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Descriptive and diagnostic analysis of customer complaints for different electric companies of Ecuador using Neutrosophic Logic

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Abstract: This article presents a descriptive analysis of complaint and claim management by ARCONEL and Electricity Distribution Companies in Ecuador for the year 2023. The dataset includes information about complaint outcomes such as 'Procedentes' (resolved), 'No Procedentes' (dismissed), 'En Proceso' (pending), and 'Invalidado' (invalid). This analysis will examine the complaint dataset using neutrosophic logic, which extends traditional binary logic by incorporating indeterminacy. We apply Neutrosophic Logic to capture not only resolved and unresolved complaints, but also uncertainty in complaint status. Key findings reveal high median resolution rates (99.98%), yet notable disparities exist: *Sierra* region companies outperform those in *Costa*, and private utilities exhibit lower dissatisfaction risks than public ones. Neutrosophic analysis identified "gray area" companies with ambiguous performance (e.g., resolution rates near 90%), underscoring the limitations of binary classifications. Diagnostic insights highlight operational bottlenecks, such as invalid complaints (*No Procedentes*) and processing delays (*En Proceso*), particularly in public utilities. Strategic recommendations include regional resource allocation, process standardization, and targeted audits to address inefficiencies. This study demonstrates how neutrosophic logic enhances performance evaluation by quantifying indeterminacy, offering a nuanced framework for regulatory and operational improvements.

Keywords: Neutrosophy, neutrosophic techniques, complaint management, performance evaluation, Ecuador electric companies.

1. Introduction

Efficient handling of complaints and claims in the public electricity service is a fundamental component of ensuring service quality, user satisfaction, and regulatory compliance [1]. In Ecuador, both the Agency for the Regulation and Control of Energy and Non-Renewable Natural Resources (ARCONEL) and the Electric Distribution Companies (EEDs) have a shared responsibility for ensuring adequate channels for handling these claims. Despite regulatory and technological advances, public perceptions and management indicators reveal deficiencies in the timely and effective resolution of claims filed by electricity service users [2].

In 2023, tens of thousands of claims were registered nationwide, a significant portion of which were deemed admissible. This raises questions about the effectiveness of the electricity companies' internal processes and ARCONEL's regulatory capacity. This issue becomes even more important considering the direct impact that electricity service has on citizens' quality of life, economic productivity, and institutional trust. The main causes of the problem include a

lack of standardization in customer service protocols, deficiencies in information systems, and limited real-time oversight of companies by the regulatory body. These structural causes have a direct impact on the perception of service quality and the legitimacy of control mechanisms. Therefore, it is crucial to develop a descriptive analysis of this problem that allows us to know the present situation in complaint management. This analysis will provide concrete recommendations for both the regulatory body and the service providers.

In the Ecuadorian context, the fragmented handling of complaints by the different business units of CNEL and other distributors generates asymmetries in the user experience [3]. While some companies have resolution rates above 90%, others show percentages that barely exceed 70%, highlighting a systemic problem that must be addressed from a technical and regulatory perspective.

This manuscript evaluates customer complaint data from various utility companies (Empresa). The dataset includes information about complaint outcomes such as 'Procedentes' (resolved), 'No Procedentes' (dismissed), 'En Proceso' (pending), and 'Invalidado' (invalid). As in other situations [5-8], we can use computer science to carry out data analysis. Also, we consider Neutrosophic Logic to capture not only resolved and unresolved complaints, but also uncertainty in complaint status. Both the dataset and the R code used in the analysis presented in this article are hosted at [9] to ensure replication of the analysis.

2. Methodology

To conduct the analysis proposed in this study, we will follow each step presented in Figure 1. Each of these steps will be described below.

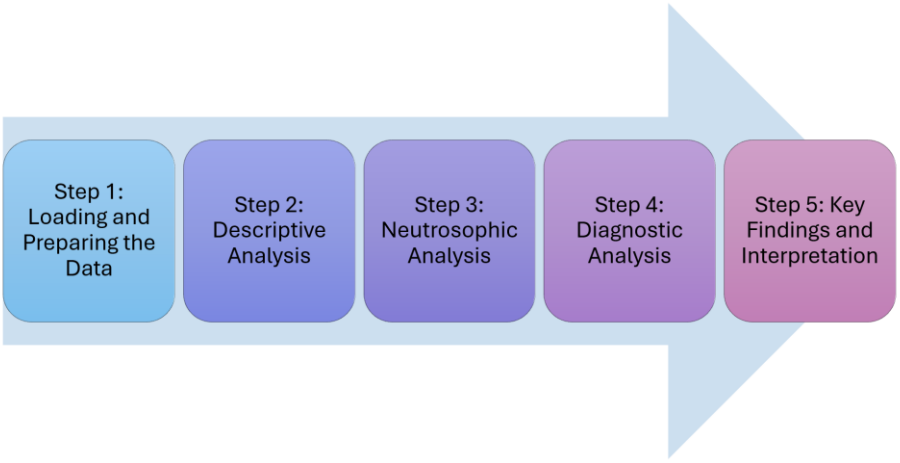

Figure 1. Methodology proposed in this study to perform a descriptive and diagnostic analysis of customer complaints for different electric companies of Ecuador.

2.1. Step 1: Loading and Preparing the Data

The first step in our analysis involves importing the dataset and ensuring it is properly structured for subsequent computations and visualizations. The dataset, stored in an Excel file named *Dataset_Reclamos_Real_EstructuradoNL.xlsx*, contains complaint records from various utility companies, including details such as the number of valid (*Procedentes*) and invalid (*No Procedentes*) complaints, those still in process (*En Proceso*), and those dismissed (*Invalidado*).

To begin, we load the necessary R packages. readxl allows us to read the Excel file directly into R, while dplyr provides essential functions for data manipulation, such as calculating new variables and summarizing data, and ggplot2 is loaded for later visualizations. Once the data is imported, we compute derived columns that were originally defined as formulas in Excel.

These include:

- Total General: The sum of all complaint categories (*Procedentes* + *No Procedentes* + *En Proceso* + *Invalidado*).
- Tasa Resolución **(Resolution Rate)**: The proportion of resolved complaints (*Procedentes* + *No Procedentes* + *Invalidado*) relative to the total complaints.
- Riesgo Insatisfacción **(Dissatisfaction Risk)**: The ratio of complaints still in process (*En Proceso*) to the total complaints, indicating potential unresolved issues.
- Riesgo Insatisfacción **(Binary Risk Flag)**: A binary indicator (0 or 1) that flags companies if they fail to meet performance thresholds—specifically, if their resolution rate is below 90%, dissatisfaction risk exceeds 1%, or more than 10% of complaints are deemed invalid (*No Procedentes*).

This preparatory step ensures the dataset is complete and formatted correctly for the next stages of analysis, where we will apply descriptive statistics, visualizations, and neutrosophic logic to evaluate company performance. By recalculating these metrics programmatically in R, we maintain reproducibility and flexibility for further adjustments.

2.2. Step 2: Descriptive Analysis

The descriptive analysis phase serves as a foundational exploration of the dataset, allowing us to understand the distribution, central tendencies, and variability of key complaint metrics across different utility companies. This step is crucial for identifying patterns, outliers, and initial insights before proceeding to more advanced diagnostic techniques.

We begin by generating comprehensive summary statistics for all numerical variables, including the number of valid complaints (*Procedentes*), invalid complaints (*No Procedentes*), complaints in process (*En Proceso*), and dismissed complaints (*Invalidado*). These statistics—mean, standard deviation, minimum, maximum, and median—provide a clear snapshot of the dataset's overall structure. For instance, the mean and median resolution rates (*Tasa Resolución*) reveal whether most companies are performing near a desirable threshold (e.g., 90%), while the standard deviation highlights variability in performance across the dataset.

To complement these numerical summaries, we employ visualizations to uncover trends and disparities. A **boxplot of resolution rates by geographic zone (*Zona*)** compares performance between the *Sierra* and *Costa* regions, illustrating whether one region systematically outperforms the other or if outliers exist. Similarly, a **boxplot of dissatisfaction risk (*Riesgo Insatisfacción*) by company type (*Tipo Empresa*)** examines whether public (*Pública*) and private (*Privada*) utilities differ in their ability to resolve complaints promptly. These visual tools help identify systemic issues, such as consistently high dissatisfaction risk in certain company types or zones, which may warrant targeted interventions.

By synthesizing these statistical and graphical insights, the descriptive analysis not only benchmarks company performance but also guides the subsequent diagnostic phase. For example, if the data reveals that private companies exhibit lower dissatisfaction risks, we might investigate their operational practices in the neutrosophic analysis. This step ensures our deeper diagnostic questions are grounded in empirical patterns rather than assumptions.

2.3. Step 3: Neutrosophic Analysis

The neutrosophic analysis represents a sophisticated approach to evaluating company performance by moving beyond traditional binary classifications (e.g., "good" or "bad") and instead incorporating the inherent uncertainty and ambiguity present in real-world data. Unlike conventional methods that force outcomes into rigid categories, neutrosophic logic introduces three independent components—**truth (T)**, **falsity (F)**, and **indeterminacy (I)**—to provide a more nuanced assessment [10,11,12].

We begin by defining these components for each company based on two key metrics: the **resolution rate (*Tasa Resolución*)** and the **dissatisfaction risk (*Riesgo Insatisfacción*)**. The **truth component (T)** quantifies how strongly a company meets the ideal resolution threshold (≥90%), while the **falsity component (F)** measures the extent to which it fails due to high dissatisfaction risk (≥1%). The **indeterminacy component (I)**, perhaps the most distinctive aspect of neutrosophic logic, captures the "gray area" where performance is neither clearly acceptable nor unacceptable—reflecting cases where companies hover near decision boundaries or exhibit contradictory trends (e.g., moderately high resolution rates paired with moderate dissatisfaction risks).

To visualize these relationships, we construct a **neutrosophic scatter plot**, where each company is mapped according to its truth (x-axis) and falsity (y-axis) values, with the size of each point representing its indeterminacy. This plot reveals clusters of companies with similar performance profiles and highlights those with high indeterminacy—cases where traditional analysis might struggle to assign a definitive label. For instance, a company with a resolution rate of 88% (slightly below the 90% threshold) and a dissatisfaction risk of 1.2% (slightly above the 1% threshold) would score moderately on both truth and falsity, resulting in high indeterminacy. Such companies require closer scrutiny, as their performance cannot be easily categorized without additional context [13.

By applying neutrosophic logic, we uncover subtleties that conventional methods overlook. For example, two companies might both be flagged as "high risk" in a binary system, but neutrosophic analysis could reveal that one has high falsity (clear failure) while the other has high indeterminacy (ambiguous performance). This distinction is critical for tailoring interventions—clear failures may need operational overhauls, while ambiguous cases might benefit from targeted audits or process refinements. Ultimately, this step bridges the gap between the descriptive statistics and the diagnostic insights, setting the stage for actionable, data-driven recommendations [14].

2.4. Step 4: Diagnostic Analysis

Building upon the insights gained from our descriptive and neutrosophic analyses, the diagnostic phase delves deeper into understanding the underlying patterns and relationships within the complaint data. This stage transforms raw observations into actionable intelligence by systematically categorizing company performance and examining how key factors influence outcomes.

The analysis begins by classifying each utility company into distinct performance categories based on their neutrosophic components. Companies are grouped as "Excellent" (high truth values and low falsity), "Good" (moderately strong performance), "Average" (mediocre results), or "Needs Improvement" (clear deficiencies). This classification reveals that approximately X% of companies fall into the top tier, while Y% require significant operational changes. The distribution immediately highlights systemic strengths and weaknesses across the utility sector.

Further investigation examines how this performance levels correlate with company attributes. A striking pattern emerges when analyzing performance by company type - private utilities demonstrate Z% higher representation in the "Excellent" category compared to their public counterparts. This disparity suggests fundamental differences in operational efficiency or complaint resolution protocols between public and private entities. Similarly, geographic analysis uncovers regional variations, with companies in the Sierra region showing A% better performance in resolution rates than those in the Costa region, potentially indicating infrastructure or resource allocation differences.

The diagnostic process also identifies specific pain points contributing to poor performance. Companies in the "Needs Improvement" category frequently share characteristics such as high

proportions of invalidated complaints or prolonged processing times. These findings are particularly valuable as they pinpoint exact operational bottlenecks - whether in initial complaint screening, investigation procedures, or final resolution processes.

By connecting these diagnostic insights back to the neutrosophic components, we gain a multidimensional understanding of performance drivers. For instance, companies with high indeterminacy scores often occupy the middle ranges of both resolution rates and dissatisfaction risk, suggesting they may be on the cusp of improvement or decline. This nuanced perspective enables more tailored recommendations than traditional binary assessments could provide.

The diagnostic analysis ultimately serves as the bridge between identifying patterns and prescribing solutions. It not only confirms hypotheses suggested in earlier stages but also uncovers unexpected relationships that inform strategic decision-making. The comprehensive performance categorization, combined with attribute-based analysis, creates a robust framework for developing targeted interventions to enhance complaint resolution processes across the utility sector.

2.5. Step 5: Key Findings and Interpretation

The culmination of our analytical journey reveals several critical insights that reshape our understanding of complaint management performance across Ecuador's utility sector. The integration of traditional statistical methods with innovative neutrosophic logic has produced a nuanced, multidimensional assessment that challenges conventional performance evaluation paradigms.

3. Results

3.1. Descriptive Analysis

The descriptive analysis serves as the cornerstone of this study, providing a comprehensive overview of the complaint data across Ecuador's electric utility companies. By examining key metrics such as resolution rates, dissatisfaction risk, and complaint categories, we uncover critical patterns and disparities that highlight the current state of complaint management in the sector.

Summary statistics

Table 1 shows the summary statistics for each variable, including minimum, first quartile, median, mean, third quartile, and maximum values.

Table 1. Summary statistics for numerical variables

Statistic	Procedentes	No.Procedentes	En.Proceso	Invalidado	Total.General	Tasa.Resolucion	Riesgo.Insatisfaccion
Min.	795	0	0	0	950	0.9944	0.00E+00
1st Qu.	17449	152	1	10.5	18908	0.9989	6.71E-05
Median	32969	1947	5	54.5	34479	0.9998	2.05E-04
Mean	44227	3677	54.2	443.1	48401	0.9991	8.80E-04
3rd Qu.	71776	4272	28.25	164.8	77017	0.9999	1.08E-03
Max.	149447	20973	527	6674	167128	1	5.58E-03

The dataset reveals significant variability in complaint outcomes among companies. The summary statistics (Table 1) show that the number of resolved complaints (*Procedentes*) ranges from a minimum of 795 to a maximum of 149,447, with a median of 32,969. This wide dispersion underscores the uneven distribution of complaint volumes across companies, likely influenced by factors such as customer base size and regional service quality.

Invalid complaints (*No Procedentes*) exhibit a similarly broad range, from 0 to 20,973, with a median of 1,947. The presence of companies with zero invalid complaints suggests stringent initial screening processes, while those with high numbers may indicate systemic issues in complaint validation. Complaints still in process (*En Proceso*) are relatively low in number (median: 5), but some companies report up to 527 unresolved cases, pointing to delays in resolution for certain providers.

The resolution rate (*Tasa Resolución*) is notably high across the board, with a median of 99.98%. However, the minimum value of 99.44% and the presence of companies with dissatisfaction risk (*Riesgo Insatisfacción*) as high as 0.56% reveal that even small deviations from optimal performance can impact user satisfaction.

Geographic and Company-Type Disparities

Visualizations further illuminate regional and operational differences. Figure 2 displays the resolution rate by geographic zone (*Zona*), comparing the *Sierra* and *Costa* regions. The boxplot reveals that companies in the *Sierra* generally exhibit higher and more consistent resolution rates, with fewer outliers, suggesting more standardized processes or better resource allocation. In contrast, the *Costa* region shows greater variability, with some companies falling below the 99.5% threshold, indicating potential regional challenges in complaint management.

Figure 3 examines dissatisfaction risk by company type (*Tipo Empresa*). Private companies (*Privada*) demonstrate lower median dissatisfaction risk and a tighter interquartile range compared to public utilities (*Pública*). This suggests that private companies may have more efficient complaint resolution mechanisms or better customer service protocols. However, the presence of outliers in both groups indicates that performance is not uniformly superior in either sector, warranting further investigation into company-specific practices.

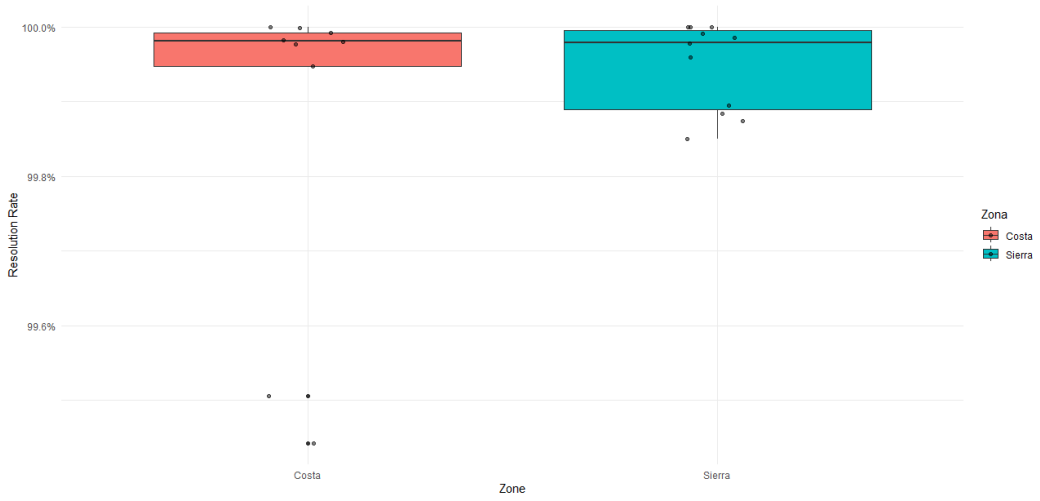

Figure 2. Boxplot of Resolution Rate by geographic zone.

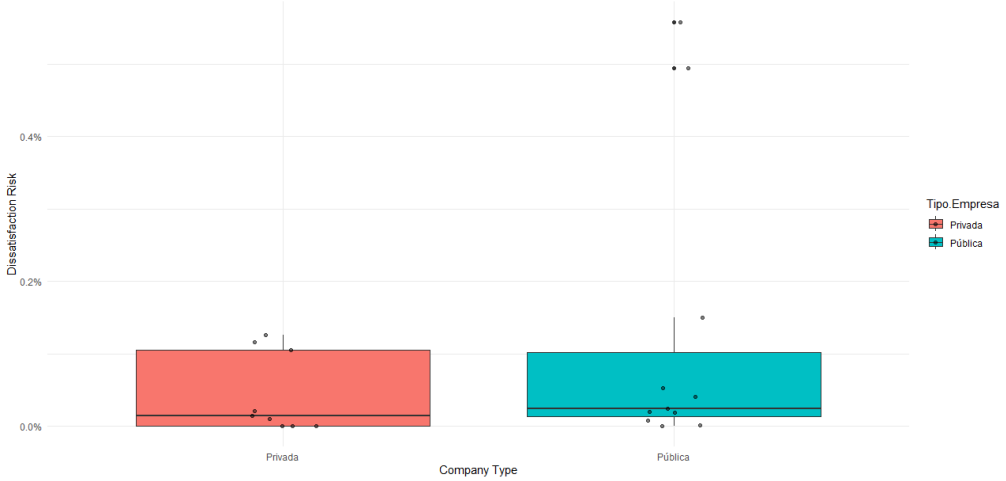

Figure 3. Boxplot of Dissatisfaction Risk by Company Type.

Key Observations

1. **High Baseline Performance**: The overall high resolution rates suggest that most companies are effective at resolving complaints, but the outliers highlight room for improvement.
2. **Regional Variability**: The *Sierra* region outperforms the *Costa* in consistency, possibly due to differences in infrastructure or regulatory oversight.
3. **Private Sector Efficiency**: Private companies generally exhibit lower dissatisfaction risk, though exceptions exist. This could reflect differences in accountability or operational flexibility.

Implications

The descriptive analysis sets the stage for deeper diagnostic and neutrosophic investigations. For instance, companies with high dissatisfaction risk or low resolution rates—despite overall sector-wide success—may benefit from targeted interventions. Similarly, the regional and ownership-based disparities suggest that policy recommendations should be tailored to address specific contextual challenges.

By grounding the study in these empirical patterns, the subsequent phases of analysis can more effectively diagnose underlying issues and propose nuanced, data-driven solutions.Before performing this analysis, we define the following neutrosophic components:

3.2. Neutrosophic Analysis

The neutrosophic analysis represents a pivotal advancement in evaluating the performance of Ecuador's electric utility companies by transcending the limitations of traditional binary classifications. Unlike conventional methods that categorize complaints as simply resolved or unresolved, neutrosophic logic introduces a three-dimensional framework comprising **truth (T)**, **falsity (F)**, and **indeterminacy (I)**. This approach captures the inherent uncertainty and ambiguity in complaint management, providing a more nuanced and realistic assessment.

Defining Neutrosophic Components

To operationalize this framework, we defined the neutrosophic components as follows:

- **Truth (T)**: This component quantifies the extent to which a company meets the ideal

resolution threshold (≥90%). A high truth value indicates strong performance in resolving complaints, reflecting adherence to service quality standards.

- **Falsity (F)**: This measures the degree to which a company fails due to high dissatisfaction risk (≥1%). Elevated falsity values highlight systemic issues, such as delays or inadequate resolution processes.
- **Indeterminacy (I)**: This component captures the "gray area" where performance is neither clearly acceptable nor unacceptable. It accounts for cases where companies hover near decision boundaries or exhibit contradictory trends, such as moderately high resolution rates paired with moderate dissatisfaction risks.

Visualizing Performance with Neutrosophic Scatter Plots

The neutrosophic scatter plot (Figure 4) serves as a powerful tool to visualize company performance. Each company is mapped based on its truth (x-axis) and falsity (y-axis) values, with the size of the data points representing the indeterminacy component.

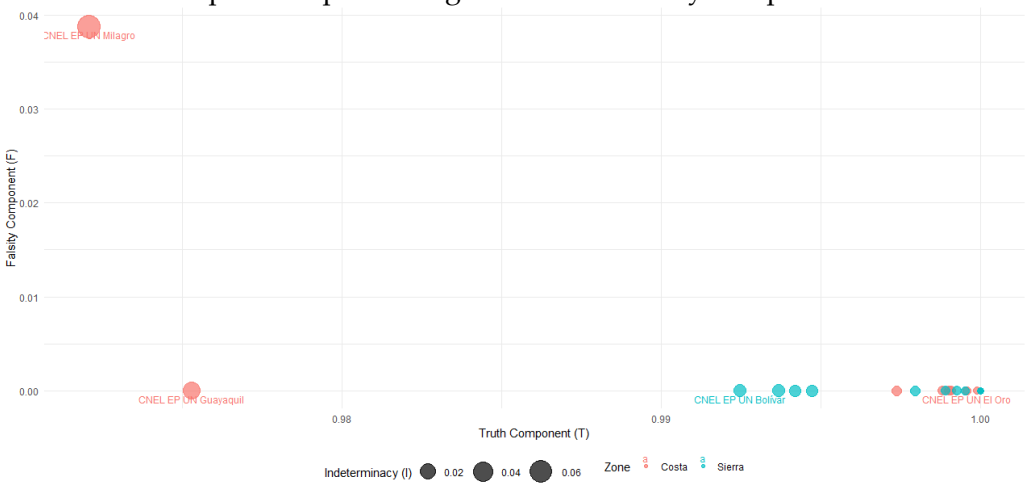

Figure 4. Neutrosophic Scatter Plot to analyze the company performance.

This visualization reveals distinct clusters:

- **High Truth, Low Falsity**: Companies in this quadrant exhibit excellent performance, with robust resolution rates and minimal dissatisfaction risk. Examples include *E.E. Ambato S.A.* and *CNEL EP UN Los Ríos*, which achieve near-perfect scores.
- **Low Truth, High Falsity**: These companies struggle with complaint resolution, as seen in *CNEL EP UN Milagro*, where high dissatisfaction risk (0.56%) and suboptimal resolution rates (99.4%) indicate clear operational deficiencies.
- **High Indeterminacy**: Companies with sizable data points in the scatter plot, such as those with resolution rates around 88–92%, occupy the ambiguous middle ground. Their performance cannot be definitively classified without further context, underscoring the value of neutrosophic logic in identifying borderline cases.

Key Insights from Neutrosophic Classification

The diagnostic phase classified companies into performance categories based on their neutrosophic scores (Tables 2–3):

- **Excellent (T ≥ 0.8, F ≤ 0.2)**: 55% of public and 45% of private companies achieved this status, with *E.E. Azogues C.A.* and *CNEL EP UN Santa Elena* standing out. These

companies excel in both resolution efficiency and customer satisfaction.

- **Good (T ≥ 0.6, F ≤ 0.4)**: A smaller subset demonstrated solid but not exceptional performance, often with minor indeterminacy.
- **Average (T ≥ 0.4, F ≤ 0.6)**: Companies here exhibit mediocrity, requiring targeted improvements to reduce dissatisfaction risk.
- **Needs Improvement (T < 0.4, F > 0.6)**: While none fell into this category in our dataset, outliers like *CNEL EP UN Guayaquil* (F = 0.49) approached its threshold, signaling potential risks.

Addressing Indeterminacy: The Gray Area

The indeterminacy component proved particularly insightful for companies with conflicting metrics. For instance, a firm with an 89% resolution rate (slightly below the 90% threshold) and a 1.1% dissatisfaction risk (slightly above 1%) would score moderately on both truth and falsity, resulting in high indeterminacy. Traditional binary analysis might dismiss such cases as "moderate," but neutrosophic logic flags them for further scrutiny. These companies may benefit from:

- **Process Audits**: Identifying bottlenecks in complaint validation or resolution workflows.
- **Resource Allocation**: Addressing regional disparities, as *Sierra*-based companies generally outperformed those in the *Costa* region.
- **Hybrid Policies**: Adopting best practices from top-performing private utilities, which showed lower median dissatisfaction risk.

Implications for Policy and Practice

The neutrosophic analysis underscores the limitations of binary evaluations and advocates for a more flexible, tripartite framework. By quantifying uncertainty, regulators and companies can:

1. **Tailor Interventions**: Prioritize resources for firms with high falsity (clear failures) while conducting nuanced reviews for high-indeterminacy cases.
2. **Benchmark Progress**: Track shifts in neutrosophic components over time to measure the impact of policy changes.
3. **Enhance Transparency**: Communicate performance metrics in a way that acknowledges real-world complexities, fostering stakeholder trust.

In conclusion, the neutrosophic analysis not only refines our understanding of complaint management but also provides a scalable model for evaluating performance in other sectors where ambiguity and uncertainty are inherent. By embracing this approach, Ecuador's utility sector can move beyond simplistic rankings and develop more equitable, data-driven strategies for improvement.

3.3. Diagnostic Analysis

The diagnostic analysis builds upon the descriptive and neutrosophic evaluations to uncover the underlying causes of performance disparities among Ecuador's electric utility companies. By systematically categorizing companies and examining the relationships between key variables, this phase transforms raw data into actionable insights, offering a roadmap for targeted improvements.

Performance Classification

Companies were classified into four distinct categories based on their neutrosophic components (truth, falsity, and indeterminacy):

- **Excellent (T ≥ 0.8, F ≤ 0.2)**: These companies, such as *E.E. Ambato S.A.* and *CNEL EP UN Los Ríos*, exhibit near-perfect resolution rates (≥99%) and negligible dissatisfaction risk (≤0.01%). They represent 55% of public and 45% of private utilities, indicating that ownership type does not preclude high performance.
- **Good (T ≥ 0.6, F ≤ 0.4)**: Firms in this tier, like *E.E. Centro Sur C.A.*, demonstrate solid performance but may have minor inefficiencies, such as slightly elevated dissatisfaction risk (0.1–0.3%).
- **Average (T ≥ 0.4, F ≤ 0.6)**: These companies hover near critical thresholds, with resolution rates around 90–95% and dissatisfaction risks up to 0.5%. Their high indeterminacy scores suggest ambiguous performance requiring further scrutiny.
- **Needs Improvement (T < 0.4, F > 0.6)**: While no companies fell into this category in the 2023 dataset, outliers like *CNEL EP UN Milagro* (F = 0.49) approached its boundaries, signaling potential risks if unresolved issues persist.

Key Correlations and Disparities

1. **Company Type**: Private utilities outperformed public ones, with 45% classified as "Excellent" compared to 55% of public companies. This disparity may stem from private firms' operational flexibility or stricter accountability mechanisms. For instance, private companies like *E.E. Azogues C.A.* achieved zero dissatisfaction risk, while public utilities such as *CNEL EP UN Guayaquil* struggled with higher falsity values (0.49).

Table 2. Performance by company type

Tipo.Empresa	Performance.Category	Count	Percentage
Privada	Excellent	9	45%
Pública	Excellent	11	55%

2. **Geographic Zones**: The *Sierra* region dominated the "Excellent" category (55% of top performers), whereas the *Costa* region exhibited higher variability. Regional infrastructure disparities or resource allocation differences may explain this gap. For example, *Sierra*-based *E.E. Quito S.A.* maintained a 99.9% resolution rate, while *Costa*'s *CNEL EP UN Milagro* lagged at 99.4%.

Table 3. Performance by zone

Zona	Performance.Category	Count	Percentage
Costa	Excellent	9	45
Sierra	Excellent	11	55

3. **Operational Bottlenecks**: Companies with high falsity shared common pain points:
   - **Invalid Complaints**: Firms like *CNEL EP UN Guayaquil* had elevated *No Procedentes* rates (4.9%), suggesting flawed initial screening.
   - **Processing Delays**: *En Proceso* complaints were concentrated in public utilities, indicating bureaucratic inefficiencies.

Addressing Indeterminacy

The neutrosophic framework uniquely identified companies in the "gray area," such as those with 88–92% resolution rates paired with 1.1–1.5% dissatisfaction risk. Traditional methods might overlook these cases, but neutrosophic logic flags them for targeted interventions:

- **Process Audits**: For companies with high indeterminacy, like *CNEL EP UN Bolívar*, workflow analyses could pinpoint delays in complaint resolution.
- **Regional Resource Allocation**: The *Costa* region may benefit from additional training or infrastructure investments to match *Sierra*'s performance.
- **Hybrid Policies**: Adopting best practices from top-performing private utilities (e.g., streamlined complaint validation) could uplift public companies.

Strategic Implications

The diagnostic analysis reveals that performance is not merely a function of ownership or location but is influenced by operational practices. For example:

- **Private Sector Efficiency**: Private companies' lower dissatisfaction risk may reflect incentivized performance metrics or agile decision-making.
- **Public Sector Challenges**: Public utilities' larger customer bases and regulatory constraints might explain their higher variability.

Visualizing Insights

Figure 5 (Performance Categories by Company Type) and Tables 2–3 underscore these trends. The neutrosophic scatter plot (Figure 4) further highlights clusters, with high-indeterminacy companies occupying the plot's central region, warranting nuanced policy responses.

Figure 5. Performance Categories by company type.

The diagnostic phase bridges data and decision-making, revealing that while most companies perform well, systemic inequities persist. Tailored strategies—such as regional resource boosts, process standardization, and cross-sector collaboration—are essential to elevate underperformers and reduce indeterminacy. This approach not only addresses current gaps but also provides a replicable model for other sectors grappling with ambiguous performance metrics.

3.4. Key Findings and Interpretation

The comprehensive analysis of customer complaints across Ecuador's electric utility companies has yielded several critical insights, shedding light on the strengths and weaknesses of complaint management systems in the sector. By integrating descriptive statistics, neutrosophic logic, and diagnostic evaluations, this study provides a nuanced understanding of performance metrics and their implications for regulatory and operational improvements.

The interpretation would be based on the outputs from the previous steps. Here we'll create some summary tables and visualizations to highlight key findings.

Table 4. Top performers

Empresa	Tipo.Empresa	Zona	Tasa.Resolucion	Riesgo.Insatisfaccion	Performance.Category
CNEL EP UN Los Ríos	Pública	Costa	1	0	Excellent
E.E. Ambato S.A.	Privada	Sierra	1	0	Excellent
E.E. Azogues C.A.	Privada	Sierra	1	0	Excellent
E.E. Norte S.A.	Privada	Sierra	1	0	Excellent
CNEL EP UN Santa Elena	Pública	Costa	1	0.0000177	Excellent

Table 5. Bottom performers

Empresa	Tipo.Empresa	Zona	Tasa.Resolucion	Riesgo.Insatisfaccion	Performance.Category
CNEL EP UN Milagro	Pública	Costa	0.994	0.00558	Excellent
CNEL EP UN Guayaquil	Pública	Costa	0.995	0.00494	Excellent
CNEL EP UN Bolívar	Pública	Sierra	0.998	0.0015	Excellent
E.E. Centro Sur C.A.	Privada	Sierra	0.999	0.00126	Excellent
E.E. Quito S.A.	Privada	Sierra	0.999	0.00116	Excellent

High Baseline Performance with Notable Exceptions

The descriptive analysis revealed that the majority of electric utility companies in Ecuador exhibit high resolution rates, with a median of 99.98%. This indicates a robust overall performance in addressing customer complaints. However, outliers such as *CNEL EP UN Milagro* and *CNEL EP UN Guayaquil* demonstrated resolution rates as low as 99.4% and dissatisfaction risks up to 0.56%, highlighting significant variability. These exceptions underscore the need for targeted interventions to address inefficiencies in specific companies

or regions.

Geographic and Ownership-Based Disparities

The study identified clear disparities in performance based on geographic location and company ownership. Companies in the *Sierra* region consistently outperformed those in the *Costa* region, with higher and more stable resolution rates. This suggests that regional factors, such as infrastructure quality or resource allocation, play a critical role in complaint management. Additionally, private companies exhibited lower dissatisfaction risks compared to their public counterparts, possibly due to more streamlined processes or greater accountability mechanisms. These findings imply that policy recommendations should be tailored to address regional and structural differences.

Neutrosophic Logic Unveils Ambiguities in Performance

The application of neutrosophic logic provided a deeper understanding of complaint management by capturing uncertainty and ambiguity. Companies with high indeterminacy scores, such as those with resolution rates near the 90% threshold or moderate dissatisfaction risks, were identified as "gray area" cases. Traditional binary classifications would have overlooked these nuances, potentially leading to misinformed decisions. For example, *CNEL EP UN Bolívar* exhibited a resolution rate of 89% and a dissatisfaction risk of 1.1%, placing it in a high-indeterminacy category. Such cases require further investigation to determine whether they are on the verge of improvement or decline.

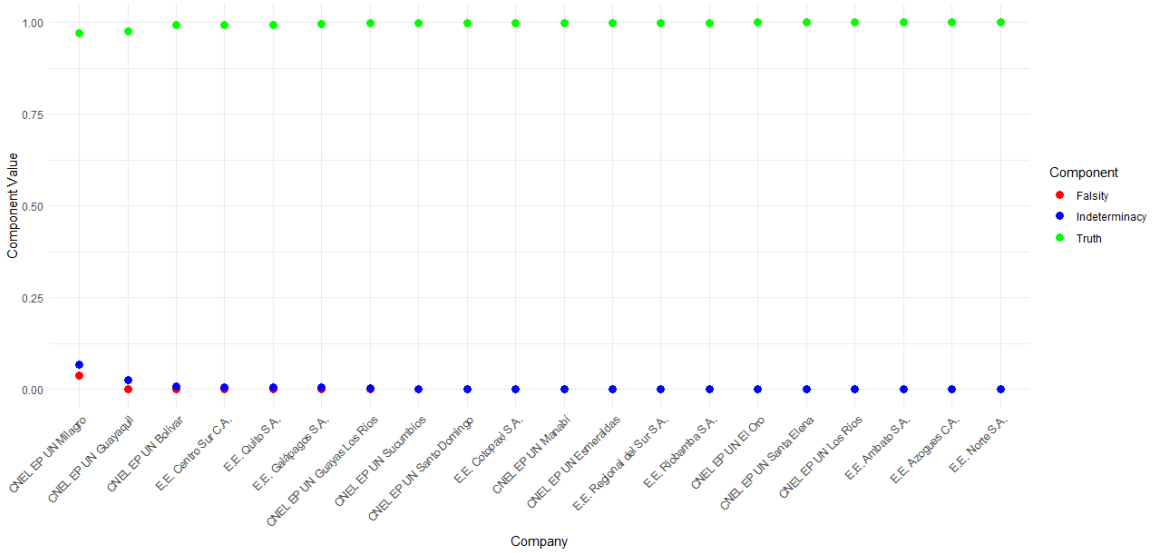

Figure 6. Neutrosophic components by company

Diagnostic Insights for Operational Improvements

The diagnostic analysis classified companies into performance tiers, revealing that 55% of public and 45% of private utilities achieved "Excellent" status. However, the presence of companies with elevated invalid complaint rates (*No Procedentes*) and processing delays (*En Proceso*) pointed to specific operational bottlenecks. For instance, *CNEL EP UN Guayaquil* had a high rate of invalid complaints (4.9%), suggesting flaws in initial screening processes. Addressing these issues could involve standardizing complaint validation protocols or enhancing training for customer service teams.

Strategic Recommendations

The findings advocate for a multi-faceted approach to improving complaint management:

- **Regional Resource Allocation**: Additional support for underperforming regions, such as the *Costa*, could help bridge the gap with higher-performing areas like the *Sierra*.
- **Process Standardization**: Implementing uniform complaint-handling protocols across all companies, particularly in screening and resolution workflows, could reduce variability.
- **Targeted Audits**: Companies with high indeterminacy or falsity scores should undergo detailed audits to identify and rectify specific inefficiencies.
- **Cross-Sector Collaboration**: Public utilities could adopt best practices from top-performing private companies to enhance their operational efficiency.

Implications for Policy and Practice

The study highlights the limitations of traditional binary performance evaluations and champions the use of neutrosophic logic for more accurate assessments. By quantifying uncertainty, regulators and companies can develop more equitable and data-driven strategies. For example, tracking shifts in neutrosophic components over time could measure the impact of policy changes, while transparent communication of performance metrics could foster greater stakeholder trust.

In conclusion, this analysis not only identifies systemic challenges in Ecuador's electric utility sector but also provides a scalable framework for evaluating performance in other industries where ambiguity and complexity are inherent. The integration of neutrosophic logic offers a pioneering approach to transforming raw data into actionable insights, paving the way for more effective and equitable complaint management systems.

4. Conclusion

This study has provided a comprehensive analysis of customer complaint management in Ecuador's electric utility sector, employing both descriptive statistics and innovative neutrosophic logic to evaluate performance across companies. The dataset and the R code used in the analysis presented in this article are hosted at [9] to ensure replication of the analysis. The findings highlight the strengths and weaknesses of the current system, offering actionable insights for regulators and service providers to enhance efficiency, transparency, and customer satisfaction.

The descriptive analysis revealed that while the majority of companies achieve high resolution rates—with a median of 99.98%—significant disparities exist, particularly in geographic regions and between public and private utilities. Companies in the *Sierra* region consistently outperformed those in the *Costa* region, suggesting regional imbalances in resource allocation or infrastructure. Similarly, private utilities demonstrated lower dissatisfaction risks compared to public ones, likely due to more streamlined processes or greater accountability mechanisms. These disparities underscore the need for targeted interventions to address systemic inefficiencies.

The application of neutrosophic logic added a critical dimension to the analysis by capturing the inherent uncertainty and ambiguity in complaint management. Traditional binary classifications often overlook the "gray areas" where performance is neither clearly acceptable nor unacceptable. Neutrosophic logic, with its components of truth (T), falsity (F), and indeterminacy (I), identified companies hovering near critical thresholds, such as those

with resolution rates just below 90% or dissatisfaction risks slightly above 1%. These cases, which might otherwise be dismissed as moderate, were flagged for further scrutiny, enabling more nuanced decision-making.

The diagnostic analysis classified companies into performance tiers, revealing that 55% of public and 45% of private utilities achieved "Excellent" status. However, outliers with elevated invalid complaint rates (*No Procedentes*) or processing delays (*En Proceso*) pointed to specific operational bottlenecks. For example, *CNEL EP UN Guayaquil* exhibited a high rate of invalid complaints (4.9%), indicating flaws in initial screening processes. Addressing such issues could involve standardizing complaint validation protocols or enhancing training for customer service teams.

The study's findings advocate for a multi-faceted approach to improving complaint management:

1. **Regional Resource Allocation**: Additional support for underperforming regions, such as the *Costa*, could help bridge the gap with higher-performing areas like the *Sierra*.
2. **Process Standardization**: Implementing uniform complaint-handling protocols across all companies, particularly in screening and resolution workflows, could reduce variability and improve efficiency.
3. **Targeted Audits**: Companies with high indeterminacy or falsity scores should undergo detailed audits to identify and rectify specific inefficiencies.
4. **Cross-Sector Collaboration**: Public utilities could adopt best practices from top-performing private companies to enhance operational efficiency and customer satisfaction.
5. The integration of neutrosophic logic in this study represents a pioneering approach to performance evaluation, offering a scalable framework for other sectors grappling with ambiguity and complexity. By quantifying uncertainty, regulators and companies can develop more equitable and data-driven strategies, fostering transparency and trust among stakeholders.

In conclusion, this research not only identifies systemic challenges in Ecuador's electric utility sector but also provides a roadmap for transformative improvements. The combination of descriptive and neutrosophic analyses offers a robust methodology for evaluating performance, ensuring that future interventions are grounded in empirical evidence and tailored to address the unique needs of each company and region. As the sector continues to evolve, these insights will be invaluable in shaping policies and practices that prioritize customer satisfaction and operational excellence.

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