

Portuguese Service Electricity Continuity Indicators: Municipality Code and Quality Service Zones Evaluation – 2014 to 2022

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Abstract. The possibility of supply disturbances could be detrimental to some customers. Such as in some industries, where these types of disruptions can represent a serious cost. Productivity and competitiveness in manufacturing and service industries increasingly depend on the quality of electricity supply and are also dependent on the good efficiency of continuity indicators. After initially monitoring its indicators in 2001, Portugal introduced a continuity of supply incentive regime in 2003. Since the introduction of the regime, indicators have consistently improved over the years, which pressures a constant improvement of the service related to client satisfaction. Frequency and duration of continuity service indicators are here considered to study the quality of service in Portugal's mainland in the period of 2014 up to 2022. Here a two–way analysis of variance (ANOVA) was performed aiming to evaluate the existence of differences between two factors: quality service regulation (QSR) zones and municipality code. The results point to the need to seek a more accurate analysis for each of the variables that represent continuity indicators. Even so, it was possible to identify differences in the medium and low voltage indicators regarding the two factors, as well as the existence of differences in the mean values in each factor.

Keywords: electricity continuity service · Interruption Frequency Index · Interruption Duration Index · two–way ANOVA

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1 Introduction

E–Redes is the main operator of the electricity distribution network in mainland Portugal of high, medium, and low voltage networks, connecting more than 6M customers. The company's objectives are to guarantee the supply of electricity to all consumers, with quality, safety, and efficiency; promote the development of the distribution network that supports the energy transition; ensure, in an impartial manner, the availability of services to market agents; maintain the distribution network and guarantee the security of supply; ensure compliance with quality standards; provide services to consumers, traders and other agents in the electricity sector, among others. In this sense, it presents itself as a trusted brand close to consumers, ensuring a quality service focused on the customer. The distribution network operator must determine, in each calendar year and for all delivery points, the number of interruptions and the total duration of interruptions, in minutes, which allows for defining, evaluating, monitoring, and adjusting service quality standards. The context of service quality standards to be observed by the distribution network operator may vary according to the service quality zones. To apply the Quality Service Regulation (QSR) in mainland Portugal, the following classification of service quality zones is defined: Zone A: district capitals and locations with more than 25 000 customers; Zone B: locations with the number of customers between 2 500 and 25 000; and Zone C: the remaining locations.

Low voltage connection is typically intended for residential customers, stores, offices, and small businesses. Within the low voltage connection, it may be chosen between a normal low voltage connection (NLV), for contracted powers equal to or less than 41.4 kVA, and a special low voltage connection (SLV), for contracted powers greater than 41.4 kVA. 4 kVA. The medium voltage connection is aimed more at companies with energy needs greater than 200 kVA, such as the automotive, metallurgical, or hotel industries. The high voltage connection is intended for companies typically with installed powers greater than 10 MVA, supplied at a voltage level of 60 kV. Here will be considered the medium voltage connection and low voltage connection, which we believe covers a large part of the business sector in mainland Portugal and private customers.

In November 2022, E–Redes launched the Open Data Portal[1] to share relevant data from its activity, to also contribute to *"the transparency of its activity data in the community, serve as a catalyst for the country's energy transition"* This initiative thus seeks to *"serve as a catalyst for the energy transition and design of smart cities; promote product or service innovation by extending data analytics to community members, such as the Scientific Community; strengthen interactions with the community and encourage the co-creation of value with Local Authorities, Energy Agencies, the research community, etc."*.

The E–Redes "explore" tab allows access to all datasets organized by categories - Consumption and Energy; Electrical network; Electric Mobility; Renewables and Operation and Quality of Service. It is part of this category - Operation

[1] https://e-redes.opendatasoft.com.

and Service Quality - that this work focuses on. The topic is vast, covering the number of low voltage consumption sites with remote readings; active power outages; scheduled power outages; number of remote service orders carried out; number of low voltage consumption sites with collection of load diagrams; network connections; and service continuity indicators by municipality. Here we are interested in studying a subset of data on service continuity indicators per municipality, as already mentioned for medium and low voltage, it is intended to study the System Average Interruption Frequency Index (SAIFI), and the System Average Interruption Duration Index (SAIDI), both indexes are commonly used as a reliability index by electric power utilities. SAIFI refers to the average number of interruptions that a customer would experience and SAIDI is the average outage duration for each customer served.

Service Continuity expressed by the number and duration of electricity supply interruptions is a technical aspect of service quality. Continuity of service characterizes and evaluates situations in which there is an interruption in the supply of electrical energy to the delivery points of a network, whether customers or connections to other networks. Service continuity indicators are general when they refer to the entire system, a group of customers, or a geographic area. The indicators are individual when referring to each of the delivery points.

For electric utilities, ensuring high continuity of service is crucial to maintaining customer trust and complying with government regulations. Frequent or prolonged outages can cause significant inconvenience to customers, negatively impact productivity in commercial and industrial environments, and even pose public safety risks in certain cases. Electricity companies frequently monitor and seek to improve service continuity through investments in infrastructure, preventive maintenance, use of advanced monitoring technologies, and quick response to network failures. This aims to minimize outages and ensure a reliable supply of electricity to all consumers. In summary, service continuity is an essential technical measure of service quality in an electrical utility, assessing the consistency and reliability of energy supply over time and playing a crucial role in customer satisfaction and the efficient functioning of modern society. Additionally to the assessment carried out by E-Redes, the energy services regulatory entity (ERSE) annually assesses the technical quality of the service provided, where the continuity of the service is an item of interest. This procedure also results from the need to fulfill the regulations of the Council of European Energy Regulators, similar to other European countries. Apart from this study, we are not aware of his topic being studied in Portugal.

In this work, we consider medium voltage, (mt), and low voltage, (bt), networks in mainland Portugal for which individual indicator limits are defined annually that must not be exceeded, per year and customer. These standards are grouped by quality of service regulation zone - QSR zone - and refer to long accidental interruptions (more than 3 min). Customers are entitled to automatic compensation whenever there is non-compliance with the standards of individual quality indicators relating to service continuity established, in each case. Consistent with this, the distributor monitors and seeks the best standards for

their product/service, which we will address in this work. Thus, this paper is divided into four sections. Following this introduction in Sect. 2, the methodology is exposed. Section 3 presents the data and the results of the data analysis, and in Sect. 4 a discussion of the results accompanied by possible future work is presented.

2 Methodology

2.1 ANOVA Two–Way

ANOVA stands for analysis of variance and tests for differences in the effects of independent variables on a dependent variable. A two–way ANOVA test is a statistical test used to determine the effect of two nominal predictor variables on a continuous outcome variable. The ANOVA test is the first step in identifying if factors influence the outcomes of interest, to evaluate how variables affect each other. The ANOVA test group's differences by comparing the means of each group and includes the distribution of variance between multiple origins. Used for subjects, test groups, between groups, and within groups [1,4,7]. A two–way ANOVA was considered to evaluate the impact of quality service regulation (QSR) zone, Factor A, and municipality code, Factor B, on the continuous variables' outcomes - SAIFI and SAIDI measures - both in medium and low voltage connection which result in four measurements, i.e., four different variables. Being the continuous variables - SAIFI and SAIDI - the dependent variables and the nominal variables of each factor the independent variables.

The two–way ANOVA model, replicated four times, i.e., for each combination between variable (SAIFI and SAIDI) medium and low voltage (mt and bt), may be written as

$$Y_{ijr} = \mu + \alpha_i + \beta_j + \gamma_{ij} + \varepsilon_{ijr} \tag{1}$$

with Y_{ijr} the dependent variable measurement, α_i the effect of QSR Zone, β_j the effect of municipality code, γ_{ij} the interaction between factors, and μ and ε_{ijr}, the global mean and the error, respectively, with ε_{ijr} normally distributed with zero mean and standard deviation σ.

If interactions are not significant, then the model and interpretations are simpler, in that case, the effects of the two factors may be analyzed separately. Such a model is said to be "additive" because the effects of the factors sum.

The interaction test hypotheses are

- H_0 : There is no interaction between the two factors, i.e., all terms $\gamma_{ij} = 0$.
- *vs.*
- H_A : There is interaction between the two factors, i.e., at least one $\gamma_{ij} \neq 0$.

It is important to note that if an interaction is found to be important so the main effect tests may not be very interesting in an interaction model.

Factor Effects Model (Without Interactions): The Main Effects Model is

$$Y_{ijr} = \mu + \alpha_i + \beta_j + \varepsilon_{ijr} \tag{2}$$

where

- Y_{ijr} is the rth observation on $ijth$ treatment, where $0 \leq r \leq n$, and n is the size of the sample drawn from each treatment (here it is considered a balanced design);
- α_i is the differential effect of the ith level of factor A on the mean response (the mean of the dependent variable), with $\sum_i \alpha_i = 0$;
- β_j is the differential effect of the jth level of factor B on the mean response (the mean of the dependent variable) with $\sum_j \beta_j = 0$;
- ε_{ijr} is the error, assumed to be iid normally distributed with zero mean and standard deviation σ.

The α_i and β_j are called the "main effects" of factors A and B, respectively, to distinguish them from interactions, that is, effects of the levels on the mean response simply add.

As for the one–way ANOVA also the two–way ANOVA requires that the assumptions of normality and homogeneity of variance are met.

Testing the Two Main Effects. The hypotheses that are of interest to evaluate concerning the two main effects are:

Main effect test for factor A:

- H_0 : There are no differences in means across levels of factor A in population, given factor B is in the model, i.e., all terms $\alpha_i = 0$, in the additive model.
- *vs.*
- H_A : There are some differences in means across levels of factor A in population, given factor B is in the model, i.e., at least one $\alpha_i \neq 0$, in the additive model.

Main effect test for B:

- H_0 : There are no differences in means across levels of factor B in population, given factor A is in the model, i.e., all terms $\beta_j = 0$, in the additive model.
- *vs.*
- H_A : There are some differences in means across levels of factor B in population, given factor A is in the model, i.e., at least one $\beta_j \neq 0$, in the additive model.

If the null hypothesis is rejected, then further analysis is performed to explore where the individual differences are [8].

The ANOVA analysis assumes that the underlying data distribution is the normal distribution, the variance is the same in the population, and the observations are independent [4,7].

3 Data and Data Analysis

In this work service continuity indicators, SAIFI, concerning the frequency, and SAIDI, concerning the duration, of interruptions (accidental + foreseen) for medium voltage (mt) and low voltage (bt) indicators by quality service regulation (QSR) and municipality codes for 9 years, from 2014 up to 2022 were registered. The information made available by E-REDES establishes an approximation to the values taken from the system and is based on the moment it is collected. The available information may be subject to successive changes and updates since it is a result of the dynamic measures from the connection points, the electricity distribution network, and the consumption and production values themselves.

In the E–Redes Portal the data organization follows the QSR zones (Zone A, Zone B and Zone C) and presents also a category Municipality concerning the values for the municipality center as a separate category. Concerning the municipality code are available 35 codes thus having 35 categories for this factor.

3.1 Descriptive Measures

The data here considered, concerns the frequency of the interruptions and also the duration of the interruptions, for both the medium and low voltage, therefore the analysis is divided for the SAIFI and SAIDI variables, in each voltage, separated.

Along the nine years of observed values were collected 140 observations per year. As mentioned data are observed and presented, for each year, in two different categories of interest: the four categories of QSR Zone – Municipality, Zone A, Zone B, and Zone C – and the municipality code – in 35 different codes, i.e., the 35 categories of factor municipality code. Thus, one can count for each of the QSR Zone a total of around 315 observation measurements, and for the municipality codes a total of around 36 observation measurements.

SAIFI Medium and Low Voltage

Below are presented the descriptive statistics for both variables, SAIFI medium (mt) and low (bt) voltage, in Table 1, and the graphical representations, violin graphs in Fig. 1 and box-plot representations in Fig. 2:

Table 1. SAIFI mt and SAIFI bt descriptive statistics.

QSR Zone	SAIFI mt					SAIFI bt				
	Sum	Mean	St.d.	Min.	Max.	Sum	Mean	St.d.	Min.	Max.
Municipality	272.23	0.867	0.829	0.0	6.997	308.30	0.979	1.230	0.0	7.66
Zone A	244.61	0.774	0.793	0.0	3.907	267.31	0.846	0.822	0.0	4.882
Zone B	311.80	0.989	0.642	0.0	4.010	340.72	1.082	0.705	0.0	5.000
Zone C	259.06	0.825	0.759	0.0	3.291	283.75	0.904	0.814	0.0	4.865

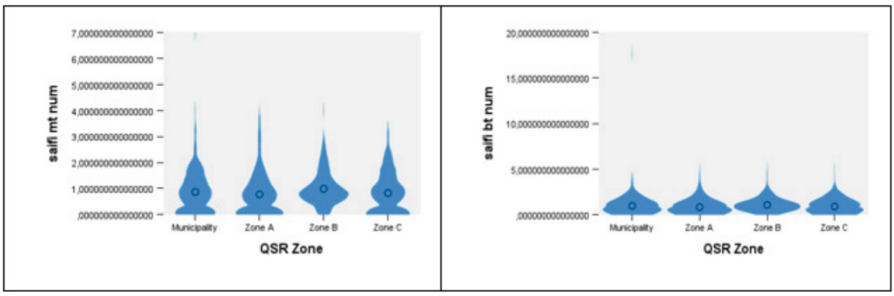

Fig. 1. SAIFI mt and SAIFI bt Violin graphs, by QSR zone

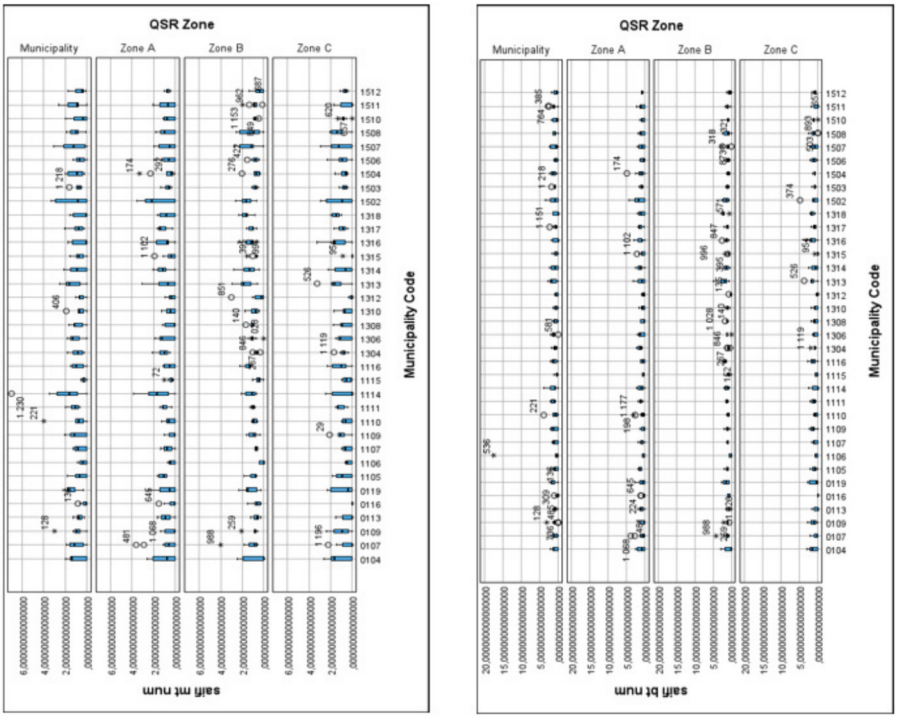

Fig. 2. SAIFI mt and SAIFI bt Boxplot graphs, by municipality code and QSR zone

SAIDI Medium and Low Voltage

Below are presented the descriptive statistics for both variables in Table 2, and the graphical representations, violin graphs in Fig. 3 for the SAIDI variables concerning medium and low voltage observed measurements.

Table 2. SAIDI mt and SAIDI bt descriptive statistics.

QSR Zone	SAIDI mt					SAIDI bt				
	Sum	Mean	St.d.	Min.	Max.	Sum	Mean	St.d.	Min.	Max.
Municipality	12219.9	38.8	37.9	0.0	233.7	14918.8	47.4	53.6	0.0	643.1
Zone A	11217.9	35.4	37.8	0.0	241.7	14292.5	45.3	66.2	0.0	932.9
Zone B	14640.3	46.5	34.4	0.0	307.1	17040.6	45.2	66.2	0.0	931.6
Zone C	12186.5	38.8	38.3	0.0	204.6	14903.3	47.5	47.6	0.0	324.9

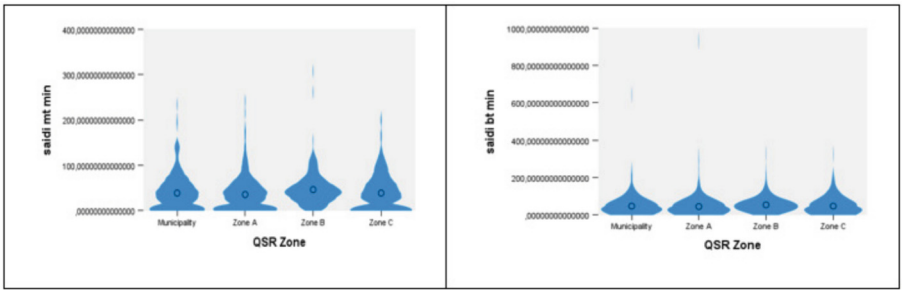

Fig. 3. SAIDI mt and SAIDI bt Violin graphs, by QSR zone

As one may observe there are some pattern similarities with SAIFI graph representations, either for the medium and the low voltage measurements. The box-plot representations concerning the QSR Zone and municipality code exhibit a similar pattern and therefore are not presented here.

For the duration of the interruption, both in medium and low voltage, it is possible to observe larger values for the standard deviation. Thus, below are presented the histograms of each variable across the four QSR zones, Fig. 4 where may be observed the asymmetry of the data that will influence the fulfillment of the required assumptions.

The descriptive analysis of data for medium and low voltage measurements, whether about the frequency with which they occur or their duration, in the categories of interest makes it possible to identify the existence of discordant observations. In the descriptive analysis, it was identified the presence of outliers, both moderate and even extreme, in those observations. This is certainly also influencing the variability in the data and conditioning the analysis as the confidence in the results.

An identical descriptive analysis to the one presented was also carried out per year. Apart from the existence of discordant observations, each year, the importance of comparatively analyzing the data obtained by year was not identified.

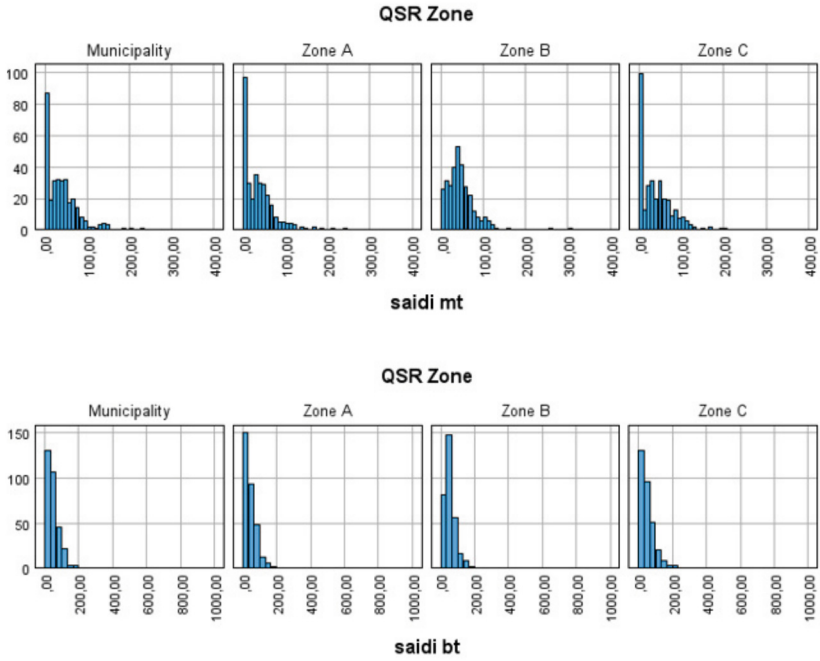

Fig. 4. SAIDI mt and SAIDI bt histogram graphs, by QSR zone

3.2 Model Analysis

After the descriptive analysis mentioned above, we are interested in evaluating whether the average values of the observations, frequency, and duration both at medium and low voltage, are identical in both factors - the categorical variables - or if there is at least one different value, in each case.

For this purpose, a two-factor analysis of variance, Sect. 2.1, was considered for the four mentioned variables starting to test, in each case, the possibility of interaction between the factors QSR Zone and municipality code.

Below, in Table 3 are presented the results of the two-way ANOVA for the variable SAIFI mt (medium voltage), i.e., if the model is the one referred to in Eq. 1. If the interaction is not relevant one can proceed to the Main Effects Model, i.e., to consider the additive model as mentioned in Eq. 2.

The ANOVA table analyzes the total variation by decomposing the sum of squares, (SS), into components that add to the total. The table also presents the degrees of freedom, (df), and add up for the corrected model + error = corrected total. The null hypothesis for the interaction F–statistic is that there is an additive relationship between the two categorical variables in their effects on the outcome variable.

Table 3. SAIFI mt – Tests of Between–Subjects Effects with interactions.

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	175.406	139	1.262	2.536	< 0.001
Municipality Code	100.854	34	2.966	5.962	< 0.001
QSR Zone	6.872	3	2.291	4.604	0.003
Mun. Code*QSR Zone	54.826	102	0.538	1.080	0.283
Error	557.238	1120	0.498		
Corrected Total	732.644	1259			

The interaction line in the table presents an F–statistic 1.080 and a significance of 0.283 in the test. The test significance is also named the p-value of the test, as will be referred to in what follows. In this work the significance level of interest is 0.05, meaning that the values of the test below the test are significant and values above the test are not significant. It can be concluded that the interaction test is not significant, there is no evidence to reject the additive model, and the conclusion is that QSR zones are the same for the different municipality codes, and vice-versa. Therefore it is appropriate to re-run the ANOVA with an additive model.

Considering the limitation of written space, the tests of between-subjects effects are omitted and referred to only, and in each case, the F–statistics and p-values for the remaining variables concerning testing the factor's interaction. The obtained values are: for variable SAIFI bt, the F–statistic is 1.059 and the respective p-value 0.331; for variable SAIDI mt the F–statistic is 1.143 and a p-value of 0.165; and for variable SAIDI bt the F–statistic observed is 0.891 with a p-value of 0.770.

Since the p-values for the four variables under study are greater than 0.05 the interactions are not significant, and the model to adopt is the additive model. Therefore, it is appropriate to re-run the ANOVA two–way with a different means model, i.e., with an additive model presented in Eq. 2.

Additive Model (Without Interactions)

As before, in what follows are presented the results for variable SAIFI mt, Table 4 and the remaining results are just discussed. It is then important to test the two main effects to proceed with the analysis. Table 4 exhibits the results for SAIFI mt, and as it can be observed, at a significant level of 0.05 both factors affect SAIFI mt. The square root of the mean square of the error, $\left(\sqrt{0.501} = 0.708\right)$ indicates that the residual (within-group) variance is about 0.708.

Table 4. SAIFI mt – Tests of Between–Subjects Effect, without interactions.

Source	Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	120.580	37	3.259	6.506	< 0.001
Municipality Code	112.556	34	3.310	6.609	< 0.001
QSR Zone	6.856	3	2.285	4.563	0.003
Error	612.064	1222	0.501		
Corrected Total	732.644	1259			

The estimated means table for each factor allows us to directly check the existence of differences in different municipality codes and also in the different QSR zones. Here is only presented the estimated means for the QSR zones, Table 5, easily to check since this factor has four levels (the municipality code factor has 35 different codes).

Table 5. SAIFI mt – Marginal Means Estimates.

QSR Zone	Mean	Std. Error	95% Confidence	Interval
			Lower Bound	Upper Bound
Municipality	0.870	0.040	0.791	0.949
Zone A	0.788	0.040	0.709	0.868
Zone B	0.982	0.040	0.904	1.061
Zone C	0.816	0.040	0.737	0.895

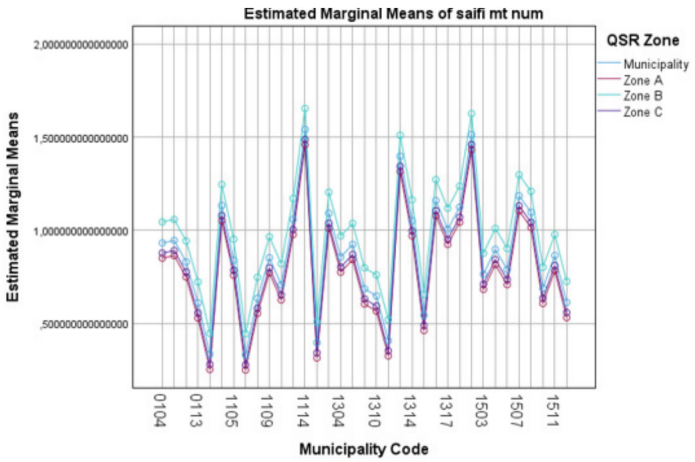

Fig. 5. SAIDI mt profile plots for the two factors.

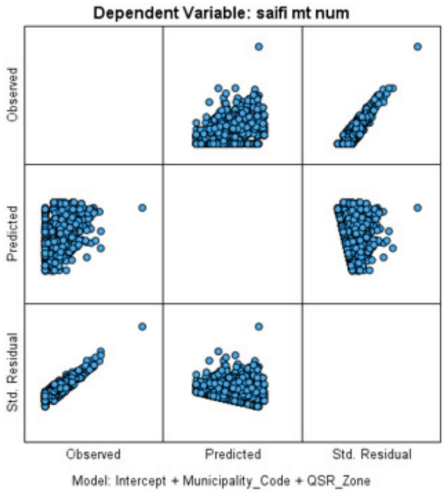

Fig. 6. SAIDI mt residuals plot.

As it can be observed the estimated mean for Zone B is higher than the remaining ones. This fact allows us to consider two different homogeneous subsets, one formed with the municipality, Zone A and Zone C leaving Zone B separated; or another possibility a homogeneous subset with Zone A and Zone C and a homogeneous subset with the municipality and Zone C.

In the figure below, Fig. 5, it is possible to observe the profile plots of both factors, for variable SAIFI mt. the graph shows a very similar profile for all QSR zones although the Municipality is always higher. This is interesting and it is important to determine if it is important or not, as well as its meaning.

In Fig. 6, are presented the residuals plots for variable SAIFI mt.

Table 6, summarizes the information for the remaining variables subject to the same analysis. A brief analysis of the table shows that the two factors are significant for the variables SAIFI bt and SAIDI mt, even though the respective MSE presents large differences. For factor Municipality the formed homogeneous subsets are six varying between 16 municipality codes up to 27 municipality codes, not shown here resulting of the limitation of written space. For SAIDI bt only the municipality code is a significant factor.

A test is only meaningful if the assumptions of the test we are performing are reasonably well met. Therefore, it is important to check the assumptions involved in the model construction so that one can rely on the inferences that follow. Similarly, models cannot perfectly capture the fundamental realities of nature. That is why it is common to say, “All models are wrong, but some are useful”. And for that, it takes some experience to evaluate how far an assumption can be distorted before reasoning stops. Thus, if the normality assumption is significantly violated, if the equal variance assumption is moderately violated,

Table 6. Estimates.

	SAIFI bt	SAIDI mt	SAIDI bt
Mun. Code p-value	< 0.001	< 0.001	< 0.001
QSR Zone p-value	0.012	0.002	0.191
Error $\sqrt{\text{MSE}}$	0.884	34.83	50.59
Homogeneous subsets for QSR Zone	{A, C and Mun.} *vs* {B} or {B, C and Mun.} *vs* {A}	{A, C and Mun.} *vs* {B}	all

or if the independent error assumption is slightly violated the obtained results and the model use are compromised.

During the descriptive analysis of the variables, the existence of several discordant observations was noted, which led to difficulties being foreseen both about the normality of the data and the homogeneity of variability within the groups, as was confirmed. The homogeneity of variances is not verified and the residuals are not all independent for the four variables.

3.3 Some Remarks

Simultaneous confidence intervals [8] were not created due to the inadequacy of the model. The one–way ANOVA test was conducted for variable SAIDI bt which does not perform differently, being the heteroscedasticity slightly accentuated, i.e., $\sqrt{\text{MSE}} = 50.63$.

Given the above, non-parametric tests were also carried out [2,9], highlighting the differences postulated at the beginning of the work. Considering the observed violation of the assumptions of the additive ANOVA model, even with large samples, a non-parametric approach was considered. Hence, either for QSR zone or municipality code as group variables, the equality of medians across the groups was tested using the Kruskal-Wallis H test. This exposes that a new methodological approach is necessary, eventually correcting the discordant observations and rerunning the analysis.

For each variable, the data sets exhibit an equal number of observations in each category on both factors, that is, the groups are balanced, and in all cases, with more than 30 observations. Still, it is important have present the violation of assumptions. Therefore, it is important to consider a new analysis with variable transformation to at least minimize the effect of outliers. As several values of zero are observed, the most appropriate transformation seems to be the transformation of the square root to stabilize the variability of the data. At the same time, evaluate outlier observations and evaluate the impact of these observations on the analysis and what information these observations relate to. This can give us new insights into what to do next and is thought to future work.

4 Conclusion

The continuity of the electrical service is one of the important quality elements for both the consumer and the electrical energy supplier, in this case, the quality of technical service [11,12]. This quality of technical service is measured by the number of interruptions as well as the duration of these interruptions in the service provided [10].

The regulation of service continuity considers the set of installations with equal characteristics related to the quality of service. In this way, three different service quality zones are defined, the division of which results from distinguishing the zones by population density. In this work, the center of the municipality is still considered a QSR zone. Naturally, locations with a higher density of customers have more demanding quality levels. This is why the QSR zone was considered a factor of interest, except for variable SAIDI bt.

In this work, general continuity indicators were studied, namely the frequency and duration of service interruptions, and it is clear the need to improve and refine this study. However, differences were identified in the average values of the variables of interest - SAIFI and SAIDI - also noticing the distinction between medium and low voltage indicators, which allows a new perspective on what to evaluate of these indicators in the future as mentioned.

It is easy to recognize that maintaining an electrical network in continuous service is neither technically nor economically viable. Therefore, it is important to evaluate and outline measures that allow mitigating the interruption of continuity indicators, and consequently to improve consumer satisfaction standards.

This may be central to identifying the specificity and difficulties assessed in the indicators and trying to detect how to correct them. Here, characteristics or factors to consider were highlighted, making clear the need for a more refined and targeted analysis for each of the variables that represent the continuity indicators that we intend to address in future work.

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