POLITECNICO DI TORINO

Master of Science Program
ARCHITECTURE FOR THE SUSTAINABILITY DESIGN

Thesis of Master’s Degree

Building Energy Modelling at Urban Scale In Mendoza (AR)

Statistical Models For Space Heating & Domestic Hot Water

Supervisor:

Prof. Gugliemina Mutani

Co Supervisor:
Prof. Mariela Arboit

Author:

Nima Pouraminaein

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Abstract

Cities are home to half of the world's population. By 2050, 70% of people would live in different cities, based on UN reports. Obviously, the population growth has made serious environmental consequences such as climate change and GHG emissions. More specifically, one of the main actors regarding energy consumption is construction sector or more specifically residential buildings where energy is needed for various activities, which, the main contributors of consumption are space heating & hot water. Therefore, understanding of buildings characteristics & thermal energy profile in existing situation, and predicting it for future has a considerable importance. Therefore, applying energy consumption analysis should be at city scale instead of a single building

The selected case study is the metropolitan area of gran Mendoza located in Argentina. Total primary energy of Argentina is dominated by natural gas (55%) & oil (33%), both as fossil fuels [1]. Relatively, the energy source in Mendoza is mostly supported by natural gas, in addition to, its expansion during past 30 years, it has provided harmful environmental impacts [2]. This research aims to describe how to model thermal energy consumption of whole Mendoza with aid of existing census database, annual NG consumption data and a GIS-based methodology. Consequently, we will be able to acquire most energy related variables, correlating to both space heating & domestic hot water consumption and a statistical model of natural gas consumption. Regarding this, after leveling all data in same scale, a sensitivity analysis carried on identifying most correlated variables to energy consumption. After this a multiple linear regression analysis is adopted to predict NG consumption & compare it with real data. At last, two types of modelling presented for central & peripheral areas with their most energy related variables for reference year of 2016 & three scenarios of kWh, kWh/m2, kWh/family once for normal NG consumption & once for Normalized NG consumption (total six scenarios).

Lastly, having energy consumption data & its influential variables will assist us to spot critical areas of a city & discovering the variables that made great impact on them. Besides, applying the correct decisions or relevant interventions towards more sustainable city & energy systems.

1. Introduction

1.1. Project Background

Human Actions & Environmental Impacts

Since, industrial revolution has started in 18th century the human needs and activities just grown to the highest priority of societies. This was followed by excessing raw material extraction, population growth in cities, fossil fuels combustion, deforestation & high CO2 emission. As a result of these human actions, the global temperature has been rising since 1880. According to united nations framework convention on climate change (UNCCC) between years 1880 & 2012 the temperature has risen about 0.84 °C and it is predicted to rise about 4.8 °C by 2100 [12].

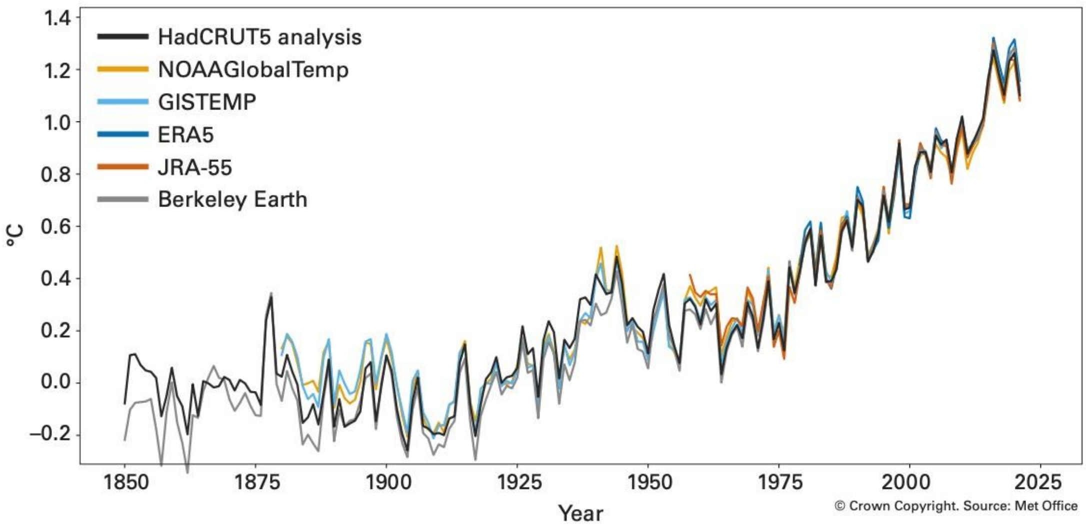


Figure 1 - Global annual mean temperature difference from pre-industrial conditions, for six global temperature data sets (1850–2021). (source: Met Office)

Alongside of above trend, there is a second increasing factor called greenhouse gas (GHG) emission which is, in fact, one of the main reasons of temperature rising. Burning fossil fuels generates greenhouse gas emissions that act like a blanket wrapped around the Earth, trapping the sun's heat and raising temperatures. The main contributor gases of these emissions are Carbon dioxide (CO2) & Methane (CH4). In summary energy, industry, transport, buildings, agriculture, and land use are main emitters for GHG emissions.

A major part of burning fossil fuels is contributing to production of energy for different sectors. As it is shown below the city or more specifically buildings of a city have a substantial share in energy use and GHG emissions.

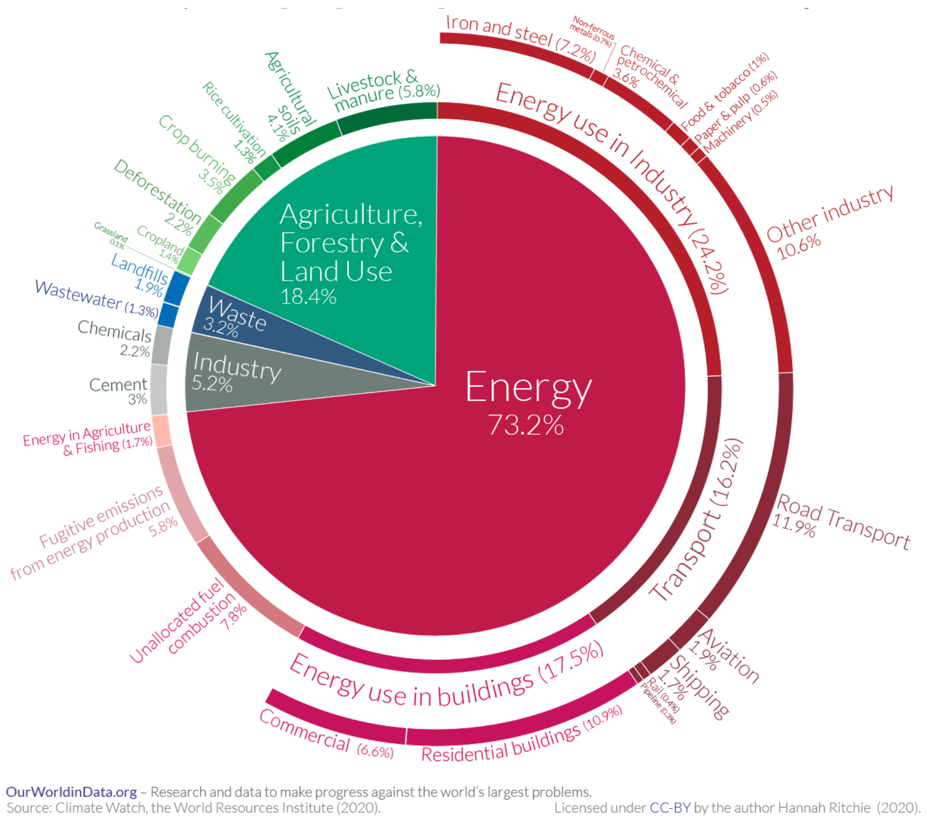


Figure 2 - Global greenhouse gas emissions by sector year 2016. (source: Climate Watch, the World Resources Institute 2020)

Based on Hannah Ritchie, Max Roser and Pablo Rosado work in 2020 [3][4] Building sector has a substantial share about 17.5 % form energy production emissions. As it is obvious there are two types of buildings, residential & commercial. In both cases an energy related emissions are present due to the generation of electricity or space heating. On the other hand, buildings have also significant share in the energy consumption. So, all these conclude that buildings strongly contribute in GHG emissions & energy consumption. Nevertheless, the optimization building's energy performance has become a priority for Designers, Architects & Urban planners. Transition towards a more efficient & environment friendly buildings need holistic and public effort in order to transform our built environment to a healthy & sustainable world, although, applying energy efficiency interventions on random single buildings won't be a solution. In other words, we need to assess the situation at city scale to have a complete overview about existing context and consequently, adopt the right policies or decisions. The city or neighbourhood scale model can provide us an easier identification of critical areas, more sustainable management and specification of related variables in different cases and scenarios.

This approach will allow different decision makers in different countries to find out which are the most effective elements of energy consumption in each neighbourhood of a city. Additionally, Knowing the statistical distribution of energy consumption allows planners to better implement retrofit interventions and optimize the energy supply. [5] This could vary from existing socio-economic variables to geometric characteristics of buildings or districts such as buildings surface area, S/V, distances, etc.

1.2. Objectives of Research

As a result of mentioned anthropogenic activities and dramatic cities growing, many experts & stakeholders involved in order to compensate the harms and negative impacts that happened. Since, most people lives in cities, it is not possible to ignore the consequences anymore, if we would like to have a healthy & prospect society. Moreover, with modern living standards there many factors which need to reach the minimum acceptable range, such as thermal comfort, indoor air quality and outdoor environment. Therefore, this research aims to introduce a method to assess heating energy need for residential buildings consumption at urban scale which lead to a predicted energy model by discovering environmental or social variables that influence the energy most, as a result, it is possible to provide insight about identification of critical districts, then short-term or long-term interventions and planning for each one of them, through combination of a place-based methodology (GIS) & statistical models. The case study is metropolitan area of city of Mendoza (AR), located in central western area of Argentina, with natural gas as the main fuel for energy consumption. The city data is available at three levels which are districts, the containing census sections inside each district & buildings of each census section. Since, the available energy consumption data is at districts scale, a top-down model has been adopted to process & create the model at micro scale of census sections. Firstly, for creating a precise database, the existing census data base of Mendoza has been used to insert in QGIS for visualizing the distribution of constant data and also calculation of some other buildings or urban parameters, for further analysis of modelling. Then heating volumes of the buildings of all districts selected for acquiring the most energy related variables for calculating natural gas consumption. Once, the model is created it will compare with real data of consumption by supplier to validate the model, also, calibrate it for error reductions. Applying this method will guide planners or designers to understand the location and intensity of energetic problems in existing situation, which enlighten them to implement the best solution for having higher energy efficiency, better thermal comfort situation, less environmental impacts and last, but not least energy savings for families.

1.3. Research Structure

This research work is containing six chapters. The first one is introduction and explains energy role in daily human life and how buildings sector contribute within. Also, addresses environmental issues that have been made through energy production, in addition to, actions that need to be done for its justification. The objectives of project and document structure find in chapter one as well.

The second chapter refers to literature review and relevant terminology. Starts with sustainability concept background, energy performances & space heating in buildings, CO_2 emissions from building sector, thermal comfort & HDD concept plus definition of USEMs and its different approaches.

Chapter three is about methodological procedure that has been carried on in research to meet the defined objectives. Starts with a place-based model in QGIS for localizing existing urban shapefiles and calculation of geometric parameters, which will follow by normalization of energy consumption based on altitude change. Lastly, correlation between most energy related variables & consumption data for regression & statistical analysis to create energy model.

The case study is described in chapter four. The background of main energy resources at national territory level and specified targets Argentina. Introducing the territorial characteristics of city of Mendoza, including meteorological stations that has been used for climatic analysis with different altitudes from sea level. The classification of existing building stock of Mendoza with the relevant natural gas consumption at district scale, which is provided by local supplier, including details about year of consumption, location and kWh data. Additionally, information of the existing census database of Mendoza that aided to create other new variables to form a new database. Finally, a top-down model which processed NG consumption data from census sections to districts levels for final energy model of city.

The fifth chapter is about outcome of the research project and the analysis results. In summary, the main figures & maps are found in this chapter, showing the pattern or distribution of different measured parameters. It also provides any table, chart or graph that is explain the acquired results. These include distribution maps of various data such as altitude range, social, buildings geometry and typology, thermal energy consumption, the energy related data correlations and charts of multiple linear regression analysis between chosen variables. Finally, the most energy intensive sections of the city are specified and illustrated.

At last, in chapter six the conclusion of obtained results in chapter five will be discussed.

2. State of The Art

2.1. Sustainable Development Concept

Since, the global warming is increasing the need for sustainability & resiliency for future is in demand. The concept tries to protect environment from degradation & at the same time provide social & economic growth. Below, the summary of most relevant conferences or reports of sustainability are organized based on the timeline.

1972 - Club of Rome

The evolution of a sustainable development began with report the limits to growth (1972) from “Club of Rome” by MIT. It stated that the use of natural resources is involved with an uncontrolled growth of population. Therefore, one of the leaders of this group called ‘Aurelio Peccei’ proposed to forecast a long-term plan with global governance. [6]

1972 - Earth Summit Stockholm

First international conference by UN (UNCHE, United Nations Conference on Human Environment), which focused the attention on the necessity to protect the environment and the impact of technology on the environment for the development of current and future generations by presenting Stockholm declaration document. Milestone in the definition of the concept of sustainable development [7].

1987 - Our Common Future

Another important document was introduced, called ‘Our Common Future’ also Brundtland report, provided by ‘Brundtland Commission’ & prepared by World Commission on Environment and Development (WCED) under the UN. The document’s holistic approach states that “Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs”. Moreover, it defined a new and fundamental concept about sustainability which recognized economy, ecology & social equity, as pillars of sustainability [7].

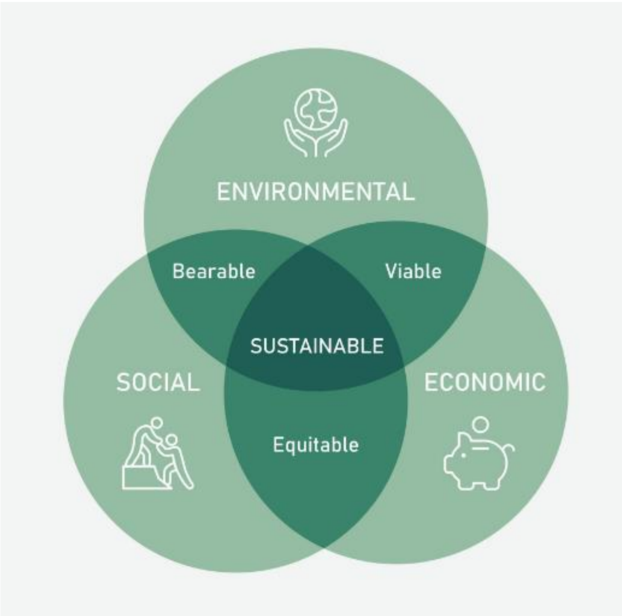


Figure 3 - Sustainability Pillars. (Source: SNC-Lavalin Group 2021)

1987 – IPCC Creation

Intergovernmental Panel on Climate Change, to provide the world with a clear scientific view on climate change and its consequences [11].

1992 – Earth Summit Rio

United Nations Conference on Environment and Development (UNCED)', held in Rio de Janeiro. Several agreements have been made to save the planet & also a sustainable growth for future. One of the main documents that has been agreed was called 'Agenda 21'. The latter is a non-binding, voluntarily implemented action plan of the UN, made of 40 chapters, describing "the things to do and to insert in the agenda of 21st century for a sustainable development [7].

1997 - COP3, Kyoto Protocol

Intergovernmental Panel on Climate Change (to provide the world with a clear scientific view on climate change and its consequences. The primary goal was to obligate other countries to agree with this protocol cut their co2 emissions by 30 years of period to 30 percent [12].

2007 – IPCC Fourth Assessment Report

Report of the Intergovernmental Panel on Climate Change (IPCC) establishes beyond any doubt the correlation between CO2 concentration in the atmosphere and climate change [11].

2015 - Agenda 2030

The 2030 Agenda for Sustainable Development was launched by a UN Summit in New York in September 2015 under UNFCCC. UN stated that "The Sustainable Development Goals are a universal call to action to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere." For this development, 17 goals are presented for all UN members to set out a 15-years plan (by 2030).

In addition, the 2030 Agenda integrates in a balanced manner the three dimensions of sustainable development – economic, social and environmental [7] [13].

Figure 4 - Agenda 2030, 17 SDGs. (Source: ie.edu)

2015 - COP21, Paris Agreement

The first-ever universal climate change agreement was introduced called 'Paris Agreement' which binds countries globally to counteract climate changes beyond 2020. The agreement is adopted at the Paris climate conference (COP21) in December 2015 [12]. European commission has identified the main goal of 'Paris Agreement' would be:

- Limit the global temperature rise below 2 degrees compared to pre-industrial levels
- Limit this increase even to 1.5 degrees to reduce risk & impacts

2.2. Buildings Energy Trend

2.2.1. Global Situation

As it is expressed previously, massive development of urban areas and population growth, has increased the standards of living citizens. The latter was resulted in technological breakthrough, especially in 20th century. Bigger cities mean bigger societies which supported by higher need for natural resources and higher primary energy demand. Moreover, energy is a key factor in global efforts to achieve sustainable development, and buildings can be essential to achieving this goal [8]. According to IEA in 2019, the global total primary energy demand (energy production plus energy imports, minus energy exports) was increased around 2.3% between years 2010 & 2018. On the other hand, building construction and operations accounted for the largest share of both global final energy use (36%) and energy-related CO_2 emissions (39%) in 2018. [1][7]

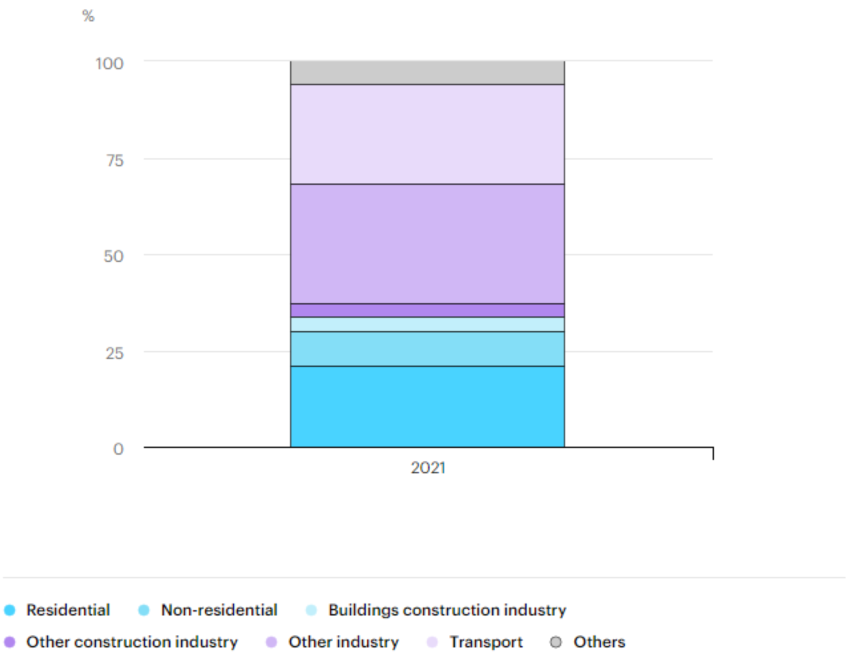


Figure 5 - Final Energy Consumption in Building Sector 2021 [9]. (Source: IEA)

2.2.2. Residential Sector

Based on above data by IEA (Figure 5), when the construction sector is considered the residentials share a significant portion of the final consumption. Within households there are different purposes for energy use, Europe commission defines them as space and water heating, space cooling, cooking, lighting and electrical appliances [10]. Among the mentioned end-users, space heating plays a key role. (Figure 6)

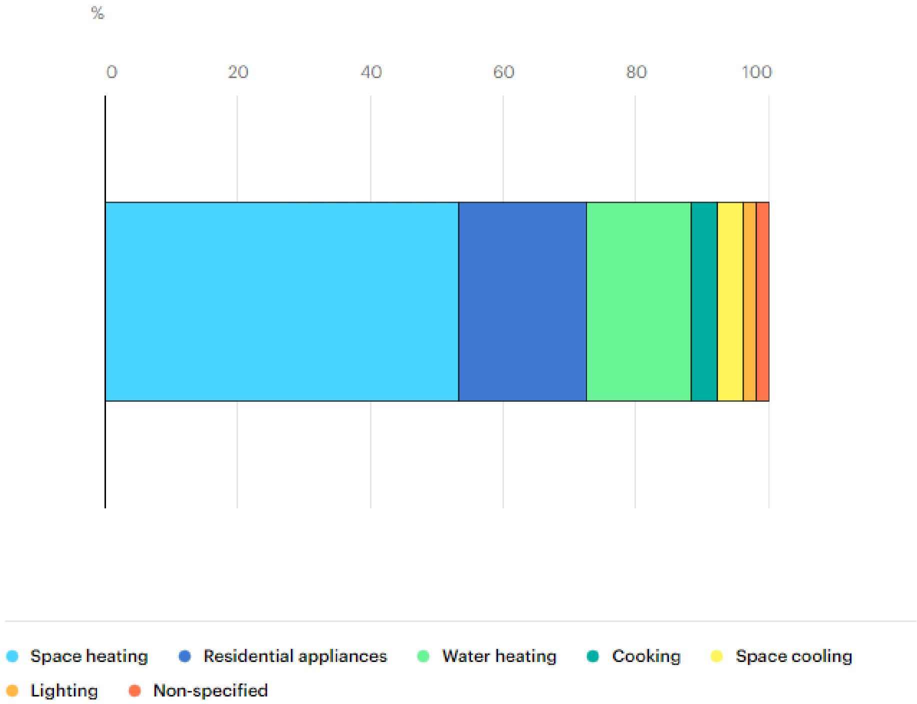


Figure 6 - Shares of residential energy consumption by end use in selected IEA countries, 2019. (Source: IEA)

2.3. Energy Efficiency & Decarbonisation

High demand of energy & massive emission of CO2 due to energy production, obligated modern communities to counteract the consequences of their own action. One of the main important & effective solutions has been increasing the energy efficiency. In summary, 'Environmental and Energy Study Institute' defined that energy efficiency means using less energy to reach the same performance we had before, in order to prevent energy waste. Applying an energy efficiency strategy could lead to lower GHG emission, reduced energy imports, & lowering households consumption bills, & environment protection, therefore, it is considered one of the best options to eliminate fossil fuel use. The efficiency improvements bring opportunities for higher performance in various sectors such as buildings, transportation, industry, etc [14].

Additionally, Although, in recent years innovative & technological solutions emerged to aid human in controlling the GHG and reduced carbon intensity of energy production, the trend of emissions is still rising, caused also to global temperature change as the most important result. As defined in Paris Agreement we have a limit of

2 degree temperature rise by 2050 (compared to pre-industrial levels) [12], which international scientific community estimates this budget to be around 1 trillion tones of carbon. By 2011 the world had already reached the half of this budget, so, this indicates a global critical situation and requires policies that support decarbonised energy systems.

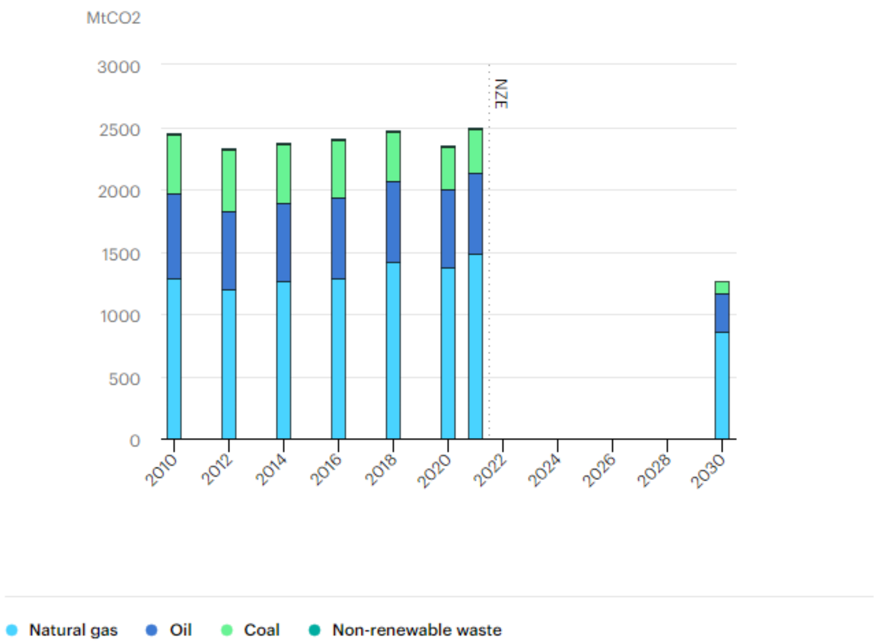


Figure 7 - Direct CO2 emissions from buildings-related heating by fuel in the Net Zero Scenario, 2010-2030. (Source: IEA)

To combat the mentioned issues a transition from a conventional system to a sustainable system is required. In addition to, providing a clean, safe and efficient energy. Therefore, investment on energy efficient interventions, electrification of energy systems and use of clean renewable resources are considered the main trend in present time [15].

2.4. Thermal Comfort

Being comfortable psychologically & physically, is an essential factor for users of buildings or indoor environments. In summary, thermal comfort means satisfaction with hygrothermal condition, without feeling any sensation of heat or cold [17]. In other words, the thermal state of human body should stay neutral, meaning the body do not need to reduce heat loses or increase heat gains [16]. There are two environments category for measuring thermal comfort: 1. Moderate environments 2. Severe environments. For residential buildings, offices & educational places we refer to moderate environments.

The human body produces heat, exchanges heat with the environment, and loses heat by diffusion and evaporation of body liquids. During normal activities these processes result in an average core body temperature of approximately 37°C [18]. Whenever the balance between human body temperature & environment is contradicted, the discomfort situation occurs. There are numbers of dependents contributing to thermal comfort achievement such as air temperature, humidity, air velocity, clothing, metabolism etc. A model was developed by Fanger (1970) to calculate thermal comfort, called PMV/PPD model. Standard thermal comfort surveys ask subjects about their thermal sensation on a seven-point scale from cold (-3) to hot (+3). PMV equal to zero is representing thermal neutrality, and the comfort zone is defined by the combinations of the six parameters for which the PMV is within the recommended limits (-0.5<PMV<+0.5) [17] [19]. Fanger's research & model led to creation of a psychrometric chart by ASHRAE Standard 55-2017, that, uses the PMV model to set the requirements for indoor thermal conditions, that requires at least 80% of the occupants must be satisfied.

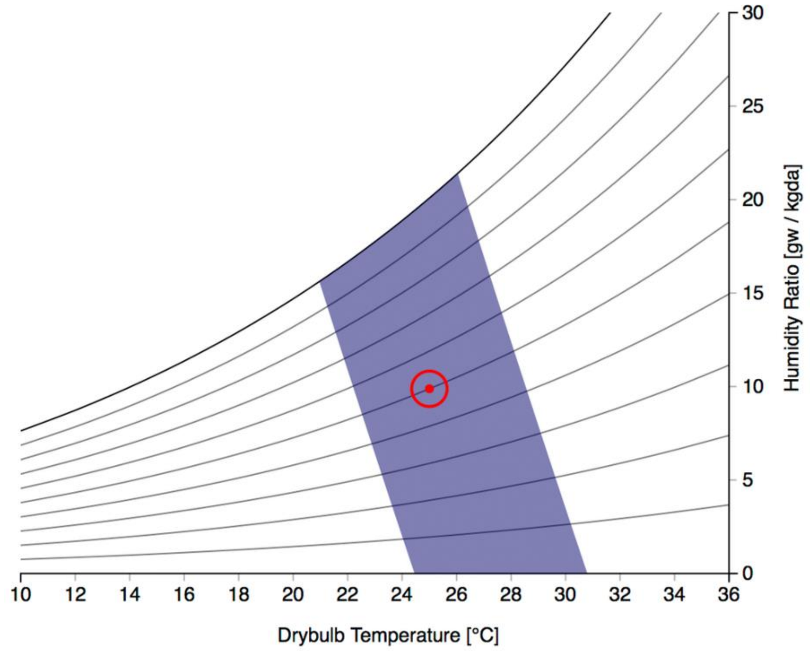


Figure 8 - Psychrometric Chart of thermal comfort zone. (Source: Center for the Built Environment, University of California Berkeley)

Figure 8, represents the acceptable combination of air temperature and humidity values, according to the PMV/PPD method in the ASHRAE 55-2010 Standard. The comfort zone in blue represents the 90% of acceptability, which means the conditions between -0.5 and +0.5 PMV, or PPD < 10%.

2.5. Climate Analysis

2.5.1. Definition

In perspective of a sustainable & energy efficient design, climate analysis always has a key role in setting considerable limits or guidelines. Parameters such as indoor/outdoor temperature, cooling & heating degree days, wind direction & its velocity, solar irradiance, etc are among the most important ones which are determined according to the geographical location of the case study.

2.5.2. Air Temperature

Normally, it is measured by meteorological stations and provides information about the external behaviour of weather besides, ranges of quantities either in monthly pattern or hourly profiles. External air temperature is one of the most important factors that affect energy consumption of buildings.

2.5.3. HDD & CDD

Heating degree days (HDD) is one of the main measurements that is designed to quantify demand of energy based on outdoor temperature. In this case firstly, we need to acquire the location of case study to understand the local climate condition and outside temperature trends and reach the number of days that we need for seasonal heating of the building, to quantify the energy demand. Obviously, cooling demand calculations it is necessary to specify the number of warm days that need air-conditioning (CDD) [20].

2.5.4. Base Temperature

HDD & CDD are relative to a concept called base temperature. It refers to a specified limit of outside air temperature, that buildings do not need heating energy in cases of equal or higher degree of that limit [21]. In other words it is the minimum/maximum temperature that thermal comfort would be achived.

$$\mathrm{DD} = \sum_{j=ngr} \left(t_{i,j} - t_{e,j}\right)$$

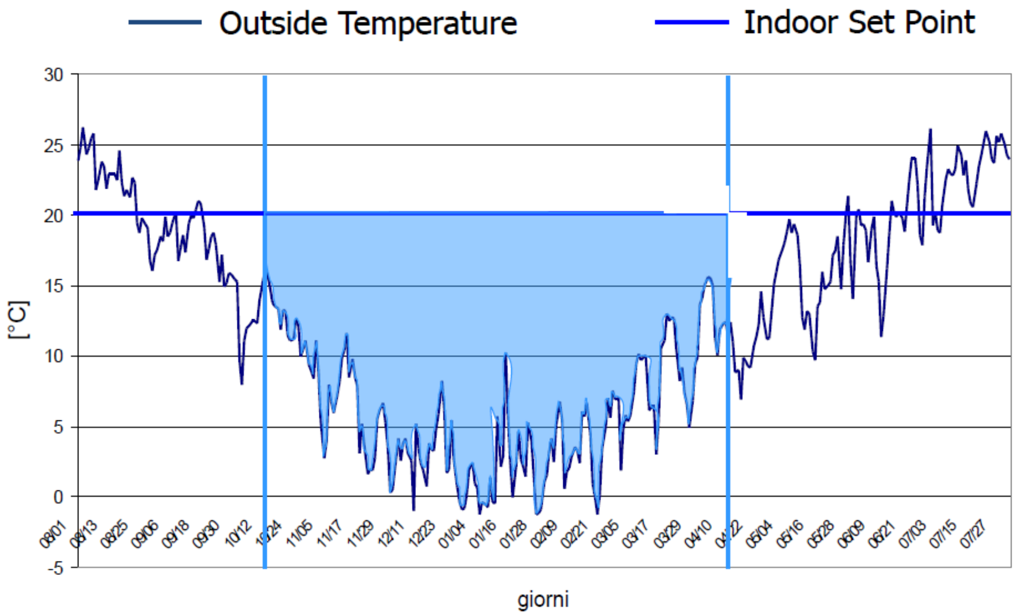


Figure 9 - Daily Temperature Data with winter period & Thermal Comfort setpoints. (Source: Prof. Favoino, Fabio. "HDD & CDD." Designing with Climate-Building Physics. 10 October 2019, Politecnico di Torino. Slide 8)

2.6. Urban Scale Energy Models

2.6.1. Intro

As discussed before, growing cities have crucial role in future energy scenarios. Therefore, for having more realistic & efficient policies, the energy estimation at urban or neighbourhood scale would be a practical tool for finer decision makings & scenario predictions.

2.6.2. Characteristics

When it comes to urban scale energy models (USEM), there is not only buildings characteristic, but different characteristics regarding the creation of a precise energy estimation for built up environments. Based on Mutani and Todeschi research, built-up urban context is another fundamental factor in simulation of USEMs. Apart from urban context there are other characteristics to be counted including buildings typologies & geometry with their relevant cooling/heating systems efficiency, plus, social characteristics like behaviour of occupants & type of users. Applying USEMs will give us the opportunity to describe energy consumption patterns all over a studied territory with providing the perception of critical areas and consequently quantifying GHG emissions. The methodology is appliable in any urban context, although the use of data & strategies is different, due to the various built environments with different locations & cultures. USEMs usually utilize three approaches: top-down, bottom-up, and hybrid. At last, it should be possible to identify the energy model and input database is accurate and reliable by comparing results with wide-ranging data on measured energy consumptions to validate the model [22].

2.6.3. Top-Down / Bottom-Up Approaches

Urban building energy models take three distinct approaches: top-down, bottom-up & hybrid. The top-down models treat a group of buildings as a single energy entity, where energy consumption is often estimated at the building sectoral level without considering differences among individual buildings or end-uses. In contrast, bottom-up modelling approaches focus on individual buildings and end-uses, so that energy consumption is modelled for individual end-uses within the buildings, which can be aggregated to the urban, state, regional, or national scale [23].

Regarding top-down method, the advantage is using a limited amount of input data which mainly focuses on aggregated socio-demographic and market economic factors. So, detailed information about buildings technology or energy consumption data is not necessary. In addition to economic variables, physical factors such as weather or climate data are also used in some cases od applying a top-down model [23].

Bottom-up method is categorized in two types: statistical & physics-based methods. The former is more or less similar with top-down approach in the terms of usinig socio-economic factors, however it uses usually disaggregated & more detailed data regrading the energy use of individual buildings. Furthermore, it is relied on long-term historical data. On the contrary, physics-based simulates energy consumption based on the physical characteristics of individual buildings, such as building geometry, non-geometric features (e.g., heating, ventilation and air conditioning (HVAC) systems, usage patterns, and building envelope), and user characteristics [23].

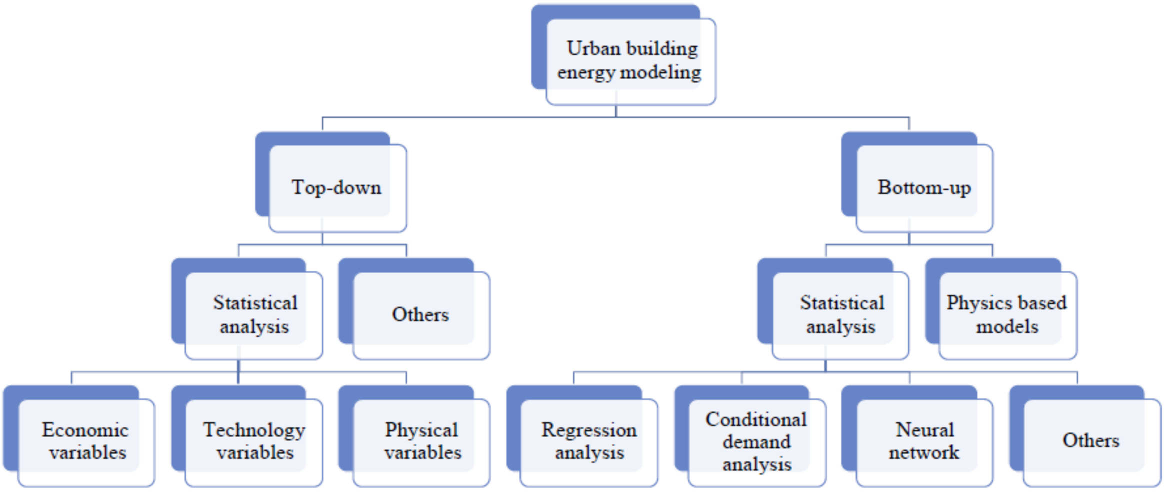


Figure 10 - Hierarchy of the urban building energy modelling approaches. (Source: W. Li et al. / Modelling urban building energy use: A review of modelling approaches and procedures (2017)) [23]

2.6.4. Statistical Method

It can be counted different classification for statistical method analysis, but the method that used in this case study, is multiple linear regression analysis. Normally, in linear regression analysis there are two types of variables: dependent (in this case energy consumption) & independents (energy related variables). The output will provide us information about which features or input data have the most influence on varying a data such as energy consumption, at different scales, and, with smaller deviation compared to real data [24].

As mentioned before, statistical methods are used to analyse building energy use based on market, economic and socio-demographic data [23].

2.6.5. Tools

There are numbers of tools and techniques for energy simulations such as CitySim, UrbanSim (UCB), Urban Modelling Interface (UMI) & GIS. Apart from GIS, the other tools have some limitations in use. The problem of these models is they need to process a large amount of data at different scales, therefore, it is likely to have lack of availability of some data or lack of variables that have more influence on energy consumption [22]. On the other hand, geographic information system (GIS) is able to geo-referenced all input data and present multi layered maps of different outputs, moreover its more flexible in managing data.

3. Methodology

3.1. Top-Down Energy Model

As it is learned from chapter state of the art, there different approaches for energy modelling that is consisted of top-down, bottom-up & hybrid. In this research project the model is created with a top-down approach. The energy consumption data is available at district level & it was provided by the local company gas supplier. Then the consumption of natural gas is calculated with multiple linear regression models and afterward calibrated by the real data. This model is later applied for calculation of micro scale areas of census sections that are located inside the districts of city.

3.2. Energy Related Variables Identification

The first step to start creating an energy model at city scale is to discover the variables that have the most effect on consumption profile. Obviously, there are numerous factors which could be influential on energy consumption including micro climatic factors, urban physical characteristics, buildings geometry & social parameters like population. In this chapter, all the variables that has been used in this research are presented. These variables can be extracted directly from database or generated during work procedure.

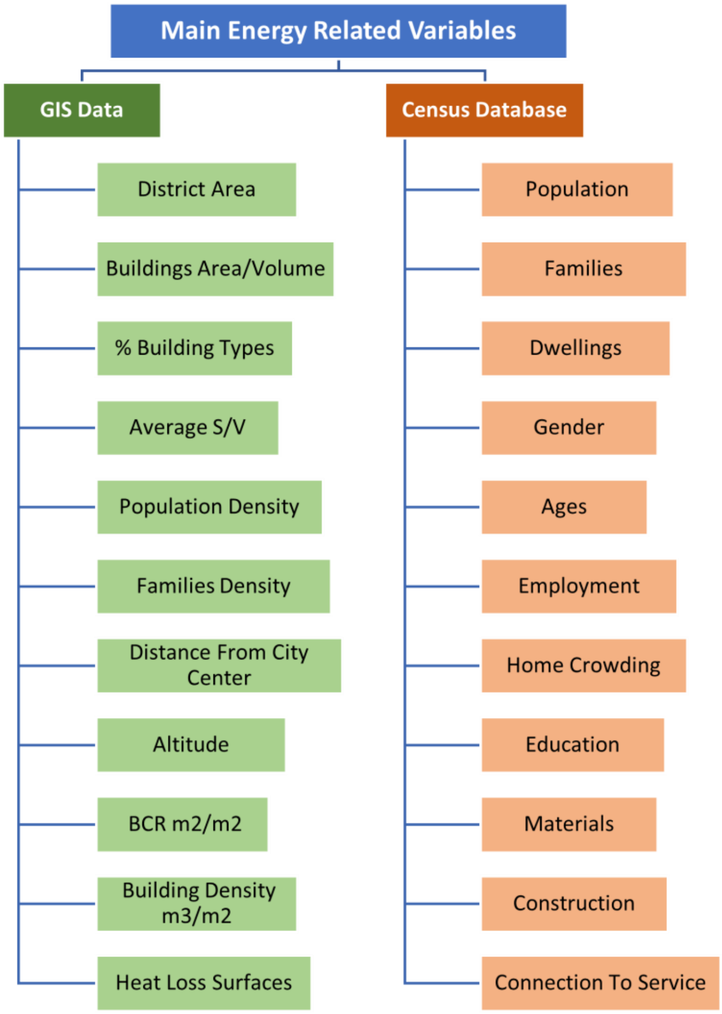


Figure 11 - Classification & Types of Energy Related Variables (By Author)

3.2.1. Local Census Database

A complex domestic database is provided by local company that supervises this research. This database is containing critical information about population, households & dwellings with reference year of 2010.

The population data is containing information about below topics:

- Gender
- Age groups
- Household relationships
- Nationality
- Educational background
- Employment situation

The household part is providing information about below topics:

- Number of families
- Building's material types
- Number of rooms
- Home crowding
- Number of people in families

The dwellings database is consisted of:

- Types of housing
- Occupancy situation of houses
- Materials quality
- Construction quality
- Connection to services quality

All above data are later presented as either percentage of their distribution or in aggregated numbers.

3.2.2. Heating Degree days Calculation

There are two methods for calculating HDD/CDD which are called "Integration Method" & "Approximation Method". Deciding which one to use is depending on type of data provided by weather stations. In integration method the data set could be provided as temperature change of hourly data, that has higher precision. However, in approximation method temperature could be considered only as highest and lowest record by weather stations. In both cases, for HDD/CDD calculations we have to multiple the number of days to temperature differences of the relevant day:

$$DD = \sum \text{Days of winter/summer period} \times (T_{base} - T_{external})$$

- T_{base} = Thermal comfort limit temperature, in Mendoza is 18 °C for winter.
- The winter period in metropolitan area of Mendoza begins from April 1st and lasts until end of October.
- The external air temperature has acquied from local weather stations data

HDD 2016

Temperature Below or Above Comfort (18 °C)				Numbers of Days								
				30	31	30	31	31	30	31		
				Winter Period								
2007	7.6	6.0	3.0	-1.3	-7.8	-9.9	-11.0	-11.0	-2.8	2.0	3.9	7.1
2008	7.4	5.9	3.2	-1.1	-5.4	-10.1	-7.7	-6.7	-3.6	1.2	6.3	7.0
2009	7.3	7.4	5.7	2.0	-4.7	-8.4	-10.0	-4.6	-5.4	1.3	4.9	6.1
2010	9.3	7.0	5.8	-1.6	-5.9	-8.6	-10.9	-8.0	-3.1	0.5	4.0	7.1
2011	7.4	5.1	3.0	0.1	-5.6	-9.4	-10.2	-7.8	-1.8	0.3	5.0	7.6
2012	9.2	6.8	4.8	-0.9	-4.5	-8.6	-10.1	-6.7	-1.9	0.6	5.3	7.6
2013	8.1	7.4	2.4	0.0	-4.5	-7.1	-9.5	-7.2	-5.5	2.2	4.7	9.5
2014	9.6	4.1	2.0	-1.7	-5.2	-8.6	-9.0	-4.9	-1.8	3.3	4.2	6.4
2015	8.9	5.5	5.0	1.1	-4.2	-7.4	-8.8	-5.0	-3.2	-3.6	1.7	6.7
2016	7.3	7.9	3.2	-3.3	-6.7	-10.2	-9.0	-4.0	-2.8	1.0	4.3	7.0

HDD

							TOTAL
2007	37.556	242.39	297.83	339.56	339.94	83.222	0	1340.5
2008	32.056	167.5	302.72	237.83	207.67	106.61	0	1054.4
2009	0	145.33	253.39	308.67	142.17	161.72	0	1011.3
2010	48.944	182.72	258.22	339.44	247.33	94.111	0	1170.8
2011	0	172.89	282.11	317.56	240.67	54.556	0	1067.8
2012	26.278	139.17	258.28	312	207.72	56.778	0	1000.2
2013	0	139.39	212.83	295.22	222.06	164.14	0	1033.6
2014	50.778	161.72	259.22	280.06	152.39	54.778	0	958.9
2015	0	130.67	223.17	271.61	155.44	96.778	113.11	990.8
2016	99.944	208.17	305.83	279.72	122.56	85.172	0	1101.4

Figure 12 - Sample of HDD Calculation for Years 2007-2016 (By Author)

3.2.3. Altitude difference & Normalization

As explained previously, air temperature is a key factor in affection of energy consumption, however, air temperature itself can be under influence of altitude. In metropolitan area of Mendoza, the altitude varies between minimum of 704 m a.s.l. & 1012 m a.s.l. maximum. These values have been acquired from raster file of digital terrain model (DTM) that is provided by local database. Regarding this, the DTM raster inserted in GIS & then by using “raster pixel to points” tool, it is possible to choose the generated points inside each district & by taking an average out of them, discover the altitude of all districts separately.

Since, Altitude changes in different location in Mendoza it is necessary to consider temperature changes in these locations as well. Consequently, to understand such changes, the energy consumption data should be normalized based on altitude increase & HDD calculations to evaluate differences in energy data more precisely.

To normalize the energy consumption based on altitude change, it is essential to normalize temperature first. The reference for this calculation is UNI 10349 standard. The formula calculates normalized temperature based on information of a reference meteorological stations. Therefore, a base temperature is needed alongside of the altitude of the reference weather station.

$$T = T_{ref} - (Z - Z_{ref}) \times d$$

However, in this case, because we have HDD as a variable that acquired from temperature ranges, it is possible to normalize HDD instead and calculate it for each district with its specific average altitude. In Mendoza T_{base} for HDD is 18 °C.

$$(18 - T) \times \text{days} = \textbf{HDD} \Longrightarrow (18 - T) \times \text{days} = \{18 - [T_{ref} - (Z - Z_{ref}) \times d]\} \times \text{days}$$

$$\Longrightarrow HDD = HDD_{ref} + (Z - Z_{ref}) \times d \times \text{days}$$

Regarding d factor, it should be mentioned that for Mendoza case wasn't available, therefore, it is calculated as a ratio between temperature & altitude differences between the examining weather station & the reference one.

$$d = (T_{ref} - T) / (Z - Z_{ref})$$

Finally, by having normalized HDD we are able to calculate the normalization of energy consumption data. The weather station "Russel" is chosen as the reference with altitude of 850 m a.s.l. & HDD of 1456 for year 2016.

$$\frac{Energy\ Consumption}{Energy\ Consumption\ \boldsymbol{norm}} = \frac{HDD}{HDD\ Russel}$$

$$Energy\ Consumption\ \boldsymbol{norm} = \frac{Energy\ Cosumption\ \times HDD\ Russel}{HDD}$$

3.2.4. Residential Buildings Geometry

Building's parameters have always important influence on energy consumption, consequently, one of the most important steps in energy modelling is to identify & generate the geometry parameters of buildings. It is worth to mention that all the geometries less than 32 m2 have been deleted as they can't be considered as residential buildings.

The following generated variables are calculated by GIS tool field calculator for case study of Mendoza.

Buildings Height: according to the local database information, the number of floors for each building is provided in relevant shapefiles, also the average height of one floor in Mendoza is equal to 3. So, buildings height calculation is achieved by multiplying these two variables:

$$H_{\text{Building}} = N_{\text{floors}} \times 3$$

Buildings Footprint Area: The area of external envelope of buildings on the ground floor, calculated by area function in GIS.

Buildings Volume: by multiplying of footprint area with acquire buildings height:

$$V = A_{\text{footprint}} \times H_{\text{buildings}}$$

Gross Heated Area: Achievable by multiplying the footprint area with number of floors in Mendoza:

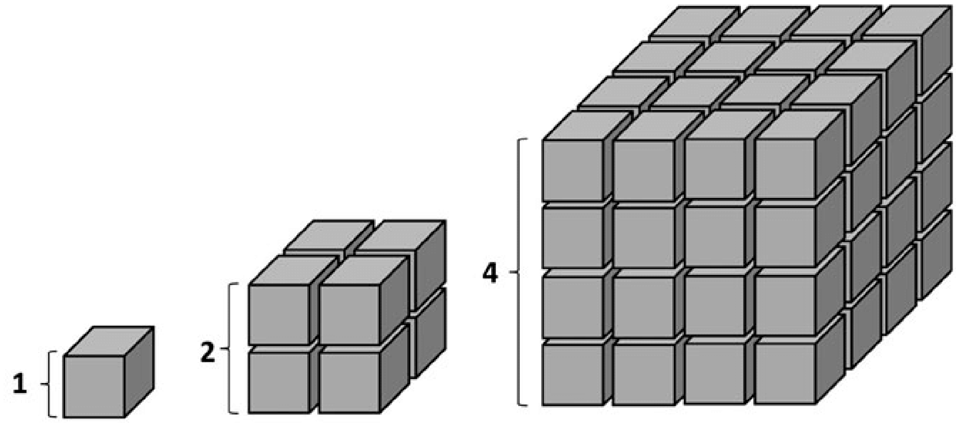
$$A_{\text{Gross}} = A_{\text{footprint}} \times N_{\text{floors}}$$

Heat Loss Surface: it is the summarized area of buildings surfaces that are in direct contact with outdoor environment. To calculate the parameter the general formula is given below:

$$S_{\text{loss}} = (A_{\text{footprint}} \times 2) + (\text{Perimeter} \times H_{\text{building}})$$

Surface to Volume Ratio: the parameter aims to evaluate the compactness of buildings. The less S/V value means a more compact building. It is defined by dividing the heat loss surface over the volume of building:

$$S/V = S_{loss} / V_{building}$$



Side of Cube	Area of side	Area of cube surface	Volume	Ration of surface area to volume
1 cm	1 cm^2	6 * 1 cm^2	1 cm^3	6/1
2 cm	4 cm^2	6 * 4 cm^2	8 cm^3	24/8 =3/1
4 cm	16 cm^2	6 * 16 cm^2	64 cm^3	96/64 = 3/2

Figure 13 - Changes in the surface area to volume ratio of a cube.

(Source: Pouran, Hamid. (2018). Engineered Nanomaterials in the Environment, their Potential Fate and Behaviour and Emerging Techniques to Measure Them. 10.1007/978-3-319-58538-3_95-2.) [35]

Although, in reality, buildings in an urban environment share some surfaces with each other. So, there will be some overlaps between at least one building with the other. Therefore, these overlaps must be extracted from heat loss surface calculation.

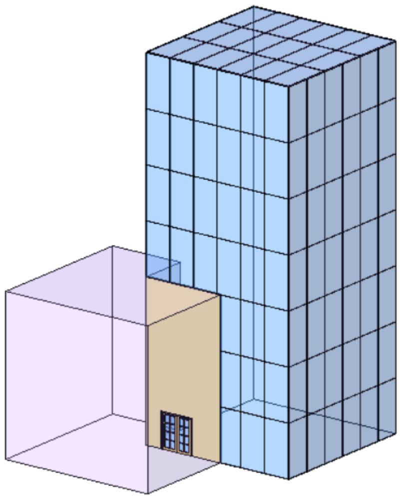


Figure 14 - Sample of adjoining wall between two buildings surfaces (Source: Autodesk.com)

Regarding eliminating shared walls between buildings for heat loss surface calculations, a method in GIS tool has been used to solve the issue. At last, for eliminating the indoor unheated spaces the S/V should be multiplied to a multiplicative factor that is given in following table.

Buildings Typologies: After calculation S/V values for all the buildings, the results have been classified in 5 different ranges. Based on these ranges the residential buildings typologies are identifiable.

Typology	Tower	Condominiums	Mixed	Mostly Detached	Detached
S/V	< 0.45	0.45<S/V< 0.92	0.92<S/V< 1.23	1.23<S/V< 1.38	1.38<S/V< 1.76

Table 1 - Different classes of S/V & their relevant multiplicative factor (By Author)

3.2.5. Population & Family Density

By having summarized area & volumes of buildings in each census section, it is possible to calculate the population or family density for each section, simply by dividing their value over summarized m2 or m3 of buildings at census scale.

3.2.6. Urban Morphology Factors

To have a better understanding of urban environment of Mendoza & also to find more energy related variables, the following parameters were calculated.

Building Coverage Ratio: is the ratio between the built surface (plan) and the census section surface (m2/m2).

$$BCR = \sum A_{\text{building}} / A_{\text{census}}$$

Building Density: it is defined by ratio of total volumes of a building inside a census section divide by the relevant area of that section. Higher the value of building density is, the denser is the area & vice versa.

$$BD = \sum V_{\text{building}} / A_{\text{census}}$$

Distance From City Center: it is the calculated distance from each district center to the center of metropolitan area of Mendoza, which in this case is located in independence square of capital department & district of "Segunda Seccion", where the big extension of the city began in 19^{th} century. The parameter is a suitable measure for gaining idea about the situation of urban heat island effect in the city & identification of peripheral areas.

3.3. Data Integration at District Level

3.3.1. Data Aggregation of Census Sections

In this stage all the calculated or referenced data from previous stage was gathered, to combine & integrate with energy consumption data (natural gas), for having a complete overview of each district or department characteristics, besides, analysing all these data in order to find the most energy related variables with energy consumption. Since, most of the acquired data is available at census scale, & on the other hand, the energy consumption data is at district scale, so, it was necessary to summarize all data of the census sections of each district. Thus, all the variables will be in same scale & balanced.

Department	Districts	Census No.	Perimeter	Area
Capital	Cuarta S.	27	9,029.65	3,193,480.11
	Primera S.	17	5,579.03	1,635,482.25
	Quinta S.	24	6,963.95	2,442,873.63
	Segunda S.	33	6,765.93	2,341,492.41
	Sexta S.	24	7,229.26	2,720,978.42
	Tercera S.	17	5,178.43	1,502,809.53
Godoy Cruz	Ciudad (GC)	106	14,815.04	12,240,623.95
	Gob. Benegas	26	9,615.25	3,993,820.96
	Las Tortugas	33	10,193.63	4,873,152.58
	Pr. Sarmiento	42	30,621.60	5,875,615.26
	S. Fr. del Monte-GC	13	9,599.59	5,344,194.23
Guaymallen	Belgrano	34	9,703.11	4,596,361.13
	Bermejo	14	12,552.11	5,493,452.35
	Buena Nueva	11	12,012.53	5,681,397.35
	Capilla del Rosario	19	8,372.88	3,580,712.38
	Dorrego	35	10,246.18	4,727,571.00
	El Sauce	7	25,624.88	3,285,776.99
	J. Nazareno	7	8,088.38	3,682,870.65
	Las Canas	17	7,863.95	2,919,814.32
	Nueva Ciudad	9	6,514.29	1,531,987.53
	Pedro Molina	11	6,316.32	1,565,061.36
	Rodeo de La Cruz	21	11,128.04	7,772,629.55
	S. Fr. del Monte-Gy	8	9,318.91	4,072,746.38
	San Jose (Gy)	16	6,592.00	2,143,717.43
	Villa Nueva	41	12,082.21	6,255,646.90
Las Heras	Ciudad (LH)	39	12,710.46	5,038,775.02
	El Challao	28	84,874.78	7,461,273.03
	El Plumerillo	32	17,478.89	8,647,583.43
	El Resguardo	17	12,687.81	5,011,122.15
	El Zapallar	14	6,289.85	1,853,809.42
	La Cieneguita	17	10,469.40	4,044,792.86
	Panquegua	14	6,348.06	1,762,217.06
Lujan	Carrodilla	23	16,277.35	14,033,242.36
	Chacras de Coria	15	22,002.62	14,572,632.05
	Ciudad (L)	29	17,944.20	6,923,316.69
	La Puntilla	3	5,487.08	1,220,172.20
	Mayor Drummond	10	19,568.36	5,729,549.61
	Vistalba	9	27,218.54	19,825,350.95
Maipu	Coquimbito	15	25,055.28	34,676,705.59
	Gen.Gutierrez	18	16,332.47	7,458,604.70
	Luzuriaga	21	15,123.72	8,602,004.04
	Maipu	44	20,754.00	19,432,257.65

Table 2 - Departments & Districts of Mendoza (By Author)

Census Data (2010)

- Population
- Families
- Materials
- Group Ages
- Employment
- Education

GIS Data

- Buildings Geometry
- S/V
- HDD
- Altitudes
- Buildings Types
- BCR
- Building Density
- Inhabitants Density

Annual Energy Consumption Data (2016)

- kWh
- kWh/m2
- kWh/family

(With & without normalization)

3.3.2. Annual Energy Consumption Data

The energy consumption data is available annually in kWh. Relatively, for better understanding of energy efficiency 5 other scenarios were generated. Firstly, the kWh data is normalized based on altitude change for discovering the temperature change effects on consumption. At last, for each scenario of normalized kWh & kWh, 2 other outputs are generated, kWh/m2 & kWh/family.

Energy Consumption Statistical Model Results in 6 Scenarios		
	(Not Normalized)	kWh
		kWh/m2
		kWh/family
	(Normalized) Based on Altitude	kWh
		kWh/m2
		kWh/family

Table 3 - Menodza Annual energy consumption scenarios (By Author)

3.4. Sensitivity Analysis

3.4.1. Intro

Since, the quantity of input variables is quite high & there is uncertainty about the one that have high influence on energy consumption, a sensitivity analysis is adopted to find the most energy related variables among the total data series. Another reason for applying the sensitivity analysis is to find out the relationship between input variables & targeted data, which in this case the relationship between main energy related data & energy consumption data is studied [25].

3.4.2. Correlations

For this project the correlations analysis has been adopted regarding sensitivity studies. Correlations describe how two variables are related in statistical models with a linear behaviour & constant rate [26].

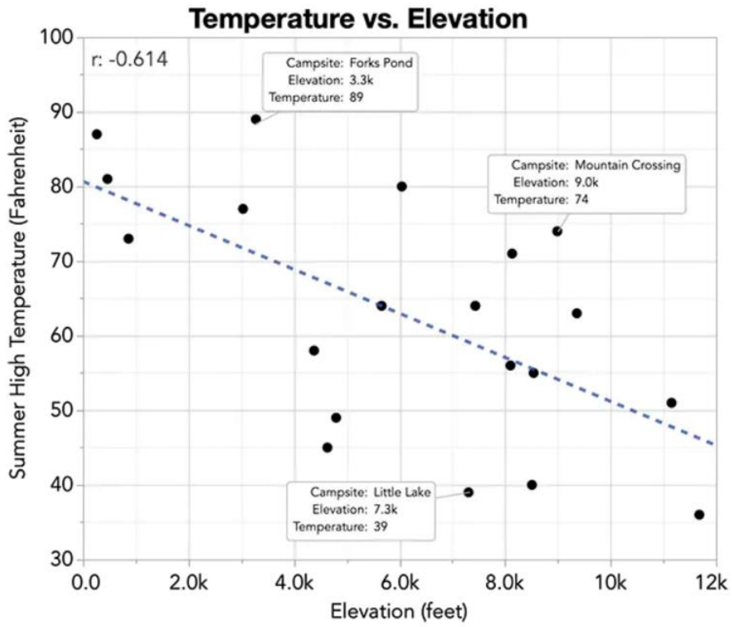


Figure 15 - Sample of linear behaviour of variables in correlation analysis (Source: www.jmp.com)

Correlations express the data relationships with a unit-free measure called correlation coefficient and it ranges between +1 & -1. The closer this value to zero is, signifies a very weak or no correlations among variables. On the other hand, a positive value show that both data has a positive effect on each other, means by increasing one of them also other one increases. Although, about negative correlation the story is vice versa, and two variables will have opposite behaviour.

3.4.3. EXCEL Tool

For this project the correlations are made by EXCEL tool, between energy related variables from created database & the existing energy consumption data by supplier. Table 3 below illustrates a sample of these results.

Sample Of Aggregated Variables of All Districts

CORRELATIONS	Perimeter depatimentos	Area depatimentos	Total Population	Total Families	Pop/Families	Vivienda number of dwellings
Natural Gas	0.24	0.64	-0.22	-0.15	-0.23	-0.12
kWh / m3	0.37	0.02	0.28	0.19	0.36	-0.01
kWh / m2	0.35	0.00	0.21	0.12	0.29	0.00
kWh / m2 GROSS	0.37	0.02	0.28	0.19	0.37	0.00
Normalized consumption based on:						
(Altitude) kWh	0.16	0.56	-0.19	-0.10	-0.24	-0.07
kWh / m2	0.31	-0.06	0.41	0.33	0.41	0.20
kWh / m3	0.33	-0.02	0.49	0.40	0.49	0.19
kWh / m2 GROSS	0.33	-0.02	0.49	0.41	0.49	0.19

Annual Energy Consumption Scenarios

Table 4 - Sample of correlation analysis results (By Author)

For this analysis the correlation above +0.30 or below -0.30 were considered good & significant for further steps.

3.5. Multiple Linear Regression Analysis

3.5.1. Intro

For this case study the statistical method that used is multiple linear regression analysis, done by EXCEL tool. It is a statistical technique which is based on one or two or even more variables (called explanatory or independent) for prediction of another variable called response or dependent. Therefore, in regression analysis there are two types of data:

1. Dependent variables
2. Independent variables

If there would be only one variable to predict the outcome one, then it is called simple linear regression. However, in presence of two or more independents, it will be called multiple linear regression analysis [27].

For Mendoza case as it is explained above, before starting multiple linear regression analysis all the data was integrated together at the same scale of energy consumption data. So, as same as the correlation analysis part, this time we do a regression analysis between most correlated energy variables & energy consumption data to find the prediction of consumption.

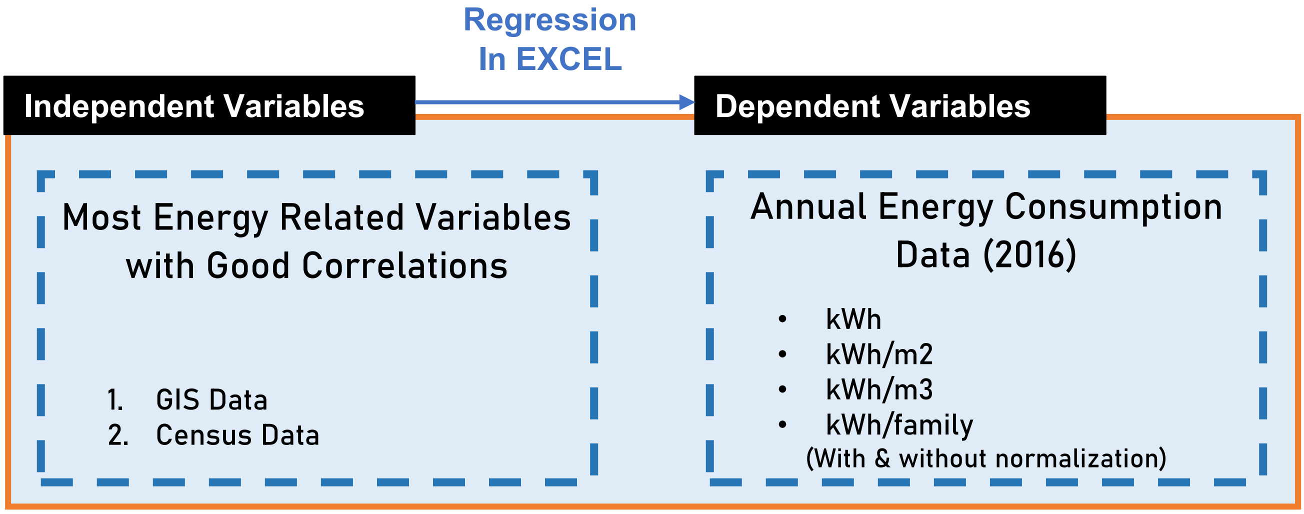


Figure 16 - Scheme of regression analysis between variables (By Author)

3.5.2. Regression Analysis Significance Test

After running multiple linear regression analysis there will be several elements to be controlled for determination of the significance of results. This means to have a perfect or high reliable model the regression must prove that the input data has a strong effect on energy consumption with high significance. Below each one of these elements are defined.

R Square Value (R2): Defines the percentage or amount of variation that is demonstrated by studied model. Higher the value of R square is, the better is model. In this project the R square values greater that 80% considered as significance.

R2 > 80%

Significance-F: In general, express if the model is significant or not.

Significance-F < 0.05

p-value: It is a test to observe how all coefficients values are close to zero. If values are much bigger that zero it proves that they don't have effect on dependent variable. So, p-value bigger than 5% would not be ideal.

p-value < 0.05

3.5.3. Validation of The Model

Mean Absolute Errors Calculations

After the creation of models, the output data is validated by real consumption data provided by local supplier "Distribudora de gas Cuyana". Since, the model only shows a prediction of output data there will be some errors in any case. These errors are observable in regression chart through differences between the trendline and predicted points [28].

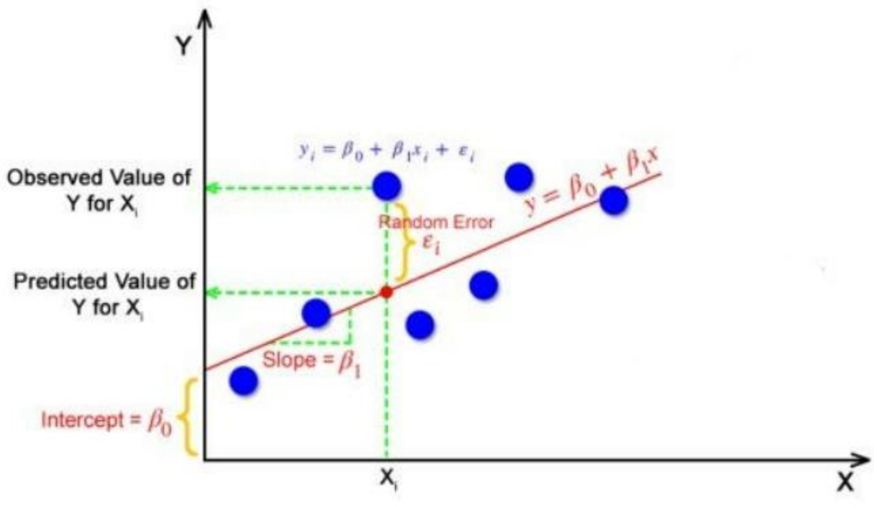


Figure 17 - Errors between variables in linear regression chart (source: Analytics Vidhya)

However, these errors can also be calculated through a formula that is called "Mean Absolute Error Percentage". With this calculation the percentage of error is identified through subtracting the predicted value from real data, then dividing it by the real data.

$$\textbf{MAPE} = \frac{|\,\textit{The Real Data} - \textit{The Predicted Data}\,|}{\textit{The Real Data}} \times 100$$

High Errors & Specific Modelling

Normally the maximum error percentage is 15 or 20 (for big areas), therefore, the data with higher errors could be considered as outliers and be separated from the main model for creation of its specific model type with new regression analysis. So, in case of the presence of outliers with high errors & same characteristics we would need a specific modelling for them.

3.6. Flowchart of Methodology

Below all the procedure in methodology chapter is summarized with a flowchart for better understanding of different steps and details.

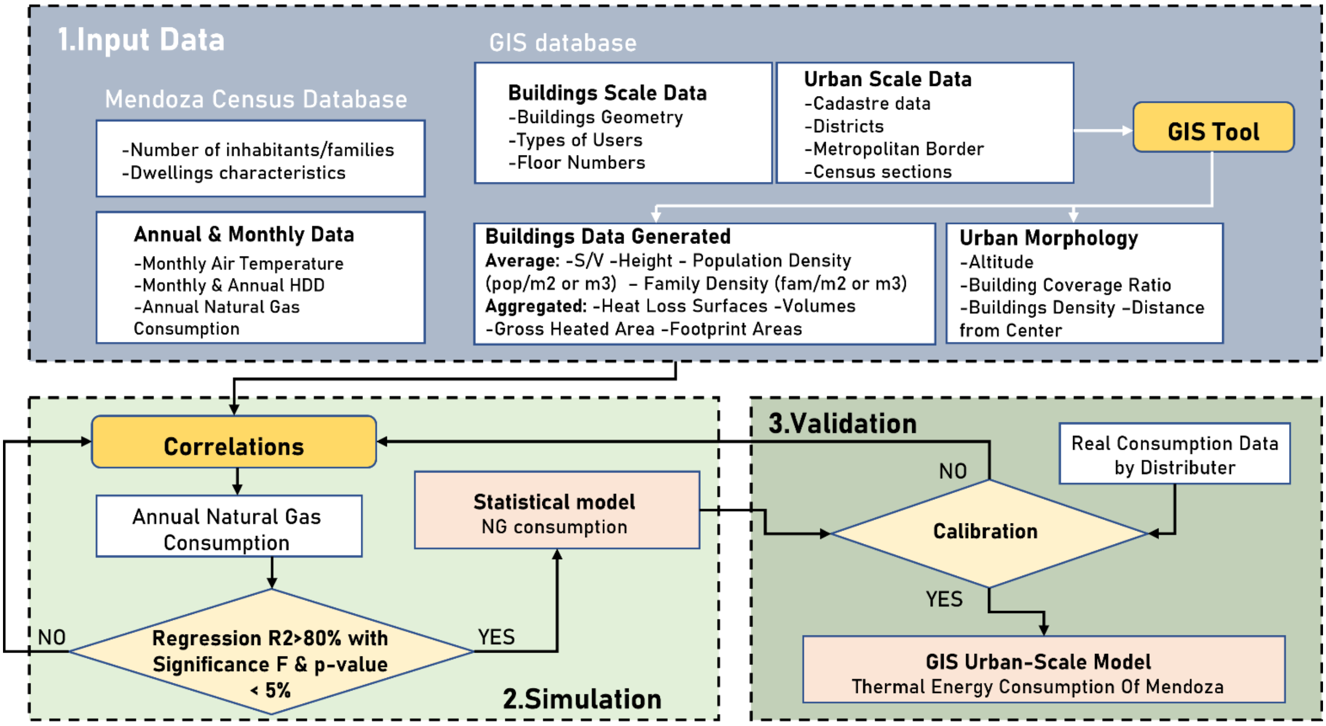


Figure 18 - Flowchart of The Methodology (By Author)

4. The Case Study

4.1. Location & Territorial Characteristics

Gran Mendoza, located in the province of Mendoza, Argentina, is a region known for its stunning natural beauty, thriving wine industry, and vibrant cultural heritage. Situated at the foot of the Andes Mountains, the territory of Gran Mendoza spans over 5,000 square kilometres (1,930 square miles) and encompasses six departments, which the city of Mendoza is in Capital department. Other departments that aggregate with Capital are Lujan de Cuyo, Las Heras, Maipu, Godoy Cruz, Guaymallen [29].

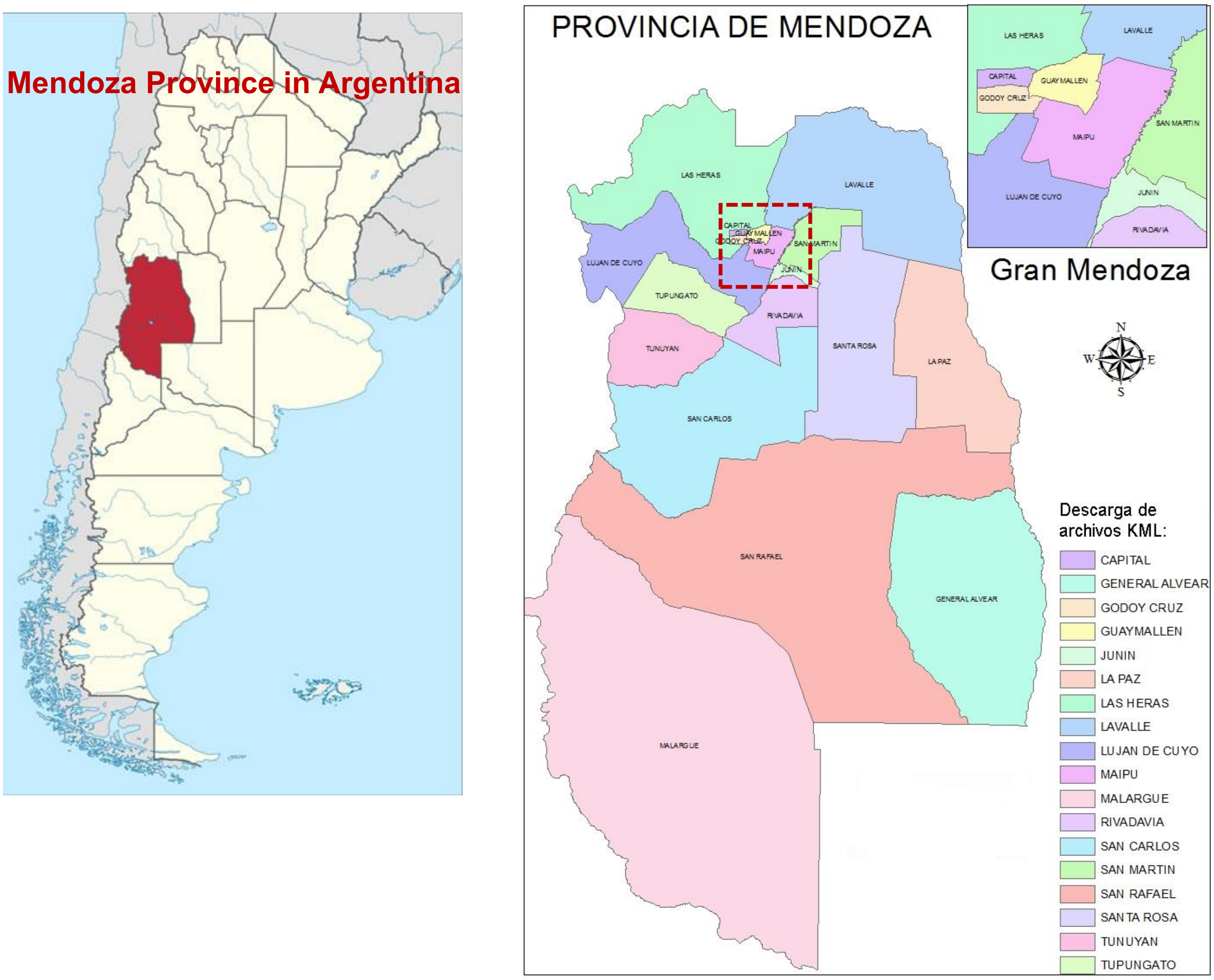


Figure 19 - Mendoza Province & Gran Metropolitan Area Locations (source:Todo Argentina & Social Mendoza Atlas Maps)

The territorial characteristics of Gran Mendoza are defined by its diverse landscapes. The region is dominated by the Andes Mountains, which provide a picturesque backdrop and contribute to the unique microclimates found within the area. The eastern part of Gran Mendoza consists of plains and valleys, where the majority of agricultural activities take place. The western portion is characterized by higher elevations, including the foothills and peaks of the Andes, offering breath-taking views and opportunities for outdoor recreation [29].

4.2. The Climate

4.2.1. Weather Characteristics

The climate in Gran Mendoza is predominantly arid and semi-arid, with warm summers and mild winters. The area receives an average annual rainfall of around 200 millimetres (7.9 inches), which is significantly lower than other regions in Argentina. The combination of low precipitation and high evaporation rates contributes to the aridity of the area with exposure to high solar radiation [30].

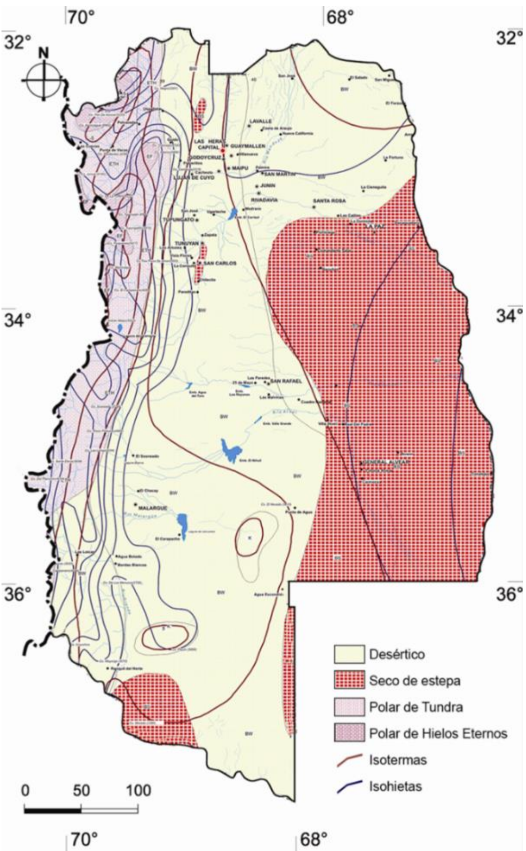


Figure 20 - The Climate Map of Mendoza Province (source: Conicet Incihusa-Local Database)

Summer period is hot with a temperature above 25 ^{o}C, while, during winter period weather is cold & dry with mean temperature below 8 ^{o}C. Winter begins from month April and last until end of October [30].

For using & analysing the climatic data it should be referred to meteorological stations which are in different spots of province. Meteorological stations are essential for monitoring and recording weather data in Gran Mendoza. These stations collect information such as temperature, humidity, wind speed, and precipitation levels, which help in forecasting and understanding the local climate patterns.

4.2.2. The Altitude Influence

Since Mendoza is located in eastern side of Andes mountains in Argentina, the altitude is quite diverse from one another. The median altitude of gran Mendoza is 740 m a.s.l. however, this ranges from 600 m a.s.l. n most north-eastern part of city to 1200 m a.s.l. alongside of foothills of Andes mountains. After analysis of DTM raster file in GIS, it is obvious that as we go further toward the west where Andes mountains begin, the altitude of region increases. In Figure 22, the surrounding of metropolitan area of Mendoza is illustrated.

As mentioned above the meteorological stations have key role in understanding of microclimatic data. For this research 3 weather stations are considered to use their Temperature & thermal comfort data in calculation of HDD & altitude normalization of NG consumption. The locations of these stations are specified in Figure 8. The stations & their relevant altitudes are:

-El Plumerillo /Airport (703 m a.s.l.) -Perdriel (960 m a.s.l.) -Russel (850 m a.s.l.)

Furthermore, based on database provided by CONICET Incihusa the thermal comfort limit of Mendoza is considered as 18 degree C. in Figure 9, the temperature changes during reference year of 2016 is shown in chart with specification of months which & three chosen weather stations registered data, which demonstrate the winter period of city & need of heating consumption regarding months that are below the thermal comfort line.

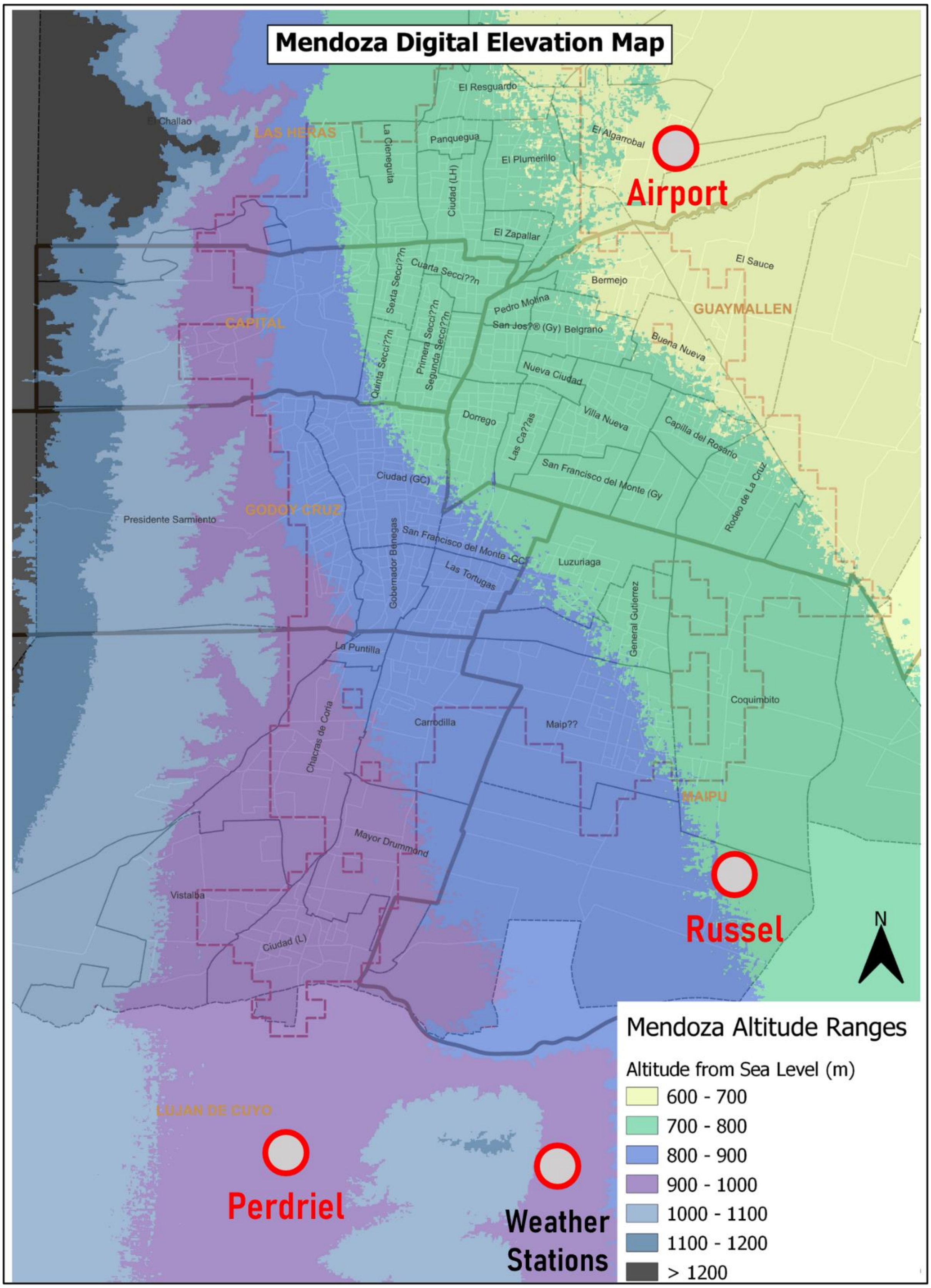


Figure 21 - The DTM Map of Gran Mendoza with Altitude Ranges (By Author)

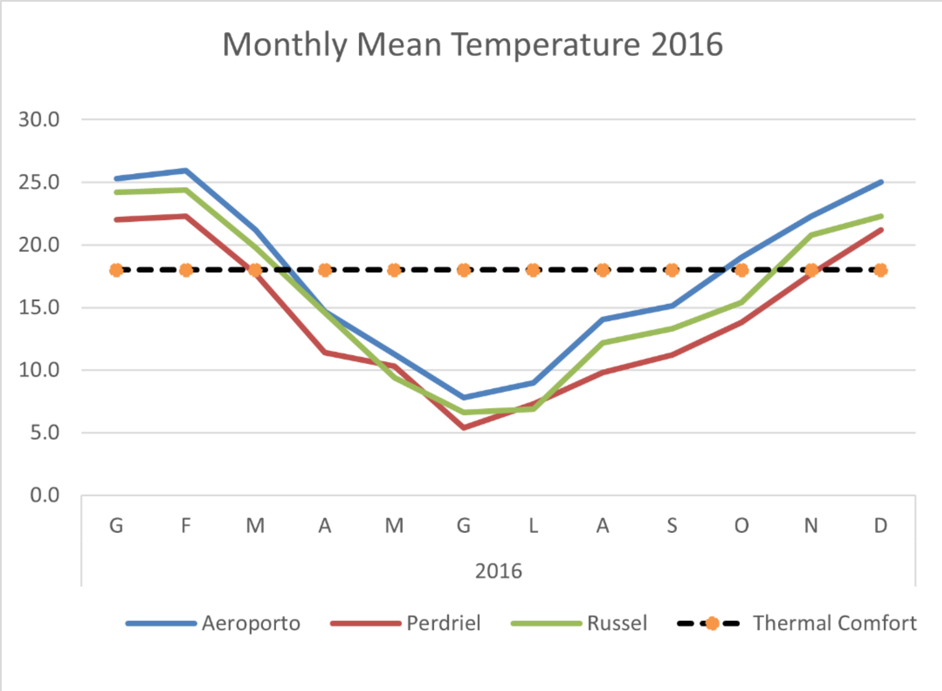


Figure 22 - Temperature Ranges of Meteorological Stations, Year 2016 (By Author)

4.3. Departments & Districts

The gran Mendoza area is consisted of 6 major departments. The city of Mendoza is located in Capital department which is the area that city was found primarily. Moreover, 5 other departments are aggregated with Capital as urban agglomeration. Departments of Las Heras to the north, Luján de Cuyo and Godoy Cruz to the south, Maipú to the southeast, Guaymallén to the east.

Furthermore, inside each of mentioned departments there are several districts. These districts vary according to size, population, building characteristics, altitude & so on. The most key point about these districts is that the energy consumption data is available at this scale, which later is used to scale all other data from smaller scale to predict the whole city consumption model & its most related variables.

Finally, there are census sections of each district, which contain several & important data sources of city loke populations, dwellings, material quality & so on. Census database is provided by CONICET Incihusa with reference year of 2010.

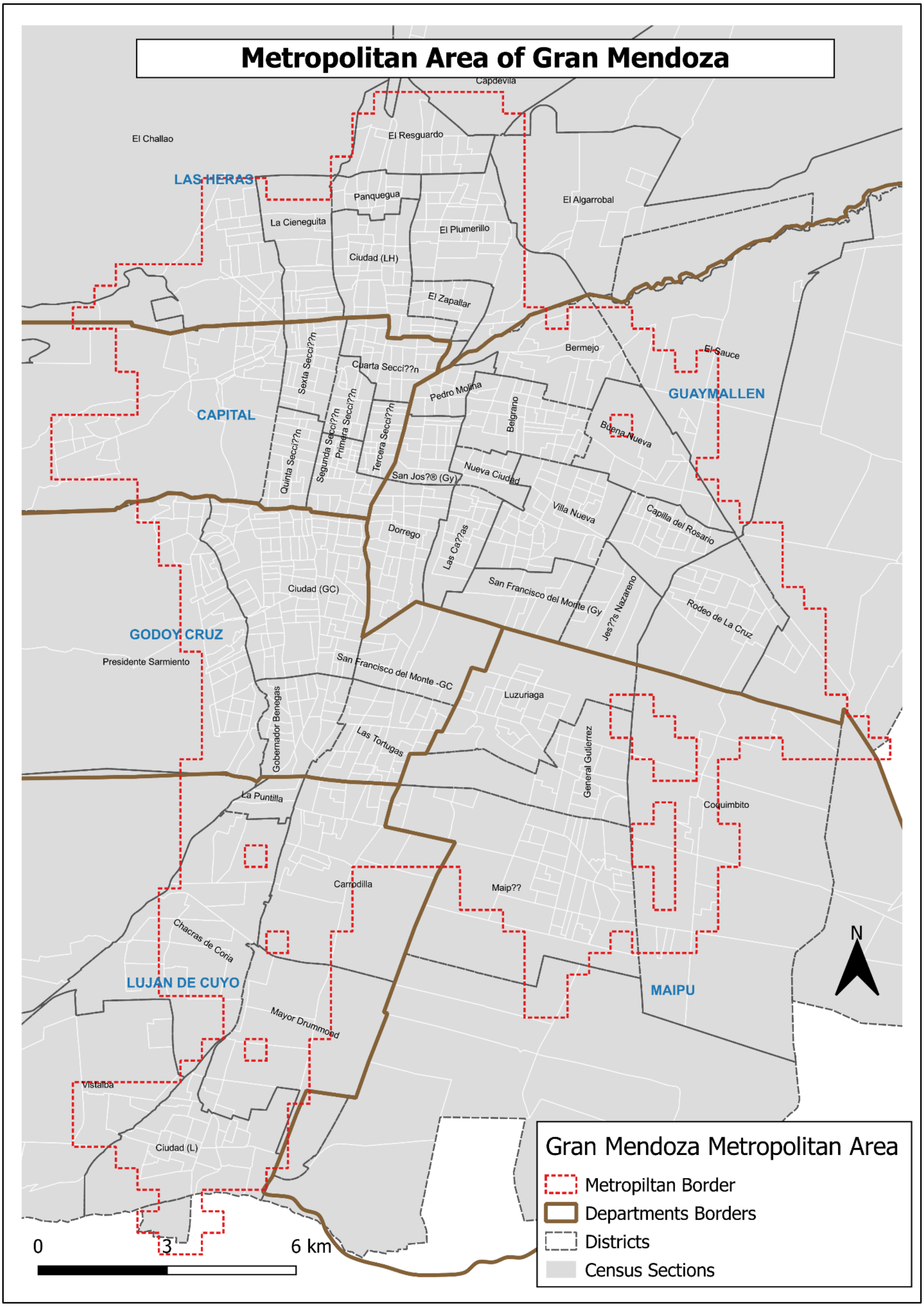


Figure 23 - Classification of Gran Mendoza Urabn Environmnet (By Author)

4.4. The City Center

Initially the city was founded in 1561, when Pedro del Castillo arrived in the Huentota Valley, and took possession of the region hoisting the royal standard. Between two sandstorms he founded the new City, naming it Ciudad de Mendoza del Nuevo Valle de La Rioja. The initial location of Mendoza was located in what is currently known as La Media Luna in the District of Pedro Molina (which was on eastern side of today Capital department) , located in the Department of Guaymallén , on the eastern bank of the channel currently known as Cacique Guaymallén. On the other hand, in 1861 a massive earthquake happened & destroyed much of colonial buildings. This event led to new construction of city in the area of the old Hacienda de San Nicolás, approximately 1 km southwest of the founding area [31].

Figure 24 - Mendoza City Centeral Area (source: gifex.com)

The base foundation of the new city of Mendoza that arose city from 19th century until this day, was arranged in 1863 by French surveyor Julio Balloffet and which includes the strategic arrangement of four smaller squares surrounding a larger square. This large square is called Plaza Independencia & the city is centered around it. This plaza is located in Capital department & district Segunda Seccion [31].

The central point is used to calculate the distances of other districts from city center to find peripheral areas & observe their distance from urban eat island effect.

4.5. The Population

It is worth to mention that at the time of carrying on this research, the census database was available only for the reference year of 2010, consequently, in future works using an updated data about population could result in more precise output.

The population of Gran Mendoza is approximately 937,154 inhabitants in 2010, 10% more than the 848,660 inhabitants registered in 2001 making it one of the most populous regions & fourth populated area in Argentina. The department of Mendoza, which includes the capital city, is the largest urban center in the region and serves as an economic and cultural hub. [31]

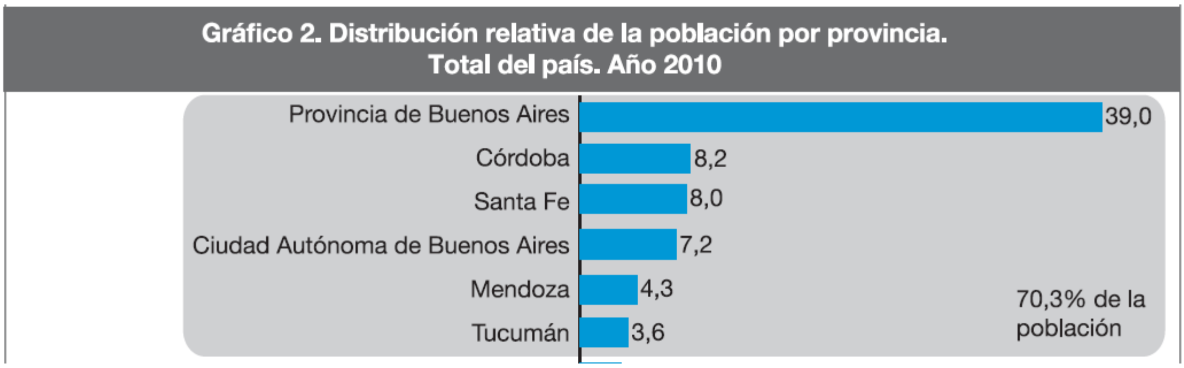


Figure 25 - Most Poulated Provinces of all Argentina (source: Instituto Nacional de Estadística Censos)

The most populated departments in gran Mendoza are firstly Guaymallen & secondly Godoy Cruz. Both are very big areas & situated around the Capital department, Guaymallen on eastern side & Godoy Cruz on the southern borders. In Figure 12 the pattern of population concentration in each department is shown.

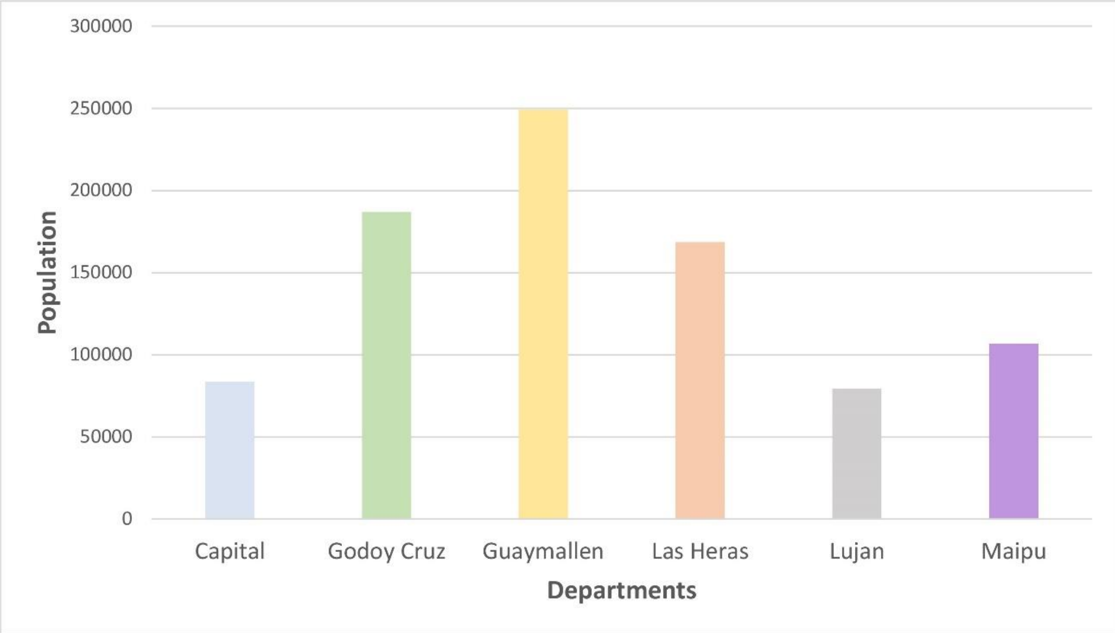


Figure 26 - The Population Distribution by Departments in Mendoza (By Author)

4.6. Residential Built Environment

After surface to volume ratios calculations for all the buildings of Mendoza by GIS, it is possible to make hypothesis at census scale to find residential characteristics.

After classification of S/V ranges at building scale, an aggregated average value of S/V calculated for each census section.

S/V values vary in following ranges:

1. 1.38 < S/V < 1.76
2. 1.23 < S/V < 1.38
3. 0.92 < S/V < 0.1.23
4. 0.45 < S/V < 0.92 (Condominiums)
5. S/V < 0.45 (Towers)

The results show that central area has the most concentration of condos, while, other places are mixed or mostly detached houses.

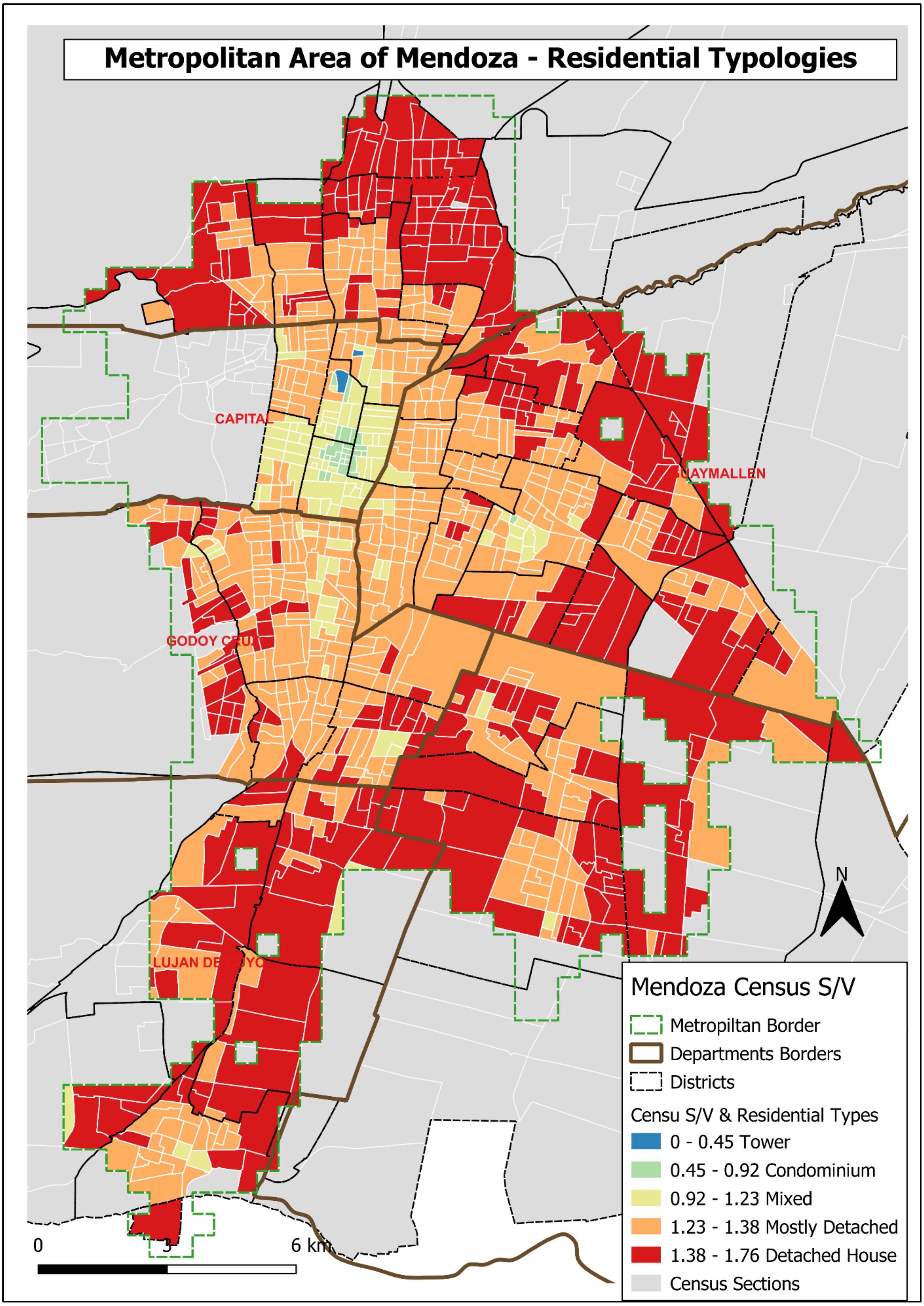


Figure 27 - The Map of Buildings S/V & Types at Census Scale (By Author)

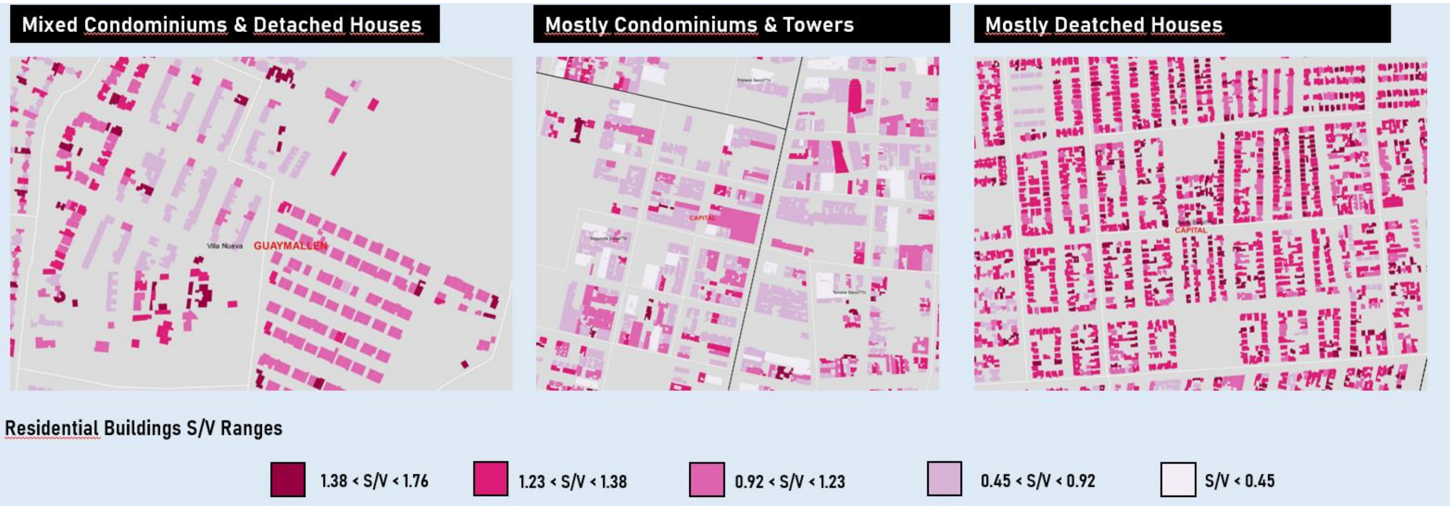
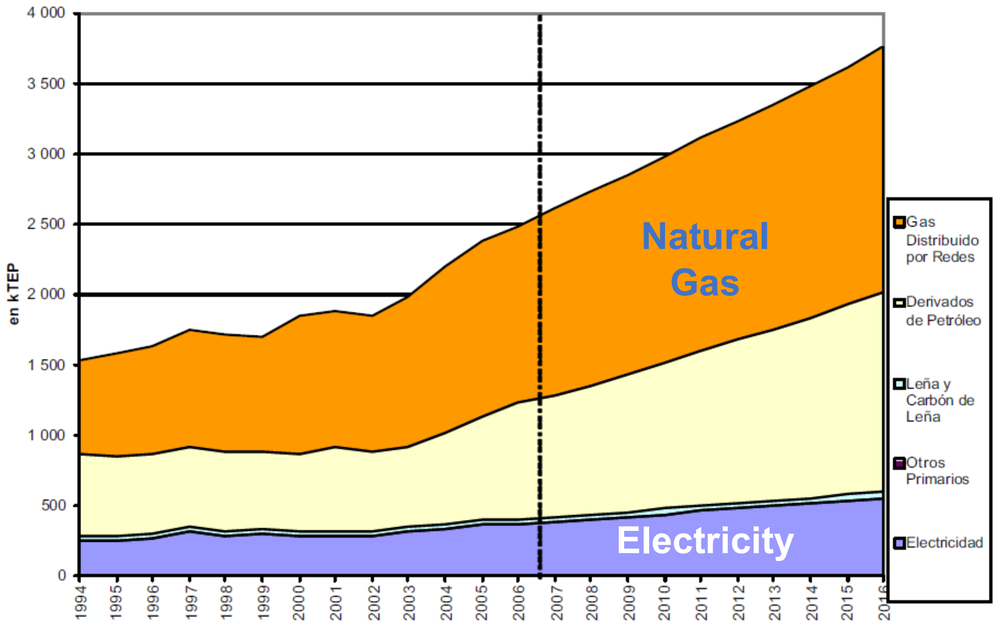


Figure 28 - Different Buildings Composition in Mnedoza Based on S/V (By Author)

4.7. Mendoza Energy Technological Systems

In general, the fossil fuels have a great share in energy production of Mendoza are. Based on Mendoza energy matrix scenarios the trend of energy consumption by sources express that natural gas & derivatives of oil sahre 90% of sources & have essential role in energy system of Mendoza, while electricity is around 15%. Figure 16 illustrates the prediction of different sources share in energy production in Mendoza from 2006 to 2017.



Fuente: Elaboración Propia

Figure 29 - Energy Production Trend in Mendoza (source: Energy Matrix of Mendoza Province)

Among the sectors connected to gas network, the industry has highest share about 59%. The second sector is residential with almost 22%, howevere the trend is not growing for years after. Still highest share of gas network consumption is for residential sector if we exclude industry (Figure 17).

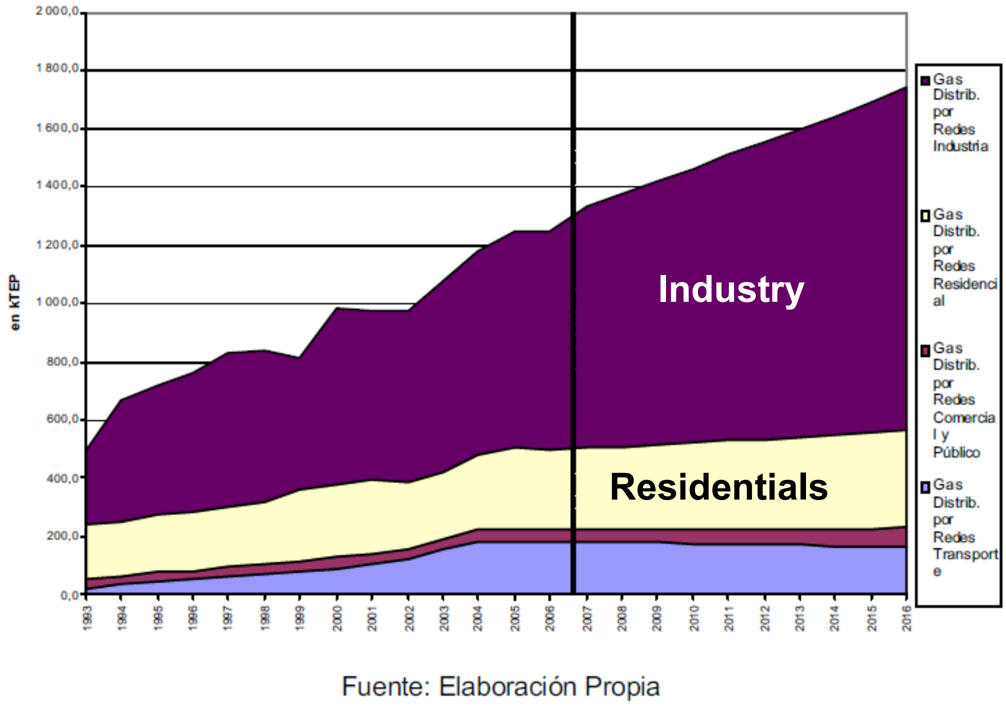


Figure 30 - Natural Gas Consumption Trend by Sector in Mendoza (source: Energy Matrix of Mendoza Province)

About the residential building sector, it is worth to mention that of the 100% of the energy used in the urban domestic building sector, 37.8% of consumption corresponds to heating and 30.8% to water heating (Figure 18),

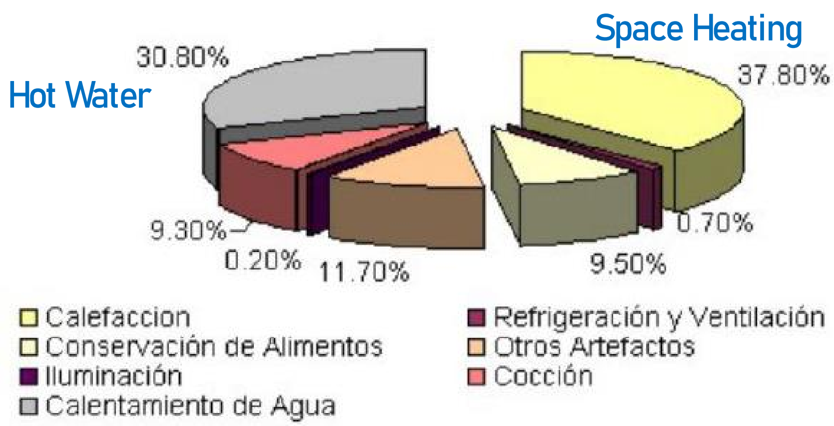


Figure 31 - Energy Consumption in Buildings By End-use (source: [32])

The largest uses of distributed gas occur in heating (48% of the total), water heating (42%) and cooking (10%). The two uses located heating and water heating explain 90% of the total consumption (Figure 19).

Figure 32 - Natural Gas Share in Residential Buildings End-use (source; [32])

For having a better overview of natural gas consumption in Figure 20, the aggregated consumption of all six departments is shown. This data is provided by local supplier "Distribudora de gas Cuyana" at district scale and annual periods. Besides, natural gas is distributed in the network with a lower calorific power of 10.81 kWh/m3.

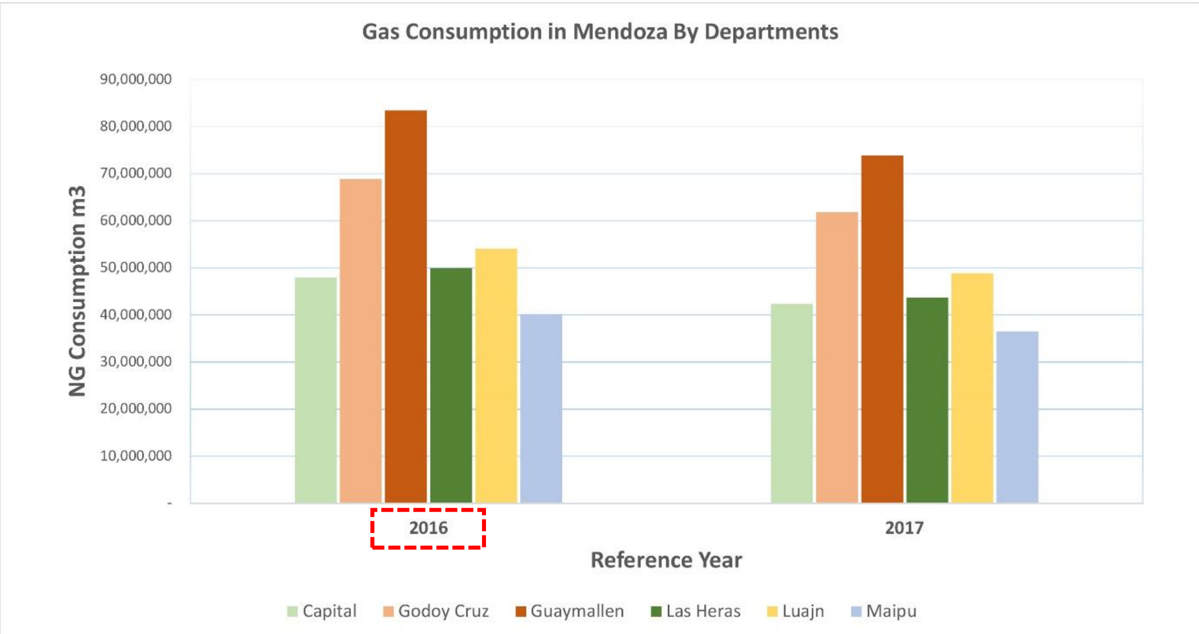


Figure 33 - Aggregated Annual NG Consumption at Departments Level (By Author)

5. The Results

5.1. Models Application Fields

From the analysis in previous steps, it is realized that energy model of whole Mendoza will be divided in two separate models, Standard model (majority of city) & Outliers model (low built density or peripheral). The reason is After the first results of statistical analysis to create the energy model of Mendoza, it was realized that some group of districts have odd behaviours.

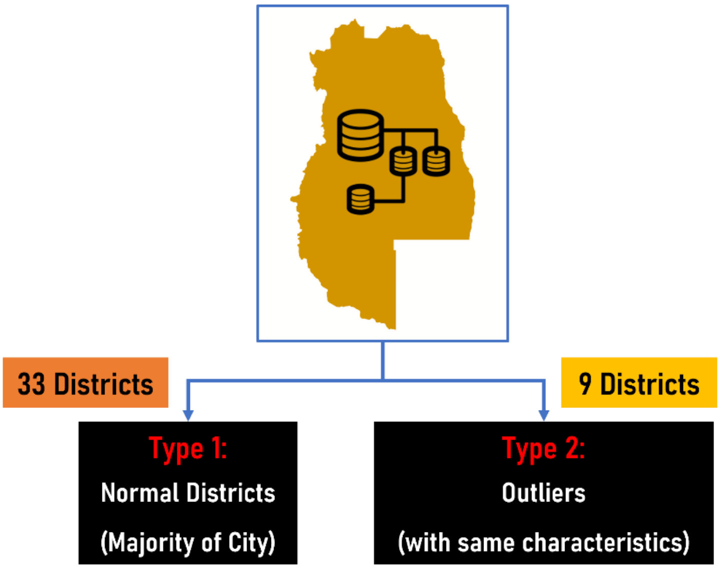


Figure 34 - Mendoza Energy Models Types (By Author)

About the second type of energy model (outliers), it should be mentioned that they are chosen based on first statistical results, in which they had high percentage of error. Moreover, all these districts have the same special characteristics such as: low building coverage ratio, low building density, far from city center, located in higher altitudes area & very large district area. As a result of this division the precision of models increased significantly.

These characteristics are compared to standard districts by evaluating the median values, means that all above variables are either much higher or lower than the standard median values. In Table 5, the characteristics of outlier districts are shown.

Department	Districts	District No.	Area	BCR m2/m2	Building Density m3/m2	Districts Distance from Center km	Avg-altitude
Capital	Cuarta S.	1	3,193,480.11	0.253	0.922	2.468	735.555
	Primera S.	2	1,635,482.25	0.179	1.166	1.165	754.389
	Quinta S.	3	2,442,873.63	0.281	1.276	0.744	788.145
	Segunda S.	4	2,341,492.41	0.448	2.357	2.050	771.399
	Sexta S.	5	2,720,978.42	0.265	0.952	1.015	764.922
	Tercera S.	6	1,502,809.53	0.237	1.470	1.105	748.153
Godoy Cruz	Ciudad (GC)	7	12,240,623.95	0.208	0.723	3.373	842.554
	Gob. Benegas	8	3,993,820.96	0.198	0.649	6.437	877.513
	Las Tortugas	9	4,873,152.58	0.150	0.492	6.742	859.162
	Pr. Sarmiento	10	**51,809,714.58**	**0.012**	**0.038**	**7.910**	**902.155**
	S. Fr. del Monte-GC	11	**5,344,194.23**	**0.073**	**0.225**	**5.166**	**834.738**
Guaymallen	Belgrano	12	4,596,361.13	0.185	0.579	4.272	735.224
	Bermejo	13	5,493,452.35	0.051	0.157	5.565	723.689
	Buena Nueva	14	5,681,397.35	0.043	0.131	7.087	725.238
	Capilla del Rosario	15	3,580,712.38	0.130	0.401	7.775	736.280
	Dorrego	16	4,727,571.00	0.229	0.760	2.678	796.317
	El Sauce	17	**18,875,239.84**	**0.003**	**0.009**	**9.260**	**704.640**
	J. Nazareno	18	3,682,870.65	0.041	0.129	7.359	771.629
	Las Canas	19	2,919,814.32	0.132	0.439	3.533	779.707
	Nueva Ciudad	20	1,531,987.53	0.202	0.648	3.532	757.083
	Pedro Molina	21	1,565,061.36	0.237	0.749	2.838	748.547
	Rodeo de La Cruz	22	7,772,629.55	0.061	0.188	9.561	737.405
	S. Fr. del Monte-Gy	23	4,072,746.38	0.044	0.139	5.503	785.743
	San Jose (Gy)	24	2,143,717.43	0.246	0.817	2.033	761.182
	Villa Nueva	25	6,255,646.90	0.164	0.579	5.232	758.901
Las Heras	Ciudad (LH)	26	5,038,775.02	0.227	0.730	4.205	749.437
	El Challao	27	**103,583,361.00**	**0.067**	**0.207**	**6.886**	**836.760**
	El Plumerillo	28	8,647,583.43	0.076	0.233	5.645	733.097
	El Resguardo	29	5,011,122.15	0.053	0.159	7.401	733.360
	El Zapallar	30	1,853,809.42	0.189	0.592	4.232	739.635
	La Cieneguita	31	4,044,792.86	0.101	0.321	4.839	774.044
	Panquegua	32	1,762,217.06	0.151	0.463	5.973	742.833
Lujan	Carrodilla	33	14,033,242.36	0.036	0.111	10.067	895.198
	Chacras de Coria	34	**14,572,632.05**	**0.033**	**0.105**	**11.873**	**956.571**
	Ciudad (L)	35	**6,923,316.69**	**0.080**	**0.301**	**16.750**	**977.516**
	La Puntilla	36	1,220,172.20	0.119	0.386	8.341	909.888
	Mayor Drummond	37	**5,729,549.61**	**0.038**	**0.118**	**14.012**	**958.098**
	Vistalba	38	**19,825,350.95**	**0.011**	**0.034**	**16.885**	**1012.548**
Maipu	Coquimbito	39	**34,676,705.59**	**0.007**	**0.022**	**13.049**	**790.321**
	Gen.Gutierrez	40	7,458,604.70	0.076	0.236	8.900	818.150
	Luzuriaga	41	8,602,004.04	0.065	0.201	7.319	819.474
	Maipu	42	19,432,257.65	0.057	0.177	11.014	840.194
		Median	4,942,137.36	0.11	0.35	5.81	772.84

Table 5 - Table of Outliers Districts Characteristics (By Author)

In above table the variables values of the odd districts, in outlier model, is specified with colour of red. All of them are located in peripheral or suburban areas, except one. Number 11 or district “San Francisco del monte GC” is near the central part of the city although it has the exact characteristics of outliers, so, it is included in this application field, for having a more precise & better model.

As it is obvious in table, most of these districts are located in department of Lujan de Cuyo which is in south & south-western part of gran Mendoza. Figure 36, show us the exact location of outliers.

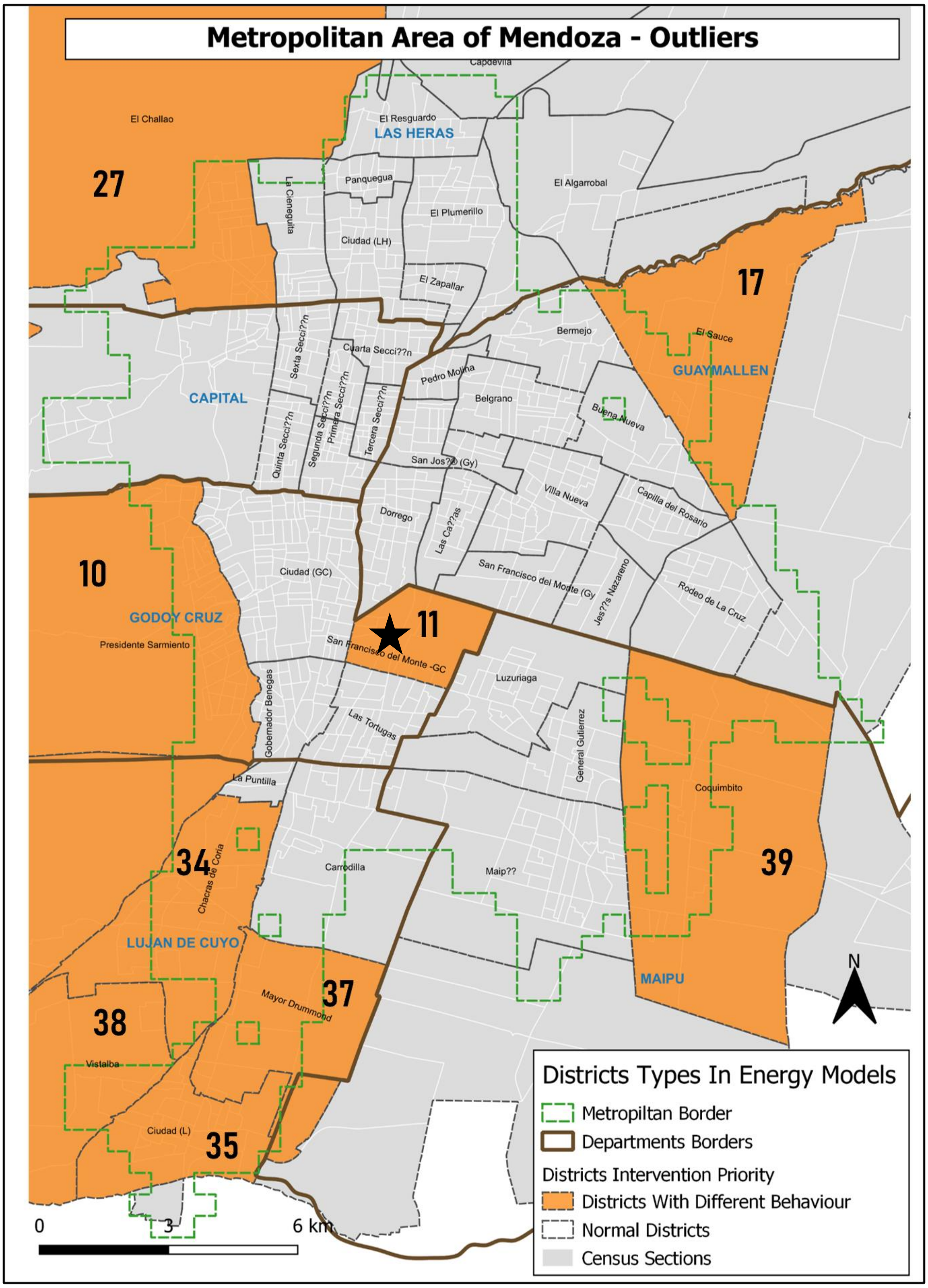


Figure 35 - The Map of Model 2 Districts or Outliers (By Author)

★ District 11 is an industrial zone with exact characteristics with suburban districts, although it is located in central part. It contains wine yards, machinery manufacturers, equipment stores & sport fields. So, there is highly tertiary activities [34].

5.2. Statistical Model #1 (Standard)

Energy Model Scenarios

In total there are six different scenarios that have been analysed & their model created. But, after the evaluating the results, it is decided to choose the not normalized scenarios (kWh, kWh/m2, kWh/family) as the best models to be explained in more detail. At the end of this chart however, there is comparison between all six scenarios final results.

5.2.1 kWh (Not Normalized)

Final Energy Related Variables

The results begin with presenting the table of most energy related variables.

Department	Districts	Districts No.	Area	Vivienda	House Crowding 0.51 - 0.99 People/Room	Total Heat Loss Surfaces m2	Gross Heated Area m2	Met_station	Gas Consumption kWh -	Calculated Energy
Capital	Cuarta S.	1	3,193,480.11	8355	23.8%	2,794,177.55	983,212.83	El Plumerill	87,188,758.41	106,858,407.94
	Primera S.	2	1,635,482.25	5005	25.4%	1,304,314.22	637,604.47	El Plumerill	39,981,023.04	48,865,243.18
	Quinta S.	3	2,442,873.63	7208	27.4%	2,673,914.30	1,041,174.54	El Plumerill	104,530,254.67	97,983,260.67
	Segunda S.	4	2,341,492.41	10874	22.8%	4,127,282.14	1,884,697.77	El Plumerill	83,832,212.33	94,016,676.32
	Sexta S.	5	2,720,978.42	7208	29.2%	2,404,890.17	863,084.66	El Plumerill	138,634,213.22	107,735,126.83
	Tercera S.	6	1,502,809.53	4933	18.8%	1,438,601.24	738,849.70	El Plumerill	33,992,762.14	25,570,706.03
Godoy Cruz	Ciudad (GC)	7	12,240,623.95	28976	22.7%	8,491,178.16	2,958,078.90	El Plumerill	323,858,033.47	331,122,894.32
	Gob. Benegas	8	3,993,820.96	7386	29.3%	2,522,967.86	864,864.36	Russel	137,977,577.50	119,105,201.79
	Las Tortugas	9	4,873,152.58	9374	20.9%	2,396,717.11	800,781.27	Russel	123,957,396.77	106,746,415.92
Guaymallen	Belgrano	12	4,596,361.13	9964	15.3%	2,682,272.16	887,278.96	El Plumerill	92,747,642.00	97,922,793.47
	Bermejo	13	5,493,452.35	4045	14.9%	890,203.68	288,193.95	El Plumerill	46,537,540.45	39,842,875.70
	Buena Nueva	14	5,681,397.35	3431	14.4%	796,719.36	247,192.56	El Plumerill	37,337,258.41	35,371,109.50
	Capilla del Rosa	15	3,580,712.38	5391	23.5%	1,449,395.76	478,893.85	El Plumerill	73,661,048.95	74,207,749.68
	Dorrego	16	4,727,571.00	10644	26.6%	3,347,643.55	1,198,002.08	El Plumerill	126,605,184.87	138,930,395.41
	J. Nazareno	18	3,682,870.65	2099	16.5%	481,162.59	158,165.30	Russel	26,368,836.78	20,657,576.42
	Las Canas	19	2,919,814.32	4708	23.9%	1,232,010.27	427,782.28	El Plumerill	75,635,638.90	63,807,574.74
	Nueva Ciudad	20	1,531,987.53	2767	23.7%	942,783.60	331,187.43	El Plumerill	29,454,348.27	43,411,260.06
	Pedro Molina	21	1,565,061.36	3432	21.6%	1,131,366.82	390,573.40	El Plumerill	36,501,647.14	44,253,591.58
	Rodeo de La Cr	22	7,772,629.55	5168	16.2%	1,455,409.63	487,813.28	Russel	62,712,690.57	66,882,709.03
	S. Fr. del Monte	23	4,072,746.38	3346	24.2%	560,450.59	189,408.24	El Plumerill	52,475,443.61	51,813,364.87
	San Jose (Gy)	24	2,143,717.43	4236	23.4%	1,601,664.45	583,949.89	El Plumerill	50,533,928.37	60,649,978.27
	Villa Nueva	25	6,255,646.90	11514	25.8%	3,165,124.47	1,207,870.91	El Plumerill	159,298,863.91	136,443,502.57
Las Heras	Ciudad (LH)	26	5,038,775.02	11506	20.6%	3,556,083.92	1,229,066.89	El Plumerill	126,793,497.34	133,645,695.61
	El Plumerillo	28	8,647,583.43	9771	15.4%	2,180,026.12	691,656.43	El Plumerill	91,303,290.44	106,364,033.52
	El Resguardo	29	5,011,122.15	5137	9.8%	937,938.45	265,414.09	El Plumerill	45,467,010.37	32,621,334.05
	El Zapallar	30	1,853,809.42	3781	24.5%	1,091,770.67	366,227.06	El Plumerill	44,393,049.95	55,832,197.92
	La Cieneguita	31	4,044,792.86	4698	28.2%	1,267,221.16	433,294.83	El Plumerill	64,445,852.14	81,957,086.92
	Panquegua	32	1,762,217.06	3432	14.5%	871,375.04	272,704.94	El Plumerill	34,804,046.15	22,102,208.27
Lujan	Carrodilla	33	14,033,242.36	6767	25.6%	1,658,383.44	528,234.81	Russel	125,832,249.44	132,429,684.74
	Chacras de Cor	34	14,572,632.05	4654	35.0%	2,131,960.16	694,905.00	Russel	174,824,964.87	160,008,831.99
	Ciudad (L)	35	6,923,316.69	7550	23.4%	2,258,276.84	770,080.59	Perdriel	113,191,740.04	109,349,505.25
	La Puntilla	36	1,220,172.20	871	33.3%	477,427.78	158,114.41	Russel	25,182,133.58	55,095,029.04
	Gen.Gutierrez	40	7,458,604.70	5746	19.0%	1,825,243.17	586,976.50	Russel	83,676,229.33	85,583,945.83
	Luzuriaga	41	8,602,004.04	6570	24.6%	1,839,466.54	580,846.10	Russel	97,875,643.64	111,852,565.12
	Maipu	42	19,432,257.65	12618	20.4%	3,570,927.57	1,156,853.53	Russel	197,777,308.94	200,348,787.46

Table 6 - kWh Scenario Model #1, Final Energy Related Variables (By Author)

Multiple Linear Regression Results

The primary regression results are shown in Figure 37, which contains all the districts. In this Scenario 7 districts are identified as outliers with red circles. Then, the calibrated model result with elimination of outliers & percentage of errors improvements (Figure 38).

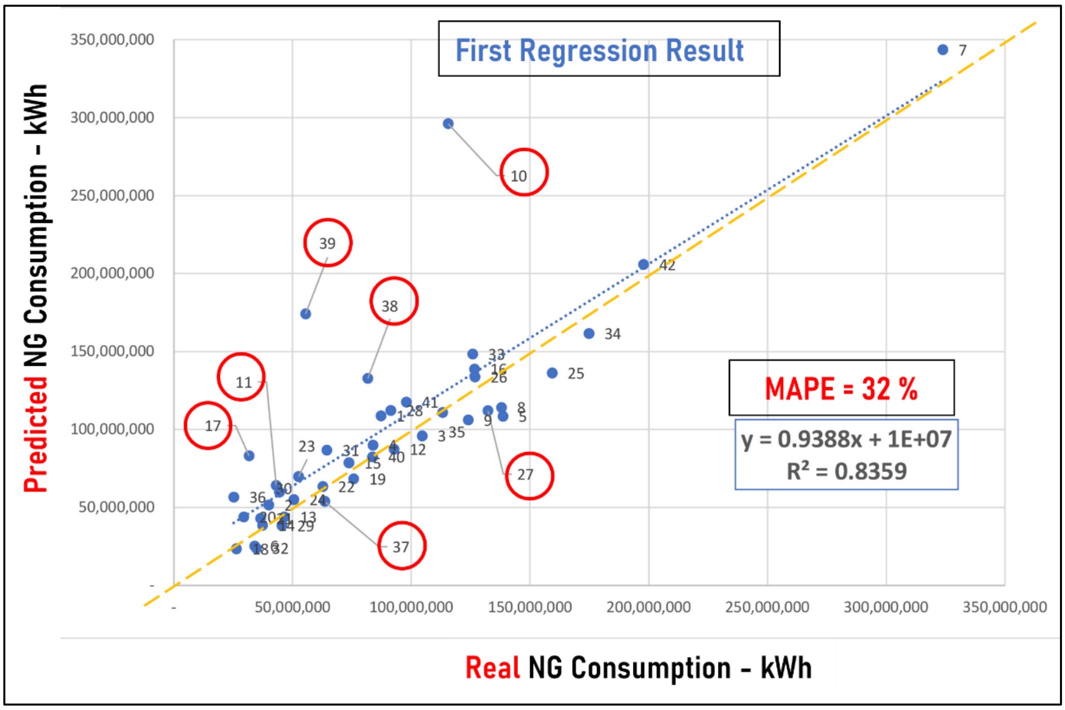


Figure 36 - The Primary ML Regression Result Chart Model #1, kWh (By Author)

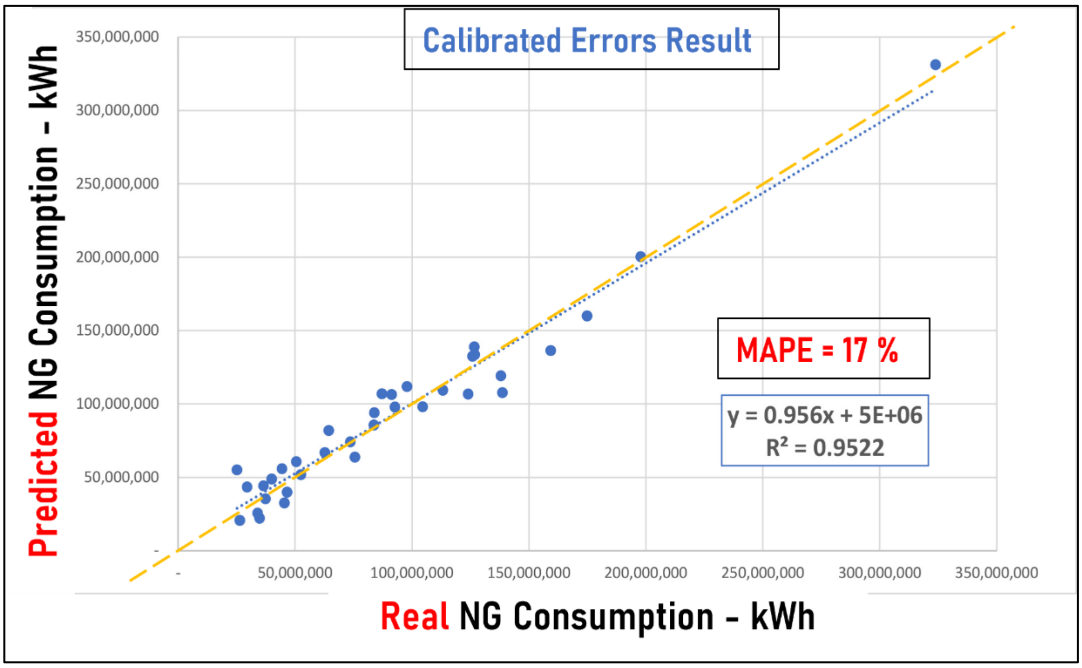


Figure 37 - The Calibrated ML Regression Result Chart Model #1, kWh (By Author)

The calibrated model demonstrates that after deleting outliers from model, the mean absolute error percentage is reduced from 32% to 17% meaning 15% of improvements. Besides, the range of NG consumption in this case signify that the application field of this model consider consumption ranges between 20,000,000 & 350,000,000 kWh.

Regarding ML regression results, the table below give us the essentials information about statistical model. R square close to 1 with significance-f & p-values lower than 0.05, mean a very strong relationship between variables & energy consumption with good significance. These rules are considered in all statistical models for analysing regression results.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.96545925
R Square	0.932111563
Adjusted R Square	0.92040666
Standard Error	17430291.6
Observations	35

X = -61173056.23 + (3.8 x Area) + (4734.25 x Vivienda)
+ (296768657.4 x 0.51 – 0.99 people/room) +
(49 x Heat Loss Surface) +
(-92.9 x Gross Heated Area)

ANOVA

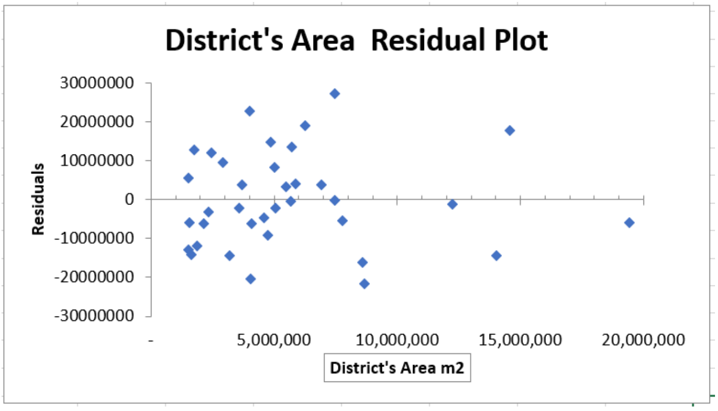
	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	1.21E+17	2.42E+16	79.63428	4.90282E-16
Residual	29	8.81E+15	3.04E+14		
Total	34	1.3E+17			

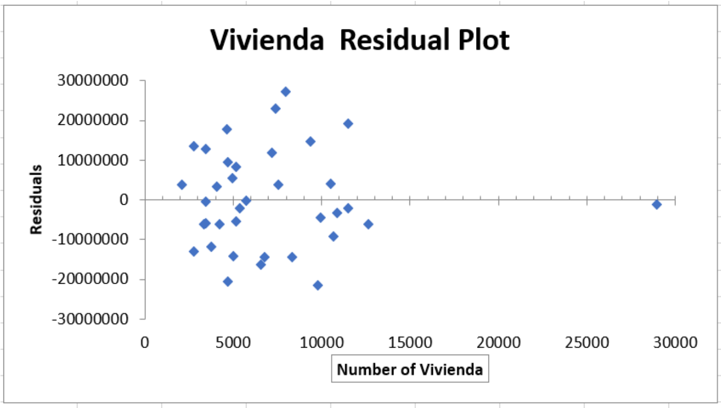
	Coefficients	*andard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Ipper 95.0%*
Intercept	-61173056.25	16014482	-3.81986	0.000651	-93926349.2	-2.8E+07	-9.4E+07	-2.8E+07
Area	3.802084323	0.922723	4.120503	0.000288	1.914903258	5.689265	1.914903	5.689265
Vivienda	4734.258969	3646.153	1.298426	0.204372	-2722.96135	12191.48	-2722.96	12191.48
0.51 - 0.99 People/Room	296768657.4	66935615	4.433644	0.000122	159869953.1	4.34E+08	1.6E+08	4.34E+08
Total Heat Loss Surfaces m2	49.00018803	21.82309	2.245337	0.032538	4.366953302	93.63342	4.366953	93.63342
Gross Heated Area	-92.90209255	38.74891	-2.39754	0.023168	-172.152517	-13.6517	-172.153	-13.6517

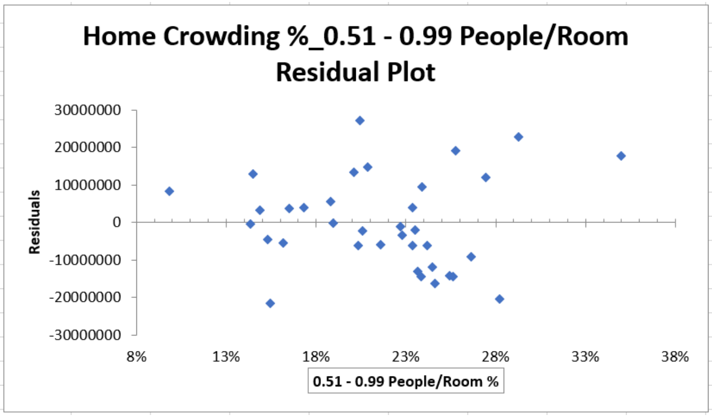
Table 7 - Regression Summary for Model #1, kWh (By Author)

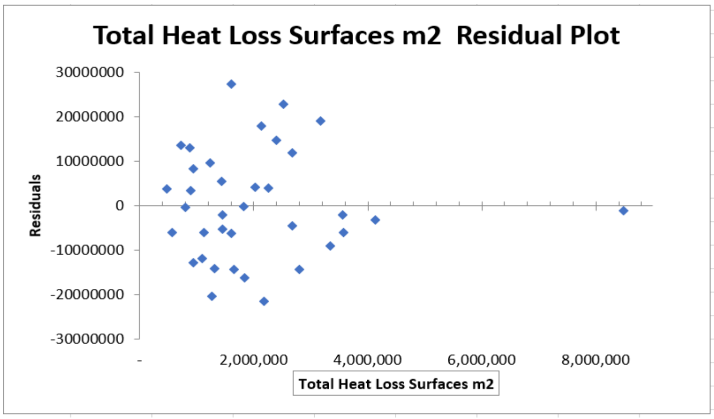
The Residual Plots

The charts below are going to explain the residual values of each energy related variables in our MLR model. Residuals express the vertical distances between real data points & predicted ones. The values could be negative or positives. In charts below vertical axis is the residual values from MLR model & horizontal one is the independent variable. As more constant & random points are, more correct model is.









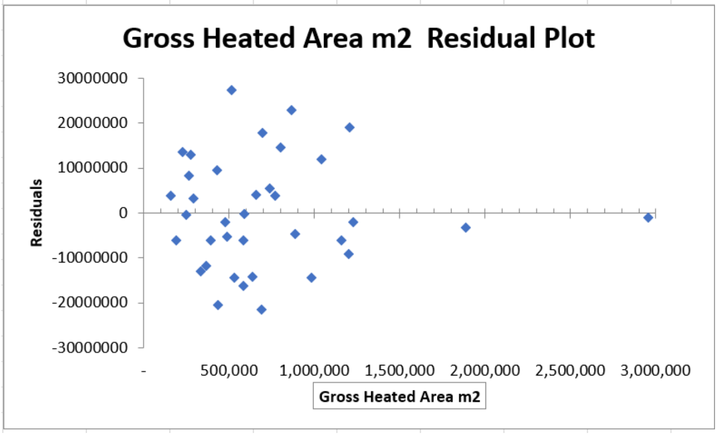


Figure 38 - The Residual Plots for Model #1, kWh (By Author)

5.2.2. kWh/m2 (Not Normalized)

Final Energy Related Variables

Final Energy Related Variables for kWh/m2 (Not Normalized) scenarios is illustrated in Table 7.

			TOPPING MATERIAL %	MATERIAL QUALITY %				
Department	Districts	Pop/Families	Slate or Roof Tiles	M Quality 1	Gross Heated Area m2	Gas Consumption kWh - 2016	Gas Consumption kWh/m2 (GROSS)	Calculated Energy
Capital	Cuarta S.	2.90	10.5%	81.9%	36415.29	87,188,758.41	88.68	97.36
	Primera S.	2.73	4.3%	83.9%	37506.15	39,981,023.04	62.71	67.77
	Quinta S.	2.62	18.7%	89.2%	43382.27	104,530,254.67	100.40	108.65
	Segunda S.	2.38	6.5%	87.0%	57112.05	83,832,212.33	41.48	22.54
	Sexta S.	2.80	22.7%	80.1%	35961.86	168,634,213.22	195.39	165.46
	Tercera S.	2.55	4.4%	83.7%	43461.75	33,992,762.14	46.01	57.03
Godoy Cruz	Ciudad (GC)	3.04	11.5%	75.0%	28172.18	323,858,033.47	109.48	138.95
	Gob. Benegas	3.14	17.3%	75.4%	33264.014	137,977,577.50	159.54	144.50
	Las Tortugas	3.69	7.4%	62.3%	24266.10	123,957,396.77	154.80	133.24
	S. Fr. del Monte-GC	3.40	14.7%	69.9%	30818.79	43,052,572.76	107.46	141.36
Guaymallen	Belgrano	3.83	2.8%	56.2%	26096.44	92,747,642.00	104.53	113.67
	Bermejo	3.98	8.0%	54.5%	20585.282	46,537,540.45	161.48	153.55
	Buena Nueva	3.90	7.8%	47.3%	22472.051	37,337,258.41	151.05	166.91
	Capilla del Rosario	3.51	15.4%	72.3%	25204.939	73,661,048.95	153.81	152.02
	Dorrego	3.09	14.5%	80.3%	34228.631	126,605,184.87	105.68	119.13
	J. Nazareno	3.85	7.5%	53.6%	22595.043	26,368,836.78	166.72	152.59
	Las Canas	3.32	13.6%	75.1%	25163.664	75,635,638.90	176.81	145.91
	Nueva Ciudad	3.36	7.4%	75.1%	36798.60	29,454,348.27	88.94	76.65
	Pedro Molina	3.33	5.0%	72.2%	35506.673	36,501,647.14	93.46	78.20
	Rodeo de La Cruz	3.70	5.2%	51.2%	24390.664	62,712,690.57	128.56	148.04
	S. Fr. del Monte-Gy	3.74	27.7%	63.6%	23676.030	52,475,443.61	277.05	225.94
	San Jose (Gy)	3.16	7.7%	81.4%	36496.868	50,533,928.37	86.54	73.75
	Villa Nueva	3.21	15.3%	79.7%	29460.266	159,298,863.91	131.88	133.79
Las Heras	Ciudad (LH)	3.37	6.9%	68.8%	31514.536	126,793,497.34	103.16	105.89
	El Plumerillo	3.95	2.8%	47.4%	21022.510	91,303,290.44	135.90	145.52
	El Resguardo	4.26	2.5%	39.7%	15612.594	45,467,010.37	171.31	166.32
	El Zapallar	3.43	17.4%	71.8%	26159.076	44,393,049.95	131.22	163.34
	La Cieneguita	3.49	25.1%	70.8%	25487.931	64,445,852.14	158.73	201.71
	Panquegua	3.85	3.8%	52.2%	19478.924	34,804,046.15	127.63	148.85
Lujan	Carrodilla	3.660	21.7%	59.4%	22760.467	125,832,249.44	240.37	213.72
	La Puntilla	3.460	38.2%	69.2%	52704.803	25,182,133.58	159.27	180.53
Maipu	Coquimbito	3.770	8.9%	40.4%	16635.500	55,469,803.56	222.29	213.02
	Gen.Gutierrez	3.547	6.6%	54.8%	32609.806	83,676,229.33	142.55	126.29
	Luzuriaga	3.530	15.1%	66.8%	27659.338	97,875,643.64	168.51	154.91
	Maipu	3.594	16.0%	57.7%	26903.570	197,777,308.94	170.96	180.22

Table 8 - kWh/m2 Scenario Model #1, Final Energy Related Variables (By Author)

Multiple Linear Regression Results

The primary regression results are shown in Figure 40. In this Scenario 6 districts are identified as outliers with red circles. Then, the calibrated model result with elimination of outliers & percentage of errors improvements (Figure 41).

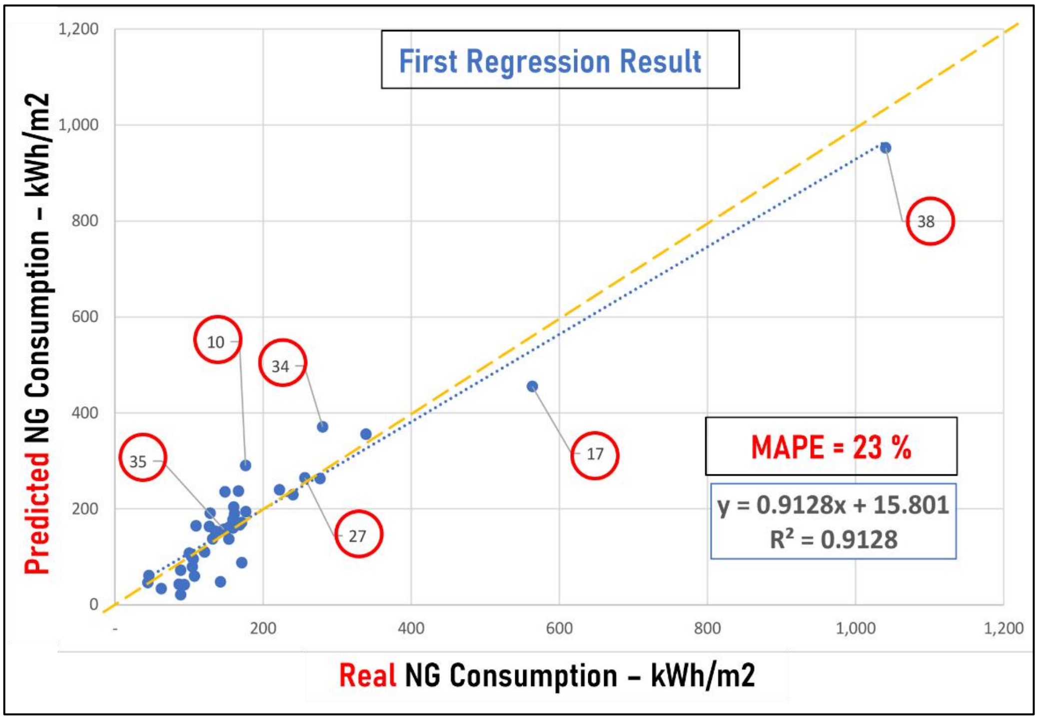


Figure 39 - The Primary ML Regression Result Chart Model #1, kWh/m2 (By Author)

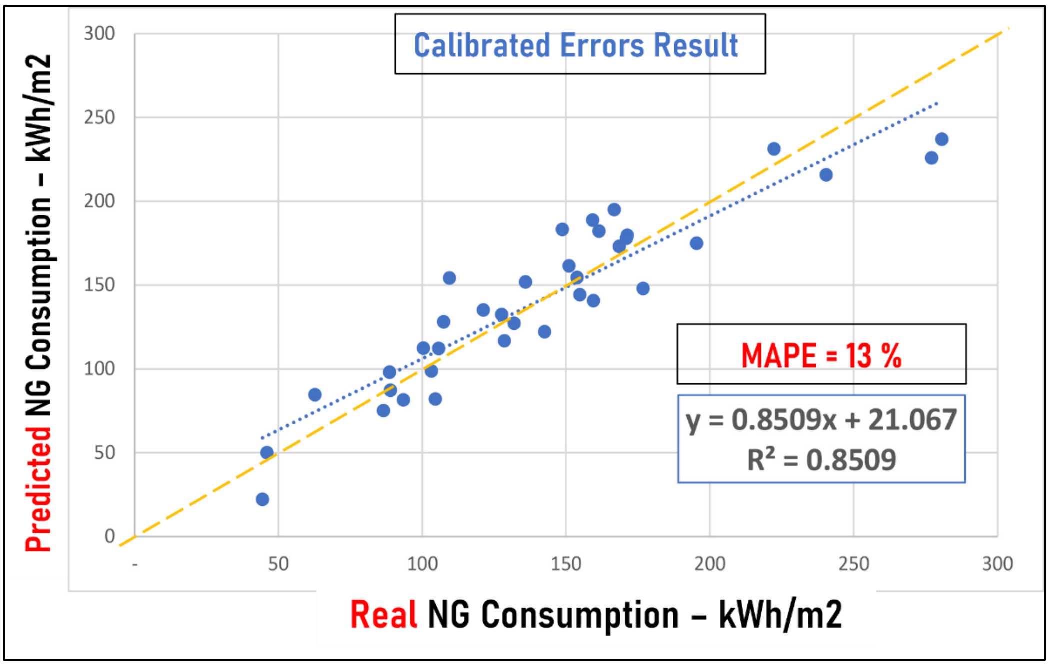


Figure 40 - The Calibrated ML Regression Result Chart Model #1, kWh/m2 (By Author)

The calibrated model demonstrates that after deleting outliers from model, the mean absolute error percentage is reduced from 23% to 13% meaning 10% of improvements. Besides, the range of kWh/m2 consumption in this case explain that the application field of this model consider consumption ranges between 40 & 300 kWh/m2. Table 9, express the details of model's strength in regression summary of kWh/m2 scenario.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.90648801
R Square	0.85092051
Adjusted R Square	0.79794992
Standard Error	22.8285501
Observations	35

X = 488.77 + (-44.61 x Pop/fam) + (472.61 x Slate Roof Tiles) + (-235.80 x M Quality 1) + (-0.0032 x Gross Heated Area)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	72061.06	18015.27	34.5687774	7.7842E-11
Residual	30	15634.28	521.1427		
Total	34	87695.35			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Ipper 95.0%*
Intercept	488.778625	138.0531	3.540512	0.00132596	206.8366206	770.7206	206.8366	770.7206
Pop/Families	-44.6139057	25.67809	-1.73743	0.09256903	-97.0555606	7.827749	-97.0556	7.827749
Slate or Roof Tiles	472.616439	54.12	8.732751	9.7234E-10	362.0886595	583.1442	362.0887	583.1442
M Quality 1	-235.802192	75.01811	-3.14327	0.00374669	-389.009605	-82.5948	-389.01	-82.5948
Gross Heated Area m2	-0.00325383	0.000738	-4.40948	0.00012264	-0.00476086	-0.00175	-0.00476	-0.00175

Table 9 - Regression Summary for Model #1, kWh/m2 (By Author)

The Residual Plots

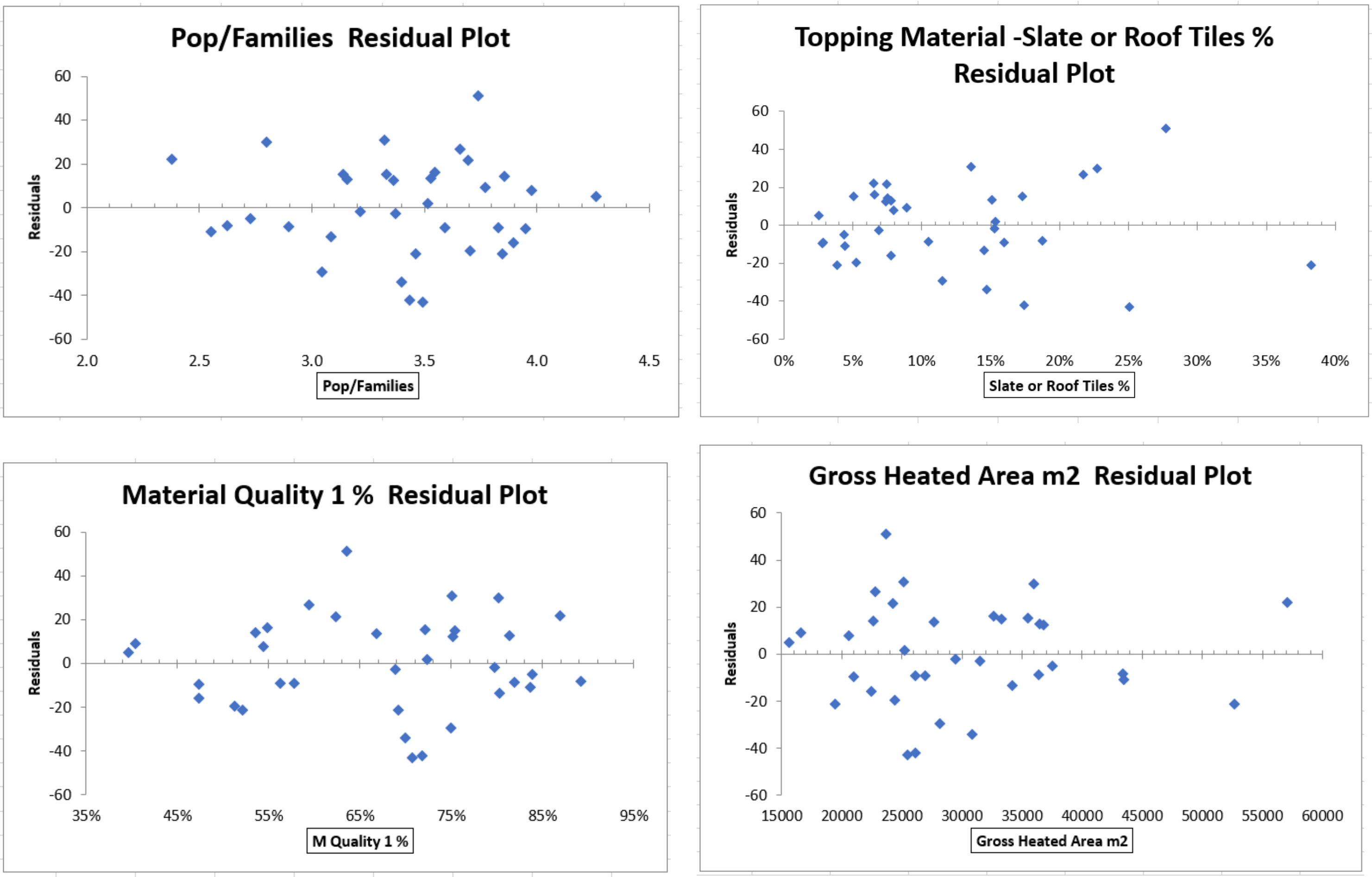


Figure 41 - The Residual Plots for Model #1, kWh/m2 (1) (By Author)

5.2.3. kWh/family (Not Normalized)

Final Energy Related Variables

Final Energy Related Variables for kWh/family (Not Normalized) scenarios is illustrated in Table 10.

				AGES	EMPLOYMENT	TOPPING MATERIAL					
Department	Districts	Census No.	Total Population	15-64	Unemployed	Slate or Roof Tiles	Avg-altitude	Met_station	Gas Consumption kWh - 2016	Gas Consumption kWh/family	Calculated Energy
Capital	Cuarta S.	27	20668	66.0%	4.3%	10.5%	758.55	El Plumerillo	87,188,758.41	12,214.73	13,316.50
	Primera S.	17	9464	68.9%	3.8%	4.3%	780.39	El Plumerillo	39,981,023.04	11,281.33	11,667.26
	Quinta S.	24	14188	68.4%	2.8%	18.7%	813.14	El Plumerillo	104,530,254.67	19,254.05	19,474.30
	Segunda S.	33	14013	69.4%	3.2%	6.5%	794.40	El Plumerillo	83,832,212.33	14,468.80	13,349.87
	Sexta S.	24	17502	66.3%	3.6%	22.7%	789.92	El Plumerillo	168,634,213.22	22,128.37	19,773.47
	Tercera S.	17	7770	69.4%	4.5%	4.4%	776.15	El Plumerillo	33,992,762.14	11,418.46	10,381.96
Godoy Cruz	Ciudad (GC)	106	78795	64.7%	4.8%	11.5%	842.55	El Plumerillo	323,858,033.47	12,575.06	13,036.54
	Gob. Benegas	26	22433	66.2%	4.0%	17.3%	877.51	Russel	137,977,577.50	19,292.17	20,606.73
	Las Tortugas	33	36007	64.3%	5.6%	7.4%	859.16	Russel	123,957,396.77	12,781.75	14,511.53
	Belgrano	34	41835	63.1%	5.3%	2.8%	735.22	El Plumerillo	92,747,642.00	8,469.33	8,549.40
	Bermejo	14	16286	63.8%	4.5%	8.0%	723.69	El Plumerillo	46,537,540.45	11,420.26	12,370.20
	Buena Nueva	11	13668	63.9%	5.2%	7.8%	725.24	El Plumerillo	37,337,258.41	10,640.43	11,529.77
Guaymallen	Capilla del Ros	19	18284	65.3%	4.8%	15.4%	736.28	El Plumerillo	73,661,048.95	14,160.14	13,864.69
	Dorrego	35	29463	66.5%	4.2%	14.5%	796.32	El Plumerillo	126,605,184.87	13,294.67	15,375.31
	J. Nazareno	7	7979	65.9%	4.3%	7.5%	771.63	Russel	26,368,836.78	12,732.42	13,762.87
	Las Canas	17	14650	67.7%	4.2%	13.6%	779.71	El Plumerillo	75,635,638.90	17,143.16	14,656.61
	Nueva Ciudad	9	8438	64.2%	5.5%	7.4%	757.08	El Plumerillo	29,454,348.27	11,734.80	12,409.82
	Pedro Molina	11	10992	65.2%	4.8%	5.0%	748.55	El Plumerillo	36,501,647.14	11,084.62	11,528.26
	Rodeo de La C	21	20106	63.5%	5.6%	5.2%	737.41	Russel	62,712,690.57	11,549.30	10,393.07
	S. Fr. del Mont	8	10927	65.4%	5.5%	27.7%	785.74	El Plumerillo	52,475,443.61	21,737.96	19,567.96
	San Jose (Gy)	16	12095	65.6%	4.5%	7.7%	761.18	El Plumerillo	50,533,928.37	13,041.01	13,100.36
	Villa Nueva	41	33737	65.8%	4.6%	15.3%	758.90	El Plumerillo	159,298,863.91	15,203.17	13,643.28
Las Heras	Ciudad (LH)	39	35590	64.5%	5.6%	6.9%	749.44	El Plumerillo	126,793,497.34	12,034.31	9,609.14
	El Challao	28	28145	64.7%	5.3%	11.0%	836.76	El Plumerillo	132,259,792.74	17,490.05	15,560.00
	El Plumerillo	32	40123	62.5%	5.8%	2.8%	733.10	El Plumerillo	91,303,290.44	8,986.54	8,282.82
	El Resguardo	17	23595	62.7%	6.3%	2.5%	733.36	El Plumerillo	45,467,010.37	8,201.12	8,440.62
	El Zapallar	14	12068	65.5%	5.3%	17.4%	739.64	El Plumerillo	44,393,049.95	12,669.25	14,324.97
	La Cieneguita	17	15544	68.0%	4.6%	25.1%	774.04	El Plumerillo	64,445,852.14	14,443.27	17,457.41
	Panquegua	14	13552	64.5%	5.5%	3.8%	742.83	El Plumerillo	34,804,046.15	9,938.33	10,084.79
Lujan	Carrodilla	23	21916	65.6%	5.1%	21.7%	895.20	Russel	125,832,249.44	20,986.03	21,773.15
	La Puntilla	3	2800	68.8%	2.6%	38.2%	909.89	Russel	25,182,133.58	31,166.01	31,020.77
	Mayor Drumm	10	9300	64.3%	4.3%	12.5%	958.10	Russel	63,555,276.78	25,432.28	24,120.00
	Gen.Gutierrez	18	21077	63.6%	4.9%	6.6%	818.15	Russel	83,676,229.33	14,208.90	15,045.72
	Luzuriaga	21	22549	67.4%	4.5%	15.1%	819.47	Russel	97,875,643.64	15,305.03	16,104.28
	Maipu	44	43680	65.1%	5.1%	16.0%	840.19	Russel	197,777,308.94	16,443.08	16,236.79

Table 10 - kWh/family Scenario Model #1, Final Energy Related Variables (By Author)

Multiple Linear Regression Results

Figure 44 & Figure 45 illustrate the primary & calibrated regression results for kWh/family models. In this Scenario 7 anomalies are identified which are observable with red circles in first chart.

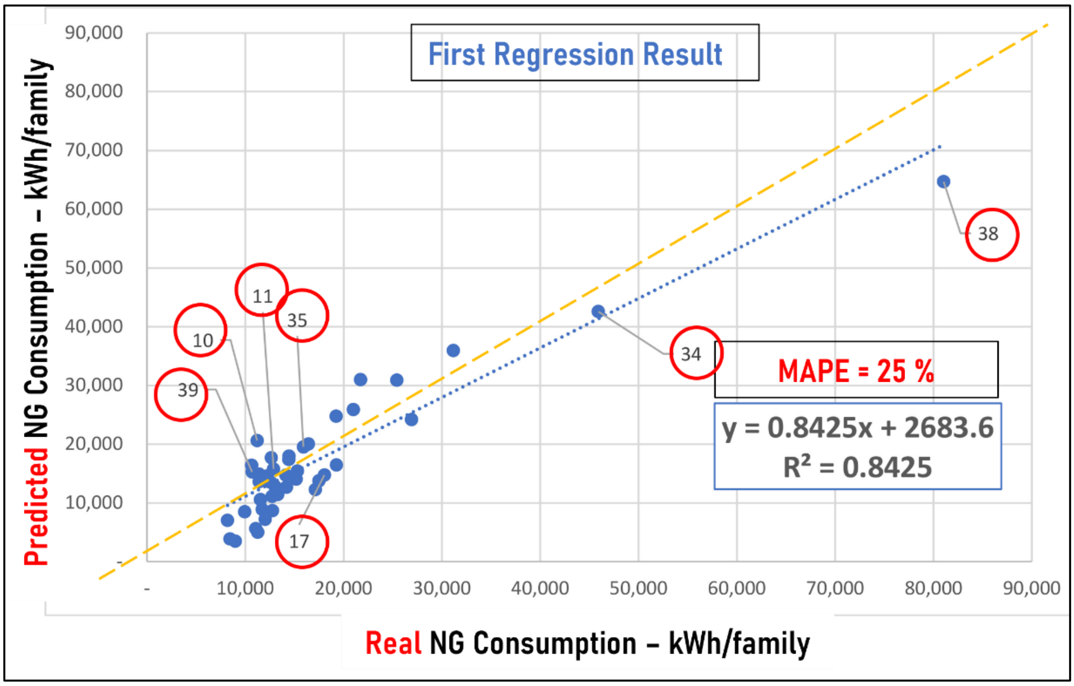


Figure 42 - The Primary ML Regression Result Chart Model #1, kWh/family (By Author)

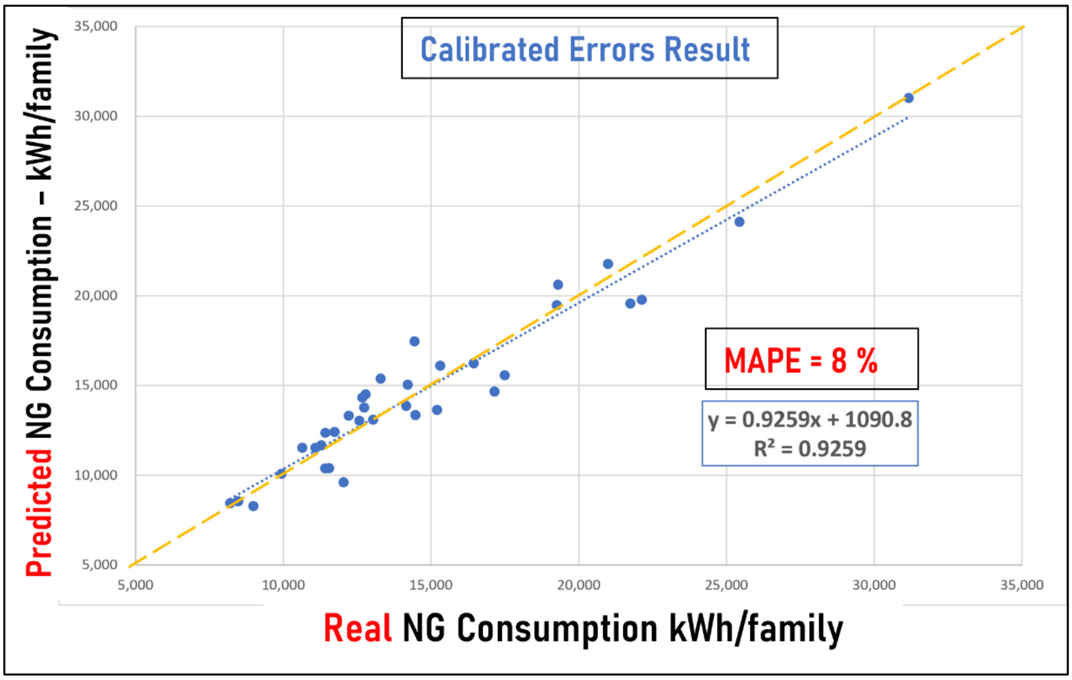


Figure 43 - The Calibrated ML Regression Result Chart Model #1, kWh/family (By Author)

The calibrated model demonstrates that after deleting outliers from model, the mean absolute error percentage is reduced from 25% to 8% meaning a significant improvement of 17%. Besides, the range of kWh/family consumption in this case explain that the application field of this model consider consumption ranges between 5000 & 35000 kWh/family.

Table 11, express the details of model's strength in regression summary of kWh/m2 scenario.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.962215
R Square	0.925857
Adjusted R Square	0.913074
Standard Error	1467.624
Observations	35

X = 28929.92+ (-0.071 x Population) + (-65051 x 15-64) + (-148216 x Unemployed) + (33981.7 x Slate) + (41.61x Avg-altitude)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	7.8E+08	1.56E+08	72.42763	1.743E-15
Residual	29	62463728	2153922		
Total	34	8.42E+08			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Ipper 95.0%*
Intercept	28929.92	17355.57	1.666895	0.106301	-6566.2072	64426.05	-6566.21	64426.05
Total Population	-0.07179	0.019298	-3.72007	0.000851	-0.1112574	-0.03232	-0.11126	-0.03232
15-64	-65051	22261.86	-2.92208	0.006673	-110581.63	-19520.4	-110582	-19520.4
Unemployed	-148216	51594.82	-2.87268	0.007536	-253738.83	-42692.3	-253739	-42692.3
Slate or Roof Tiles	33981.7	3862.708	8.797379	1.11E-09	26081.5761	41881.82	26081.58	41881.82
Avg-altitude	41.61225	5.286107	7.872003	1.11E-08	30.8009479	52.42356	30.80095	52.42356

Table 11 - Regression Summary for Model #1, kWh/family (By Author)

The Residual Plots

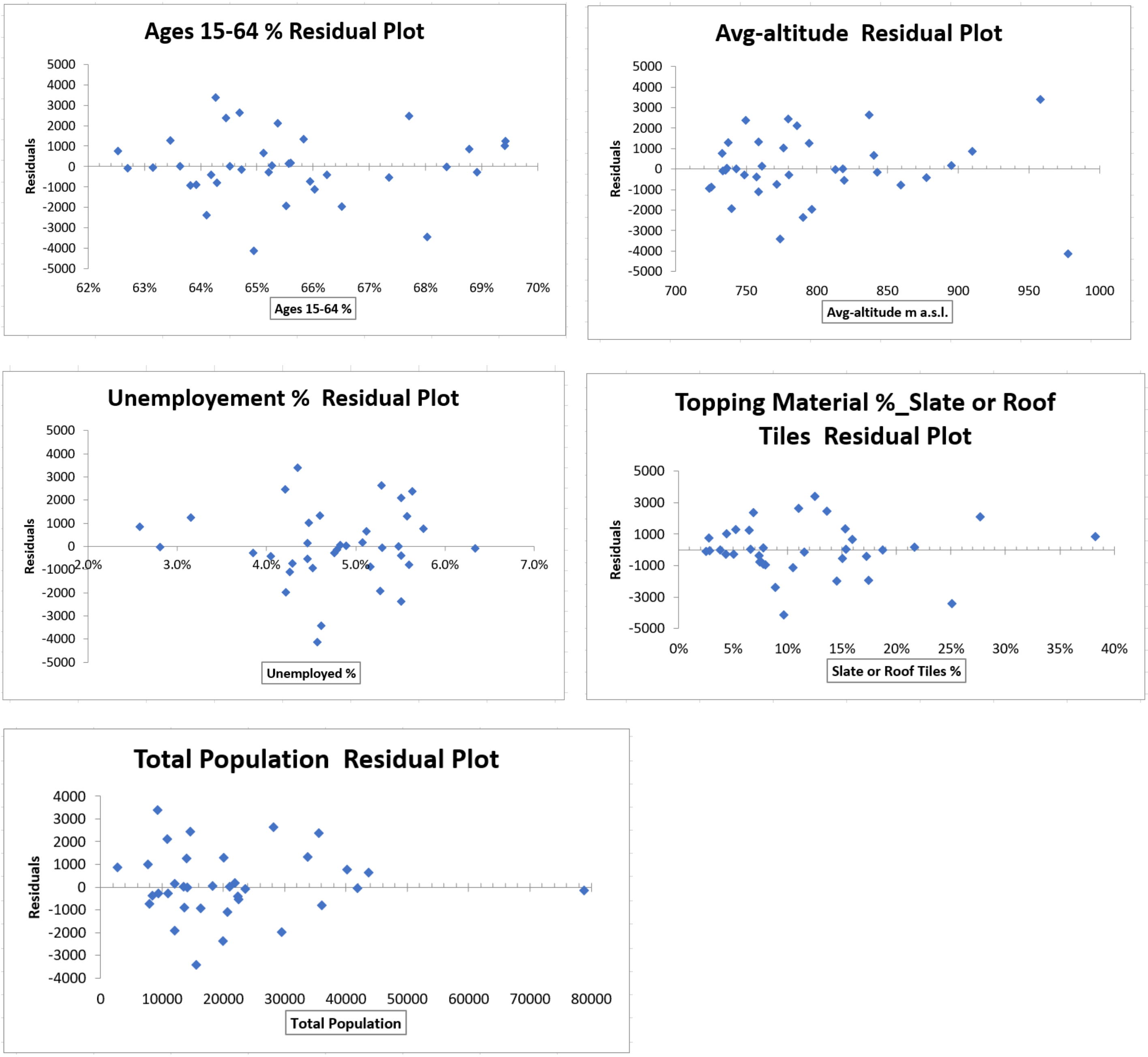


Figure 44 - The Residual Plots for Model #1 kWh/family (By Author)

5.2.4. Comparison Between Six Models

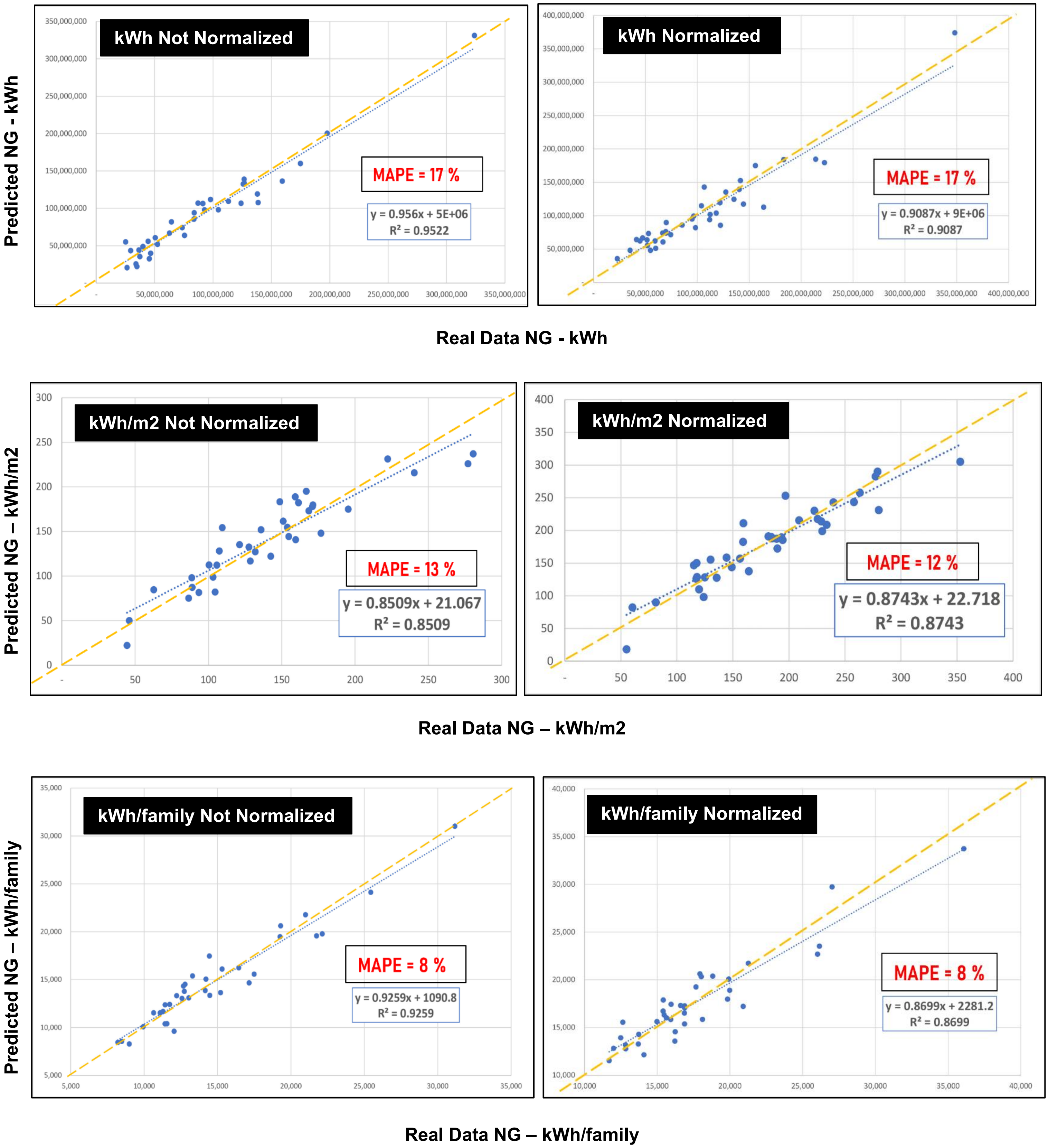


Figure 45 - Model #1 Comparison Between All Six Scenarios (By Author)

5.2.5. The Model Anomalies

There are different anomalies for each scenario which overlaps with each other in different cases. The most repeated ones are: 1. Districts in red are present in all 3 scenarios 2. Districts in orange & brown in 2 scenarios.

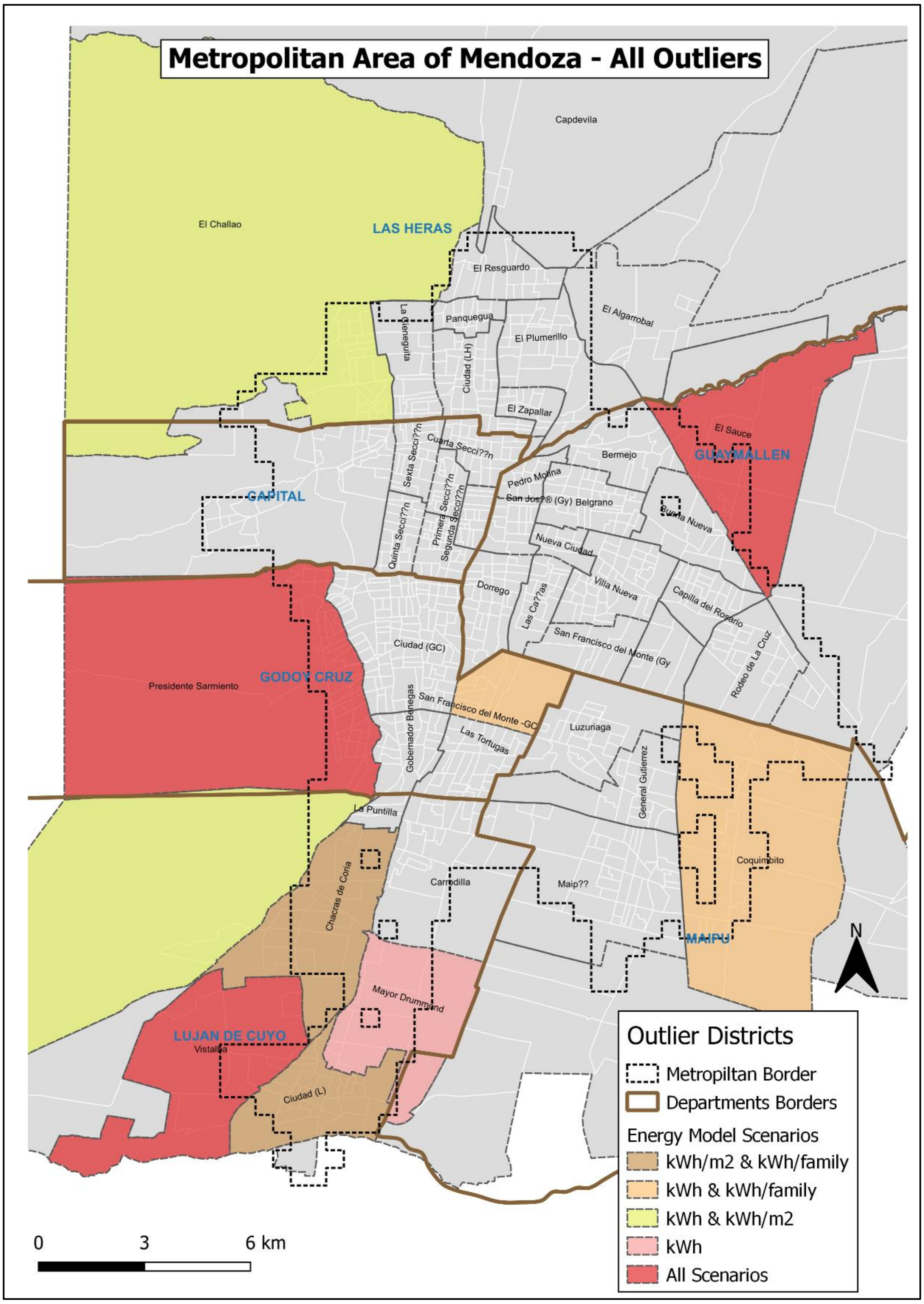


Figure 46 - Model #1 Anamolies Location Relevant To Each Scenario (By Author)

5.3. Statistical Model #2 (Outliers)

In total, for model #2 there are 9 districts from different departments, which they are analysed separately. As same as above model there are scenarios of kWh, kWh/m2, kWh/family all in not normalized data. The further information contains final energy related variables, MLR result chart & summary, Models MAPE & residual plots. At last there will be a comparison like the one in model #1 between all six scenarios of not normalized & normalized data results.

5.3.1. kWh (Not Normalized)

Final Energy Related Variables

Table 12 shows the final variables contributed in energy consumption in this scenario's model.

				OCCUPANCY %	TOPPING MATERIAL %	HOME CROWDING %			
Department	Districts	Census No.	Vivienda	Employed	Palm/Cane Board or Straw	0.51 - 0.99 People/Room	Met_station	Gas Consumption kWh - 2016	CALCULATED
Godoy Cruz	Pr. Sarmiento	42	10526	0.591246594	0.02513343	0.173216885	El Plumerillo	115,529,704.68	125,313,975.65
	S. Fr. del Monte-GC	13	2604	0.599042956	0.008380724	0.284346004	Russel	43,052,572.76	49,004,586.08
Guaymallen	El Sauce	7	2676	0.614844343	0.047917855	0.120365088	El Plumerillo	31,649,912.78	35,835,582.89
Las Heras	El Challao	28	7968	0.607958732	0.021223471	0.204605354	El Plumerillo	132,259,792.74	113,841,431.02
Lujan	Chacras de Coria	15	4654	0.669742979	0.021013922	0.349881797	Russel	174,824,964.87	173,392,246.71
	Ciudad (L)	29	7550	0.587671017	0.05398566	0.233656685	Perdriel	113,191,740.04	115,804,009.03
	Mayor Drummond	10	2774	0.59341917	0.054421769	0.201280512	Russel	63,555,276.78	45,478,570.01
	Vistalba	9	2384	0.638389648	0.033730159	0.258928571	Perdriel	81,689,211.44	90,205,995.15
Maipu	Coquimbito	15	4923	0.579933619	0.069816779	0.174734812	Russel	55,469,803.56	62,346,583.12

Table 12 - kWh Scenario Model #2, Final Energy Related Variables (By Author)

Multiple Linear Regression Results

The model #2 regression results have lower percentage of error compared to model #1 & the R squares are quite higher which shows that a stronger & more precise results, probably due to the same characteristics of all these districts & more homogeneity among them.

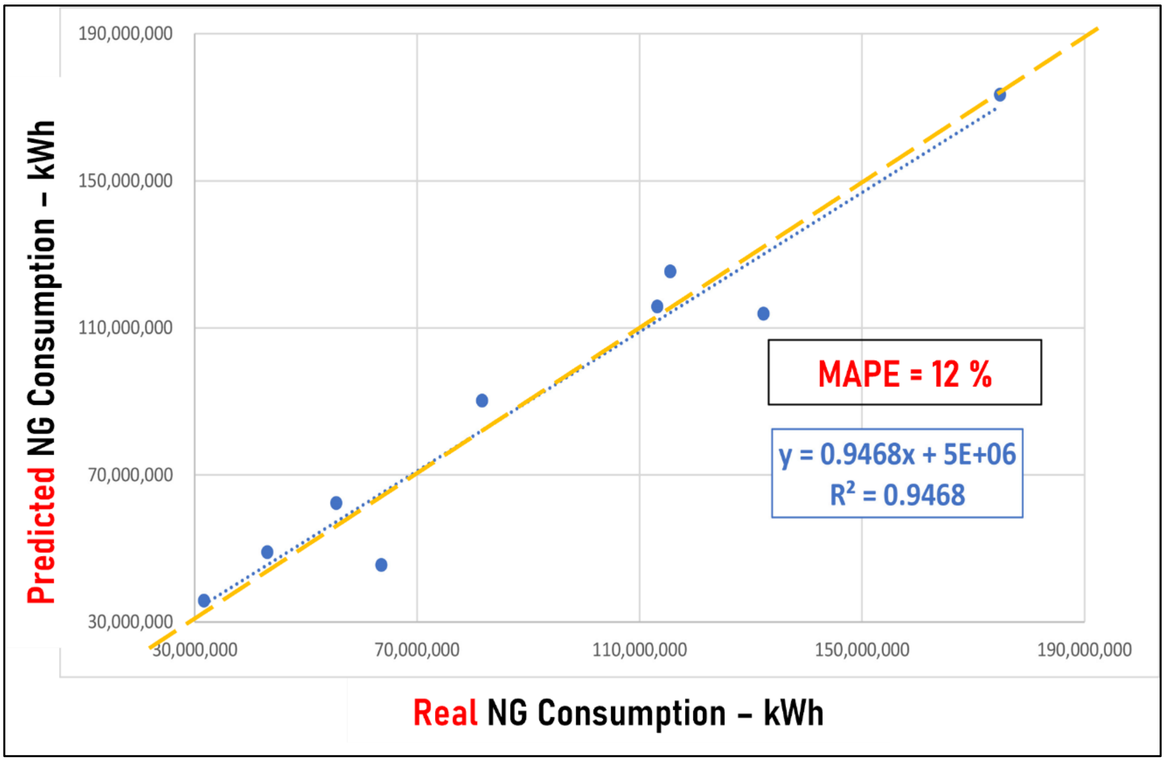


Figure 47 - The ML Regression Result Chart Model #2, kWh (By Author)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.973048
R Square	0.946822
Adjusted R Square	0.893644
Standard Error	15357278
Observations	9

X = -660929344 + (13812.18 x Vivienda) + (968219735.9 x Employed) + (557233595.8 x Palm/Cane Board) + (314025038.2 x 0.51 – 0.99 People/Room)

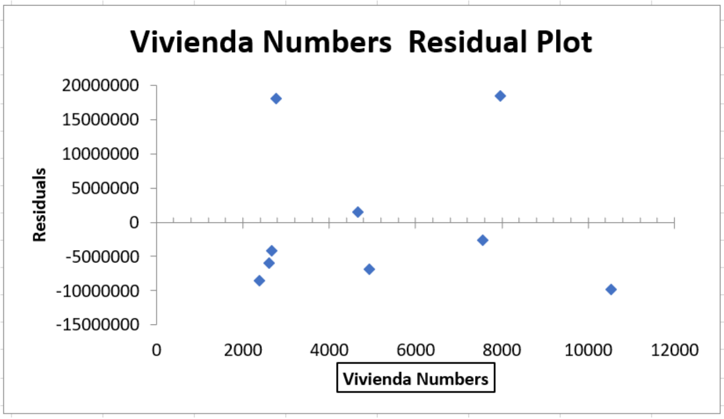
ANOVA

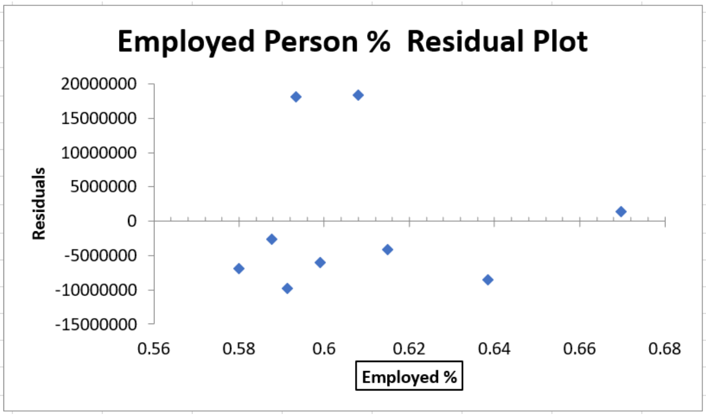
	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	1.68E+16	4.2E+15	17.804795	0.008182913
Residual	4	9.43E+14	2.36E+14		
Total	8	1.77E+16			

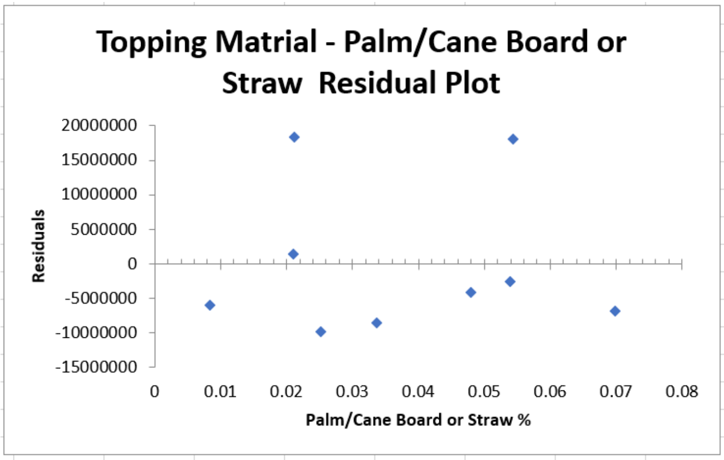
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Upper 95.0%*
Intercept	-6.6E+08	1.59E+08	-4.1633	0.0141075	-1101693860	-2.2E+08	-1.1E+09	-220164828
Vivienda	13812.19	2047.866	6.744672	0.0025188	8126.39772	19497.97	8126.398	19497.974
Employed	9.68E+08	2.63E+08	3.688213	0.0210517	239354937.6	1.7E+09	2.39E+08	1.697E+09
Palm/Cane Board (	5.57E+08	3.4E+08	1.639662	0.1764188	-386332104	1.5E+09	-3.9E+08	1.501E+09
0.51 - 0.99 People,	3.14E+08	1.11E+08	2.826711	0.0475033	5584168.574	6.22E+08	5584169	622465908

Table 13 - Regression Summary for Model #2, kWh (By Author)

The Residual Plots







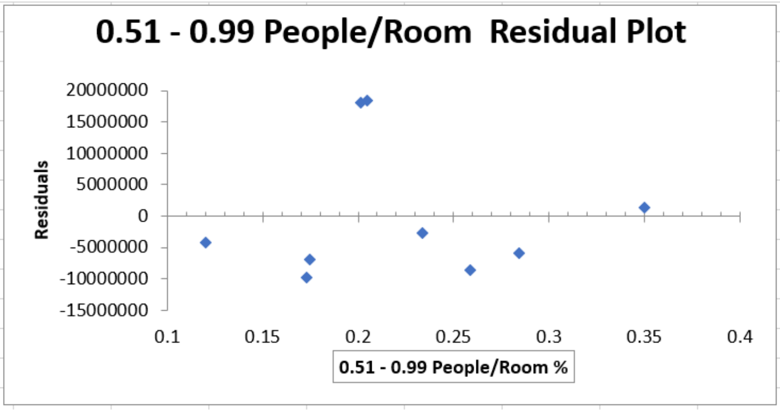


Figure 48 - The Residual Plots for Model #2 kWh (By Author)

5.3.2. kWh/m2 (Not Normalized)

Final Energy Related Variables

Department	Districts	Census No.	Total Families	Pop/Families	Total Heat Loss Surfaces m2	Gross Heated Area m2	Met_station	Gas Consumption kWh - 2016	Gas Consumption kWh/m2 (GROSS)	CALCULATED
Godoy Cruz	Pr. Sarmiento	42	10305	3.74	2,030,916.70	655173.010	El Plumerillo	115,529,704.68	176.33	180.96
	S. Fr. del Monte-GC	13	3341	3.40	1,187,755.87	400644.210	Russel	43,052,572.76	107.46	114.38
Guaymallen	El Sauce	7	1753	4.13	188,591.47	56162.360	El Plumerillo	31,649,912.78	563.54	557.98
Las Heras	El Challao	28	7562	3.77	1,598,472.04	515562.040	El Plumerillo	132,259,792.74	256.54	270.92
Lujan	Chacras de Coria	15	3807	3.531	1,581,115.86	515788.730	Russel	174,824,964.87	338.95	324.81
	Ciudad (L)	29	7113	3.432	2,258,276.84	770080.590	Perdriel	113,191,740.04	146.99	140.43
	Mayor Drummond	10	2499	3.690	717,509.39	226494.530	Russel	63,555,276.78	280.60	312.49
	Vistalba	9	2034	3.698	726,069.00	231669.900	Perdriel	81,689,211.44	352.61	347.98
Maipu	Coquimbito	15	5185	3.720	814,285.62	249532.450	Russel	55,469,803.56	222.29	195.35

Table 14 - kWh/m2 Scenario Model #2, Final Energy Related Variables (By Author)

Multiple Linear Regression Results

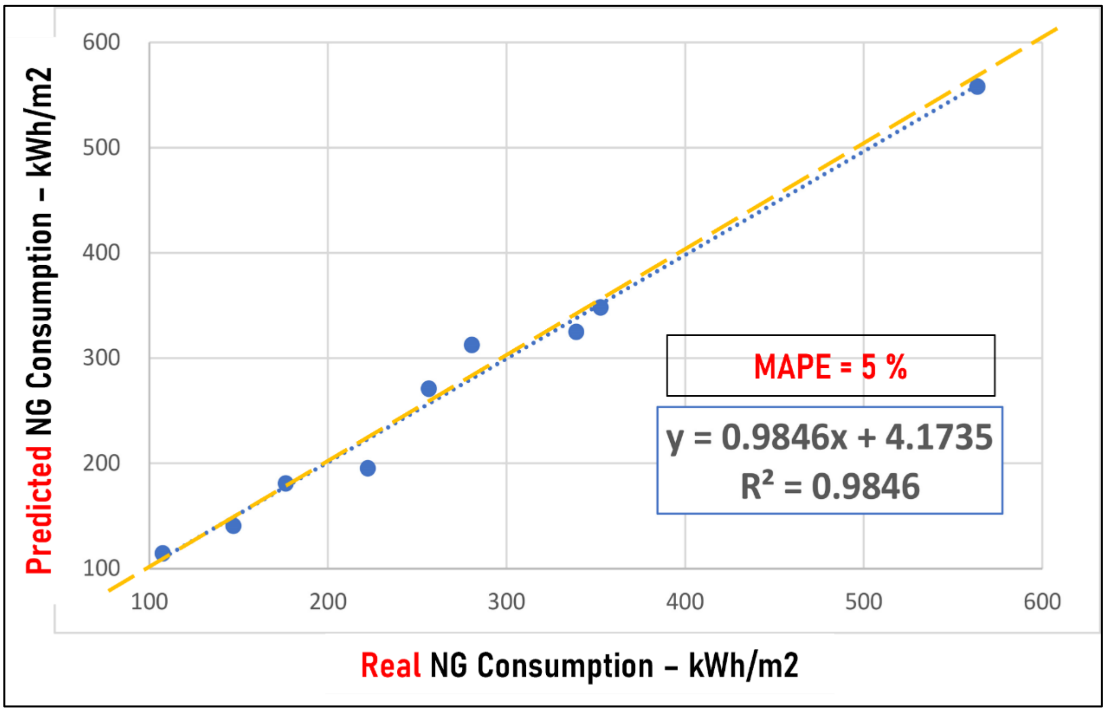


Figure 49 - The ML Regression Result Chart Model #2, kWh/m2 (By Author)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99229
R Square	0.984639
Adjusted R Square	0.969279
Standard Error	24.04955
Observations	9

X = -2669.05 + (-0.069 x Total families) + (795.23 x pop/families) + (0.00096 x Total Heat Loss) + (-0.002 x Gross Heated Area)

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	4	148300.9	37075.22	64.10171	0.000701
Residual	4	2313.524	578.3811		
Total	8	150614.4			

	Coefficients	*andard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Ipper 95.0%*
Intercept	-2669.05	267.9227	-9.962	0.00057	-3412.92	-1925.17	-3412.92	-1925.17
Total Families	-0.06921	0.008571	-8.07564	0.001277	-0.09301	-0.04542	-0.09301	-0.04542
Pop/Families	795.2365	68.70709	11.5743	0.000318	604.475	985.9979	604.475	985.9979
Total Heat Loss Surfaces m2	0.000968	0.000337	2.868586	0.045533	3.11E-05	0.001904	3.11E-05	0.001904
Gross Heated Area m2	-0.00209	0.000938	-2.2323	0.089383	-0.0047	0.000511	-0.0047	0.000511

Table 15 - Regression Summary for Model #2, kWh/m2 (By Author)

The Residual Plots

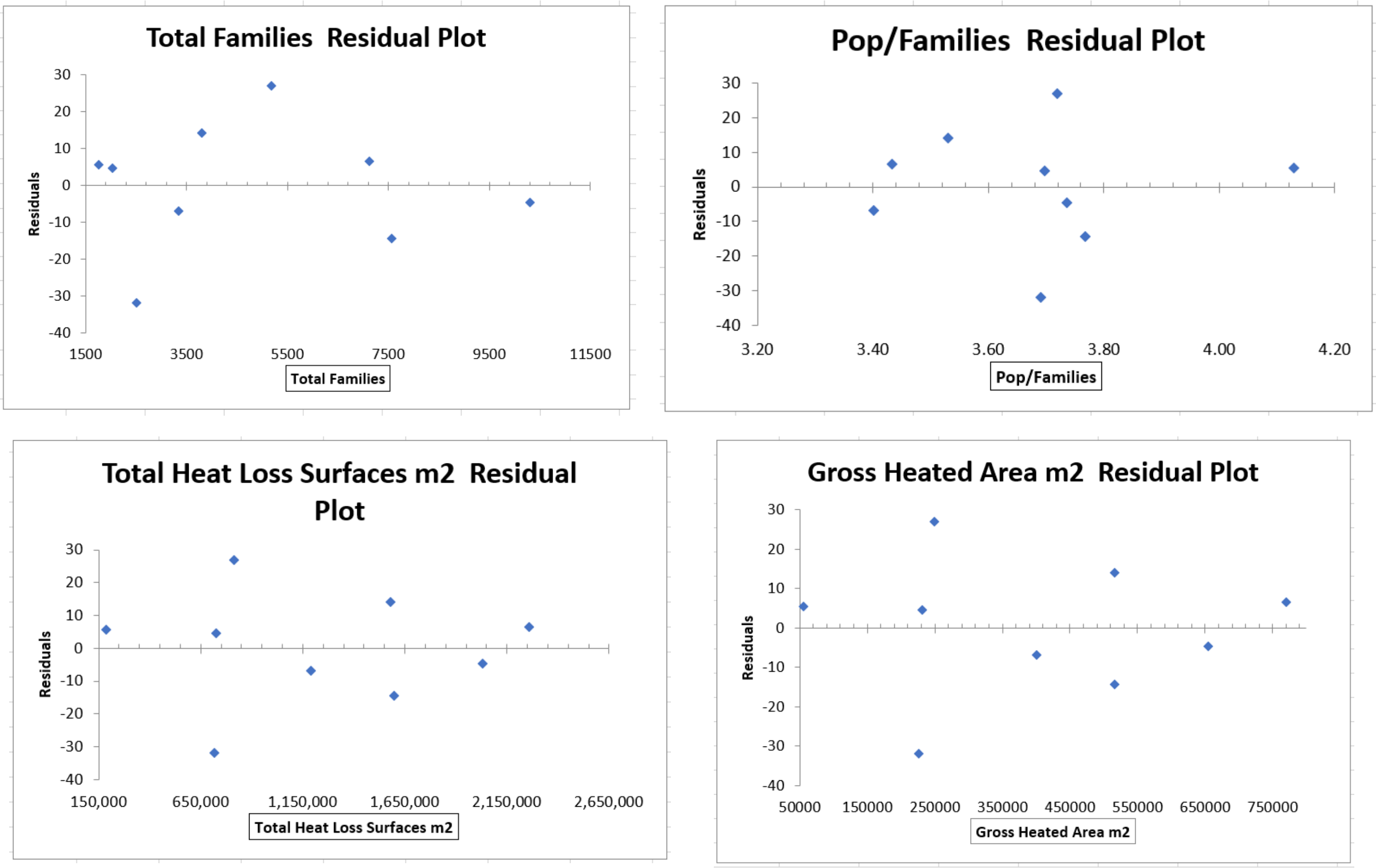


Figure 50 - The Residual Plots for Model #2 kWh/m2 (By Author)

5.3.3. kWh/family (not Normalized)

Final Energy Related Variables

				OCCUPANCY						
Department	Districts	Census No.	Total Population	Employed	Average S/V m⁻¹	Avg-altitude	Met_station	Gas Consumption kWh - 2016	Gas Consumption kWh/family	CALCULATED
Godoy Cruz	Pr. Sarmiento	42	38854	0.591247	1.391	902.16	El Plumerillo	115,529,704.68	11211.03	12018.63
	S. Fr. del Monte-GC	13	10927	0.599043	1.350	834.74	Russel	43,052,572.76	12886.13	15826.08
Guaymallen	El Sauce	7	10769	0.614844	1.478	704.64	El Plumerillo	31,649,912.78	18054.71	18235.47
Las Heras	El Challao	28	28145	0.607959	1.419	836.76	El Plumerillo	132,259,792.74	17490.05	17014.27
Lujan	Chacras de Coria	15	13441	0.669743	1.397	956.57	Russel	174,824,964.87	45921.98	44149.08
	Ciudad (L)	29	24385	0.587671	1.339	977.52	Perdriel	113,191,740.04	15913.36	16399.94
	Mayor Drummond	10	9300	0.593419	1.392	958.10	Russel	63,555,276.78	25432.28	22436.48
	Vistalba	9	7437	0.63839	1.493	1012.55	Perdriel	81,689,211.44	40161.85	42515.17
Maipu	Coquimbito	15	19515	0.579934	1.444	790.32	Russel	55,469,803.56	10698.13	9174.441

Table 16 - kWh/family Scenario Model #2, Final Energy Related Variables (By Author)

Multiple Linear Regression Results

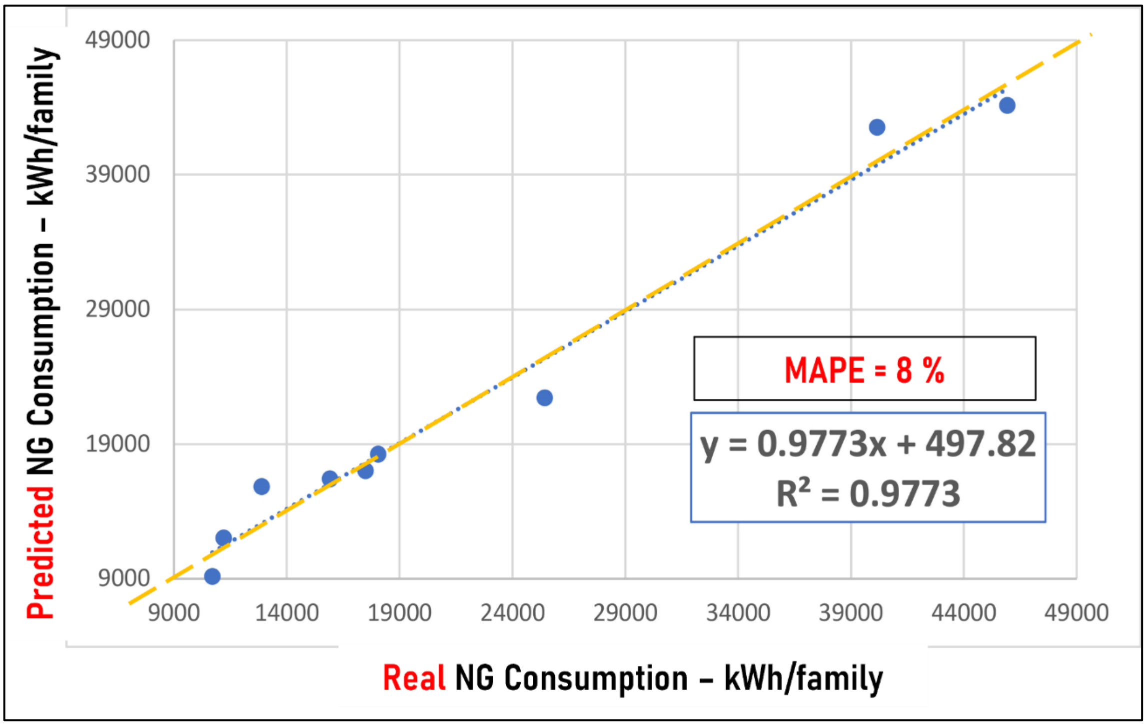


Figure 51 - The ML Regression Result Chart Model #2, kWh/family (By Author)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.98860779
R Square	0.97734537
Adjusted R Square	0.95469074
Standard Error	2728.04997
Observations	9

X = -249607.12 + (-0.23 x Total population) + (295975.48 x Employed) + (34940 x Average S/V) + (52.08 x Avg-altitude)

ANOVA

	df	*SS*	*MS*	*F*	*ignificance F*
Regression	4	1.28E+09	3.21E+08	43.14109	0.001516
Residual	4	29769026	7442257		
Total	8	1.31E+09			

	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*Ipper 95.0%*
Intercept	-249607.12	35102.75	-7.11076	0.002067	-347068	-152146	-347068	-152146
Total Population	-0.2301648	0.102784	-2.23931	0.08869	-0.51554	0.055209	-0.51554	0.055209
Employed	295975.489	41165.8	7.189839	0.001983	181680.9	410270.1	181680.9	410270.1
Average S/V m^{-1}	34940.0005	21488.29	1.626002	0.179276	-24721.1	94601.06	-24721.1	94601.06
Avg-altitude	52.0848183	10.90982	4.774124	0.008813	21.79431	82.37533	21.79431	82.37533

Table 17 - Regression Summary for Model #2, kWh/family (By Author)

The Residual Plots

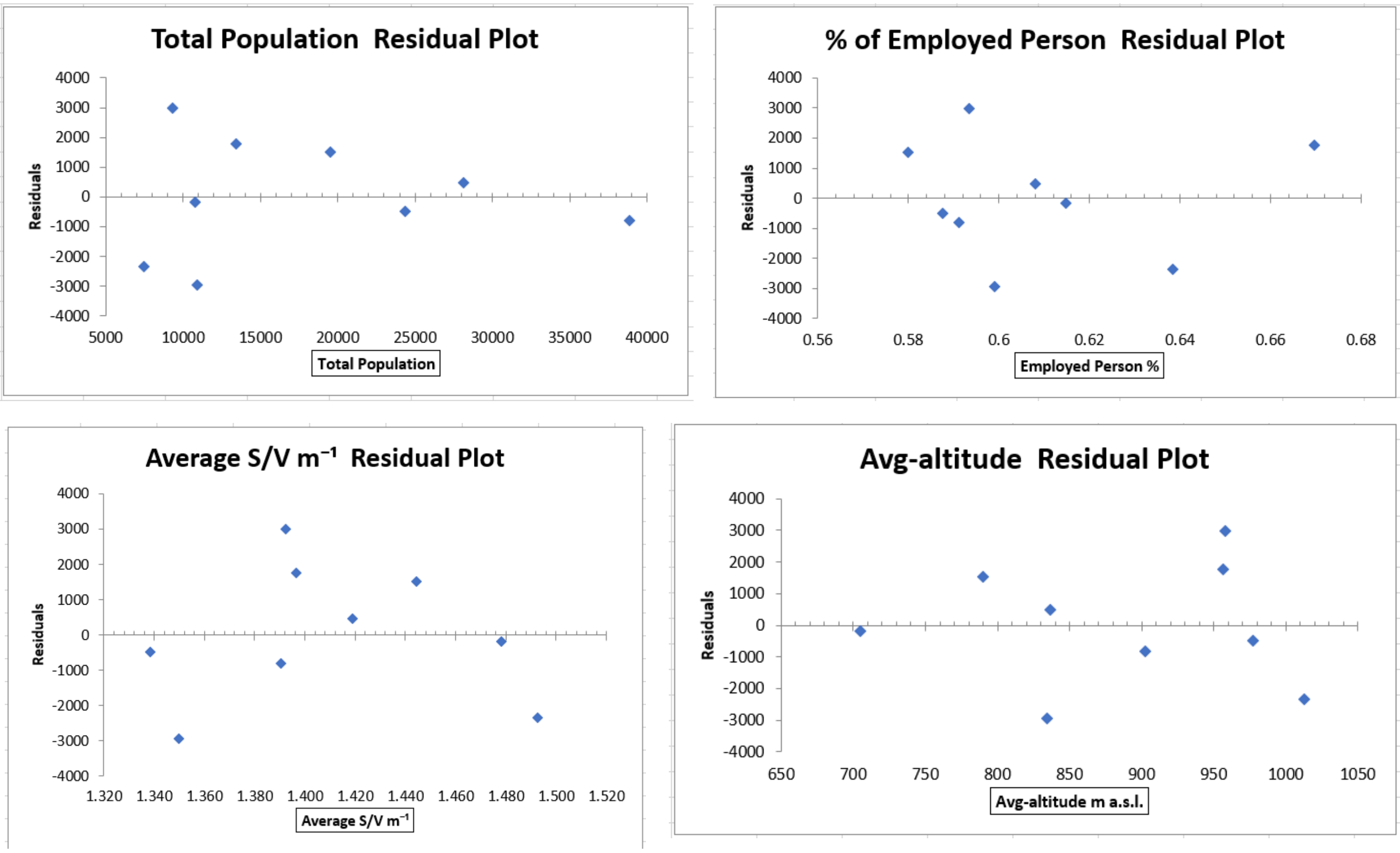


Figure 52 - The Residual Plots for Model #2 kWh/family (By Author)

5.3.4. Comparison Between Six Models

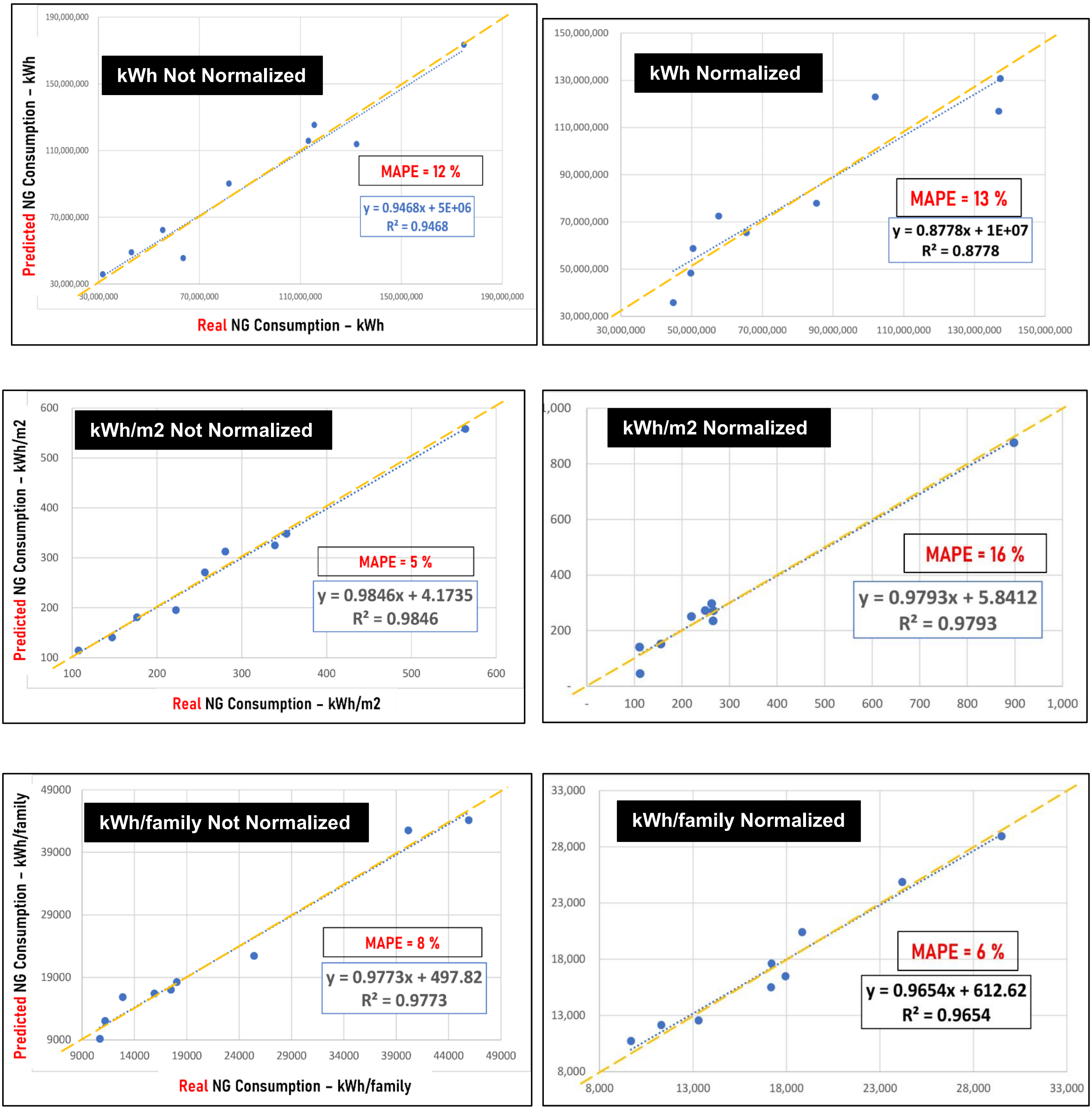


Figure 53 - Model #2 Comparison Between All Six Scenarios (By Author)

6. The Conclusion

6.1. Summary

This chapter will discuss about the outputs of 2 models that described in previous chapter & comparing different districts situation to discover which one of them are in need of any intervention of any type, based on analysing the energy related variables. The possibility of applying this method in other territories & pushing the sustainability policies regarding Energy Consumption are other discussing matters.

The research resulted in creation of two statistical models for NG consumption, applied at district scale, which distinguish peripheral areas (low built density) from other districts. In each model the main energy related variables have been specified that make it easier to target the reason of possible high consumptions & comparison between two. The analysis demonstrated that not only building characteristics are influential o energy, but also social & urban parameters were involved.

After first results for reducing high MAPE the districts with high errors & same characters are classified in new group to create a separate model for them, called outliers. By aggregation of two models, we will have the building thermal energy consumption model of whole Mendoza.

Identification of intervention priorities in all districts by quadrant graph method which categorized in 4 ranges of high, urgent, important & low priorities.

6.2. Final Outputs

By interpreting the results from both MLR & energy variables it is understood that, not only buildings characteristics caused higher consumption in some districts, due to the low efficiency of building, but also socio-economic & urban parameters are involved. On the other hand, the models could be categorized for central & peripheral areas which allow us to analyze different territories which have mixed urban context.

One of the strengths of this methodology is identification of critical areas or districts regrading NG consumption & prioritizing them by importance of interventions they need, with a deeper analysis of variables that caused the high consumption. Finally, by adoption of right energy policies & interventions for Mendoza, the sustainability of city can be pushed to new limits & developments. The main outputs of work summarized as:

1. Contribution of diverse type of variables (socio-economic, urban, Buildings)
2. Introducing the most correlated variables with energy
3. Applicable in two different territories (Central & suburban)
4. Discovering the most critical areas for interventions
5. Adopting the correct energy policies

Department	Districts	No.	MODEL TYPE #	Dstrict's Area	Total families	kWh 2016	Percentage of Total kWh	kWh/m2 (District Area)	MWh/family
Capital	Cuarta S.	1	1	3,193,480	7,138	87,188,758.4	2.4%	27.30	12.21
	Primera S.	2	1	1,635,482	3,544	39,981,023.0	1.1%	24.45	11.28
	Quinta S.	3	1	2,442,874	5,429	104,530,254.7	2.8%	42.79	19.25
	Segunda S.	4	1	2,341,492	5,794	83,832,212.3	2.3%	35.80	14.47
	Sexta S.	5	1	2,720,978	6,265	138,634,213.2	3.8%	50.95	22.13
	Tercera S.	6	1	1,502,810	2,977	33,992,762.1	0.9%	22.62	11.42
Godoy Cruz	Ciudad (GC)	7	1	12,240,624	25,754	323,858,033.5	8.8%	26.46	12.58
	Gob. Benegas	8	1	3,993,821	7,152	137,977,577.5	3.7%	34.55	19.29
	Las Tortugas	9	1	4,873,153	9,698	123,957,396.8	3.4%	25.44	12.78
	Pr. Sarmiento	10	2	51,809,715	10,305	115,529,704.7	3.1%	2.23	11.21
	S. Fr. del Monte-GC	11	2	5,344,194	3,341	43,052,572.8	1.2%	8.06	12.89
Guaymallen	Belgrano	12	1	4,596,361	10,951	92,747,642.0	2.5%	20.18	8.47
	Bermejo	13	1	5,493,452	4,075	46,537,540.4	1.3%	8.47	11.42
	Buena Nueva	14	1	5,681,397	3,509	37,337,258.4	1.0%	6.57	10.64
	Capilla del Rosario	15	1	3,580,712	5,202	73,661,049.0	2.0%	20.57	14.16
	Dorrego	16	1	4,727,571	9,523	126,605,184.9	3.4%	26.78	13.29
	El Sauce	17	2	18,875,240	1,753	31,649,912.8	0.9%	1.68	18.05
	J. Nazareno	18	1	3,682,871	2,071	26,368,836.8	0.7%	7.16	12.73
	Las Canas	19	1	2,919,814	4,412	75,635,638.9	2.0%	25.90	17.14
	Nueva Ciudad	20	1	1,531,988	2,510	29,454,348.3	0.8%	19.23	11.73
	Pedro Molina	21	1	1,565,061	3,293	36,501,647.1	1.0%	23.32	11.08
	Rodeo de La Cruz	22	1	7,772,630	5,430	62,712,690.6	1.7%	8.07	11.55
	S. Fr. del Monte-Gy	23	1	4,072,746	2,414	52,475,443.6	1.4%	12.88	21.74
	San Jose (Gy)	24	1	2,143,717	3,875	50,533,928.4	1.4%	23.57	13.04
	Villa Nueva	25	1	6,255,647	10,478	159,298,863.9	4.3%	25.46	15.20
Las Heras	Ciudad (LH)	26	1	5,038,775	10,536	126,793,497.3	3.4%	25.16	12.03
	El Challao	27	2	7,461,273	7,562	132,259,792.7	3.6%	17.73	17.49
	El Plumerillo	28	1	8,647,583	10,160	91,303,290.4	2.5%	10.56	8.99
	El Resguardo	29	1	5,011,122	5,544	45,467,010.4	1.2%	9.07	8.20
	El Zapallar	30	1	1,853,809	3,504	44,393,049.9	1.2%	23.95	12.67
	La Cieneguita	31	1	4,044,793	4,462	64,445,852.1	1.7%	15.93	14.44
	Panquegua	32	1	1,762,217	3,502	34,804,046.1	0.9%	19.75	9.94
Lujan	Carrodilla	33	1	14,033,242	5,996	125,832,249.4	3.4%	8.97	20.99
	Chacras de Coria	34	2	14,572,632	3,807	174,824,964.9	4.7%	12.00	45.92
	Ciudad (L)	35	2	6,923,317	7,113	113,191,740.0	3.1%	16.35	15.91
	La Puntilla	36	1	1,220,172	808	25,182,133.6	0.7%	20.64	31.17
	Mayor Drummond	37	2	5,729,550	2,499	63,555,276.8	1.7%	11.09	25.43
	Vistalba	38	2	19,825,351	2,034	81,689,211.4	2.2%	4.12	40.16
Maipu	Coquimbito	39	2	34,676,706	5,185	55,469,803.6	1.5%	1.60	10.70
	Gen.Gutierrez	40	1	7,458,605	5,889	83,676,229.3	2.3%	11.22	14.21
	Luzuriaga	41	1	8,602,004	6,395	97,875,643.6	2.7%	11.38	15.31
	Maipu	42	1	19,432,258	12,028	197,777,308.9	5.4%	10.18	16.44
Median				4,942,137	5,316	78,662,425	2.1%	18.48	13.17

Table 18 - Mendoza Energy Model Districts & Consumption Data (source: By Author)

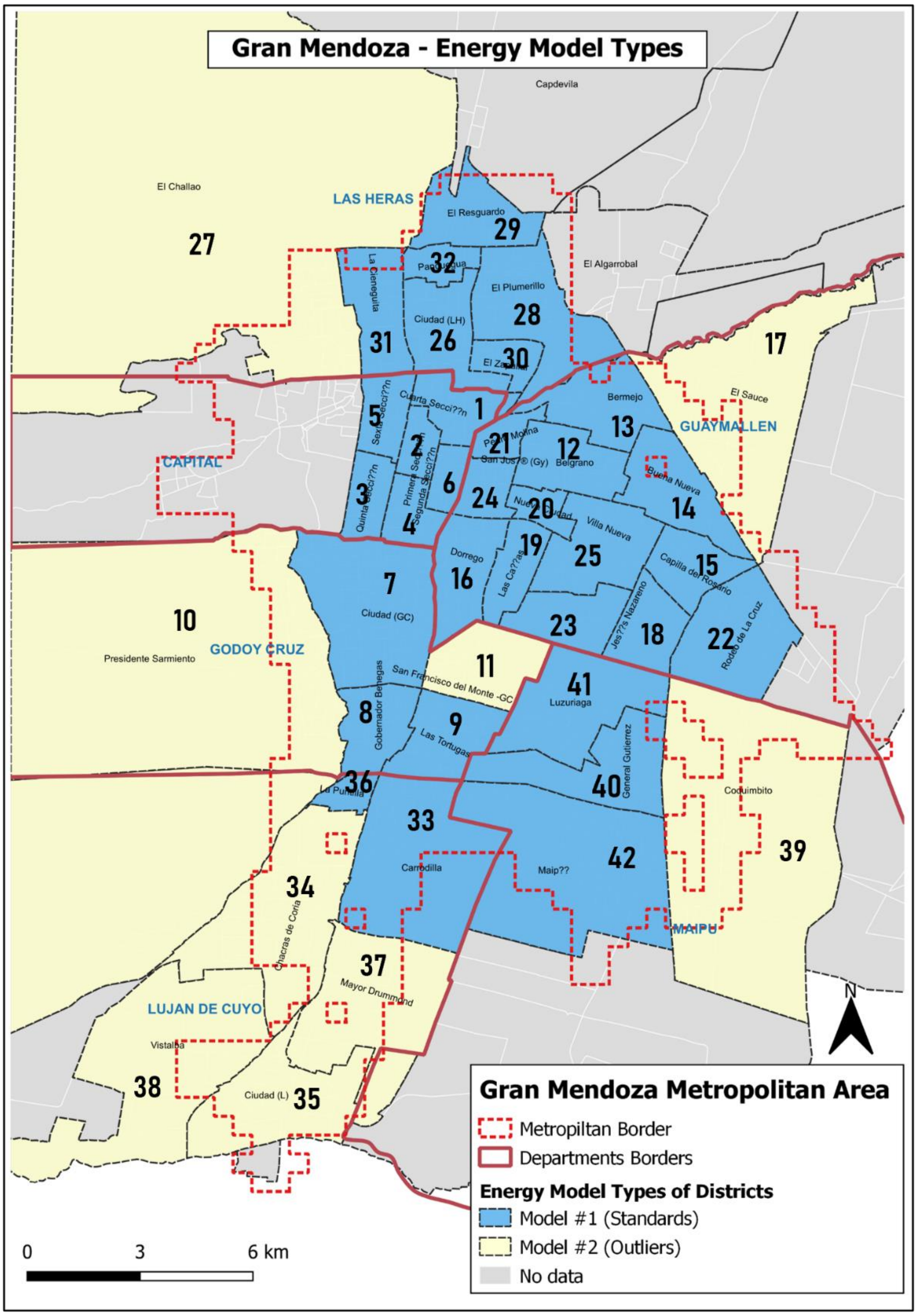


Figure 54 - Energy Model Types of Whole Mendoza (source: By Author)

In Table 18, all 42 districts of gran Mendoza which have been analysed in this work are shown. Each one of them are specified by several columns in table consisting of department, name, model type etc. The main point about the table is the report of NG consumption situation in each district. This information tells us what percentage of kWh (2016) consumption has each district & how much kWh/m2 (District's Area) & MWh/family they consume. The most critical districts are highlighted in table according to high values of kWh/m2 & MWh/family, both in red color & high MWh/family in yellow. Both of them represent critical situation regrading lack of RES use for energy technology or low efficiency of houses energy systems & families which consume more than others. Figure 54, illustrates the location & model types of all districts discussed in table before.

6.3. Effective Variables

Next step is one of the key parts of the project. After creation of an energy model for whole gran Mendoza, it is necessary to discover the reasons for high consumption & attributes that can be controlled in order to reduce energy consumption, besides, increase the efficiency of houses.

Regarding above concept, all energy elated variables of six scenarios, for both models (#1 & #2) are gathered & analysed to discover the ones which has the potential to be improved and consequently, reduce the intensity of consumption by them. In general, the variables are different, however, there are some overlaps between them which by observing their relevant coefficients, their differences are explained. According to Table 19, the most useful variables are highlighted with red dashed line rectangle which describe that by improving or applying correct policies for them, the energy efficiency of building could improve & result in lower consumption.

These variables are:

- Component per family
- Topping materials (Slate roof tiles – Palm/cane board)
- Material Quality (1 & 2)
- Employment level
- Home Crowding (0.51 – 0.99 people/room)
- Interior coating/ceiling
- Heat loss surfaces

Model #1 - Standard

					AGES %	EMPLOYMENT %	HOME CROWDING %		TOPPING MATERIAL %	INTERIOR/CEILING COATING %	CONNECTION TO SERVICES QUALITY %	MATERIAL QUALITY %						
Energy Related Variables	Total Population	Total Families	No. Dwellings	Pop/Families	15-64	Unemployed	0.51 - 0.99 People/Room	2.00 - 3.00 People/Room	Slate or Roof Tiles	No	Satisfactory	M Quality 1	Districts Area m2	Total Heat Loss Surfaces m2	Gross Heated Area m2	Average S/V m⁻¹	Avg-altitude m a.s.l.	Total Buildings Footprint Area m2
kWh																		
Coefficients			4,734.25				296,768,657.40											
kWh/m2																		
Coefficients				-44.61											-0.0032			
kWh/family																		
Coefficients	-0.071																41.61	
kWh - Normalized																		
kWh/m2 - Normalized																		
Coefficients				-26.52											0.0088			
kWh/family - Normalized																		

Energy Model Scenarios

Model #2 - Outlier

					EMPLOYMENT %	HOME CROWDING %	TOPPING MATERIAL %	MATERIAL QUALITY %					
Energy Related Variables	Total Population	Total Families	No. Dwellings	Pop/Families	Employed	0.51 - 0.99 People/Room	Palm/Cane Board or Straw	M Quality 2	M Quality 3	Total Heat Loss Surfaces m2	Gross Heated Area m2	Average S/V m⁻¹	Avg-altitude m a.s.l.
kWh													
Coefficients			13,812.18			314,025,038.20							
kWh/m2													
Coefficients				795.23							-0.002		
kWh/family													
Coefficients	-0.23												52.08
kWh - Normalized													
kWh/m2 - Normalized													
Coefficients				943.40							0.0012		
kWh/family - Normalized													

Energy Model Scenarios

Table 19 - Most Energy Related Variables of Both Models In & Scenarios (source: By Author)

6.4. Energy Policies & Intervention Priorities

The energy policy for both models are using building retrofit interventions & facilitating renewable energy technologies. The difference between them is connected to the economic incentives that they need for pushing their energy efficiency situation. Due to the lower income & higher density of component per families in model #2 (peripheral areas), it is decide that to consider them as higher priority & provide better economic incentive to support energy efficiency improvements in these areas.

6.4.1. Model #1

Thermal Insulation & Window Substitution

For modelling #1, heat loss surfaces & topping material (Slate roof tiles) are quite effective on high consumptions, while material quality type1 had a negative effect on consumption. Therefore, it can be concluded that upgrading thermal performance of the building is vital to increase efficiency in this case. So, thermal insulation upgrade & window substitution are the policies.

RES (Solar Panel, PV) Use & Boiler Substitution

For reduction of dependency on fossil fuels & consequently less expensive bills, the use of renewable energy technologies like solar panels & PV are recommended since there are high potentials of solar exploit in region. Moreover, boiler substitution is another option. This will help to increase the performance of buildings energy systems & increase the use of more updated & verified equipment with higher efficiency.

6.4.2. Model #2

Same Interventions But Higher Incentives

For the modelling #2, the situation is the same as modelling #1. But, the only difference is linked to the social & household situation. In this model there are higher concentrate for components/family (3.7 compared to 3.4 in model 1), lower employment level (59% compared to 61%), higher density of people in rooms (3% more than model 1) & lower material quality (almost 10% lower). Moreover, the NG consumption median is also higher. Therefore, in this case people needs more economic support to push the energy efficiency levels.

6.4.3. Economic Incentives Levels

About giving people the essential financial support for starting energy efficiency improvements, a comparison has been carried out between our models. The results showed that the situation regarding social variables mentioned above, are more critical in model #2. This signify that there should be higher financial support for the peripheral areas for applying energy efficiency measures. As a result, two types of incentives are defined. First, economic incentive level 1 for peripheral areas (model #2), second, economic incentive level 2 for central areas (model #1).

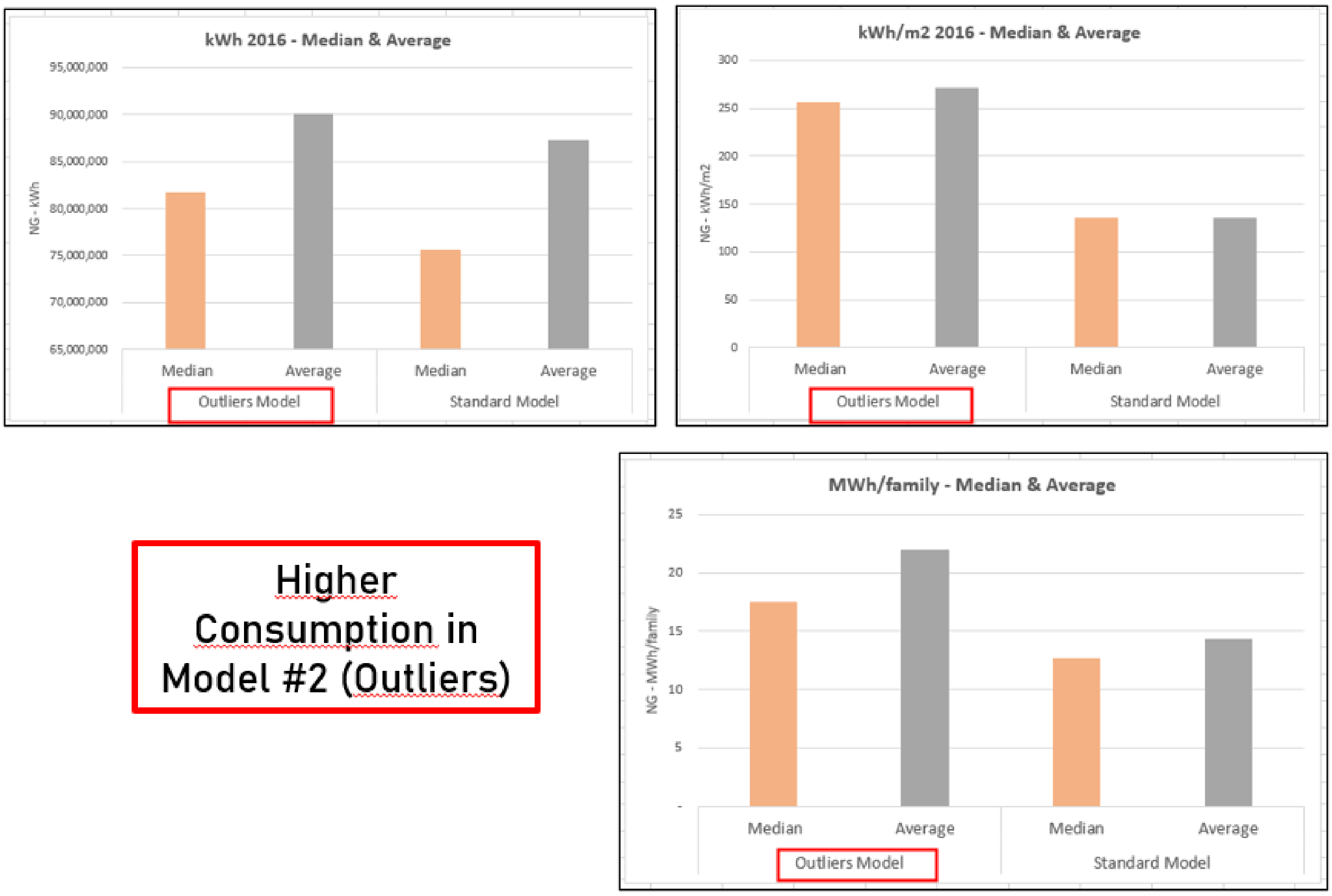


Figure 55 - Energy Consumption Comparison in Average/Median Between 2 Models (source: By Author)

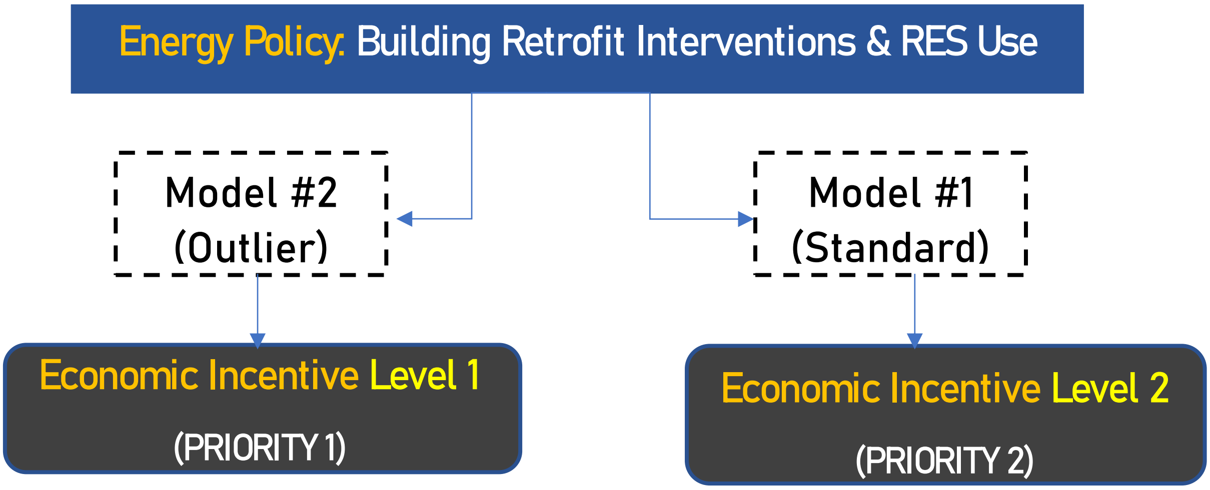


Figure 56 - Economic Incentives Levels Of Each Model (source: By Author)

Energy Savings By Applying Energy Policies & Incentives

Table 20, describe by improvements of effective variables such topping material and material quality, how much energy savings are achievable in kWh & US dollar. The amount of saved money is calculated by NG price of households per kWh in Argentina, reported by Global Petrol Prices in December 2022 [33]. These improvements planned to be implemented in ten years period.

kWh x 0.015 US dollar = Energy Savings US $/year [33]

Median Values

Model Type	Scenario	Improved Variable	% of Improvements	kWh Savings	US dollar Savings
#1	kWh/m2	Topping Material (Slate Roof Tiles)	10%	20,170,403.08	$ 302,556.05
#1	kWh/m2	Material Quality (Type 1)	10%	13,755,061.07	$ 206,325.92
#2	kWh	Topping Material (Palm/Cane Board)	10%	18,795,577.64	$ 281,933.66
#2	kWh/m2	Material Quality (Type 2)	10%	50,650,966.31	$ 759,764.49

Table 20 - Possible Energy Savings By Applying Energy Policies (source: By Author)

Above Table results indicate that in 10 period of applying retrofit interventions in Mendoza, energy efficiency could increase 7% compared to its current situation. Total median savings for all districts would be about 103,372,008 kWh & 1,550,580 US dollars.

6.4.4. Intervention Priorities

Thorough a quadrant graph method, all the districts of gran Mendoza are prioritized for carrying on interventions. Figure 55, below shows the distribution of districts by relevant numbers. Values beyond the defined median line are considered for interventions in three different levels.

1. Highest (critical in both kWh/m2 & kWh)
2. Urgent (high kWh)
3. Important (high kWh/m2)
4. Low

At las, the highest consumed districts are specified with red circles. This graph includes districts of both model #1 6 model #2.

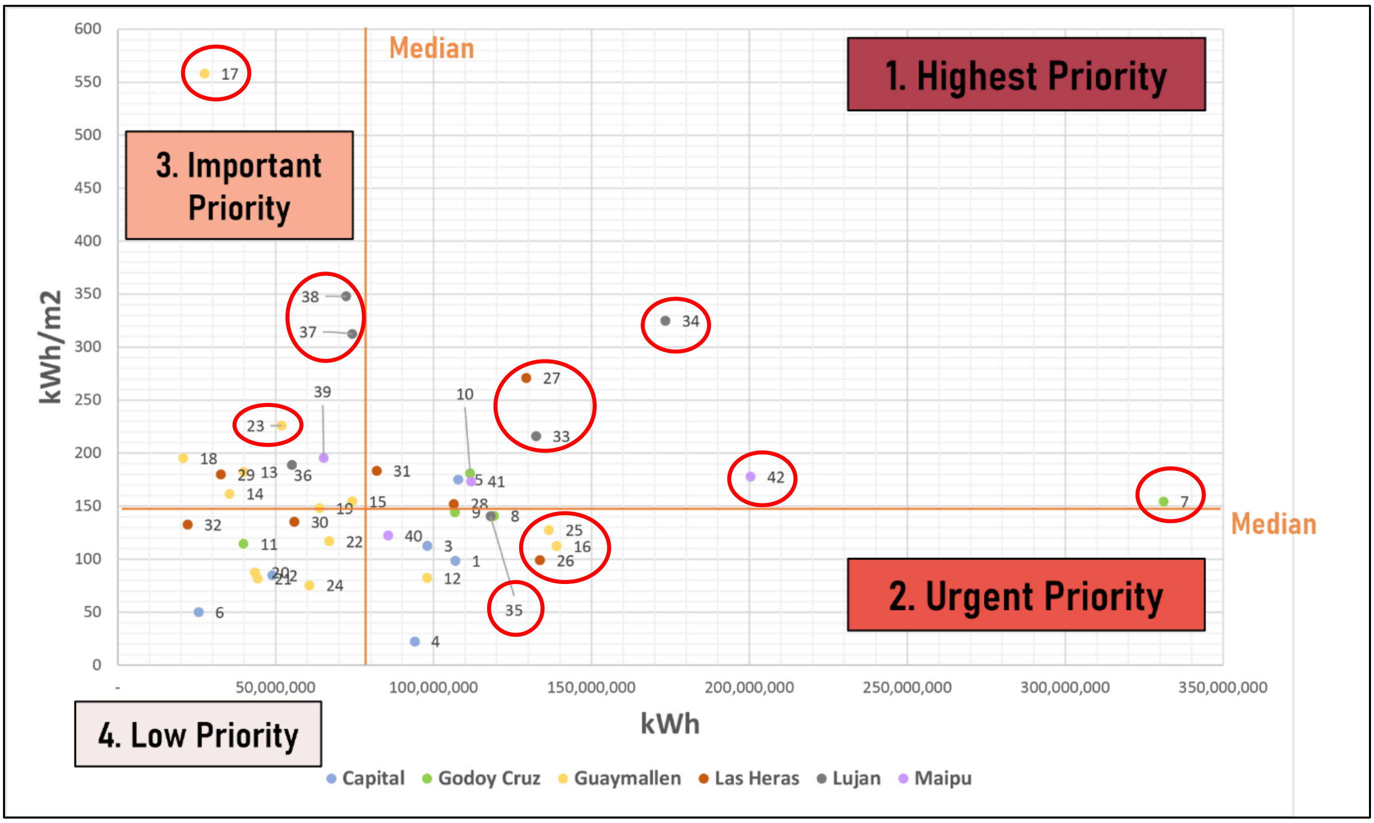


Figure 57 - Quadrant Graph of Intervention Priorities For Both Models (source: By Author)

Following maps illustrate the location of each district by number and classify them by their priority for intervention in relevant colors. Models are separated regarding this information based on their type of modelling.

Intervention Priorities Model #1

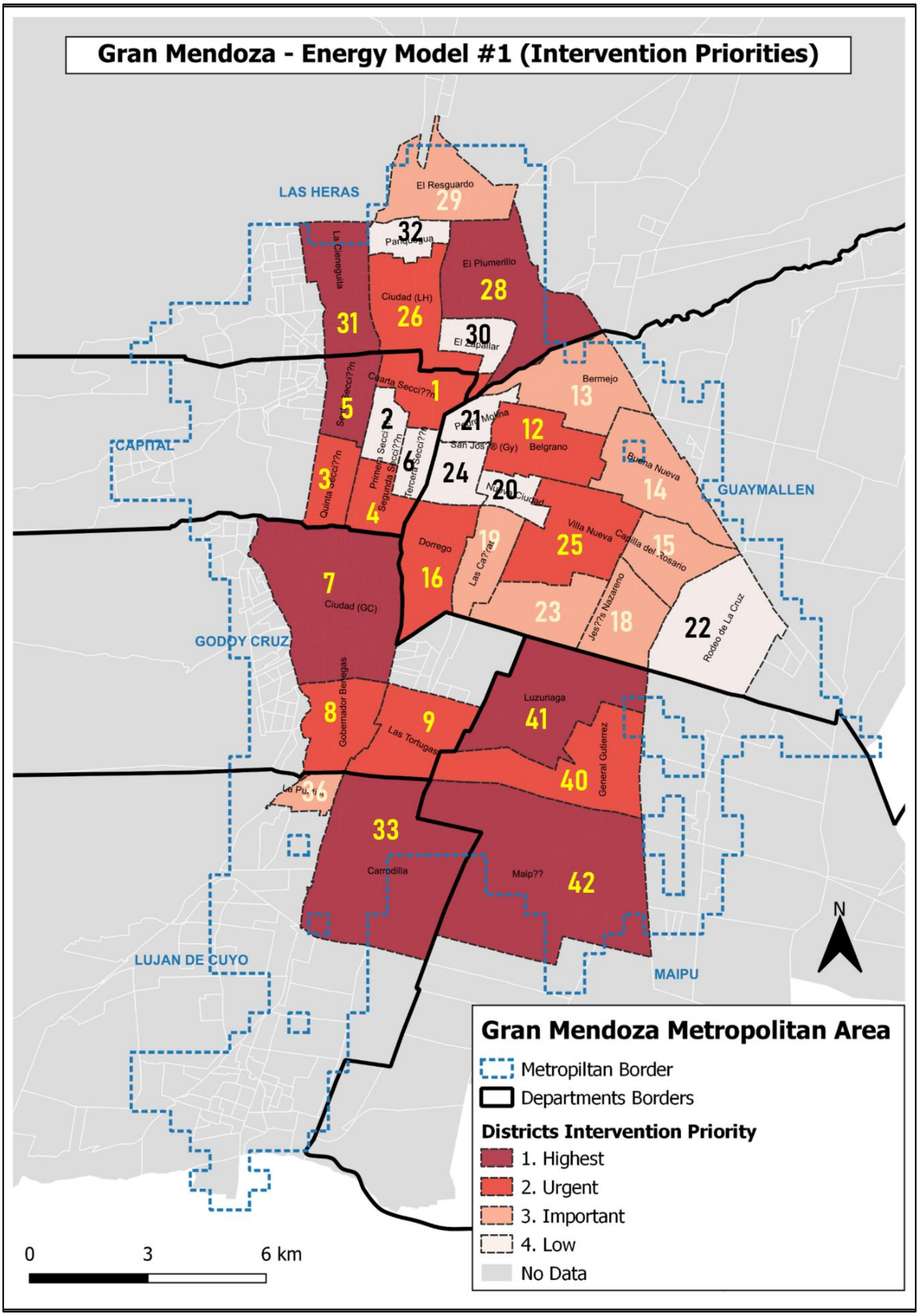


Figure 58 - Intervention Priorities Model #1 (source: By Author)

Intervention Priorities Model #2

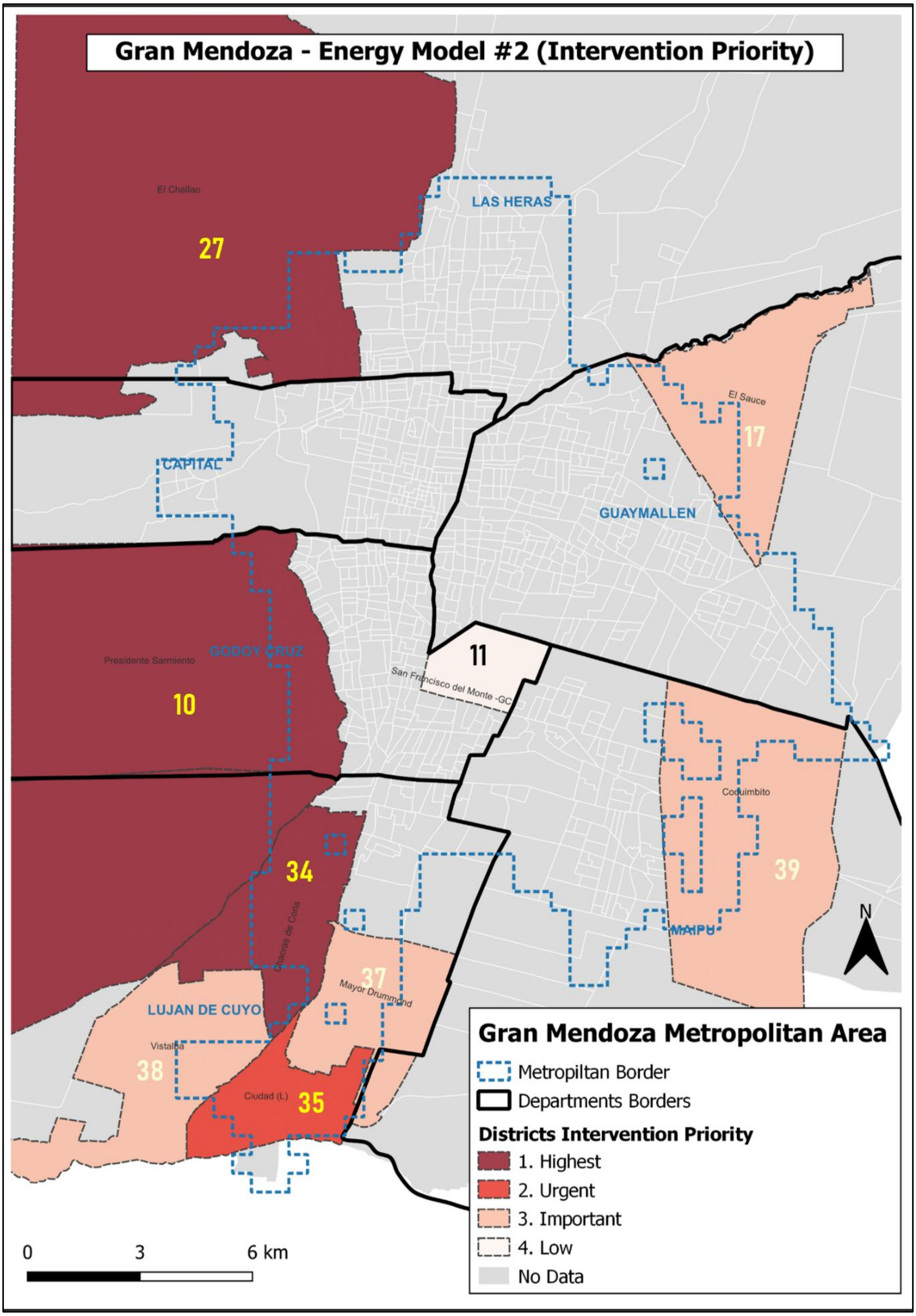


Figure 59 - Intervention Priorities Model #2 (source: By Author)

Project Challenges & Applicability in Other Cities

- Dealing with a large number of data & variables
- Finding the best & most effective energy variables
- Applicable in Other territories in case of availability of different data types (social, urban, building,..)
- Applicable in other cities since it can separate districts or area with same characteristics for creation of different models

References & sources

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