5		$ 16.167,02		$ 54.856,75		$ 61.087,82	481.504,7TJ	454.913,5TJ	26.591,2TJ	5,85%
2015			6,8%		$ 48,6		$ 11.723,22		$ 36.017,52		$ 51.598,04	511.137,8TJ	494.560,3TJ	16.577,5TJ	3,35%
2016			5,8%		$ 43,3		$ 13.850,06		$ 31.768,34		$ 42.849,44	499.992,9TJ	512.901,7TJ	12.908,8TJ	2,52%
2017			4,1%		$ 50,7		$ 13.836,16		$ 37.880,56		$ 43.972,26	483.407,0TJ	507.519,6TJ	24.112,6TJ	4,75%
Sampling Error: Transport sector															**2,77%**

Figure 4.13: Spurious probability analysis of Transport energy demand

$$246795,9437 + 940212,8344\,\mathbf{CPI}^2 - 9,5809\,\mathbf{WTI}^2 + 2,20x10^{-8}\,\mathbf{FDI}^3 - 6,3967x10^{-10}\,\mathbf{Exports}^3 + 5,3701\,\mathbf{Imports} \qquad (4.1)$$

4.5.5 Industrial Sector

Industrial energy demand of Colombia is projected using economic variables. The overall error between theory energy and energy projected within this sector is 6.16%, as shown in figure 4.14 and 4.15. GDP^2, PPI, USD^3, FDI^2, $Exports$ and $Imports^3$ were the variables considered within this study to accomplish the energy-based model of industrial energy demand of Colombia, as shown in equation 4.2. The regression used to project the energy demand was Opt. 38441.

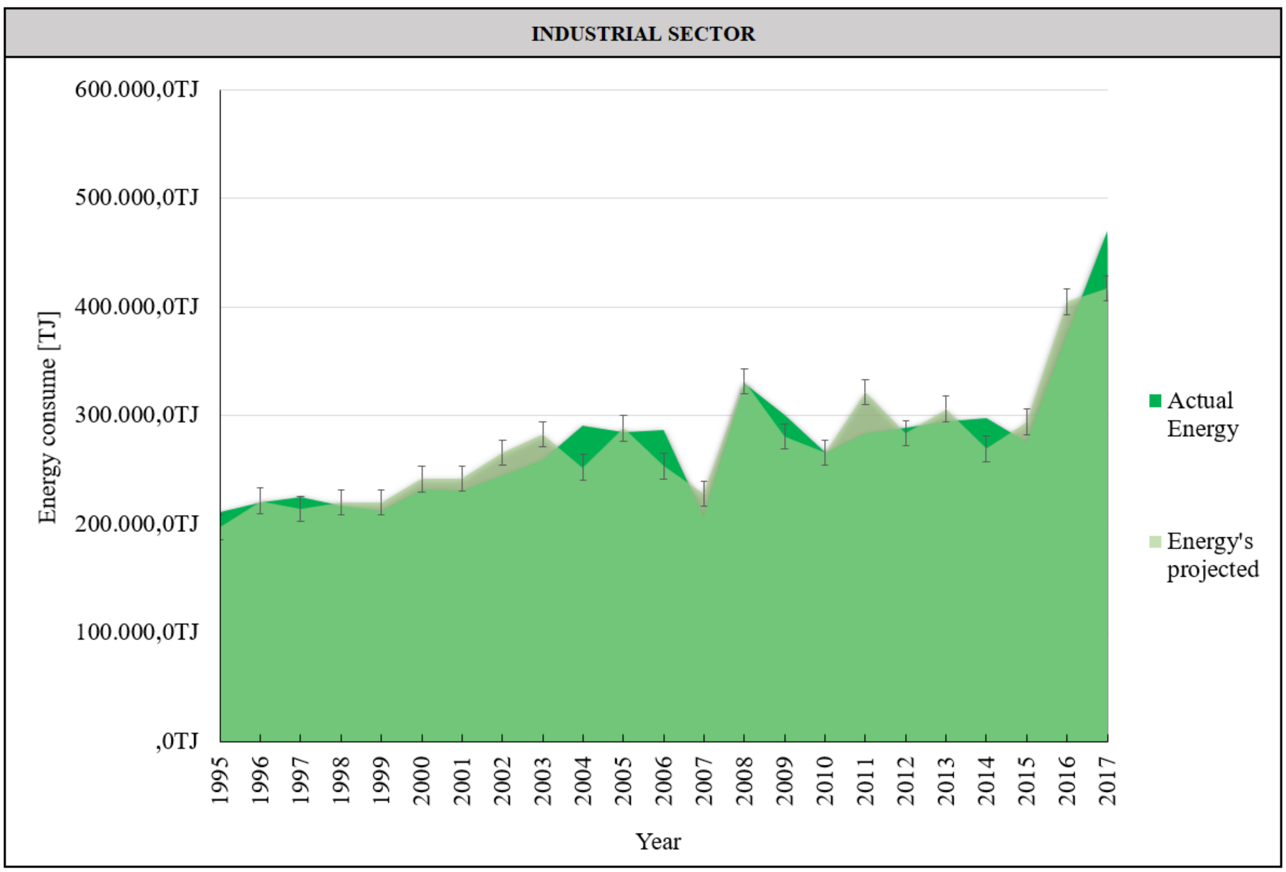


Figure 4.14: Energy demand of Industrial sector

Opt. 38441																	
Year	β_0	β_1	**GDP^2**	β_2	**PPI**	β_3	**USD^3**	β_4	**FDI^2**	β_5	**Exports**	β_6	**Imports^3**	**Energy Projected**	**Theory Energy**	**Differ**	**Error**
1995			5,2%		18,1%		$ 909,23		$ 968,37		$ 10.201,06		$ 12.952,34	196.926,5TJ	211.101,2TJ	14.174,7TJ	6,71%
1996			0,8%		15,0%		$ 1.031,89		$ 3.111,68		$ 10.647,56		$ 12.791,87	221.487,6TJ	220.407,5TJ	1.080,0TJ	0,49%
1997			4,9%		15,4%		$ 1.136,82		$ 5.562,22		$ 11.549,03		$ 14.369,19	214.131,9TJ	224.721,2TJ	10.589,3TJ	4,71%
1998			-4,4%		17,3%		$ 1.420,54		$ 2.828,83		$ 10.865,63		$ 13.768,06	219.852,6TJ	216.876,7TJ	2.975,9TJ	1,37%
1999			-0,7%		9,8%		$ 1.752,94		$ 1.507,91		$ 11.617,04		$ 9.991,05	220.092,7TJ	212.361,7TJ	7.731,0TJ	3,64%
2000			3,3%		11,0%		$ 2.082,77		$ 2.436,46		$ 13.158,40		$ 10.997,92	241.559,2TJ	231.655,4TJ	9.903,8TJ	4,28%
2001			1,7%		6,9%		$ 2.291,21		$ 2.541,94		$ 12.329,90		$ 11.996,61	242.287,2TJ	230.865,1TJ	11.422,1TJ	4,95%
2002			2,5%		9,3%		$ 2.499,79		$ 2.133,70		$ 11.975,42		$ 11.897,23	265.678,5TJ	244.919,0TJ	20.759,5TJ	8,48%
2003			3,9%		5,7%		$ 2.865,36		$ 1.720,49		$ 13.128,52		$ 13.025,68	282.595,9TJ	258.579,6TJ	24.016,2TJ	9,29%
2004			5,3%		4,6%		$ 2.615,92		$ 3.115,80		$ 16.788,33		$ 15.648,65	252.361,1TJ	291.139,2TJ	38.778,0TJ	13,32%
2005			4,7%		2,1%		$ 2.312,20		$ 10.235,42		$ 21.146,09		$ 19.798,91	288.285,0TJ	284.839,2TJ	3.445,9TJ	1,21%
2006	92454,5874	-11442106,78	6,8%	482347,417	5,5%	5,14423E-06	$ 2.351,07	0,000575	$ 6.750,62	4,55976	$ 24.511,97	-1,186E-09	$ 24.534,00	253.593,3TJ	287.201,1TJ	33.607,8TJ	11,70%
2007			7,5%		1,3%		$ 2.067,47		$ 8.885,77		$ 30.279,24		$ 30.807,39	228.140,0TJ	206.682,3TJ	21.457,7TJ	10,38%
2008			3,5%		9,0%		$ 1.962,62		$ 10.564,15		$ 36.786,38		$ 37.152,39	331.796,1TJ	329.851,4TJ	1.944,8TJ	0,59%
2009			1,5%		-2,2%		$ 2.146,08		$ 8.034,57		$ 32.846,33		$ 31.181,28	281.107,0TJ	300.634,5TJ	19.527,5TJ	6,50%
2010			4,3%		4,4%		$ 1.889,99		$ 6.429,94		$ 39.713,34		$ 38.153,97	266.108,2TJ	266.071,1TJ	37,1TJ	0,01%
2011			6,6%		5,5%		$ 1.838,67		$ 14.646,78		$ 56.914,94		$ 51.556,49	321.548,2TJ	283.686,5TJ	37.861,8TJ	13,35%
2012			4,0%		-3,0%		$ 1.788,65		$ 15.039,37		$ 60.125,17		$ 56.102,15	284.111,2TJ	288.672,5TJ	4.561,3TJ	1,58%
2013			4,3%		-0,5%		$ 1.860,93		$ 16.209,39		$ 58.826,37		$ 56.620,33	306.146,4TJ	294.543,7TJ	11.602,7TJ	3,94%
2014			4,6%		6,3%		$ 1.993,48		$ 16.167,02		$ 54.856,75		$ 61.087,82	269.557,8TJ	297.781,9TJ	28.224,1TJ	9,48%
2015			3,1%		5,5%		$ 2.741,17		$ 11.723,22		$ 36.017,52		$ 51.598,04	294.165,9TJ	276.134,2TJ	18.031,7TJ	6,53%
2016			2,0%		2,2%		$ 3.040,74		$ 13.850,06		$ 31.768,34		$ 42.849,44	404.807,8TJ	375.096,0TJ	29.711,8TJ	7,92%
2017			1,8%		3,3%		$ 2.937,86		$ 13.836,16		$ 37.880,56		$ 43.972,26	416.959,5TJ	469.478,7TJ	52.519,3TJ	11,19%
Sampling Error: Industrial sector																	**6,16%**

Figure 4.15: Spurious probability analysis of Industrial energy demand

$$92454,5873 - 11442106,7786\,\mathbf{GDP}^2 + 482347,4172\,\mathbf{PPI} + 5,1442x10^{-6}\,\mathbf{USD}^3 + 5,75x10^{-4}\,\mathbf{FDI}^2 + 4,5597\,\mathbf{Exports} - 1,1865x10^{-9}\,\mathbf{Imports}^3 \quad (4.2)$$

4.5.5 Commercial Sector

Commercial energy demand of Colombia is projected using economic variables. The overall error between theory energy and energy projected within this sector is 3.83%, as shown in figure 4.16 and 4.17. GDP^2, PPI, WTI^2, USD and $Exports^3$ were the variables considered within this study to accomplish the energy-based model of commercial energy demand of Colombia, as shown in equation 4.3. The regression used to project the energy demand was Opt. 49583.

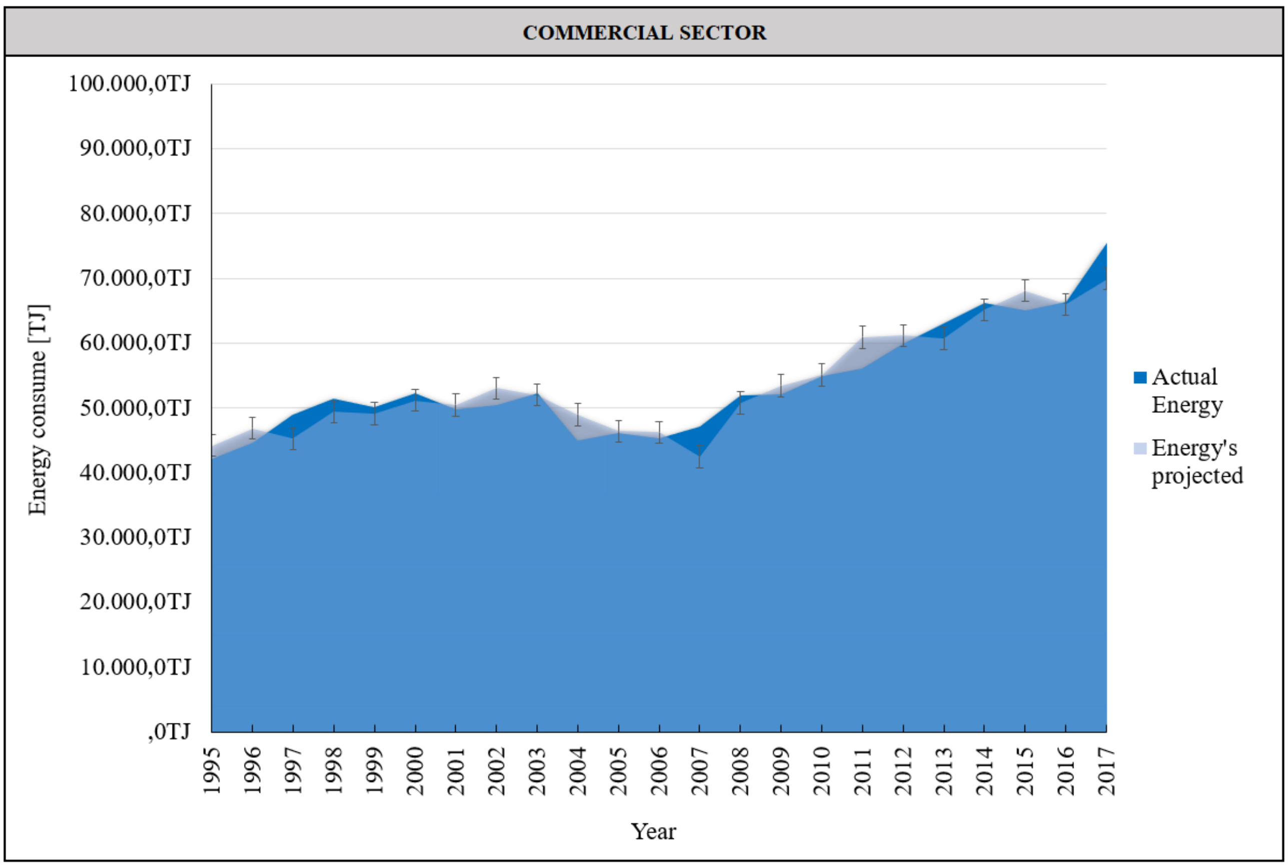


Figure 4.16: Energy demand of Commercial sector

Opt. 49583															
Year	β_0	β_1	GDP^2	β_2	PPI	β_3	WTI^2	β_4	USD	β_5	Exports	Energy Projected	Theory Energy	Differ	Error
1995			5,2%		18,1%		$ 18,4		$ 909,23		$ 10.201,06	44.229,0TJ	42.210,5TJ	2.018,5TJ	4,78%
1996			0,8%		15,0%		$ 22,0		$1.031,89		$ 10.647,56	46.883,9TJ	44.686,1TJ	2.197,8TJ	4,92%
1997			4,9%		15,4%		$ 20,6		$1.136,82		$ 11.549,03	45.300,3TJ	49.014,6TJ	3.714,3TJ	7,58%
1998			-4,4%		17,3%		$ 14,4		$1.420,54		$ 10.865,63	49.399,5TJ	51.538,7TJ	2.139,2TJ	4,15%
1999			-0,7%		9,8%		$ 19,3		$1.752,94		$ 11.617,04	49.178,5TJ	50.182,2TJ	1.003,7TJ	2,00%
2000			3,3%		11,0%		$ 30,3		$2.082,77		$ 13.158,40	51.175,0TJ	52.358,1TJ	1.183,1TJ	2,26%
2001			1,7%		6,9%		$ 26,0		$2.291,21		$ 12.329,90	50.506,9TJ	49.871,0TJ	636,0TJ	1,28%
2002			2,5%		9,3%		$ 26,0		$2.499,79		$ 11.975,42	53.049,6TJ	50.421,1TJ	2.628,5TJ	5,21%
2003			3,9%		5,7%		$ 30,9		$2.865,36		$ 13.128,52	52.023,1TJ	52.298,7TJ	275,6TJ	0,53%
2004			5,3%		4,6%		$ 41,3		$2.615,92		$ 16.788,33	48.986,3TJ	45.022,4TJ	3.963,9TJ	8,80%
2005			4,7%		2,1%		$ 56,5		$2.312,20		$ 21.146,09	46.445,9TJ	46.085,2TJ	360,7TJ	0,78%
2006	19884,9111	-1523229,4	6,8%	77404,085	5,5%	-1,93948455	$ 66,0	7,31241834	$2.351,07	0,83213301	$ 24.511,97	46.274,6TJ	45.307,3TJ	967,4TJ	2,14%
2007			7,5%		1,3%		$ 72,1		$2.067,47		$ 30.279,24	42.492,3TJ	47.121,8TJ	4.629,4TJ	9,82%
2008			3,5%		9,0%		$ 99,4		$1.962,62		$ 36.786,38	50.793,3TJ	51.956,7TJ	1.163,3TJ	2,24%
2009			1,5%		-2,2%		$ 61,8		$2.146,08		$ 32.846,33	53.453,5TJ	52.117,1TJ	1.336,4TJ	2,56%
2010			4,3%		4,4%		$ 79,3		$1.889,99		$ 39.713,34	55.127,9TJ	54.868,2TJ	259,7TJ	0,47%
2011			6,6%		5,5%		$ 94,7		$1.838,67		$ 56.914,94	60.916,9TJ	56.099,5TJ	4.817,4TJ	8,59%
2012			4,0%		-3,0%		$ 93,8		$1.788,65		$ 60.125,17	61.215,7TJ	59.885,0TJ	1.330,7TJ	2,22%
2013			4,3%		-0,5%		$ 97,7		$1.860,93		$ 58.826,37	60.753,3TJ	62.997,1TJ	2.243,8TJ	3,56%
2014			4,6%		6,3%		$ 92,5		$1.993,48		$ 54.856,75	65.174,7TJ	66.198,1TJ	1.023,4TJ	1,55%
2015			3,1%		5,5%		$ 48,6		$2.741,17		$ 36.017,52	68.103,7TJ	65.144,0TJ	2.959,7TJ	4,54%
2016			2,0%		2,2%		$ 43,3		$3.040,74		$ 31.768,34	65.982,7TJ	66.472,6TJ	489,9TJ	0,74%
2017			1,8%		3,3%		$ 50,7		$2.937,86		$ 37.880,56	69.951,2TJ	75.562,1TJ	5.610,9TJ	7,43%
Sampling Error: Commercial sector															**3,83%**

Figure 4.17: Spurious probability analysis of Commercial energy demand

$$19884,9110 - 1523229,4345\,\mathbf{GDP}^2 + 77404,0850\,\mathbf{PPI} - 1,9394\,\mathbf{WTI}^2 + 7,3124\,\mathbf{USD} + 0,8321\,\mathbf{Exports}^3 \tag{4.3}$$

4.5.5 Residential Sector

Residential energy demand of Colombia is projected using economic variables. The overall error between theory energy and energy projected within this sector is 0.96%, as shown in figure 4.18 and 4.19 . GDP^3, CPI^2, PPI, WTI^2, FDI, $Exports$, and $Imports^3$ were the variables considered within this study to accomplish the energy-based model of commercial energy demand of Colombia, as shown in equation 4.4. The regression used to project the energy demand was Opt. 14613.

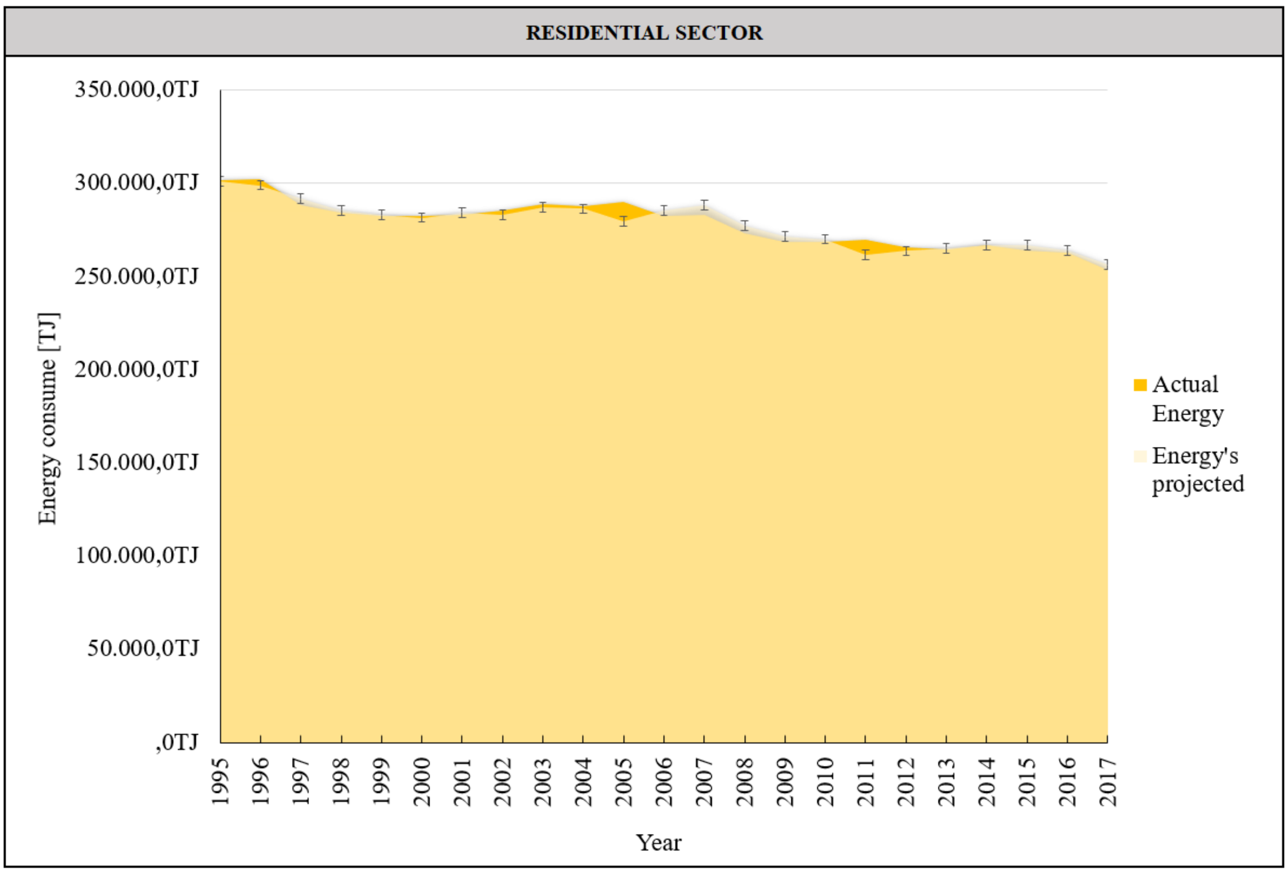


Figure 4.18: Energy demand of Residential sector

Opt. 14613																			
Year	β_0	β_1	GDP^3	β_2	PCI^2	β_3	PPI	β_4	WTI^2	β_5	FDI	β_6	Exports	β_7	Imports^3	Energy Projected	Theory Energy	Differ	Error
1995			5,2%		20,2%		18,1%		$ 18,4		$ 968,37		$ 10.201,06		$12.952,34	300.882,3TJ	301.550,1TJ	667,8TJ	0,22%
1996			0,8%		20,6%		15,0%		$ 22,0		$ 3.111,68		$ 10.647,56		$12.791,87	298.912,1TJ	301.997,2TJ	3.085,1TJ	1,02%
1997			4,9%		17,8%		15,4%		$ 20,6		$ 5.562,22		$ 11.549,03		$14.369,19	291.555,1TJ	288.237,6TJ	3.317,5TJ	1,15%
1998			-4,4%		17,2%		17,3%		$ 14,4		$ 2.828,83		$ 10.865,63		$13.768,06	285.358,4TJ	284.065,3TJ	1.293,1TJ	0,46%
1999			-0,7%		8,3%		9,8%		$ 19,3		$ 1.507,91		$ 11.617,04		$ 9.991,05	282.798,5TJ	282.670,9TJ	127,6TJ	0,05%
2000			3,3%		8,5%		11,0%		$ 30,3		$ 2.436,46		$ 13.158,40		$10.997,92	281.498,0TJ	282.633,3TJ	1.135,3TJ	0,40%
2001			1,7%		7,4%		6,9%		$ 26,0		$ 2.541,94		$ 12.329,90		$11.996,61	284.348,2TJ	283.242,6TJ	1.105,7TJ	0,39%
2002			2,5%		7,4%		9,3%		$ 26,0		$ 2.133,70		$ 11.975,42		$11.897,23	282.992,6TJ	285.511,2TJ	2.518,6TJ	0,88%
2003			3,9%		6,2%		5,7%		$ 30,9		$ 1.720,49		$ 13.128,52		$13.025,68	286.890,0TJ	288.554,9TJ	1.664,9TJ	0,58%
2004			5,3%		5,4%		4,6%		$ 41,3		$ 3.115,80		$ 16.788,33		$15.648,65	286.261,2TJ	287.652,8TJ	1.391,6TJ	0,48%
2005			4,7%		4,6%		2,1%		$ 56,5		$ 10.235,42		$ 21.146,09		$19.798,91	279.530,3TJ	289.690,2TJ	10.159,9TJ	3,51%
2006	305627,56	28115093,6	6,8%	601640,978	4,7%	-108770,67	5,5%	3,245838	$ 66,0	-0,98394	$ 6.750,62	-1,38395	$ 24.511,97	1,3E-10	$24.534,00	285.198,7TJ	282.396,8TJ	2.801,9TJ	0,99%
2007			7,5%		6,0%		1,3%		$ 72,1		$ 8.885,77		$ 30.279,24		$30.807,39	288.257,2TJ	282.868,6TJ	5.388,6TJ	1,90%
2008			3,5%		7,2%		9,0%		$ 99,4		$ 10.564,15		$ 36.786,38		$37.152,39	277.338,0TJ	273.338,2TJ	3.999,8TJ	1,46%
2009			1,5%		2,1%		-2,2%		$ 61,8		$ 8.034,57		$ 32.846,33		$31.181,28	271.232,0TJ	268.229,5TJ	3.002,5TJ	1,12%
2010			4,3%		3,4%		4,4%		$ 79,3		$ 6.429,94		$ 39.713,34		$38.153,97	269.898,3TJ	268.398,3TJ	1.500,0TJ	0,56%
2011			6,6%		3,5%		5,5%		$ 94,7		$ 14.646,78		$ 56.914,94		$51.556,49	261.638,4TJ	269.647,0TJ	8.008,6TJ	2,97%
2012			4,0%		2,0%		-3,0%		$ 93,8		$ 15.039,37		$ 60.125,17		$56.102,15	263.604,8TJ	265.593,8TJ	1.989,0TJ	0,75%
2013			4,3%		2,1%		-0,5%		$ 97,7		$ 16.209,39		$ 58.826,37		$56.620,33	265.067,8TJ	264.246,2TJ	821,6TJ	0,31%
2014			4,6%		3,8%		6,3%		$ 92,5		$ 16.167,02		$ 54.856,75		$61.087,82	266.974,2TJ	266.593,4TJ	380,8TJ	0,14%
2015			3,1%		6,8%		5,5%		$ 48,6		$ 11.723,22		$ 36.017,52		$51.598,04	266.798,0TJ	264.026,8TJ	2.771,1TJ	1,05%
2016			2,0%		5,8%		2,2%		$ 43,3		$ 13.850,06		$ 31.768,34		$42.849,44	263.882,3TJ	262.381,0TJ	1.501,3TJ	0,57%
2017			1,8%		4,1%		3,3%		$ 50,7		$ 13.836,16		$ 37.880,56		$43.972,26	256.212,8TJ	253.603,4TJ	2.609,4TJ	1,03%
Sampling Error: Residential sector																			**0,96%**

Figure 4.19: Spurious probability analysis of Residential energy demand

$$305627,5584 + 28115093,6374\,\mathbf{GDP}^3 + 601640,9775\,\mathbf{CPI}^2 - 108770,6713\,\mathbf{PPI} + 3,2458\,\mathbf{WTI}^2 - 0,9839\,\mathbf{FDI} - 1,3839\,\mathbf{Exports} + 1,2565x10^{-10}\,\mathbf{Imports}^3. \tag{4.4}$$

4.5.5 Agriculture Sector

Agriculture energy demand of Colombia is projected using economic variables. The overall error between theory energy and energy projected within this sector is 32.74%, as shown in figure 4.20 and 4.21. The error in this sector is high due to economic variables can not reflects by their own agriculture energy consumption, following the MCDM approach is necessary to apply more factors such as environmental, geographic and political aspects. However, the multi-regression analysis provide one model (Opt. 65131) to project the energy demand. WTI, $Exports^3$, and $Imports$ were the variables considered within this study to accomplish the energy-based model of agriculture energy demand of Colombia, as shown in equation 4.5.

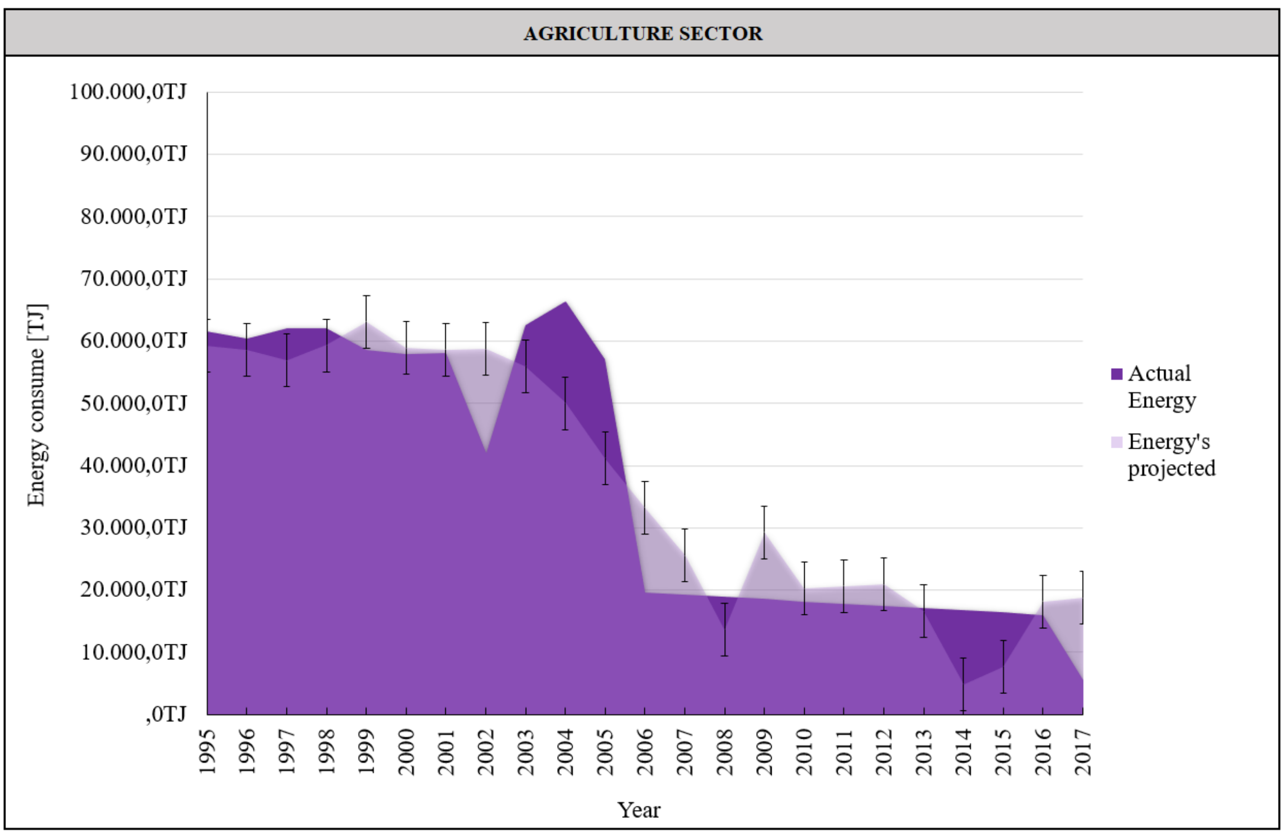


Figure 4.20: Energy demand of Agriculture sector

Opt. 65131											
Year	β_0	β_1	WTI	β_2	Exports^3	β_3	Imports	Energy Projected	Theory Energy	Differ	Error
1995			$ 18,4		$ 10.201,06		$ 12.952,34	59.287,6TJ	61.507,0TJ	2.219,4TJ	3,61%
1996			$ 22,0		$ 10.647,56		$ 12.791,87	58.530,9TJ	60.350,0TJ	1.819,1TJ	3,01%
1997			$ 20,6		$ 11.549,03		$ 14.369,19	56.870,5TJ	62.061,0TJ	5.190,5TJ	8,36%
1998			$ 14,4		$ 10.865,63		$ 13.768,06	59.348,1TJ	62.002,0TJ	2.653,9TJ	4,28%
1999			$ 19,3		$ 11.617,04		$ 9.991,05	63.097,3TJ	58.669,0TJ	4.428,3TJ	7,55%
2000			$ 30,3		$ 13.158,40		$ 10.997,92	58.862,0TJ	57.945,0TJ	917,0TJ	1,58%
2001			$ 26,0		$ 12.329,90		$ 11.996,61	58.633,1TJ	58.082,0TJ	551,1TJ	0,95%
2002			$ 26,0		$ 11.975,42		$ 11.897,23	58.715,5TJ	41.924,0TJ	16.791,5TJ	40,05%
2003			$ 30,9		$ 13.128,52		$ 13.025,68	55.977,0TJ	62.595,0TJ	6.618,0TJ	10,57%
2004			$ 41,3		$ 16.788,33		$ 15.648,65	50.050,9TJ	66.325,0TJ	16.274,1TJ	24,54%
2005			$ 56,5		$ 21.146,09		$ 19.798,91	41.192,3TJ	57.163,0TJ	15.970,7TJ	27,94%
2006	81496,21273	-275,424181	$ 66,0	1,8567E-10	$ 24.511,97	-1,338643594	$ 24.534,00	33.214,1TJ	19.677,0TJ	13.537,1TJ	68,80%
2007			$ 72,1		$ 30.279,24		$ 30.807,39	25.558,4TJ	19.269,0TJ	6.289,4TJ	32,64%
2008			$ 99,4		$ 36.786,38		$ 37.152,39	13.639,4TJ	18.916,0TJ	5.276,6TJ	27,89%
2009			$ 61,8		$ 32.846,33		$ 31.181,28	29.300,7TJ	18.615,0TJ	10.685,7TJ	57,40%
2010			$ 79,3		$ 39.713,34		$ 38.153,97	20.211,2TJ	18.151,0TJ	2.060,2TJ	11,35%
2011			$ 94,7		$ 56.914,94		$ 51.556,49	20.618,6TJ	17.704,0TJ	2.914,6TJ	16,46%
2012			$ 93,8		$ 60.125,17		$ 56.102,15	20.924,6TJ	17.441,0TJ	3.483,6TJ	19,97%
2013			$ 97,7		$ 58.826,37		$ 56.620,33	16.601,5TJ	17.143,0TJ	541,5TJ	3,16%
2014			$ 92,5		$ 54.856,75		$ 61.087,82	4.884,2TJ	16.839,0TJ	11.954,8TJ	71,00%
2015			$ 48,6		$ 36.017,52		$ 51.598,04	7.723,2TJ	16.390,0TJ	8.666,8TJ	52,88%
2016			$ 43,3		$ 31.768,34		$ 42.849,44	18.164,4TJ	15.975,0TJ	2.189,4TJ	13,71%
2017			$ 50,7		$ 37.880,56		$ 43.972,26	18.774,8TJ	5.437,0TJ	13.337,8TJ	245,32%
Sampling Error: Agriculture sector											**32,74%**

Figure 4.21: Spurious probability analysis of Agriculture energy demand

$$81496,2127 - 275,4241\,\mathbf{WTI} + 1,8567x10^{-10}\,\mathbf{Exports^3} - 1,3386\,\mathbf{Imports} \tag{4.5}$$

CHAPTER 5 Conclusions

Transport, industrial, commercial, residential and agriculture sector were successfully used to accomplish the economic energy-based model. Mining and Construction sector did not accepted the P-value in multi-linear regression analysis due to the lower energy consumed based on the UPME report from 1995 to 2017, as follows: Mining sector (3.02%), and Construction sector (1,24%). Imports, Exports, USD and WTI reflected greater overall behaviour in the models compared to the GDP, CPI and PPI. In addition, the results showed that lowest error was reflected in residential sector (0.96%), followed by transport sector (2.77%), then commercial sector (3.83%), industrial sector (6.16%, finally, agriculture sector (32.74%) due to economic variables can not reflects by their own agriculture energy consumption, and it is necessary to apply more factors such as environmental, geographic and political aspects following the MCDM approach. The final result showed an overall error of 2.46% in the economic energy-based model of Colombia.

Transport energy demand of Colombia is projected using economic variables, such as CPI^2, WTI^2, FDI^3, $Export^3$, and $Import$. The regression used to project the energy demand was Opt. 56201. Furthermore, Industrial energy demand of Colombia is projected using six economic variables, such as GDP^2, PPI, USD^3, FDI^2, $Exports$ and $Imports^3$. The regression used to project the energy demand was Opt. 38441, besides, Commercial energy demand of Colombia is projected using GDP^2, PPI, WTI^2, USD and $Exports^3$. The regression used to project the energy demand was Opt. 49583, moreover Residential energy demand of Colombia is projected using seven economic variables, such as GDP^3, CPI^2, PPI, WTI^2, FDI, $Exports$, and $Imports^3$. The regression used to project the energy demand was Opt. 14613. In the same way, Agriculture energy demand of Colombia is projected using economic variables, such as WTI, $Exports^3$, and $Imports$. The regression used to project the energy demand was Opt. 65131.

The construction of dynamic macros in Microsoft Excel was established due the necessity to program the methodology based in the number of manual iterations the author would have had to do in the construction of this project. An estimated 2931 hours was saved developing a basic visual application (VBA) in Microsoft Excel.

5.1 Contributions

The implementation of an integrated energy planning methodology allows Colombia to apply a comprehensive assessment to project energy demand. EP techniques such as Multi-linear regression analysis has been applied in this study providing a cost-effective tool to evaluate random natural patterns in the variables that interact in a different population group.

In addition, this research showed that theoretical stipulation and the assumption that only population variable impacts in energy demand, is invalid. In fact, theoretical stipulation implies a support to validate results on energy planning rather than being the only approach to project energy demand. Finally, the study determined that Mining and Construction sector cannot be leaded by only the economic factor as well as those sectors do not consume high quantity of energy compared to Transport and Industrial sectors.

5.2 Future Work

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CHAPTER A Macroeconomic Variables Selection Result

A.1 Transport sector

Estadísticas de la regresión	
Coeficiente de correlación múltiple	0,981687512
Coeficiente de determinación R^2	0,96371037
R^2 ajustado	0,95303695
Error típico	14392,72341
Observaciones	23

ANÁLISIS DE VARIANZA

	Grados de libertad	*Suma de cuadrados*	*Promedio de los cuadrados*	*F*	*Valor crítico de F*
Regresión	5	93518789746	18703757949	90,29067809	1,24786E-11
Residuos	17	3521558281	207150487,1		
Total	22	97040348027			

	Coeficientes	*Error típico*	*Estadístico t*	Probabilidad	*Inferior 95%*	*Superior 95%*
Intercepción	246795,9437	10120,46123	24,38583956	0,000%	225443,637	268148,2505
PCI^2	940212,8344	279781,2713	3,360528138	0,371%	349925,9499	1530499,719
WTI^2	-9,580907055	1,956186763	-4,897746593	0,014%	-13,70810036	-5,453713749
FDI^3	2,19918E-08	6,31256E-09	3,483810408	0,284%	8,67342E-09	3,53101E-08
Exports^3	-6,39667E-10	1,24098E-10	-5,154549534	0,008%	-9,0149E-10	-3,77844E-10
Imports	5,370138972	0,495113909	10,84626966	0,000%	4,325539933	6,41473801

Figure A.1: Selected result of the Multi-Regression analysis in the Transport sector

A.2 Industrial Sector

REGRESION 29708

Estadísticas de la regresión	
Coeficiente de corr	0,929116099
Coeficiente de dete	0,863256725
R^2 ajustado	0,811977997
Error típico	26115,05352
Observaciones	23

ANÁLISIS DE VARIANZA

	Grados de libertad	Suma de cuadrados	ɔmedio de los cuadrad	F	Valor crítico de F
Regresión	6	68886769378	11481128230	1683,46%	4,24618E-06
Residuos	16	10911936327	681996020,4		
Total	22	79798705705			

	Coeficientes	Error típico	Estadístico t	Probabilidad	Inferior 95%	Superior 95%
Intercepción	-149341,7395	101908,1271	-1,465454657	16,217%	-365377,3182	66693,83924
GDP^2	-8998219,018	3942072,89	-2,282611019	3,647%	-17355040,23	-641397,8082
Ln(PCI)	-87201,95819	27111,662	-3,216400315	0,539%	-144676,1141	-29727,80224
PPI	1096315,504	325310,1256	3,370062649	0,390%	406688,8444	1785942,163
USD^3	4,39195E-06	8,94221E-07	4,911477799	0,016%	2,49628E-06	6,28761E-06
FDI [Millones USD]	14,28069815	2,592554233	5,508350787	0,005%	8,784728692	19,77666761
Imports^3	-6,7057E-10	1,90988E-10	-3,511068342	0,290%	-1,07545E-09	-2,65695E-10

Figure A.2: First regression result of the Multi-Regression analysis in the Industrial sector

REGRESION 38441

Estadísticas de la regresión	
Coeficiente de correlación múltiple	0,925402434
Coeficiente de determinación R^2	0,856369664
R^2 ajustado	0,802508288
Error típico	26764,61623
Observaciones	23

ANÁLISIS DE VARIANZA

	Grados de libertad	Suma de cuadrados	los cuadrados	F	Valor crítico de F
Regresión	6	68337190793	11389531799	1589,95%	6,20381E-06
Residuos	16	11461514912	716344682		
Total	22	79798705705			

	Coeficientes	Error típico	Estadístico t	Probabilidad	Inferior 95%	Superior 95%
Intercepción	92454,58737	41630,8409	2,220819599	4,11%	4201,147149	180708,0276
GDP^2	-11442106,78	4161201,784	-2,74971207	1,42%	-20263460,49	-2620753,065
PPI	482347,4172	186847,023	2,58150978	2,01%	86249,4231	878445,4113
USD^3	5,14423E-06	1,03002E-06	4,994279177	0,01%	2,96067E-06	7,32778E-06
FDI^2	0,000575377	0,000193407	2,974952031	0,89%	0,000165372	0,000985382
Exports	4,559762257	1,37331809	3,320252089	0,43%	1,648457961	7,471066553
Imports^3	-1,18648E-09	2,81652E-10	-4,21256733	0,07%	-1,78355E-09	-5,89402E-10

Figure A.3: Selected regression result of the Multi-Regression analysis in the Industrial sector

A.3 Commercial Sector

REGRESION 49583

Estadísticas de la regresión	
Coeficiente de correlación múltiple	0,951769363
Coeficiente de determinación R^2	0,905864921
R^2 ajustado	0,878178133
Error típico	2970,77794
Observaciones	23

ANÁLISIS DE VARIANZA

	Grados de libertad	*Suma de cuadrados*	*Promedio de los cuadrados*	*F*	*Valor crítico de F*
Regresión	5	1443780762	288756152,4	32,71831	3,79402E-08
Residuos	17	150033866,7	8825521,57		
Total	22	1593814629			

	Coeficientes	*Error típico*	*Estadístico t*	Probabilidad	*Inferior 95%*	*Superior 95%*
Intercepción	19884,91108	5197,787198	3,825649324	0,14%	8918,538678	30851,28348
GDP^2	-1523229,43	464316,7395	-3,280582639	0,44%	-2502852,12	-543606,7446
PPI	77404,08502	19516,94302	3,965994312	0,10%	36226,9346	118581,2354
WTI^2	-1,93948455	0,480842139	-4,033516193	0,09%	-2,95397279	-0,924996318
USD	7,312418336	1,550205712	4,717063211	0,02%	4,041770175	10,5830665
Exports	0,832133005	0,098259045	8,468767523	0,000017%	0,624824543	1,039441468

Figure A.4: Selected result of the Multi-Regression analysis in the Commercial sector

A.4 Residential Sector

REGRESION 14640

Estadísticas de la regresión	
Coeficiente de correlación múltiple	0,960324002
Coeficiente de determinación R^2	0,922222188
R^2 ajustado	0,885925876
Error típico	4302,369681
Observaciones	23

ANÁLISIS DE VARIANZA

	Grados de libertad	*Suma de cuadrados*	*Promedio de los cuadrados*	*F*	*Valor crítico de F*
Regresión	7	3292202616	470314659,5	25,4081513	3,12811E-07
Residuos	15	277655773,1	18510384,88		
Total	22	3569858389			

	Coeficientes	*Error típico*	*Estadístico t*	Probabilidad	*Inferior 95%*	*Superior 95%*
Intercepción	307839,0742	6279,91977	49,0195871	0,000%	294453,742	321224,4063
GDP^3	32355268,5	8689694,93	3,72340672	0,204%	13833622,19	50876914,81
PCI^2	582446,5202	132590,9871	4,392806274	0,052%	299835,5209	865057,5195
PPI	-119028,6669	39187,84721	-3,037387235	0,831%	-202555,586	-35501,74775
WTI^3	0,028600647	0,007023274	4,072266998	0,100%	0,013630893	0,043570402
FDI [Millones USD]	-0,887196188	0,449791364	-1,972461589	6,728%	-1,845903785	0,07151141
Exports	-1,321012535	0,31006275	-4,260468351	0,068%	-1,981895643	-0,660129426
Imports^3	1,12543E-10	4,39571E-11	2,560297648	2,175%	1,88509E-11	2,06236E-10

Figure A.5: First regression result of the Multi-Regression analysis in the Residential sector

REGRESION 14613

Estadísticas de la regresión	
Coeficiente de correlación múltiple	0,958631455
Coeficiente de determinación R^2	0,918974266
R^2 ajustado	0,881162257
Error típico	4391,282235
Observaciones	23

ANÁLISIS DE VARIANZA

	Grados de libertad	*Suma de cuadrados*	*Promedio de los cuadrados*	*F*	*Valor crítico de F*
Regresión	7	3280607994	468658284,9	2430,38%	4,21886E-07
Residuos	15	289250395	19283359,66		
Total	22	3569858389			

	Coeficientes	*Error típico*	*Estadístico t*	Probabilidad	*Inferior 95%*	*Superior 95%*
Intercepción	305627,5585	6094,10522	50,15134256	0,000%	292638,2807	318616,8363
GDP^3	28115093,64	9059460,758	3,103395929	0,727%	8805310,122	47424877,15
PCI^2	601640,9775	136603,6731	4,404281114	0,051%	310477,1406	892804,8145
PPI	-108770,6714	38988,09858	-2,789842934	1,374%	-191871,8364	-25669,50635
WTI^2	3,245838381	0,82934504	3,913737015	0,138%	1,478131273	5,01354549
FDI [Millones USD]	-0,983941109	0,455695181	-2,159208943	4,744%	-1,955232395	-0,012649824
Exports	-1,383953212	0,332974236	-4,156337225	0,084%	-2,093670996	-0,674235428
Imports^3	1,2565E-10	4,65293E-11	2,700452335	1,644%	2,64753E-11	2,24825E-10

Figure A.6: Selected regression result of the Multi-Regression analysis in the Residential sector

A.5 Agriculture Sector

Estadísticas de la regresión	
Coeficiente de correlación múltiple	0,981687512
Coeficiente de determinación R^2	0,96371037
R^2 ajustado	0,95303695
Error típico	14392,72341
Observaciones	23

ANÁLISIS DE VARIANZA

	Grados de libertad	*Suma de cuadrados*	*Promedio de los cuadrados*	*F*	*Valor crítico de F*
Regresión	5	93518789746	18703757949	90,29067809	1,24786E-11
Residuos	17	3521558281	207150487,1		
Total	22	97040348027			

	Coeficientes	*Error típico*	*Estadístico t*	Probabilidad	*Inferior 95%*	*Superior 95%*
Intercepción	246795,9437	10120,46123	24,38583956	0,000%	225443,637	268148,2505
PCI^2	940212,8344	279781,2713	3,360528138	0,371%	349925,9499	1530499,719
WTI^2	-9,580907055	1,956186763	-4,897746593	0,014%	-13,70810036	-5,453713749
FDI^3	2,19918E-08	6,31256E-09	3,483810408	0,284%	8,67342E-09	3,53101E-08
Exports^3	-6,39667E-10	1,24098E-10	-5,154549534	0,008%	-9,0149E-10	-3,77844E-10
Imports	5,370138972	0,495113909	10,84626966	0,000%	4,325539933	6,41473801

Figure A.7: Selected result of the Multi-Regression analysis in the Agriculture sector

CHAPTER B Cross-impact matrix applied to MICMAC analysis

B.1 Transport Sector

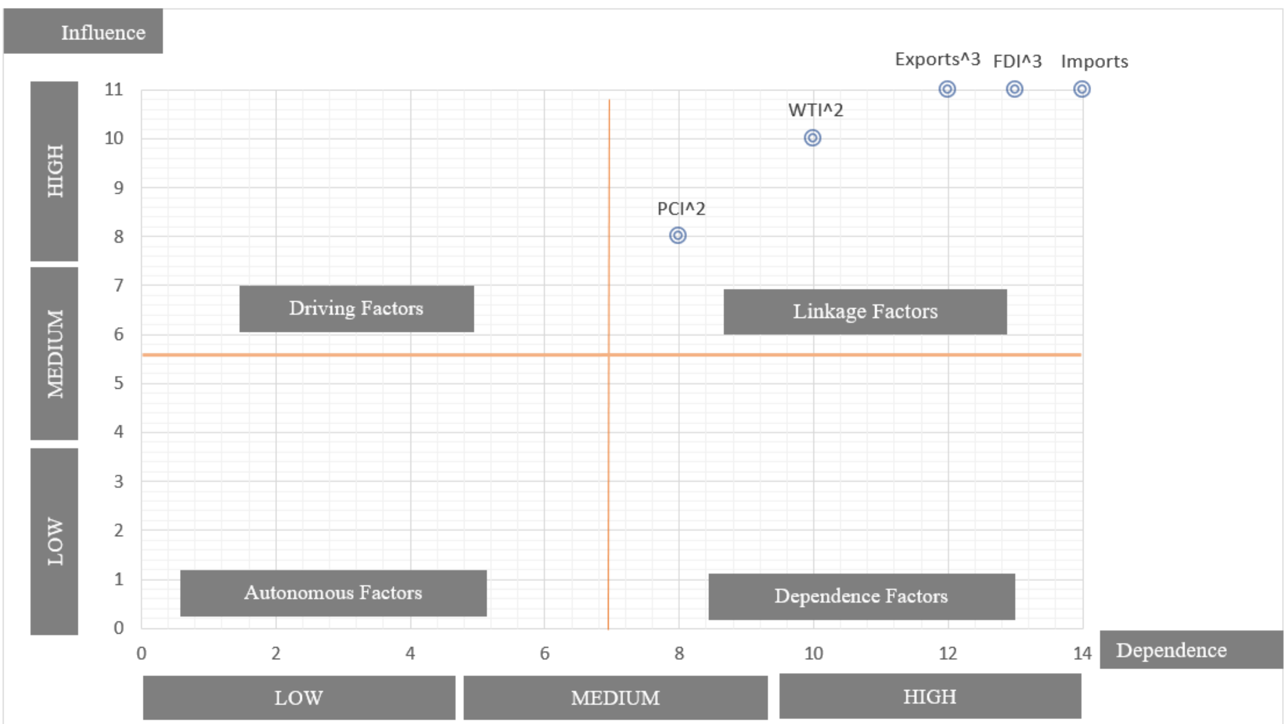

Figure B.1: Micmac Analysis of the Transport sector

B.2 Commercial Sector

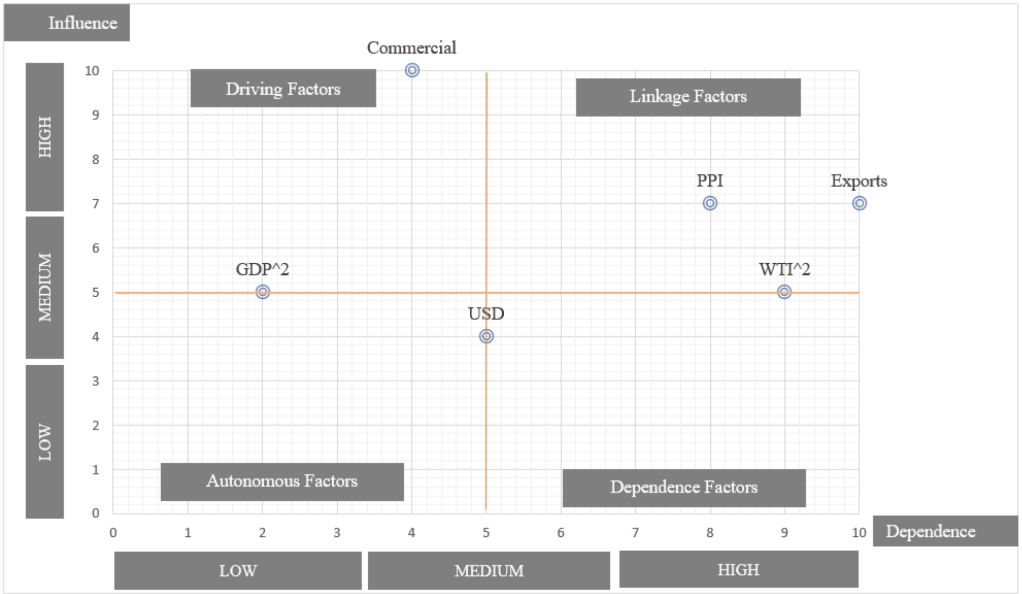

Figure B.2: Micmac Analysis of the Commercial sector

B.3 Industrial Sector

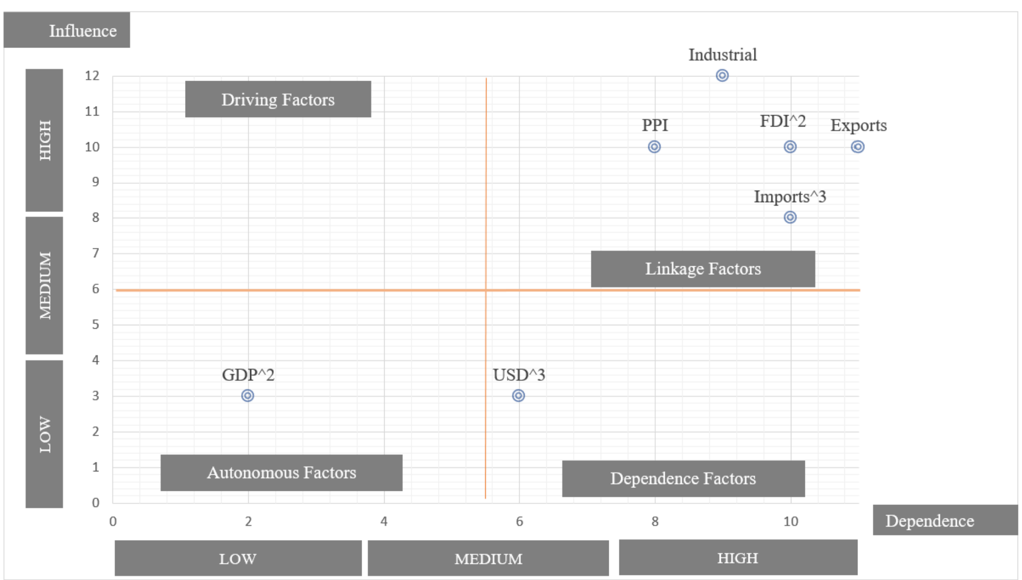

Figure B.3: Micmac Analysis of the Industrial sector

B.4 Residential Sector

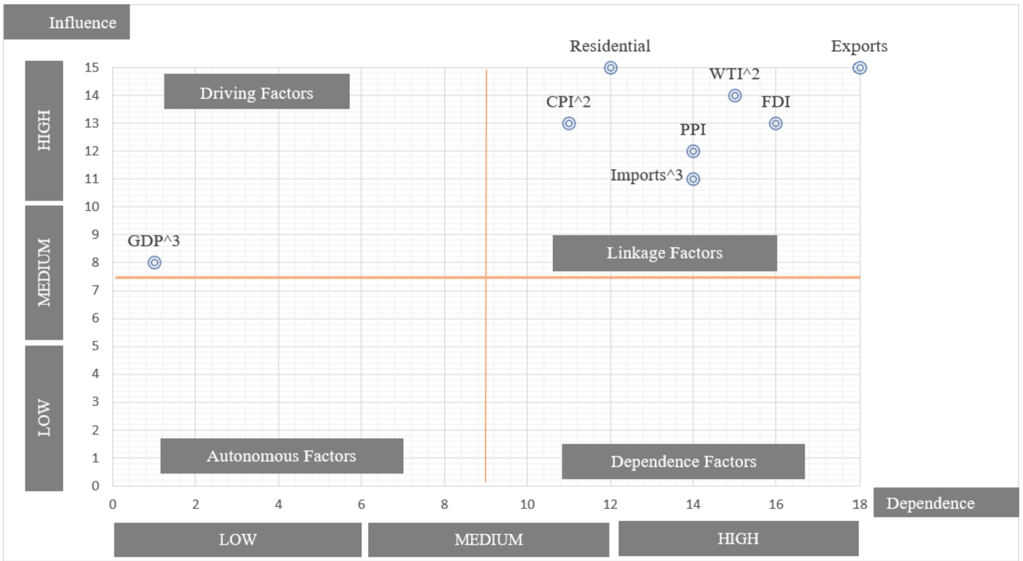

Figure B.4: Micmac Analysis of the Residential sector

B.5 Agriculture Sector

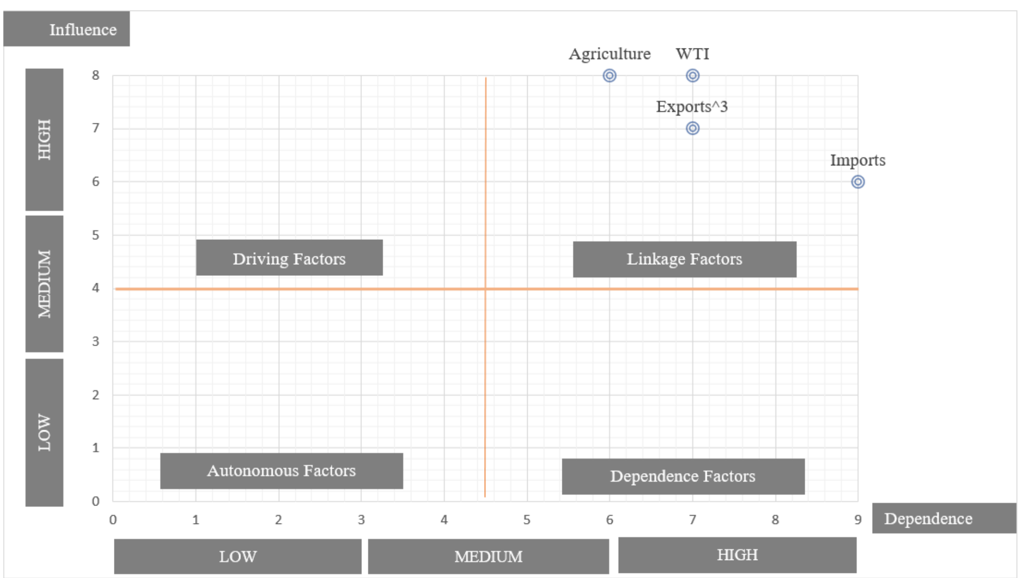

Figure B.5: Micmac Analysis of the Agriculture sector

CHAPTER C Sampling error of the Energy Demand in Colombia

Year	Transport			Industrial			Commercial			Residential			Agriculture		
	Projection 2,77%	Real	Error %	Projection 6,16%	Real	Error %	Projection 3,83%	Real	Error %	Projection 0,96%	Real	Error %	Projection 32,74%	Real	Error %
1995	350.966,3TJ	341.885,9TJ	2,66%	196.926,5TJ	211.101,2TJ	6,71%	44.229,0TJ	42.210,5TJ	4,78%	300.882,3TJ	301.550,1TJ	0,22%	59.287,6TJ	61.507,0TJ	3,61%
1996	350.710,0TJ	350.521,4TJ	0,05%	221.487,6TJ	220.407,5TJ	0,49%	46.883,9TJ	44.686,1TJ	4,92%	298.912,1TJ	301.997,2TJ	1,02%	58.530,9TJ	60.350,0TJ	3,01%
1997	352.613,6TJ	358.583,5TJ	1,66%	214.131,9TJ	224.721,2TJ	4,71%	45.300,3TJ	49.014,6TJ	7,58%	291.555,1TJ	288.237,6TJ	1,15%	56.870,5TJ	62.061,0TJ	8,36%
1998	346.183,8TJ	354.929,1TJ	2,46%	219.852,6TJ	216.876,7TJ	1,37%	49.399,5TJ	51.538,7TJ	4,15%	285.358,4TJ	284.065,3TJ	0,46%	59.348,1TJ	62.002,0TJ	4,28%
1999	302.352,5TJ	318.455,8TJ	5,06%	220.092,7TJ	212.361,7TJ	3,64%	49.178,5TJ	50.182,2TJ	2,00%	282.798,5TJ	282.670,9TJ	0,05%	63.097,3TJ	58.669,0TJ	7,55%
2000	302.720,0TJ	310.544,8TJ	2,52%	241.559,2TJ	231.655,4TJ	4,28%	51.175,0TJ	52.358,1TJ	2,26%	281.498,0TJ	282.633,3TJ	0,40%	58.862,0TJ	57.945,0TJ	1,58%
2001	309.028,1TJ	294.512,7TJ	4,93%	242.287,2TJ	230.865,1TJ	4,95%	50.506,9TJ	49.871,0TJ	1,28%	284.348,2TJ	283.242,6TJ	0,39%	58.633,1TJ	58.082,0TJ	0,95%
2002	308.436,3TJ	286.773,7TJ	7,55%	265.678,5TJ	244.919,0TJ	8,48%	53.049,6TJ	50.421,1TJ	5,21%	282.992,6TJ	285.511,2TJ	0,88%	58.715,5TJ	41.924,0TJ	40,05%
2003	309.882,0TJ	300.758,2TJ	3,03%	282.595,9TJ	258.579,6TJ	9,29%	52.023,1TJ	52.298,7TJ	0,53%	286.890,0TJ	288.554,9TJ	0,58%	55.977,0TJ	62.595,0TJ	10,57%
2004	314.897,4TJ	320.618,4TJ	1,78%	252.361,1TJ	291.139,2TJ	13,32%	48.986,3TJ	45.022,4TJ	8,80%	286.261,2TJ	287.652,8TJ	0,48%	50.050,9TJ	66.325,0TJ	24,54%
2005	342.044,6TJ	335.930,5TJ	1,82%	288.285,0TJ	284.839,2TJ	1,21%	46.445,9TJ	46.085,2TJ	0,78%	279.530,3TJ	289.690,2TJ	3,51%	41.192,3TJ	57.163,0TJ	27,94%
2006	336.259,5TJ	340.081,3TJ	1,12%	253.593,3TJ	287.201,1TJ	11,70%	46.274,6TJ	45.307,3TJ	2,14%	285.198,7TJ	282.396,8TJ	0,99%	33.214,1TJ	19.677,0TJ	68,80%
2007	363.516,3TJ	353.139,3TJ	2,94%	228.140,0TJ	206.682,3TJ	10,38%	42.492,3TJ	47.121,8TJ	9,82%	288.257,2TJ	282.868,6TJ	1,90%	25.558,4TJ	19.269,0TJ	32,64%
2008	350.656,7TJ	356.571,3TJ	1,66%	331.796,1TJ	329.851,4TJ	0,59%	50.793,3TJ	51.956,7TJ	2,24%	277.338,0TJ	273.338,2TJ	1,46%	13.639,4TJ	18.916,0TJ	27,89%
2009	366.747,3TJ	363.231,4TJ	0,97%	281.107,0TJ	300.634,5TJ	6,50%	53.453,5TJ	52.117,1TJ	2,56%	271.232,0TJ	268.229,5TJ	1,12%	29.300,7TJ	18.615,0TJ	57,40%
2010	358.314,3TJ	371.563,3TJ	3,57%	266.108,2TJ	266.071,1TJ	0,01%	55.127,9TJ	54.868,2TJ	0,47%	269.898,3TJ	268.398,3TJ	0,56%	20.211,2TJ	18.151,0TJ	11,35%
2011	390.016,5TJ	395.396,2TJ	1,36%	321.548,2TJ	283.686,5TJ	13,35%	60.916,9TJ	56.099,5TJ	8,59%	261.638,4TJ	269.647,0TJ	2,97%	20.618,6TJ	17.704,0TJ	16,46%
2012	399.973,2TJ	408.274,9TJ	2,03%	284.111,2TJ	288.672,5TJ	1,58%	61.215,7TJ	59.885,0TJ	2,22%	263.604,8TJ	265.593,8TJ	0,75%	20.924,6TJ	17.441,0TJ	19,97%
2013	423.348,8TJ	423.042,8TJ	0,07%	306.146,4TJ	294.543,7TJ	3,94%	60.753,3TJ	62.997,1TJ	3,56%	265.067,8TJ	264.246,2TJ	0,31%	16.601,5TJ	17.143,0TJ	3,16%
2014	481.504,7TJ	454.913,5TJ	5,85%	269.557,8TJ	297.781,9TJ	9,48%	65.174,7TJ	66.198,1TJ	1,55%	266.974,2TJ	266.593,4TJ	0,14%	4.884,2TJ	16.839,0TJ	71,00%
2015	511.137,8TJ	494.560,3TJ	3,35%	294.165,9TJ	276.134,2TJ	6,53%	68.103,7TJ	65.144,0TJ	4,54%	266.798,0TJ	264.026,8TJ	1,05%	7.723,2TJ	16.390,0TJ	52,88%
2016	499.992,9TJ	512.901,7TJ	2,52%	404.807,8TJ	375.096,0TJ	7,92%	65.982,7TJ	66.472,6TJ	0,74%	263.882,3TJ	262.381,0TJ	0,57%	18.164,4TJ	15.975,0TJ	13,71%
2017	483.407,0TJ	507.519,6TJ	4,75%	416.959,5TJ	469.478,7TJ	11,19%	69.951,2TJ	75.562,1TJ	7,43%	256.212,8TJ	253.603,4TJ	1,03%	18.774,8TJ	5.437,0TJ	245,32%
			2,77%			**6,16%**			**3,83%**			**0,96%**			**32,74%**

Figure C.1: Sampling error by sectors of consumption

Year	Transport		Industrial		Commercial		Residential		Agriculture	
	Projection 2,77%	Real	Projection 6,16%	Real	Projection 3,83%	Real	Projection 0,96%	Real	Projection 32,74%	Real
1995	350.966,3TJ	341.885,9TJ	196.926,5TJ	211.101,2TJ	44.229,0TJ	42.210,5TJ	300.882,3TJ	301.550,1TJ	59.287,6TJ	61.507,0TJ
1996	350.710,0TJ	350.521,4TJ	221.487,6TJ	220.407,5TJ	46.883,9TJ	44.686,1TJ	298.912,1TJ	301.997,2TJ	58.530,9TJ	60.350,0TJ
1997	352.613,6TJ	358.583,5TJ	214.131,9TJ	224.721,2TJ	45.300,3TJ	49.014,6TJ	291.555,1TJ	288.237,6TJ	56.870,5TJ	62.061,0TJ
1998	346.183,8TJ	354.929,1TJ	219.852,6TJ	216.876,7TJ	49.399,5TJ	51.538,7TJ	285.358,4TJ	284.065,3TJ	59.348,1TJ	62.002,0TJ
1999	302.352,5TJ	318.455,8TJ	220.092,7TJ	212.361,7TJ	49.178,5TJ	50.182,2TJ	282.798,5TJ	282.670,9TJ	63.097,3TJ	58.669,0TJ
2000	302.720,0TJ	310.544,8TJ	241.559,2TJ	231.655,4TJ	51.175,0TJ	52.358,1TJ	281.498,0TJ	282.633,3TJ	58.862,0TJ	57.945,0TJ
2001	309.028,1TJ	294.512,7TJ	242.287,2TJ	230.865,1TJ	50.506,9TJ	49.871,0TJ	284.348,2TJ	283.242,6TJ	58.633,1TJ	58.082,0TJ
2002	308.436,3TJ	286.773,7TJ	265.678,5TJ	244.919,0TJ	53.049,6TJ	50.421,1TJ	282.992,6TJ	285.511,2TJ	58.715,5TJ	41.924,0TJ
2003	309.882,0TJ	300.758,2TJ	282.595,9TJ	258.579,6TJ	52.023,1TJ	52.298,7TJ	286.890,0TJ	288.554,9TJ	55.977,0TJ	62.595,0TJ
2004	314.897,4TJ	320.618,4TJ	252.361,1TJ	291.139,2TJ	48.986,3TJ	45.022,4TJ	286.261,2TJ	287.652,8TJ	50.050,9TJ	66.325,0TJ
2005	342.044,6TJ	335.930,5TJ	288.285,0TJ	284.839,2TJ	46.445,9TJ	46.085,2TJ	279.530,3TJ	289.690,2TJ	41.192,3TJ	57.163,0TJ
2006	336.259,5TJ	340.081,3TJ	253.593,3TJ	287.201,1TJ	46.274,6TJ	45.307,3TJ	285.198,7TJ	282.396,8TJ	33.214,1TJ	19.677,0TJ
2007	363.516,3TJ	353.139,3TJ	228.140,0TJ	206.682,3TJ	42.492,3TJ	47.121,8TJ	288.257,2TJ	282.868,6TJ	25.558,4TJ	19.269,0TJ
2008	350.656,7TJ	356.571,3TJ	331.796,1TJ	329.851,4TJ	50.793,3TJ	51.956,7TJ	277.338,0TJ	273.338,2TJ	13.639,4TJ	18.916,0TJ
2009	366.747,3TJ	363.231,4TJ	281.107,0TJ	300.634,5TJ	53.453,5TJ	52.117,1TJ	271.232,0TJ	268.229,5TJ	29.300,7TJ	18.615,0TJ
2010	358.314,3TJ	371.563,3TJ	266.108,2TJ	266.071,1TJ	55.127,9TJ	54.868,2TJ	269.898,3TJ	268.398,3TJ	20.211,2TJ	18.151,0TJ
2011	390.016,5TJ	395.396,2TJ	321.548,2TJ	283.686,5TJ	60.916,9TJ	56.099,5TJ	261.638,4TJ	269.647,0TJ	20.618,6TJ	17.704,0TJ
2012	399.973,2TJ	408.274,9TJ	284.111,2TJ	288.672,5TJ	61.215,7TJ	59.885,0TJ	263.604,8TJ	265.593,8TJ	20.924,6TJ	17.441,0TJ
2013	423.348,8TJ	423.042,8TJ	306.146,4TJ	294.543,7TJ	60.753,3TJ	62.997,1TJ	265.067,8TJ	264.246,2TJ	16.601,5TJ	17.143,0TJ
2014	481.504,7TJ	454.913,5TJ	269.557,8TJ	297.781,9TJ	65.174,7TJ	66.198,1TJ	266.974,2TJ	266.593,4TJ	4.884,2TJ	16.839,0TJ
2015	511.137,8TJ	494.560,3TJ	294.165,9TJ	276.134,2TJ	68.103,7TJ	65.144,0TJ	266.798,0TJ	264.026,8TJ	7.723,2TJ	16.390,0TJ
2016	499.992,9TJ	512.901,7TJ	404.807,8TJ	375.096,0TJ	65.982,7TJ	66.472,6TJ	263.882,3TJ	262.381,0TJ	18.164,4TJ	15.975,0TJ
2017	483.407,0TJ	507.519,6TJ	416.959,5TJ	469.478,7TJ	69.951,2TJ	75.562,1TJ	256.212,8TJ	253.603,4TJ	18.774,8TJ	5.437,0TJ

Year	Mining		Construction		TOTAL			
	Projection	Real	Projection	Real	Projection	Real	Diference	Error %
1995	Model did not accept P-value	3.045,0TJ	Model did not accept P-value	3.785,0TJ	952.291,7TJ	965.084,7TJ	12.793,0TJ	1,33%
1996		3.289,0TJ		3.878,0TJ	976.524,4TJ	985.129,1TJ	8.604,7TJ	0,87%
1997		3.110,0TJ		4.059,0TJ	960.471,3TJ	989.787,0TJ	29.315,7TJ	2,96%
1998		2.994,0TJ		4.105,0TJ	960.142,3TJ	976.510,8TJ	16.368,4TJ	1,68%
1999		3.012,0TJ		3.703,0TJ	917.519,5TJ	929.054,6TJ	11.535,1TJ	1,24%
2000		3.256,0TJ		2.917,0TJ	935.814,2TJ	941.309,6TJ	5.495,3TJ	0,58%
2001		3.706,0TJ		2.467,0TJ	944.803,5TJ	922.746,3TJ	22.057,2TJ	2,39%
2002		3.608,0TJ		2.878,0TJ	968.872,5TJ	916.035,0TJ	52.837,5TJ	5,77%
2003		4.419,0TJ		2.908,0TJ	987.367,9TJ	970.113,4TJ	17.254,4TJ	1,78%
2004		4.612,0TJ		2.509,0TJ	952.556,8TJ	1.017.878,7TJ	65.321,9TJ	6,42%
2005		5.029,0TJ		2.864,0TJ	997.498,2TJ	1.021.601,0TJ	24.102,8TJ	2,36%
2006		8.721,0TJ		68,0TJ	954.540,2TJ	983.452,4TJ	28.912,2TJ	2,94%
2007		8.745,0TJ		112,0TJ	947.964,3TJ	917.938,0TJ	30.026,3TJ	3,27%
2008		10.061,0TJ		213,0TJ	1.024.223,6TJ	1.040.907,5TJ	16.684,0TJ	1,60%
2009		10.705,0TJ		239,0TJ	1.001.840,4TJ	1.013.771,6TJ	11.931,1TJ	1,18%
2010		11.678,0TJ		194,0TJ	969.659,9TJ	990.923,9TJ	21.264,0TJ	2,15%
2011		11.115,0TJ		159,0TJ	1.054.738,6TJ	1.033.807,2TJ	20.931,4TJ	2,02%
2012		13.473,0TJ		209,0TJ	1.029.829,4TJ	1.053.549,2TJ	23.719,7TJ	2,25%
2013		13.824,0TJ		238,0TJ	1.071.917,8TJ	1.076.034,7TJ	4.117,0TJ	0,38%
2014		19.943,0TJ		435,0TJ	1.088.095,6TJ	1.122.703,9TJ	34.608,3TJ	3,08%
2015		14.951,0TJ		336,0TJ	1.147.928,7TJ	1.131.542,3TJ	16.386,3TJ	1,45%
2016		15.108,0TJ		377,0TJ	1.252.830,1TJ	1.248.311,4TJ	4.518,7TJ	0,36%
2017		41.309,0TJ		17.004,0TJ	1.245.305,2TJ	1.369.913,8TJ	124.608,5TJ	9,10%
								2,49%

Figure C.2: Sampling error of the total energy demand