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ELBOL: An anonymized research database with monthly electricity consumption in Bolivia: 2012-2016

La Paz, June 2023

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Pablo Andrés Cuadros Roca[♠]
C. Ariel Zeballos[♠♠]
Fabian Calderón[♠♠♠]

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Abstract:

This paper documents the construction of an anonymized research database with 132 million observations of electricity consumption from individual electricity meters distributed throughout Bolivia's territory, during the period 2012 to 2016. The research database was constructed from 6101 files submitted by the different electricity distribution companies to the national Electricity Authority, and was cleaned, quality checked, simplified, harmonized, and anonymized. Each electricity meter was also attributed to one of Bolivia's 339 municipalities to facilitate sub-national level research on many different topics, such as energy consumption, poverty, inequality, and migration.

Keywords: Electricity consumption, inequality, Bolivia.

JEL classification: D30, D63, L94, O13.

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[♦] Corresponding author, Executive Director, SDSN Bolivia. Email: lykkeandersen@upb.edu.
[♦♦] Associated researcher, SDSN Bolivia. Email: adrian@bamboo-tec.com
[♦♦♦] Associated researcher, SDSN Bolivia. Email: vlady@bamboo-tec.com
[♠] Associated researcher, SDSN Bolivia. Email: pablo@bamboo-tec.com
[♠♠] Associated researcher, SDSN Bolivia. Email: ariel@bamboo-tec.com
[♠♠♠] Associated researcher, SDSN Bolivia. Email: fabiancalderoncabrera@gmail.com

1. Introduction

Understanding the distribution of income, wealth and living standards in a country, and their changes over time, is of utmost importance for policymakers. In Bolivia, one of the poorest countries in Latin America, the main source of detailed sub-national information on living standards is the Population and Housing Census, which is performed only every 10 years or so. This frequency of data collection limits the government's possibility to react to short and mid-term dynamics of the economy. To provide more frequent information on changes in living standards in different parts of the country, researchers have identified alternatives to the census data. One of the most promising alternatives is electricity consumption (Ozturk, 2010; Dinkelman, 2011; Andersen *et al.*, 2019). The intuition is simple: wealthier families will consume more electricity, as they can afford more electrical appliances, such as refrigerators, washing machines, TVs, water heaters, air conditioners, etc. Therefore, a careful analysis of changes in electricity consumption over time could reveal important changes in living standards in different parts of the country.

The purpose of this paper is to document the construction of an anonymized electricity consumption database which includes about 131 million monthly electricity consumption observations for both residential and business consumers, as well as public lighting in Bolivia from 2012 to 2016. The electricity grid in Bolivia is composed of two main systems. The National Interconnected System (NIS) and the Isolated Systems (IS). In 2020, the NIS produced 92% of the total energy in Bolivia and the IS produced 8% (AETN, 2021). The NIS is composed of 8 relatively large regional electricity distribution companies (see Table 1), while the IS includes at least 24 smaller electricity distribution companies (see Table 2), which cover the areas that are not within reach of the NIS.

Each of the electricity distribution companies submit monthly reports concerning electricity consumption by each of their users to the national Electricity Authority (*Autoridad de Fiscalización de Electricidad y Tecnología Nuclear* - AETN). However, the reports are not standardized, which greatly hinders analysis of the data.

Thanks to the collaboration of the Center for Social Research (CIS) of the Vice-Presidency of Bolivia and the Vice-ministry of Electricity and Alternative Energies, the project obtained access to around 5,000 of these non-standardized, monthly electricity consumption reports in a dozen different file formats and set out to standardize and clean the information to make it useful for socio-economic research. This process ended up taking several years, which is why we highly encourage researchers to make good use of the database.

The anonymized research database is intended to facilitate and encourage sub-national level research on a variety of topics relevant for Bolivian policymakers, such as energy consumption, poverty, inequality, migration, economic growth, and human development.

2. Examining the original data

The original data was grouped in two major groups: i) the National Interconnected System (NIS) and ii) the Isolated Systems (IS). Although the NIS accounts for most of the data points, the IS represented most of the data processing effort. The features of the two systems will be discussed separately below.

2.1. The National Interconnected System

The National Interconnected System (NIS) is a group of electricity suppliers made up of generation, transmission, and distribution facilities, which supply electricity to the departments of La Paz, Potosí, Oruro, Cochabamba, Tarija, Chuquisaca, Santa Cruz, and Beni. This group of suppliers belongs to Bolivia's interconnected grid that provides electricity to most of the households in the country. It includes the 8 electricity suppliers shown in Figure 1, and accounts for approximately 93% of the country's electricity supply.

The monthly reports from 2012 to 2016 from these 8 electricity companies provide information on electricity consumption from each electricity meter, as well as information on addresses, consumer category, discounts, and more. Just for the five years of analysis, this led to a total of 265 GB of data, as reflected in Figure 1. This amount of data could not be processed on a traditional personal computer, so we had to use the Google Cloud Platform (GCP) to store the original data, as well as a 64 GB RAM virtual machine to be able to read and process the data.

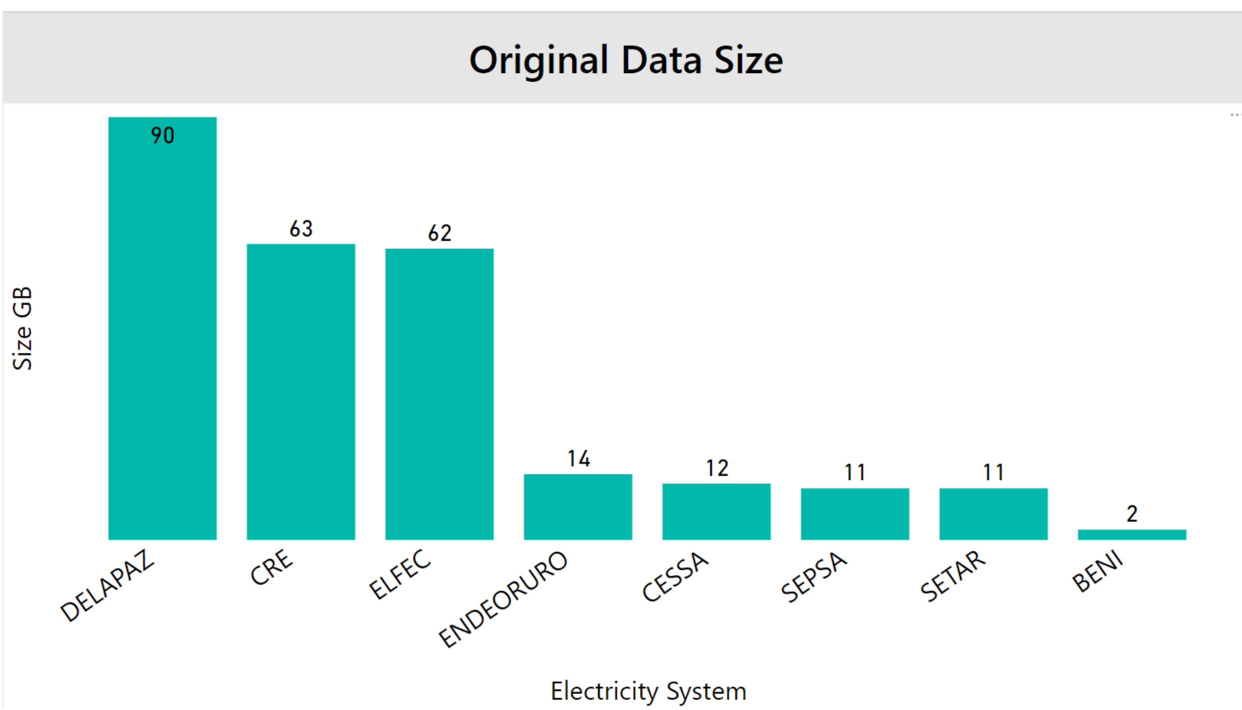

Fig. 1 – Original data size in GB for the National Interconnected Systems (NIS).

The original data was so large partly due to data redundancy and inefficient file formats. An exploration of the original data indicated that for each electricity company, there were multiple types of files with the same information in different file formats, as well as other files with complementary information. Figure 2 shows that the original data provided just for the 8 companies of the NIS consisted of more than 5000 files in 12 different file formats. The large variety of files made it impossible to use a common file format for all systems. Rather, we specifically identified the biggest file for each company-month to provide the bulk of the information, and complemented with other formats/files in case of missing information in the main files.

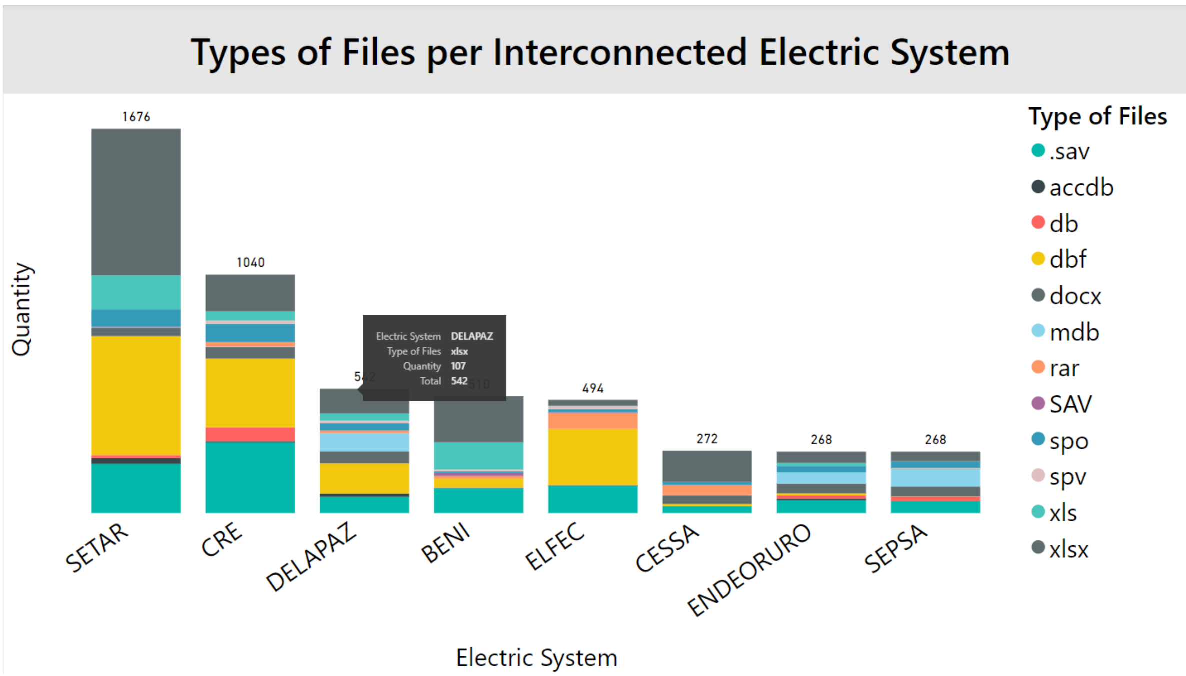

Fig. 2 – Number of original files and their formats from the 8 electricity companies of the NIS system.

In summary, the data from the NIS exceeded 250 GB, which made it impossible to perform the ETL (Extract, Transform, Load) process on a desktop computer. Therefore, cloud computing was necessary to tackle the challenge. Finally, careful multiformat data extraction was required due to the multiplicity of file formats in the database.

2.2. Isolated Systems

The Isolated Systems are a group of electricity suppliers that provide electricity where the Interconnected Systems do not reach (parts of the departments of La Paz, Oruro, Potosí, Chuquisaca, Santa Cruz, and Beni, and all of Pando). These isolated systems are distributed all around the country and each report in a different format (see Table 2).

Tab 2 - Independent systems

Distributor	Address	Municipality	Department	Comment
ASUNCIÓN	No	No	No	Does not contain information about the location
COSEP	No	No	No	Does not contain information about the location
CER	Yes	Yes	No	
CESAM	No	Yes	No	
COBEE	No	No	No	Does not contain information about the location
COSERMO	Yes	Yes	No	Municipality names were incomplete
EDEAM	No	No	No	Does not contain information about the location
ELFEDECH	Yes	No	No	Does not contain information about the location
GAM LLALLAGUA	Yes	No	No	Does not contain information about the location
PAZNA	No	No	No	
SEVARUYO	No	Yes	No	Municipality names were incomplete
15 DE NOVIEMBRE	No	No	No	
COOPSEL	Yes	Yes	No	
CERVI	No	No	No	Does not contain information about the location
COOPARACA	No	No	No	
COOPELECT	Yes	Yes	No	Municipality names were incomplete
COSEAL	Yes	Yes	No	
EMDECA	Yes	Yes	No	Does not contain information about the location
ENDE COBIJA	Yes	Yes	No	

ENDE LOS CINTIS	Yes	Yes	No	
ENDE UYUNI	Yes	Yes	No	
TOTORAL	No	No	No	Does not contain information about the location
ENDE SENA	Yes	Yes	No	Does not contain information about the location
SEYSA	No	No	No	Does not contain information about the location
COSEGUA	Yes	Yes	No	
GAM UNCIA	No	No	No	Does not contain information about the location

Note: This table is a representation of the original data and the geographical available fields.

Although the number of files and data volume of the Isolated Systems is less than that of the Interconnected Systems, the number of systems and variety of formats each system uses (as shown in Figure 3) makes the data reading and cleaning difficult. Despite this variety, by careful selection or additional data processing, we reduced it to these three easy-to-read formats: Excel, CSV, and MDB.

It is worth mentioning that files concerning the Isolated Systems have lower quality of data compared to the files in the Interconnected Systems. The most relevant problems with these files were:

- Complex arrangements of several tables rather than just one table per month
- Different column names that required interpretation to match the more standardized column names of the Interconnected System files.
- Missing columns and more blanks in the data
- Several data points in columns were filled in an anomalous way when compared to the rest of the data points in the same column

To mitigate those problems, we implemented more complex and case-by-case data processing. Additionally, the information present in the original data is only concerning electricity consumption readings and discounts, with no geographic information such as the municipality. To mitigate this issue, we had to identify where the offices of these providers are located to find the municipalities or communities that they provide electricity to.

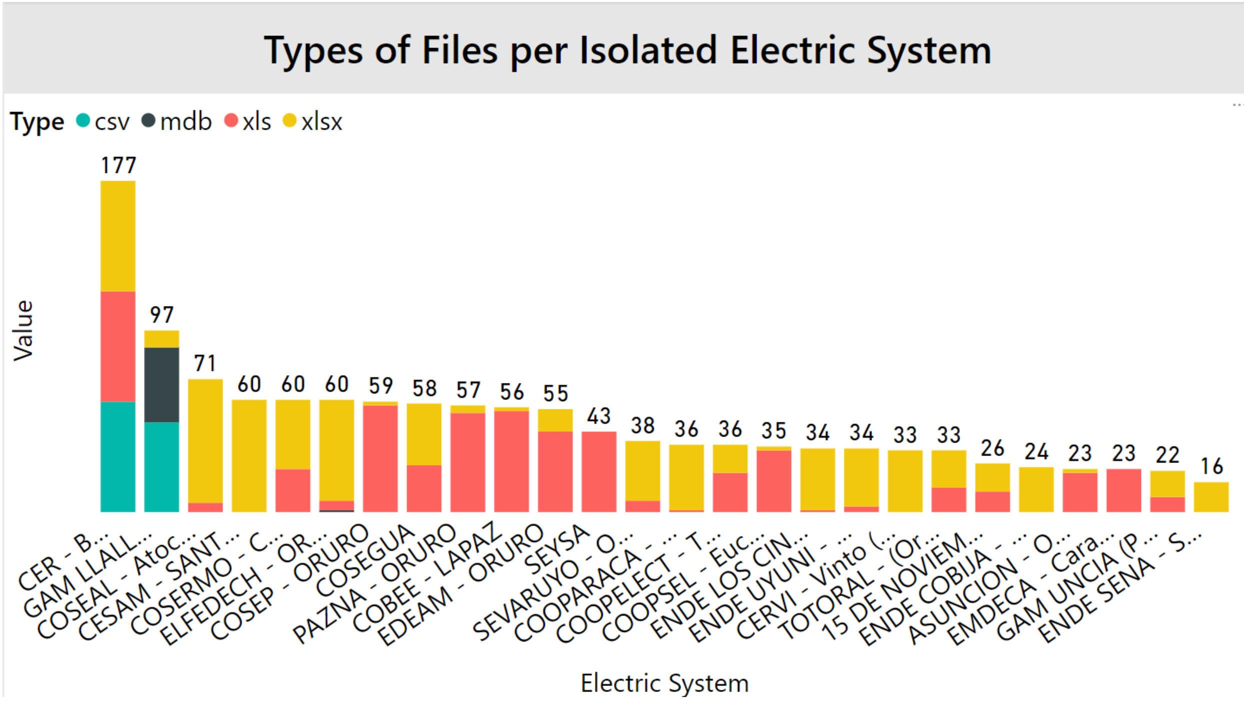

Fig. 3 – Original file types of the Isolated Systems.

Note: The original file types represent the multiple file formats to choose from for each isolated system.

In summary, Isolated Systems contain less data volume than Interconnected Systems and a smaller number of files. However, due to the significantly different organization of data within the files, Isolated Systems present a totally different data collection, focused mainly on those municipalities or localities in the departmental limits where the interconnected system does not reach.

3. Data Cleaning and Harmonization

The most important source of information on this topic is the “Anuario Estadístico''. This is a detailed report which contains the official numbers of electricity consumption and production in Bolivia (2020). These reports are excellent sources for data validation and to understand the dynamics of the electricity grid in Bolivia.

The whole process of collecting, cleaning, and understanding the country's electricity consumption data helped us to understand the scope and limits of the main network; also to approach the data in different ways, in order to obtain different analyses on multiple points, since the database is quite large and rich in categorical and numerical data.

2.1. Geographical coverage

Geographical allocation of electricity data is of utmost importance to understand how regions vary in terms of economic development. Table 1 shows the attributes of geographical data that are available in the raw data for the NIS. Although addresses are available, these are next to impossible to allocate to the right geographical location. This is because there are multiple addresses that are either empty, have incomplete naming, or lack numbering. Consequently, the next level of geographical detail which we use is a municipality. There are 325 municipalities in the database. These fields were also incomplete or had a community instead of the municipality. This has been manually filled with the use of detailed maps of Bolivia. This shows the difficulty to obtain this information in the country.

Tab 1 - Interconnected System

Distributor	**Address**	**Municipality**	**Department**	**Comment**
DELAPAZ	Yes	Yes	No	
CRE	Yes	Yes	No	
ELFEC	Yes	Yes	No	
CESSA	Yes	Yes	No	
ENDEORURO	Yes	Yes	No	
ENDEBENI	Yes	Yes	No	Municipality names were incomplete
SETAR	Yes	Yes	No	
SEPSA	Yes	Yes	No	For certain observations the name of communities were provided instead of municipalities.

Note: This table is a representation of the original data and the geographical available fields.

2.1. Overall summary of key steps to standardize and anonymize the data

The cleaning process has been performed in two steps. The first step is the setup of several servers in the Google Cloud Platform to manage the data size and the computation requirements. The second step is the implementation of a data cleaning pipeline that provides a common processing framework for all the systems. For example, data extraction, data transformation, and data validation across all systems use the same functions ensuring the traceability of operations, their inputs, outputs, and errors.

In this section, we detail the steps taken to transform raw data files to standardize the overall database. To achieve this, we have set up a cloud server to satisfy the computational requirements and have created a seven-phase flow that transforms the data in a standard fashion. There are quality checks that have been implemented at the end of each phase and overall checks for the final version of the complete database.

We briefly describe the original raw data. The electricity data consists of files with the extensions .dbf, .csv, .xls and .xlsx (depending on the system). Each one of these files stores the electricity consumption data of every electricity consumption meter registered, for the period of a month. The electricity data covers the years 2012 to 2016 for all the electrical distribution systems in Bolivia. The original raw data files were compressed into zip files (one per system) and were stored in a Google Cloud Platform (GCP) storage bucket to handle the large size (around 265 GB) of the files.

3.1. Software architecture

The architecture of the system has the following characteristics to manage the complexity and the exhaustive processing:

- The system is modular, and each component performs one specific task, i.e. modules are loosely coupled. This structure is beneficial because changes in one component do not require (or require minimal) changes in other modules.
- The system solves each problem at the appropriate level of generalization. Therefore, by checking the structure of the files, we can isolate general problems common to several (or all the) files. Then, we write a single method or a group of methods to handle this problem in all the files. This design decision is important because it eliminates redundant code, greatly reduces the amount of code to write and greatly improves our ability to debug it since there is only one place in the code that describes each operation.
- The system can create pipelines of processing. Since we have loosely coupled components and we also implemented loosely coupled methods, we can build adequate processing pipelines for each file by combining the adequate components and methods, selecting and discarding them based on conditionals.

We implemented the system fulfilling the required characteristics as can be appreciated in the simplified class diagram presented in (Figure 4).

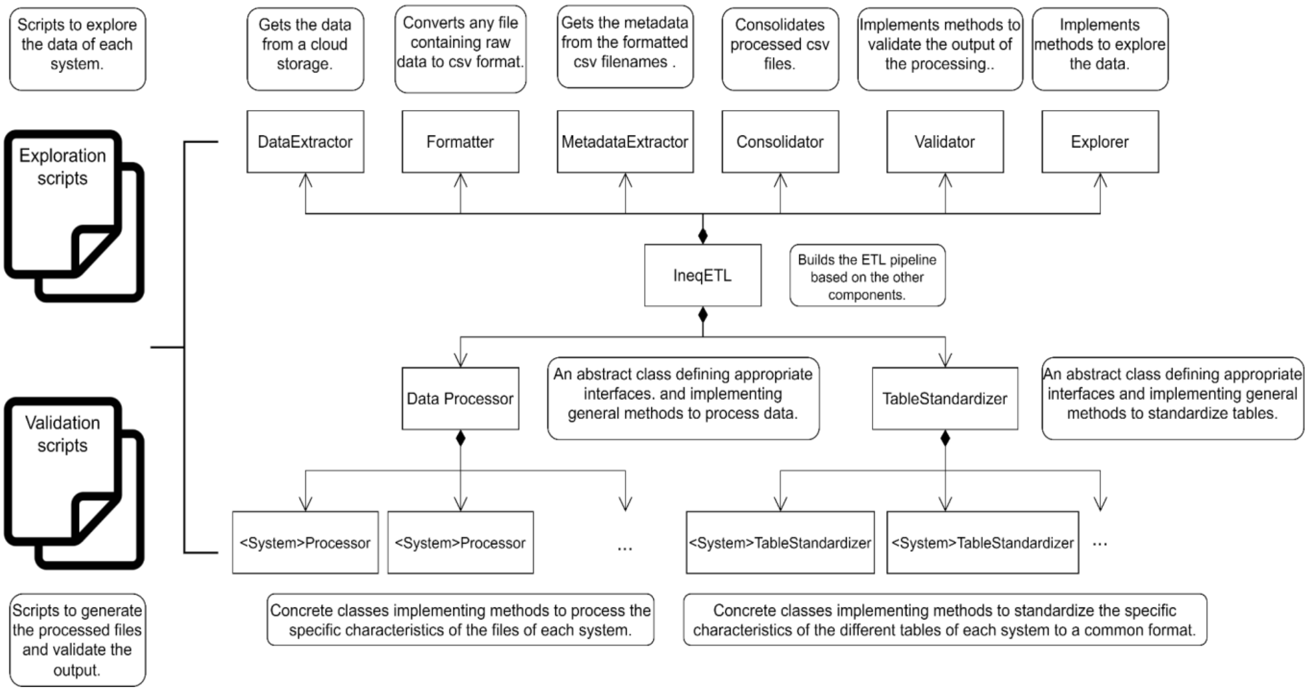

Fig. 4 – Overview of the software architecture for data processing.
Note: The system is implemented in Python.

The main abstract classes of this architecture are the DataProcessor and the Table Standardizer. These classes contain the general cleaning processes applicable to the data of any system. The concrete classes (that implement the abstract ones) handle the system specific data formatting and processing specific.

Each of the methods implemented in these classes performs a unitary operation over the data. Hence, we can easily track each processing step. These methods are called in the IneqETL class which implements all the operations that the system performs. The list below describes the function of each class.

- DataExtractor: communicates with the bucket on the GCP platform and implements methods to download the zip files.
- Formatter: reads the relevant files (which are stored using different extensions: XLSX, XLS, CSV, DBF) and transforms them into CSV files with a standard naming.
- MetadaExtractor: from the .csv standard naming we extract metadata such as year, system, month, then we associate these metadata with the actual data.
- TableStandardizer: implements all the general table formatting operations which are file-agnostic, but also calls the objects to perform the file(system)-dependent operations. Its purpose is to deliver a unique standard table format.
- DataProcessor: implements all the general data processing operations which are file-agnostic, but also calls the objects to perform the file(system)-dependent operations.

It processes data coming from standardized tables. Its purpose is to deliver clean data.

- Consolidator: merges the data from several files according to the year and the system they belong to.
- Validator: implements methods to compare statistical properties and data values of different steps in the general data processing operation. Its purpose is to help ensure data consistency across operations and avoid data loss or errors.
- Explorer: implements methods to quickly explore the data across the files, it serves the purpose of putting all the related data in one data structure for statistical description and analysis.
- IneqETL: implements methods to perform the Extract Transform Load (ETL) process and calls objects from all the previous classes.

In conclusion, the data cleaning process required the implementation of a file structure that allowed to separate the cleaning processes into different parts avoiding having a hard-to-change code. In this way, it allowed the creation of general cleaning functions as well as specific functions for each electrical system. It is important to clarify that a well implemented architecture allowed us to perform the cleaning with greater flexibility to handle changes, and reduce processing times.

3.2. Characteristics of the harmonized database

After all this process of data collection, cleaning and standardization, we have produced a database with a total data volume of 18 GB divided into 9 files, one for each of Bolivia's departments. These 9 files have data corresponding exclusively to the municipalities belonging to each department. We preferred having a file for each department rather than one for each supplier since the analyses that will be performed on the database will be aggregated using this organization.

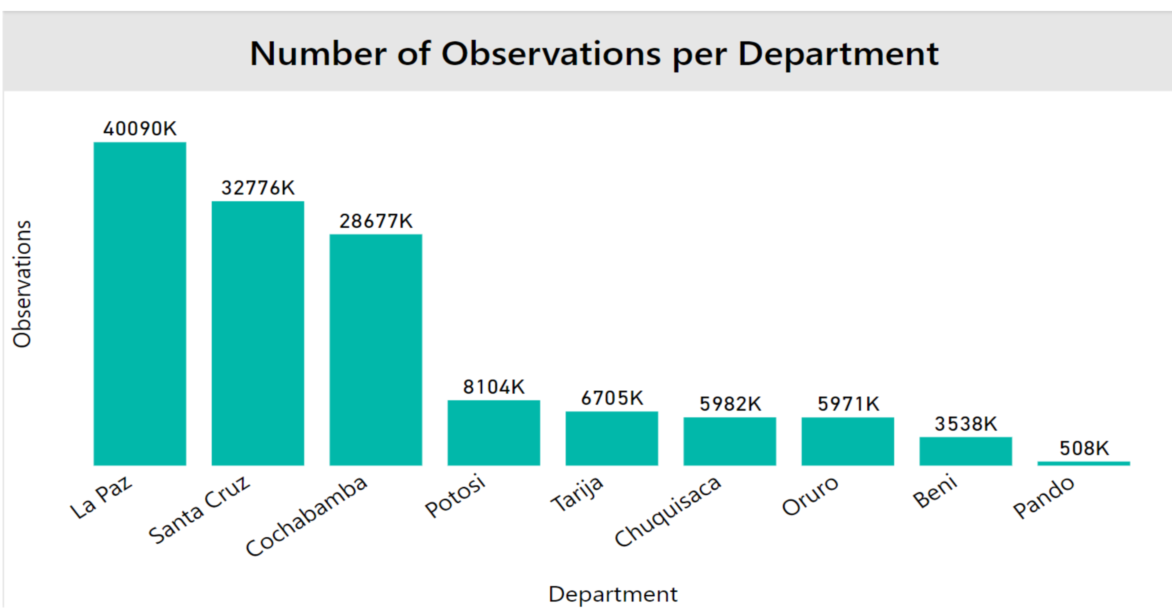

Fig. 5 – The number of observations per Department from all years (2012 - 2016).
Note: The first departments are the most populated in Bolivia.

With data from 5 years (2012 - 2016) we were able to identify that electrical consumption increases slightly year by year and is directly related to population growth. The database has electrical readings for 5 years, from 2012 to 2016, with approximately 131 million observations, which we distributed over the 5 years. Thus, we can identify the number of observations per year as shown in Figure 6.

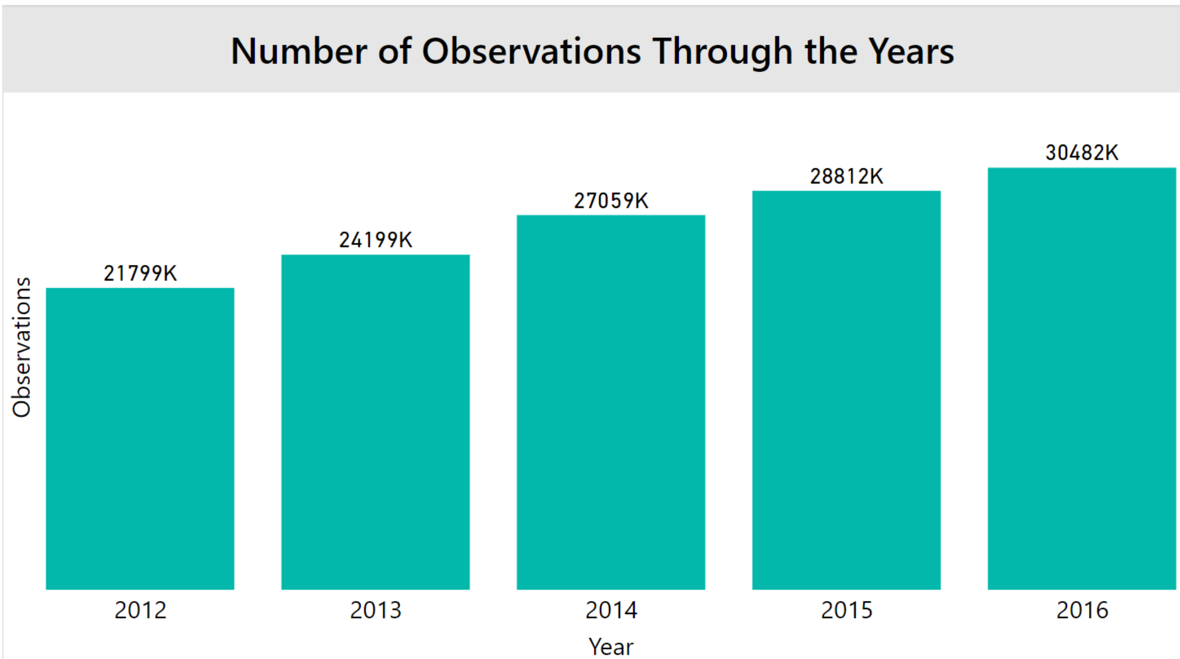

Fig. 6 – The number of observations per year from all departments.
Note: Observations obtained by counting all the records for each year.

We can classify all of the observations into 4 consumption groups:

- Residential: covers only household consumption.
- Business: includes any type of consumption of companies, neighborhood stores, city hall services, and others.
- Public Lighting: covers only the consumption of streetlights in the city or towns.
- Mining: covers only consumption related to the work of machinery and equipment in mining sites.

In the following image we can observe the average consumption for the residential category. A peculiar fact is that for the first years there is a higher consumption, even though the first years have fewer records than the last years, which gives us to understand that there was a higher consumption in the first years and that with time people began to regulate their consumption.

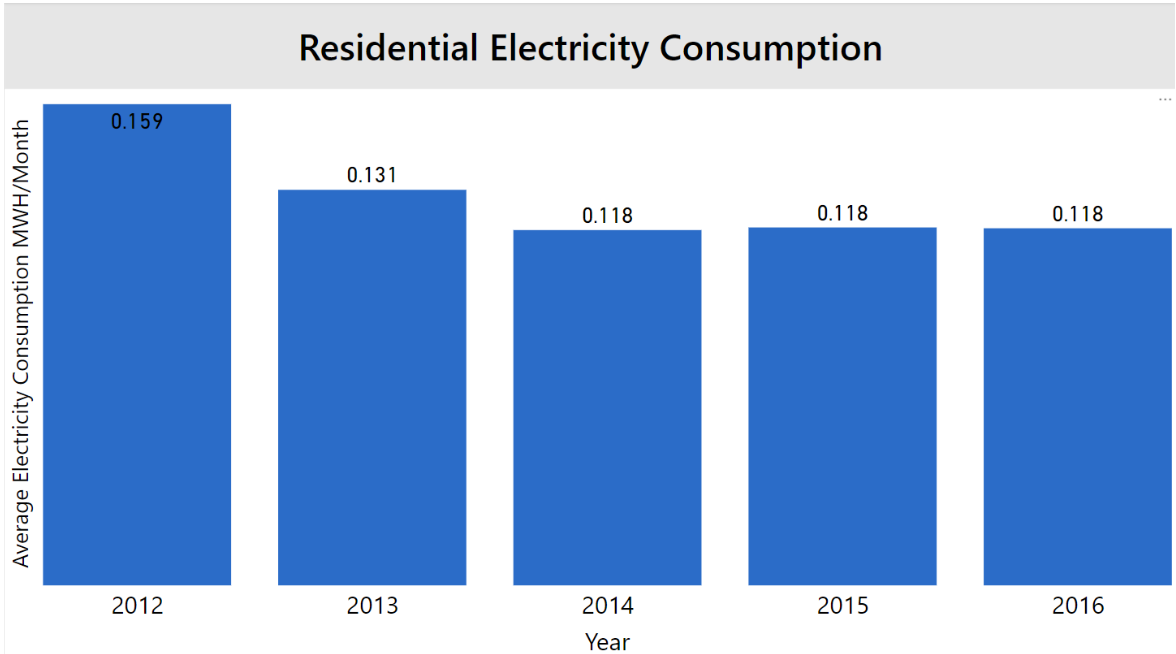

Fig. 7 – Average consumption for the Residential category.
Note: Obtained by filtering the Residential category and then averaging the consumption per year.

For the Business category, we can observe the same pattern as for the Residential category: in the early years more energy is consumed despite having fewer connections throughout Bolivia. This can also be understood as a direct relationship where both households and businesses consume more in the early years and then they regulate their consumption.

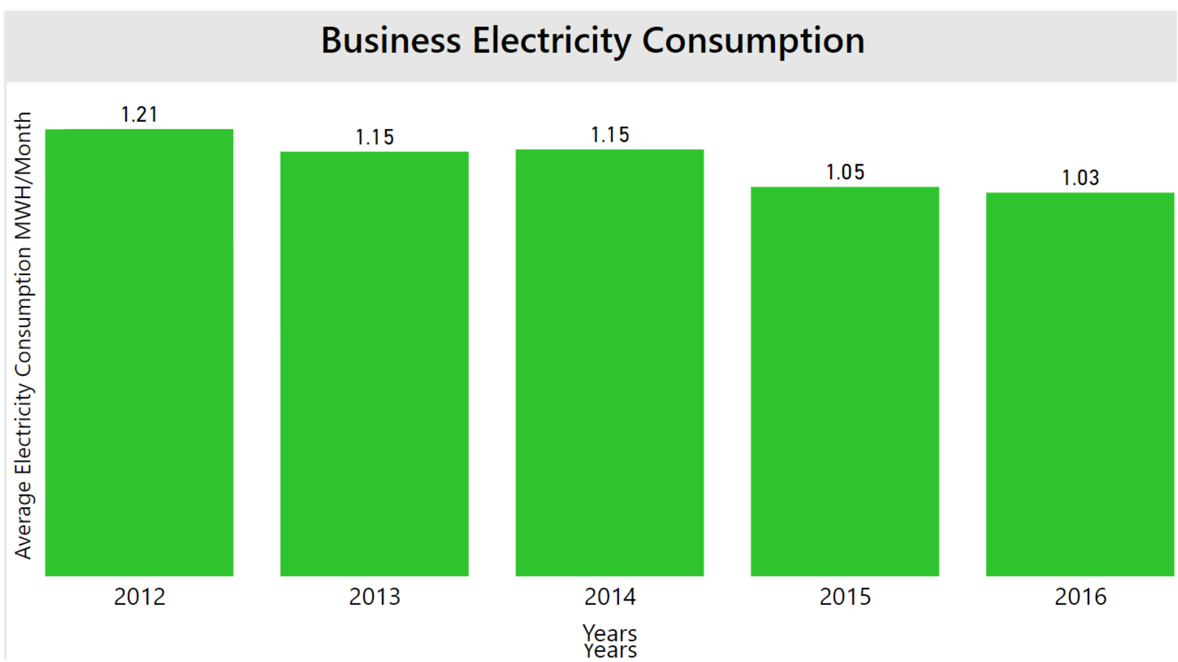

Fig. 8 – Average consumption for the Business category.
Note: Obtained by filtering the Business category and then averaging the consumption per year.

For the Public Lighting category, we can observe the same pattern that indicates higher consumption in the first years, which can be understood as a higher consumption by the mayor's office or municipality in the first years of data that we have. Indicating a better use of electricity year by year.

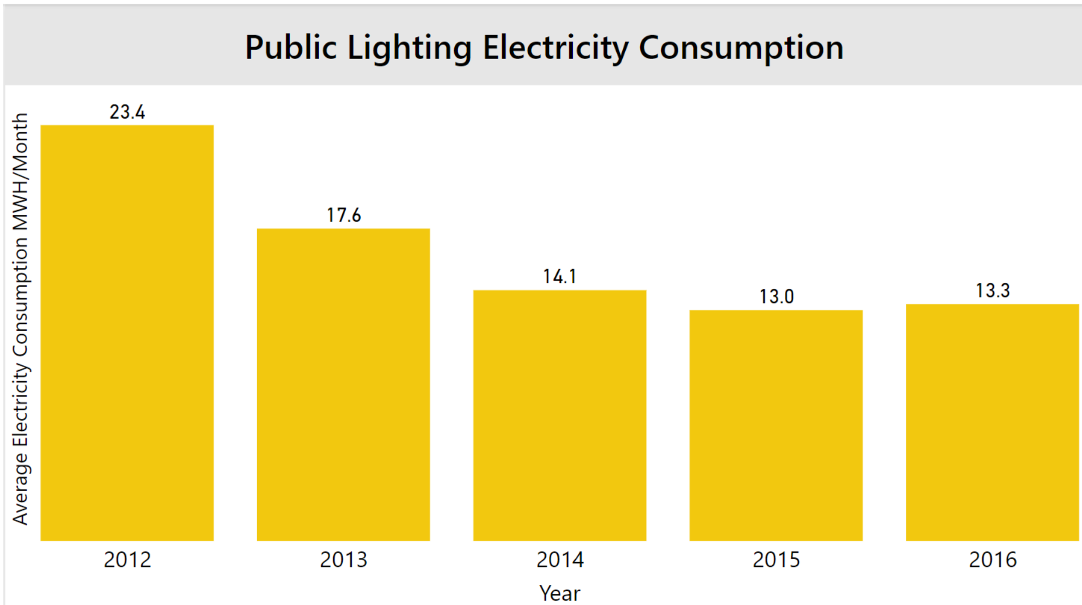

Fig. 9 – Average consumption for the Public Lighting category.
Note: Obtained by filtering the Public Lighting category and then averaging the consumption per year.

For the case of average consumption in the Mining category, we can see that in 2014 there was a large consumption compared to other years, which could be interpreted as an increase in the exploitation of minerals or metals for the 2014 management.

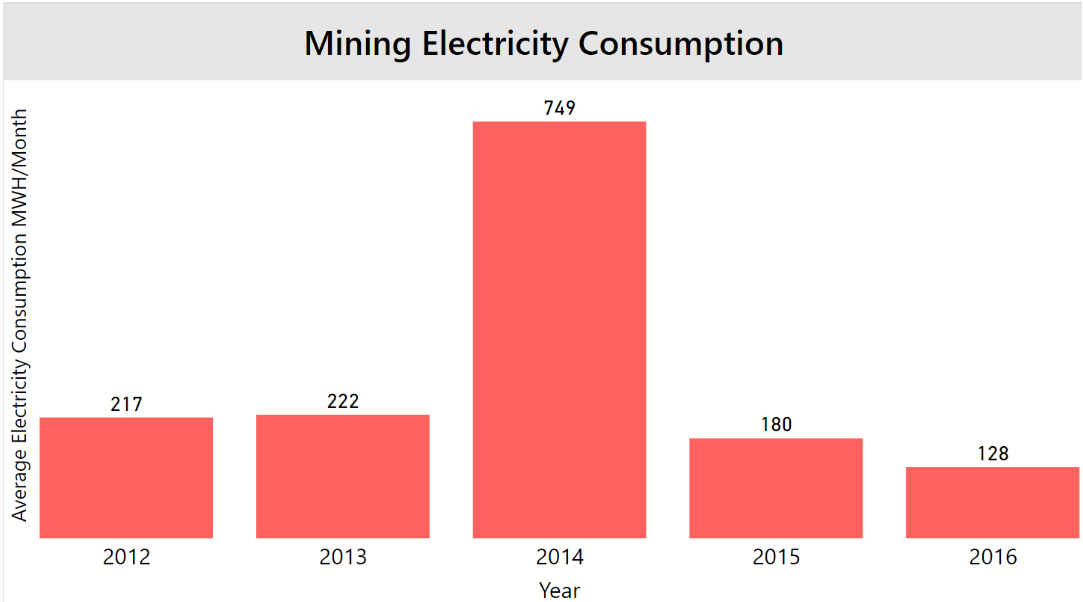

Fig. 10 – Average consumption for the Mining category.
Note: Obtained by filtering the Mining category and then averaging the consumption per year.

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In conclusion, the different categories offer us a perspective of energy use over the different years, and we can observe for the categories of Residential, Business, and Public Lighting a slight reduction that is decreasing year by year, which can be inferred as better management of consumption year by year. It also explains a pattern whereby if one category suffers a reduction in consumption, the other categories will be equally affected. However, the category of mining according to Figure 10 suffers an increase in the year 2014 that with different analyses focused exclusively on mining in the country could explain a significant increase in other areas of the country.

All these energy consumptions classified in categories are obtained from customers with electricity connections, being able to identify how many customers or unique IDs exist each year as shown in Figure 11. As expected, as the population increases every year, the number of electrical installations should follow.

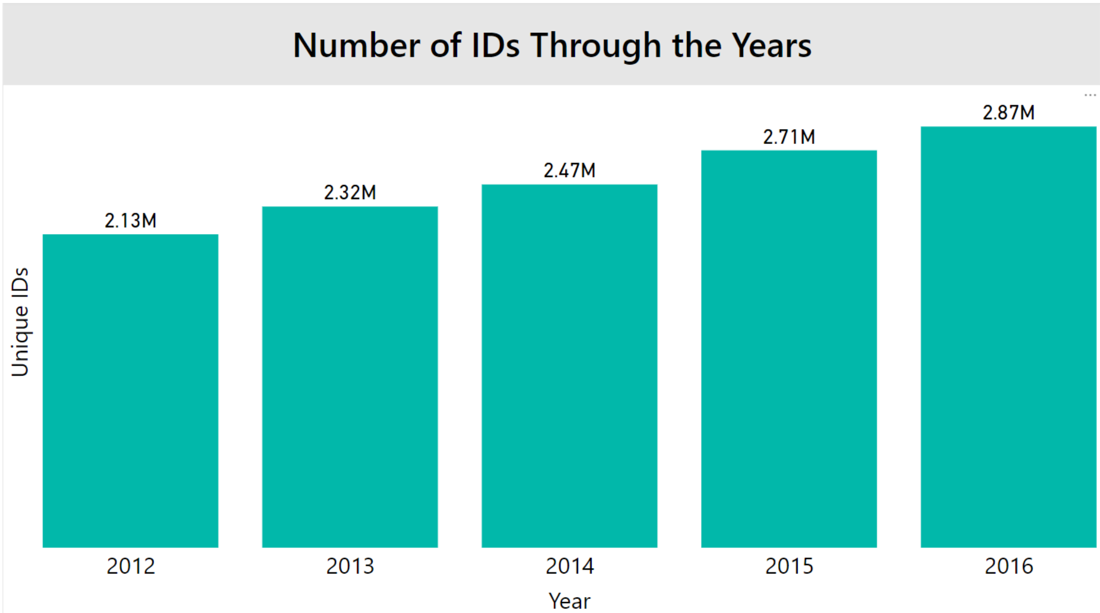

Fig. 11 – Number of Clients per Year from all departments (2012 - 2016).
Note: Obtained by grouping the data per year and counting the unique client IDs.

Using a map of Bolivia and its different municipalities, we can see that the municipalities with the highest energy readings would be the capitals of each department, which indicates the highest amount of connections among the other municipalities of each department. This can be understood since the capitals are the places with the largest population within the department is where the greatest concentration of people is located. In this way, we can also see the scope that the Interconnected System and the Isolated System have on the different municipalities of the country.

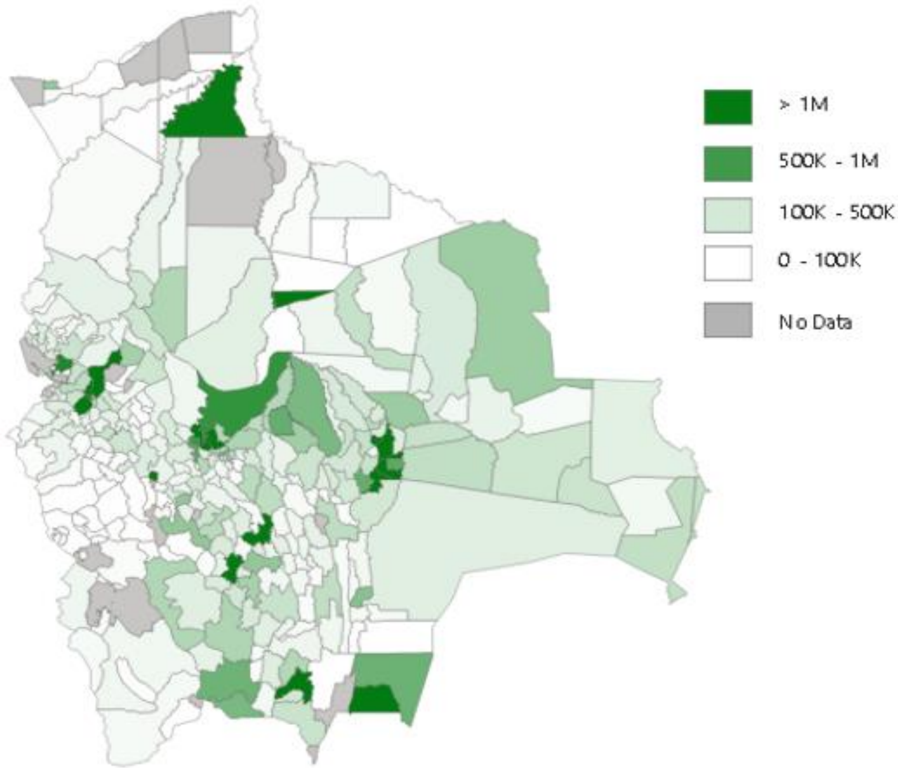

Fig. 12 – Number of observations per municipality.
Note: Obtained by grouping per municipality and counting the number of observations across all the years.

By plotting the number of municipalities with observations over the 5 years, we can observe a year-over-year growth. This is consistent with the population increase, more municipalities are created as new territories are occupied.

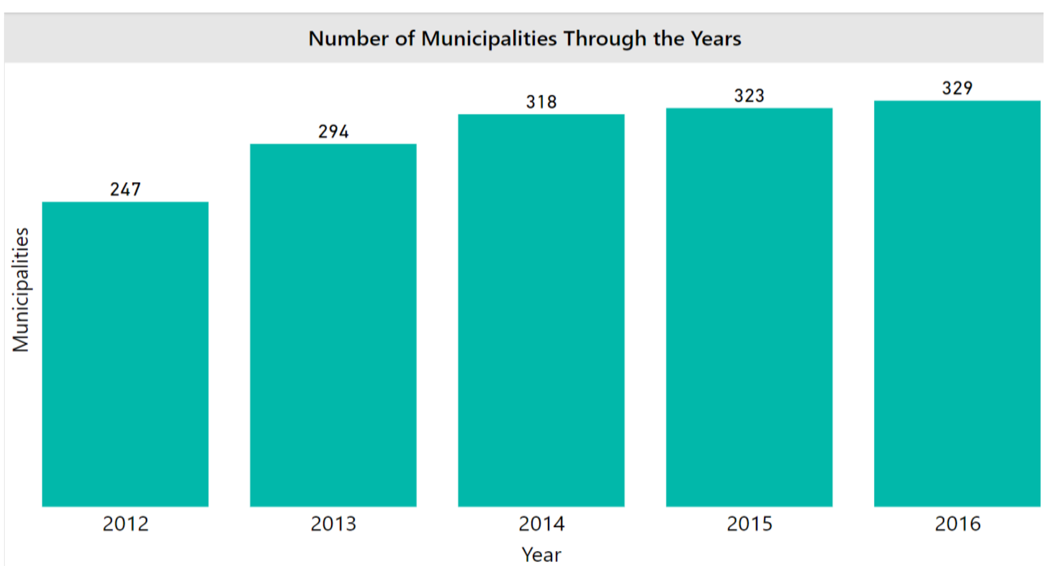

Fig. 13 – The number of municipalities per year from all departments.
Note: Obtained by grouping the year and counting unique municipality codes.

If we separate the observations municipalities in Figure 13 into the different categories, we can observe the categories present by municipality over the years as shown in Figure 14. As expected over the years the number of municipalities with access to connections increased and so do the categories for these electricity consumptions.

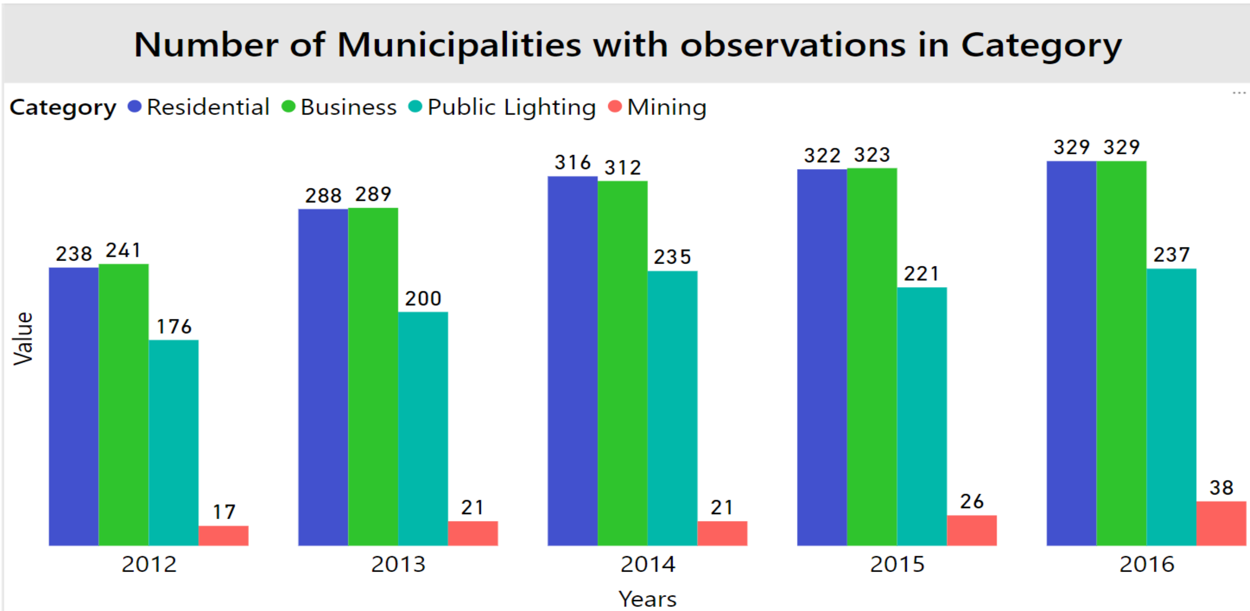

Fig. 14 – Number of municipalities per Category through the years.
Note: Obtained from the grouping of all systems per year filtering category splitting per category.

3.3. Anonymize data

To anonymize the data, we generated a hash value that transforms the client's name and the client's number into a long string of numeric and alphabetic characters. In the main database, the hash value generated for each client is used as an id.

3.4. Compare Result with Official Electricity Guide

To identify whether the data cleaning was correct we used as a reference the "A. ANNUARIO_AE_2016_web.pdf". This document contains information on both the Interconnected systems and some Isolated Systems. This information can be visualized by months in the summary table of each system, being able to compare the consumption in MWH year by year and with respect to all categories. This document is an official guide of the "Autoridad de Fiscalización y Control Social de Electricidad 2016" of Bolivia.

CUADRO V-16
VENTAS DE ELECTRICIDAD A CONSUMIDOR FINAL POR CATEGORÍA
EMPRESA: CESSA — DEPARTAMENTO: CHUQUISACA — UNIDAD: [MWh]

Año	Residencial	General	Industrial	Mineria	A.Público	Otros	Total	Tasa de Crecimiento
1991	21.766,43	5.989,40	33.933,22	-	2.804,78	-	64.493,83	3,5%
1992	22.480,37	6.384,05	35.869,74	-	3.508,75	-	68.242,91	5,8%
1993	24.237,07	7.632,05	37.675,31	-	3.804,04	-	73.348,47	7,5%
1994	26.494,98	8.294,83	39.053,20	-	4.372,78	-	78.215,79	6,6%
1995	28.199,27	8.873,39	39.273,37	-	4.555,81	-	80.901,84	3,4%
1996	31.212,11	10.189,65	37.454,76	-	5.095,28	-	83.951,80	3,8%
1997	33.453,51	11.107,86	41.381,35	-	5.405,72	-	91.348,44	8,8%
1998	36.878,36	12.022,84	45.512,89	-	5.812,51	-	100.226,60	9,7%
1999	39.469,92	13.229,05	45.002,83	-	6.267,03	-	103.968,83	3,7%
2000	41.281,43	13.988,39	41.977,61	-	5.924,66	-	103.172,09	-0,8%
2001	43.034,18	14.227,77	29.814,52	-	5.929,71	-	93.006,17	-9,9%
2002	46.113,42	14.897,13	36.253,77	-	6.208,14	-	103.472,46	11,3%
2003	48.103,70	16.159,14	41.770,01	-	6.402,48	-	112.435,34	8,7%
2004	50.554,88	16.565,97	45.121,37	-	6.724,14	-	118.966,36	5,8%
2005	53.663,64	16.891,88	48.695,21	-	6.780,23	-	126.030,97	5,9%

Fig. 15 – Results from the Official Guide of Electricity Consumption from CESSA.
Note: Page with summary information from all years and categories.

We also performed a column selection, because the original data had about 20 to 30 columns, however, we identified only 17 columns relevant for our purposes, as shown in appendix A. This operation provides value to consolidate the final database by significantly reducing the original data volume.

4. Conclusions

The data collected by both the Interconnected System and the Isolated Systems provide us with a robust 18 GB database with to perform multiple analyses, for the moment our focus was to observe the consumption patterns for the different categories and all the variety of files and data processing needed.

We realize that The Electrical data in Bolivia requires standardization to greatly facilitate future research as we can see in Table 3. We strongly recommend having a universal data registration software for all the systems. A unified database would be valuable for research and government policy implementation purposes.

5. Appendix

Tab 3 - Standardize names for the consolidated database

New Columns	Description
ID	Unique identifier for each electricity meter
COD_MUNI	Municipality code
ADDRESS	Indication of address
YEAR	Year of electricity consumption
MONTH	Month of electricity consumption
CATEGORY	Category of electricity consumption
CONS_LEI_MWH	Monthly electricity consumption in MWH (measured)
CONS_FAC_MWH	Monthly electricity consumption in MWH (charged)
FAC_ENERGY	Payment for electricity in BOB
FAC_STREETLIGHT	Payment for street illumination in BOB
FAC_WASTE	Payment for waste collection in BOB
DISCOUNTS	Discounts on the electricity bill (any reason) in BOB
FAC_TOTAL	Total monthly payment in BOB
DEBT	Unpaid electricity debt from previous months
FEE_RECONNECT	Fee charged for reconnection
DIST_SYSTEM	Electricity distribution company
DEPARTMENT	Department code

Note: This table presents the standard column names for the electrical systems data.

6. References

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