

Electrokit: Power Utility Toolkit— Quality of Technical Service

Energy Division

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Acronyms

AMI	Automated Metering Infrastructure
APPA	American Public Power Association
ASIDI	Average System Interruption Frequency Index
ASIFI	Average System Interruption Frequency Index
BI	Business Intelligence
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
CEER	Council of European Energy Regulators
CMS	Customer Management System
CTAIDI	Customer Total Average Interruption Duration Index
CREG	Comisión de Regulación de Energía y Gas
COS	Continuity of Supply
DG	Distributed Generation
ENS	Energy Not Supplied
GIS	Geographic Information System
IDB	Inter-American Development Bank
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LAC	Latin America and Caribbean
OECD	Organization for Economic Co-Operation and Development
PMU	Phasor Measurement Unit
SCADA	Supervisory Control and Data Acquisition
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
R&D	Research and Development

1. Introduction

Companies providing electricity services face the need to continuously improve the quality of its services to society, ensure and broaden its coverage, maximize the impact of its investments, and operate in an efficient manner. Distribution companies have also the need to adapt to the new demands from consumers, who are gradually having a more active role. These are some of the main characteristics of the license to operate utilities have in their geographic coverage. In addition, state-owned enterprises (SOE) in the electricity sector have the added challenges of: (i) serving policy objectives which are specific to each country and in some cases, (ii) having limited capacity to invest considering their financial constraints.

To achieve these multiple - and sometimes conflicting objectives - utility companies must have robust business models to provide services with quality; and internal learning schemes to strengthen their technical and human capabilities to improve their operational performance. In addition, utilities must have planning and management models aimed at developing and implementing successful transformation processes, assuring the viability of its investments and services.

The Electrokit: Power Utilities Toolkit was developed to support electricity companies in the Latin America and Caribbean region (LAC) identify opportunities to improve their performance, considering the important participation of SOEs in the LAC region¹. This development takes into consideration the extensive experience of the Bank working with utilities in multiple countries² and international standards in the industry such as International Organization for Standardization (ISO).

The methodology integrally evaluates the utilities, from the quantitative aspects of their performance to the qualitative elements of their processes, practices and technologies used in the management cycle. On the quantitative aspects, the toolkit brings several performance indicators for each activity which can be used as a reference to assess the utility's performance. The toolkit is universally applicable to any type and size of company worldwide, including SOEs. The document also acknowledges the different levels of maturity and sophistication of electricity utilities in the LAC region, and it has been developed to provide this guidance to utilities improve their performance.

The Electrokit however is not a certification tool or an audit instrument; it is a practical managerial and technical guide to identify improvement opportunities in priority activities, which will be specific to each utility and country setting. Moreover, the best practices do not detail the extent of applicability to a certain enterprise according to its level of maturity, scale,

¹ Government-owned utilities represent the single largest distribution companies, representing 39% of the distribution companies in the LAC region. Source: Fitch ratings https://your.fitch.group/rs/732-CKH-767/images/Fitch_10086090.pdf?mkt_tok=eyJpIjoiTXpsaF16QTBNMlExWlRJMCIlnQiOiJwVHBVZiVncDZoT29zcFZTM0JadVlcL1VjaWN1dDM2bnJHR3phU1JlSkpkVU5qNlE5OXB6MXgxSmE4ejRzcjJlVHh1ZWJEaXZBYm92amtFYW81UUZObmc9PSJ9

² For example, the Bank has developed the Aquarating toolkit (<https://aquarating.org/en/>) to improve the performance of water and sanitation companies, and the lessons learned from this development were included in this document.

regulatory framework and market context as these will be tailored to each case. These improvement opportunities are usually developed in a program of activities with targets and the IDB can make available to utilities a team to help elaboration of these activities and monitor them over time.

1.1 Defining the Electrokit

What is it?

The Electrokit is an initiative created by the Inter-American Development Bank (IDB) to strengthen transformation and continuous improvement of electric utilities. The toolkit follows international standards that characterize and evaluate utilities based on indicators and best practices. These practices are grouped in 4 areas and 16 activities that are common to most electricity utility.

The aim of the Electrokit is to provide LAC power utilities, policy and decision-makers access to best practices, current trends and expertise to: (i) identify challenges, develop a strategy and action plan for addressing them; and (ii) support utilities to be more sustainable, efficient, improve customer experience and accelerate innovation to allow the utilities to stay ahead of the rapidly sector transformation.

Companies providing electricity distribution services face the daily challenge of continuously improving services, and in this scenario, companies must seek management models aimed at continuous learning and implementing performance improvement processes. One way to achieve these objectives is to always seek the best practices in the sector.

In general, the challenges for public electricity distribution companies are to ensure:

- (i) the continuity and reliability of electricity service.
- (ii) the affordability of the service.
- (iii) the efficiency in the provision of service.
- (iv) the required transformation to embrace existing and new demands such as distributed generation and electromobility; and
- (v) the sustainability of the utility and the sector.

In addition to these, SOEs have the additional challenges due to their mix of social, economic, political, and strategic interests.

These challenges when properly managed, can be transformed into opportunities for the LAC region, such as: (i) positive impacts on the competitiveness of countries from the improvement of the quality and reliability of services ; (ii) reduce inequality by improving the affordability of service, in particular to the most vulnerable populations; (iii) better use of society's limited resources by strengthening the efficiency in provision of service and the financial sustainability

of the companies through the reduction of electricity losses; (iv) anticipate new trends to ensure they are better prepared for disruptions in the sector, incorporating new technologies, services, and business models; and (v) ensure the electricity sector is sound and has the proper resources to provide service of quality and meet investment needs.

A recent IDB book has highlighted the trend that the infrastructure sector (and thus power utilities) in LAC is moving from structures to services³, focusing not only on the investments in hard assets, but also simultaneously on the improvement of efficiencies and new services. In this scenario, utilities will need to alter their business models to adjust themselves: for example, declines in the cost of both solar electricity at small scale (and for some industries, wind) and storage have helped decentralize production and bring added competition to the provision of electricity. While the book identified 4 possible scenarios for the future of electricity, the utilities will need to have efficient operations and be financially sustainable with expertise and resource accumulated to adapt to the new market situation.

The Electrokit focuses on the distribution activities of electricity utilities. Based on the Bank's experience in the LAC region, the distribution and commercialization activities have important areas for improvement as they are the ones mostly impacted by technology disruptions and the growing role consumers have in the energy sector.

The Electrokit builds on the opportunities identified in the Energy Sector Framework (ESF)⁴ to improve performance of public utilities following the unbundling of the electricity sector in LAC that happened in the period 1980-2000s which increased competition along the value chain. This new competitive environment has led public utilities to develop plans to strengthen their corporate governance structure as well as seek ways to improve their operational efficiencies. Moreover, the ESF has identified the need to modernize the public sector incorporating new technologies, and promoting the adoption of innovation, and not only to smooth potential disruption these innovations could bring, but also to incorporate these into their operations.

The benefits of electricity distribution companies using this toolkit are: (i) have access to a comprehensive framework that consolidates the most important processes of a distribution company; (ii) review the company's practices and performance against a set of industry best practices and benchmarks; (iii) advance the analysis with the use of case studies and how other utilities are actually improving their performance and (iv) develop implementation plans with items that have the largest impact on the quality of their services and on their financial sustainability.

The next chapter presents the structure of the Electrokit with a standard approach to review the indicators and practices of each activity.

³ IDB From Structure to Services – The Path To Better Infrastructure in Latin America and the Caribbean (2020). Edited by Eduardo Carvalho, Andrew Powel, Tomás Serebrisky. Accessible at: <https://flagships.iadb.org/en/DIA2020/from-structures-to-services>

⁴ IDB Energy Sector Framework Document – Energy Division (October 2018). Accessible at: <https://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=EZSHARE-715548541-11>

2. Structuring the practices in the electricity sector

2.1 Main structure

In the context of the use of the Electrokit, the main activities of a typical electricity utility have been organized in four areas. Individual areas are broken down into sub-areas, which are further broken down into activities. Figure 2 illustrates this hierarchy. This organization is based on reviewing similar instruments and the four areas is an attempt to aggregate the activities and processes of the distribution of electricity services in a consolidated and clear manner to facilitate the analysis and implementation of the toolkit's activities.

The first area encompasses the technical and operational activities such as the provision, quality, and reliability of the electricity services, including the level of access and the efficiency in the provision of services. These are mostly related to customer service activities and this area is considered part of the core activities of a utility. The second area is related to the financial, organizational, and corporate governance activities which have dedicated literature and practices for their activities but are not very different from other regulated activities. A similar structure is used for the third area of environmental, social and resilience activities of an electricity utility. Finally, the fourth area of innovation deals with the activities that utilities need to prepare themselves to manage disruptions, technology changes, and development of new business models. In the case of SOEs, advancement in this last area will be dependent on the availability of financial resources as some of them face financial restrictions. Each of these areas is broken-down in subareas and activities and they are further described next.

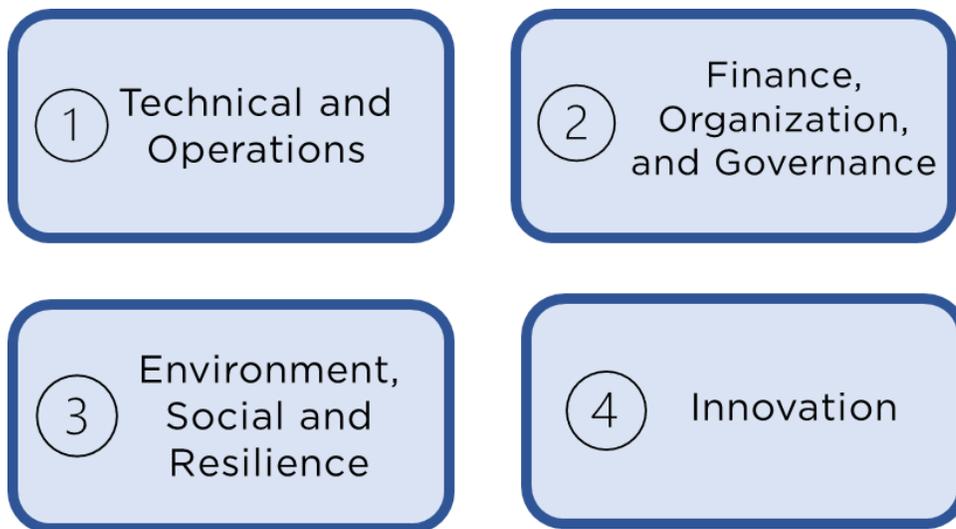


Figure 2 - Four main areas

While the analyses of the toolkit focus on the current situation of the utility, when analyzing the performance indicators, it is important to consider the previous 3 to 5 years (depending on the subarea) as time horizon of the analysis to identify trends and avoid analysis of outliers.

2.2 Structure of areas, subareas, and activities

Areas	Subareas	Activities
<p style="text-align: center;">①</p> <p>Technical and Operations</p>	Efficiency in Operation (EO)	<ul style="list-style-type: none"> Electricity loss reduction Management of O&M costs
	Quality of Service (CS)	<ul style="list-style-type: none"> Quality of the Technical Service Attention to the client
	Access (AS)	<ul style="list-style-type: none"> Access to service
	Efficiency in Investments (EI)	<ul style="list-style-type: none"> Efficiency and execution of the investment plan and asset management
<p style="text-align: center;">②</p> <p>Finance, Organization, and Corporate Governance</p>	Financial Sustainability (SF)	<ul style="list-style-type: none"> Financial management and sustainability Commercial management
	Corporate Governance (GC)	<ul style="list-style-type: none"> Autonomy, decision making, controls, and transparency. Strategic planning, organizational structure and Human Resources (HR)
<p style="text-align: center;">③</p> <p>ESR</p>	Environmental, Social and Resilience (ES)	<ul style="list-style-type: none"> Climate change mitigation Environmental and social aspects Resilience and emergency planning
<p style="text-align: center;">④</p> <p>Innovation</p>	Innovation and Vision of the Future (IN)	<ul style="list-style-type: none"> Technology, digitalization and cybersecurity Modernization and vision of the future Innovation Initiatives

Figure 3 - Areas, subareas, and activities

This structure of areas and activities will be presented in the web platform using the following visual representation:

Power utility toolkit

The toolkit is an initiative created by the Inter-American Development Bank to strengthen transformation and continuous improvement of electricity distribution companies. The toolkit is based on international available benchmarks and best practices. These practices are grouped in 4 areas and 16 activities that are common to most electricity utility.



The first area related to the technical and operational activities includes the core actions of a distribution company and it is subdivided into six main activities:

1. **Electricity Loss Reduction** – Assesses the degree of productivity and efficiency of the transmission and distribution systems of the utility. It analyzes indicators and benchmarks and introduces best practices when designing a comprehensive plan to improve the technical and non-technical (commercial) electricity losses.
2. **Management of O&M costs** – Reviews the operation and maintenance (O&M) costs of the utility to assess its efficiency and optimal costs of operation with a focus on the transmission and distribution. The analysis and benchmarking of this activity can be relevant to the determination of the electricity tariffs, as depending on each country situation, the regulators may establish the specific references and targets.

3. **Quality of the Technical Service** – Measures the reliability, continuity of supply, and the voltage quality of the electric system using a set of standard metrics. Overall, it relates to the ability of the electric system to perform its functions, measuring indicators such as SAIDI (System Average Interruption Index) and SAIFI (System Average Interruption Index)
4. **Attention to the client** – Assesses the interaction between the service provider (distribution company) and the user on services such as responsiveness to customers, billing information, service disruptions, and handling complains. Main objective is to provide best and most responsive service to the customers.
5. **Access to service** – Describes how the utility is supporting national electricity plans to achieve universal electricity coverage, which includes access to remote locations usually in rural areas, as well as those in urban areas with limited access to electricity. It also includes analysis of affordability of the electricity service to less vulnerable parts of society.
6. **Efficiency and execution of the investment plan and asset management** – Reviews the utility’s methodology and process of its investment (financial and operational) plans and the prioritization of projects. Also includes the activities of maintenance of existing assets and the mechanisms the utility have to deal with unforeseen events and shocks.

The second area relates to the financial aspects, organization considerations, and the corporate governance of the utilities. It is organized into 2 subareas and 4 main activities:

7. **Financial management and sustainability** – This activity analyzes the financial health and sustainability of the utility and to what extent its revenues cover the costs and obligations using ratios and benchmarks references. It also includes assessment of the balance sheet (e.g., asset register, short-and long-term debt) and remuneration to the capital.
8. **Commercial management** – Assesses the sales and commercial management practices and processes of an electricity utility in activities such as billing and invoicing, collection, and debt management. Also includes management of customer register and internal controls to customer databases. This is an evolving area as with the diffusion of distributed generation (DG), customers are gradually becoming producers in some countries.
9. **Autonomy, decision making, controls, and transparency** – Reviews the main activities of corporate governance of a utility in areas such as accountability, autonomy and transparency, disclosure of information, enterprise risk management, and internal control. Reviews the roles and responsibilities among the Board of Directors, Management, and the other stakeholders.
10. **Strategic planning, organizational structure, and human resources (HR)** – Assesses that a performance management is in place to monitor the utility’s

performance in the short and long term, the adequateness of its internal organizational structure and hierarchy, and the aspects of people management. Also reviews and introduces the best practices on the topics related to gender equality, diversity, and inclusion.

The third area deals with the environmental, social, and safeguard (ESR) activities of a utility. It also includes the aspects of resilience and emergency preparedness, and how it is mitigating and adapting to climate change. It is subdivided into three main activities:

11. **Climate change mitigation** – Reviews activities that distribution companies have introduced to mitigate climate change and reduce emissions, with a focus on energy efficiency measures and standards. Also reviews their commitments and activities towards distributed generation (DG) with renewable energy and electromobility.
12. **Environmental and social aspects and safeguards** – Reviews the environmental and social policies, standards, and operational practices of the utility, and their adherence to local and national legislation and international best practices. Reviews also utility's contribution to the Sustainable Development Goals (SDG).
13. **Resilience and emergency planning** – Assesses the preparedness of the utility systems and infrastructure against natural disasters and its contingency plans. Refers to the capacity of the energy systems to cope with the hazardous and external shocks and maintain its essential function.

Lastly, **the fourth area of innovation presents how utilities can transform and modernize themselves**, and it is organized in three activities:

14. **Technology, digitalization, and cybersecurity** – Reviews the initiatives utilities are undertaking to introduce new technologies and increase digitalization of its network and infrastructure to perform new or innovative services while improving efficiencies and reducing costs (e.g., artificial intelligence, predictive analytics, blockchain). Also includes information technology and cybersecurity activities and controls to mitigate its exposure to risks.
15. **Modernization and vision of the future** – Reviews how the utilities are modernizing their activities and considering new business models focused on services to meet future needs of customers, new services and technology disruptions. Also includes the activities of electromobility.
16. **Innovation initiatives** – Considers the level of readiness of innovation culture in the utility, including a review of the internal processes, its ambition and behavior, and resources dedicated to innovation, which can be to optimize *existing* customers or broader to develop breakthroughs). Also includes the partnerships (and the results) the utility has established with leading external organizations to foster innovation.

2.3 Reviewing the activities

This section of the Electrokit: Power Utility Toolkit – Quality of Technical Service presents the structure of the initiative, which will also be available in a web-enabled and digital interactive format. For each activity, the Electrokit will have the following modules ordered as:

- **Overview or Main Concepts** which presents a brief description of the activity,
- **Indicators** provides access to trends, key metrics, and data for the activity. This is the quantitative part of the analysis using external data,
- **Self-Assessment** presents a qualitative assessment of the level of maturity of the utility based on a simple set of questions, with an indicative way to elaborate an action plan,
- **Simulation** presents the functionality for the users to enter their own data and compare their performance with other utilities (available in the web version),
- **Best-Practices** presents the best practices for the activity, including insights that are used as a guide for how other companies are managing this activity and how they have benefited from the introduction of the best practices.
- **Case Studies** lists case studies, methodologies, and technical references in annexes.

The two other modules are: initial Planning activities which include the preparatory tasks to be discussed between the IDB team and the utility before initiating the utilization of the Electrokit. Data gathering is also part of the planning activities; and the final Implementation activities which follow the analysis and action plan and are to be introduced in discussion with the utility. This final stage defines how the projects identified will be implemented, including the governance, the source of funds, and executing arrangements.

The Electrokit is therefore a tool which can be reviewed independently by the utility or in cooperation with the IDB team who can help: (i) identify the opportunities for improvement; (ii) development of an action plan, and (iii) help monitor implementation over time.

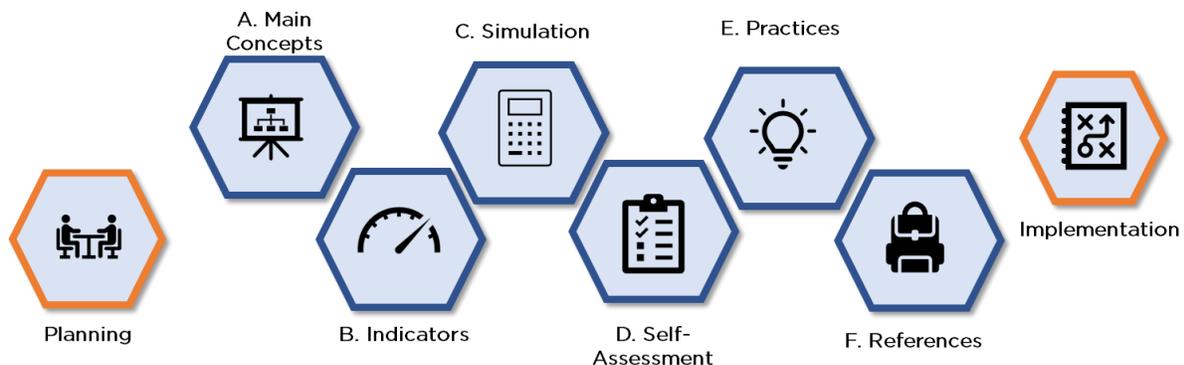


Figure 4 - Electrokit structure

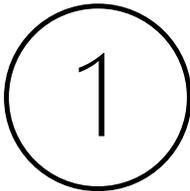
3. Designing an Action Plan



The development of an action plan is an important result from the review of the indicators and best practices for the utility. As an additional functionality of the Electrokit this chapter presents the main tasks to support the identification and prioritization of what are the most relevant practices specific to the utility and what are the best ways to develop and implement an action plan.

The definition of a comprehensive and well thought action plan is essential to attract investment opportunities and communicate the expected results. While there are different methodologies to design an action plan, most of them converge to similar activities, which are presented next as the steps in developing the plan.

Step 1 - Define problem and analyze data.



Action plans usually start by clearly defining the main problem facing the utility and political willingness to address it. This is done by collecting and analyzing the data and verifying previous assumptions of the problems that triggered the review. The Electrokit can be an important tool and methodology to identify areas where the indicators of the utility are below the references, benchmarks, or regulatory standards, and what are the best practices the utility can introduce. It is very important at this step that the leadership presents a vision for the future and its commitment towards pursuing this vision. Still within this first step, usually teams define the targets the utility would like to achieve, which in turn defines the level of ambition of the action plan.

Step 2 - Prioritize activities.



Subsequent to the definition of the problem and expected results, the utility will need to prioritize the areas of intervention. This prioritization is done by segmenting the activities in different dimensions of: (i) impact or effectiveness (i.e., which activities will deliver the highest impacts or benefits – e.g. cost reduction or revenue increase); (ii) timeframe (i.e., what is the best sequence of activities in the short, medium, and long term considering the expected benefits). It is very important to include short wins or quick wins in the timeframe, as it boosts morale of the team and confirms the direction is right; and (iii) efficiency (i.e., based on quantitative measures such as cost benefit analysis, which of these activities will deliver the highest returns for similar levels of investment). Lastly, this prioritization should also identify synergies and complementarities among the activities to be consolidated in a single action plan.

Step 3 - Identify resources.

3

Based on the action plan previously defined, it will be important for the utility to seek the financial and knowledge/expertise resources, as usually these activities need investments. Some utilities may have their own teams and financial resources to implement the action plan, while others will need to seek external financing and/or bringing technical expertise (example of new technology). Some sources of financing can be concessional with favorable commercial terms, which can make the action plan more feasible to be implemented. In this step it is also important to proactively seek and obtain support from the relevant country stakeholders (e.g., government authority, regulators, industry association, etc.) and clear understanding on the expected impacts and benefits of this action plan.

Step 4. Prepare to implement.

4

Lastly, the utility needs to develop a detailed implementation plan, not only including the activities previously defined, but also the governance model of the implementation (e.g., definition of team responsibilities and authorities, level of dedication and subordination, etc.) and how progress will be monitored and evaluated. Adaptability becomes a key ingredient of the plan, and an important reminder is to keep into perspective that⁵ “a business/action plan can't be a tightly crafted prediction of the future but rather a depiction of how events might unfold and a road map for change”. The results from the readiness to implement, together with seeking political support and securing the financial resources are the last activities before proceeding to implementation.

In sum, this chapter presented in general terms how utilities can develop an action plan and increase the likelihood of successful implementation, using the results from the areas of the Electrokit. The next chapter presents the indicators and best practices of the Quality of Technical Service.

⁵ Harvard Business Review: Updating a classic: Writing a great business plan. <https://hbswk.hbs.edu/item/updating-a-classic-writing-a-great-business-plan>

4. Quality of Service

The quality of electricity services is one of the most important elements among those when reviewing the performance of public utilities, as it has a direct impact on users and their perception of the utility. It also reflects the consequences of the utility's operating and management practices and, especially, of those carried out previously and which have made it possible to achieve current quality levels.

The assessment of the quality of service is limited to conditions and results directly linked to the service delivered, i.e., the efficacy with which the services are delivered. Hence, unlike other assessment areas, it does not fully incorporate considerations relative to the degree of efficiency in delivery of those services. It does however include certain aspects indirectly related to planning or operating practices, such as structural capacity of operation and control of equipment, facilities, or processes.

The quality-of-service subareas are: (i) quality of technical service; and (ii) attention to the client. This document presents the quality of technical service.

4.1 Quality of Technical Service

A. Main Concepts

The continuity of supply (CoS) measuring reliability and voltage quality are important issues in the electricity distribution sector. In general, the quality of service is related to the commercial relations with customers and technical perspectives. According to the American Public Power Association (APPA), reliability, from a system engineering perspective, is the ability of an electric system to perform its functions under normal and extreme circumstances.

Reliability indices help engineers and other operations personnel understand and demonstrate the interconnected nature of the many independent system components that make up an electric distribution system. This connection makes apparent that the system design, including construction practices, impacts reliability; from substation and distribution design to fusing schemes, various physical factors of system design impact system reliability. Among the commonly considered factors are system voltage, feeder length, exposure to natural elements (overhead or underground conductor routing), sectionalizing capability, redundancy, conductor type and age, and number of customers on each feeder.

The main issues related to the technical aspects of quality of service can be grouped in two main fields of power quality:

- **Continuity of supply (CoS) or supply quality** is measured by the interruptions in electricity supply identifying the events during which the voltage at the supply terminals of a network drops to zero or nearly zero. These interruptions of supply are described usually by two quality dimensions, the number of interruptions and their duration. On a system level, most common continuity indices related to long interruptions are SAIDI (System Average Interruption Duration Index),

SAIFI (System Average Interruption Frequency Index), CAIDI (Customer Average Interruption Duration Index), and ENS (Energy Not Supplied).

The SAIDI and SAIFI indicators are generally calculated within the time frame of one year as follows:

$$SAIDI \text{ (hours/customer)} = \frac{\text{Total Duration of Customer Interruptions (hours)}}{\text{Total Number of Customers Served (\#)}}$$

$$SAIFI \text{ (Interruptions/customer)} = \frac{\text{Total Number of Customer Interruptions (\#)}}{\text{Total Number of Customers Served (\#)}}$$

These formulas correspond to the most basic SAIDI and SAIFI calculations. It must however be kept in mind that specific calculations may vary between countries and regulatory contexts (for example, event exceptions that can be excluded such as planned interruptions due to network maintenance. Furthermore, there is not a single standard if exceptional events -usually weather events- are included or not in the calculation).

- **Product or voltage quality** covers a subset of possible variation of voltage characteristics from the desired values (excluding interruptions) such as: supply voltage variations; rapid voltage change; voltage swells; flickers; voltage unbalance; harmonic voltage distortions; transient overvoltage; and mains signaling voltage. For example, delivery of high-quality, flicker-free power are important considerations for industrial or commercial customers due to equipment damage and data loss. Large industrial customers that are energy intensive can suffer significant financial losses when voltage dips occur at their sites, but this is less relevant in residential customers. Measuring the voltage quality however can be a complex task due to technical difficulties to select the proper indicator and establish the limits. The Standard EN50160 provides general limits set for public supply networks and voltage disturbances; it is used in several European countries in combination with other country specific standards.

When reviewing utility reliability one of the references is the IEEE 1366 guide which establishes standard indicators for distribution reliability metrics and practices to apply to distribution systems, substations, and circuits. The Council of European Energy Regulators (CEER) has also specific guidelines and regulations on the quality of services. Within the LAC region, there are guidelines mentioned in the Project CIER 06 for the quality and continuity of electricity services. In addition to these guidelines, other aspects are important as defined in best practices.

In LAC, it is usual to use the standards established by the IEEE as well as by the IEC (International Electrotechnical Commission). For example, the Colombian Grid Code, which is currently under revision, is considering a flicker calculation or measurement

in HV according to IEC 61000-4-15:2010 - Electromagnetic compatibility (EMC) - Part 4-15: Testing and measurement techniques - Flickermeter - Functional and design specifications.

Furthermore, the use of IEEE or IEC guidelines may be complementary to existing local standards. For example, voltage and current waveforms, with respect to harmonic content and phase unbalance, shall comply with the requirements established by the Colombian Technical Standard. However, it is stated that if there is no applicable local standard, the ANSI/IEEE 519 Standard shall be used. On the other hand, the Grid Code establishes that the National Transmission System shall be planned in such a way as to allow, together with generation, regional transmission systems and local distribution systems, to ensure that the voltage at 220 kV busbars and above is not lower than 90% of the nominal value, nor higher than 110% (without reference to any international standard).

Other indicators that are mostly used in the quality of technical service are:

- Customer Average Interruption Duration Index (CAIDI)
- Customer Total Average Interruption Duration Index (CTAIDI)
- Customer Average Interruption Frequency Index (CAIFI)
- Average System Interruption Frequency Index (ASIFI)
- Average System Interruption Duration Index (ASIDI)
- Energy Not Supplied (ENS)
- Critical Voltage Index

To manage the different aspects in the quality of service, due to a managerial decision or encouraged by the current regulation, the search for high levels of service must be present in the following pillars: (i) quality indicators: selecting indicators to track and describe performance; (ii) performance standards: level of quality that the company is expected to provide; and (iii) financial incentives to discourage performance below the standard.

B. Indicators

This section presents analysis of the indicators of technical quality of utilities in the LAC region. The next section presents the background of the analysis, but the consolidated main messages of the study with date up to 2019 are:

- Between the years 2000 and 2019, there was an improvement in the SAIDI and SAIFI indicators of utilities in LAC.
- The quality of electricity service is heterogenous among LAC electricity distribution companies. The duration of system interruption varies from less than 1 hour up to 219 hours per year. In terms of interruption frequency, the companies' heterogeneity continues high - ranging from 0.36 to 120.9 interruptions per company in 2019. For

both indicators, the heterogeneity is higher between the ten companies with lower performance.

- On average, private companies have better SAIDI and SAIFI indicators than public companies. However, the worst levels of SAIDI and SAIFI were verified in private companies.

Introduction

The quality standard of electricity supply directly impacts the population's welfare, productivity, and industrial development. The quality of the electricity distribution service can be measured according to three dimensions: commercial quality, voltage quality, and continuity of supply. In this session, we focus on the continuity of supply.

Among various quality indicators of continuity of supply, SAIDI and SAIFI are the most used indicators⁶. SAIDI measures the duration of the system interruption for each customer and can be presented in hours or minutes, a certain period, such as a year or trimester. SAIFI is the index that shows the average frequency of system interruptions per customer in each period, just like SAIDI.

This document aims to verify the quality of energy distribution in LAC through SAIDI and SAIFI indicators. The analysis used public data from 128 (SAIDI) and 127 (SAIFI) energy distributors in fifteen (SAIDI) and sixteen (SAIFI) countries in LAC⁷. The availability of data for distribution companies varies according to the year of analysis and the property type (public, private, or both). The number of companies with SAIDI information available ranged from 59 distributors in 2000 up to 116 in 2019. For SAIFI, the variation was from 59 distributors with SAIFI information available in 2000 up to 111 in 2017 and 107 in 2019.

The analysis is divided as follows: (i) verification of the current state of the SAIDI and SAIFI indicators for electricity distribution companies in LAC; (ii) evolution of SAIDI and SAIFI from 2000 to 2019; (iii) evolution of SAIDI and SAIFI for distributors with worst and best performance; (iv) evolution of Improvements in SAIDI and SAIFI indicators; (v) comparison SAIDI and SAIFI by company type; (vi) international comparison; and (vii) estimation of electricity supply outage costs.

⁶ Although SAIDI and SAIFI are the most consolidated indicators of electricity service quality, it is important to note that their methodology may differ between countries. The main difference in the method of linking SAIDI and SAIFI indicators is in the weighting that can be by number of customers, by affected power, energy consumption, etc. The 6th CEER benchmarking report on the quality of electricity and gas supply - 2016 describes the differences in terms of weighting in the methodology of the SAIDI and SAIFI indicators for European countries.

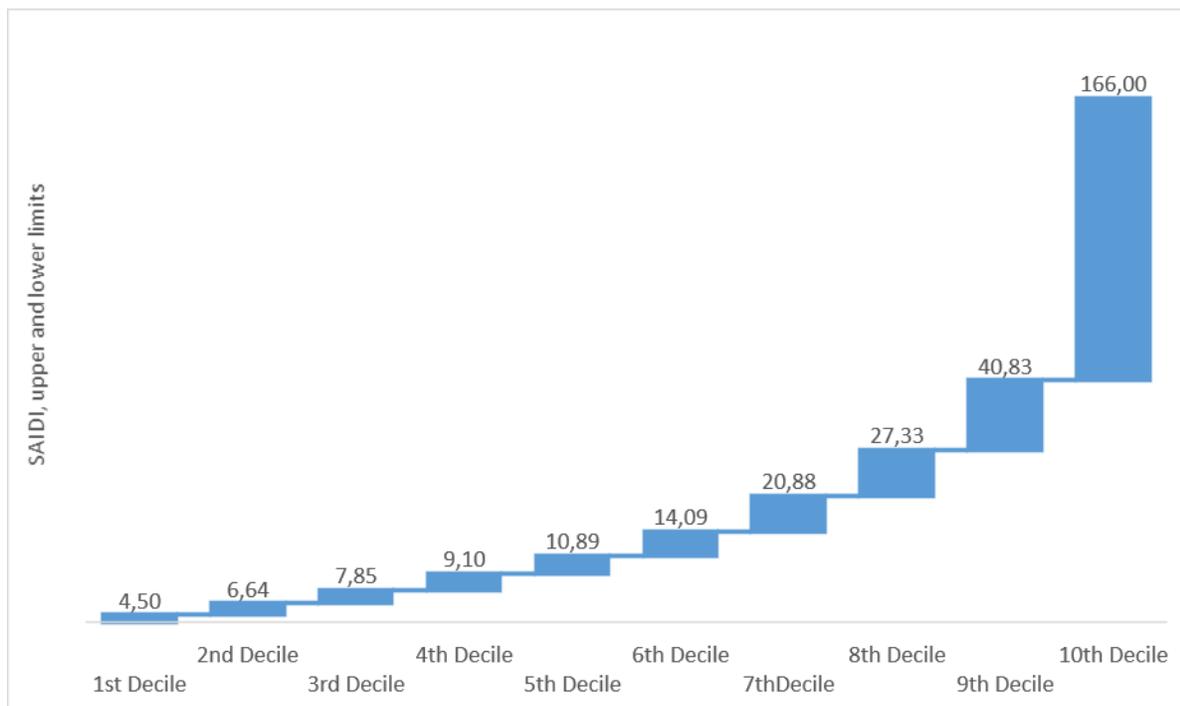
⁷ The database considers electricity utility companies information of LAC fifteen (SAIDI) and sixteen (SAIFI): Argentina, Belize, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Mexico, Panama, Peru, Dominican Republic, Trinidad and Tobago and Uruguay; SAIFI (Bolivia, Guyana more the same countries with SAIDI, except Uruguay)

Current state of SAIDI AND SAIFI indicators in LAC

In 2019, the average of the SAIDI and SAIFI indicators for distribution companies in LAC were, respectively, 20.5 hours of outages and 11.9 outages per client per year. However, there is significant variability of results between the distribution companies for both indicators. Different companies have SAIDI below 0.4 while others have a result close to 166.0 hours of outages per client per year. For SAIFI, the results vary from companies with less than 0.6 and others close to 115 interruptions per client per year.

Figure 1 and Figure 2 represent SAIDI and SAIFI's dispersion for the LAC distributors with public information consolidated into ten deciles, according to their results in 2019. In both graphs, the first decile represents the 10% of the most efficient companies, while the tenth decile represented the distributors with the 10% lower efficiency results.

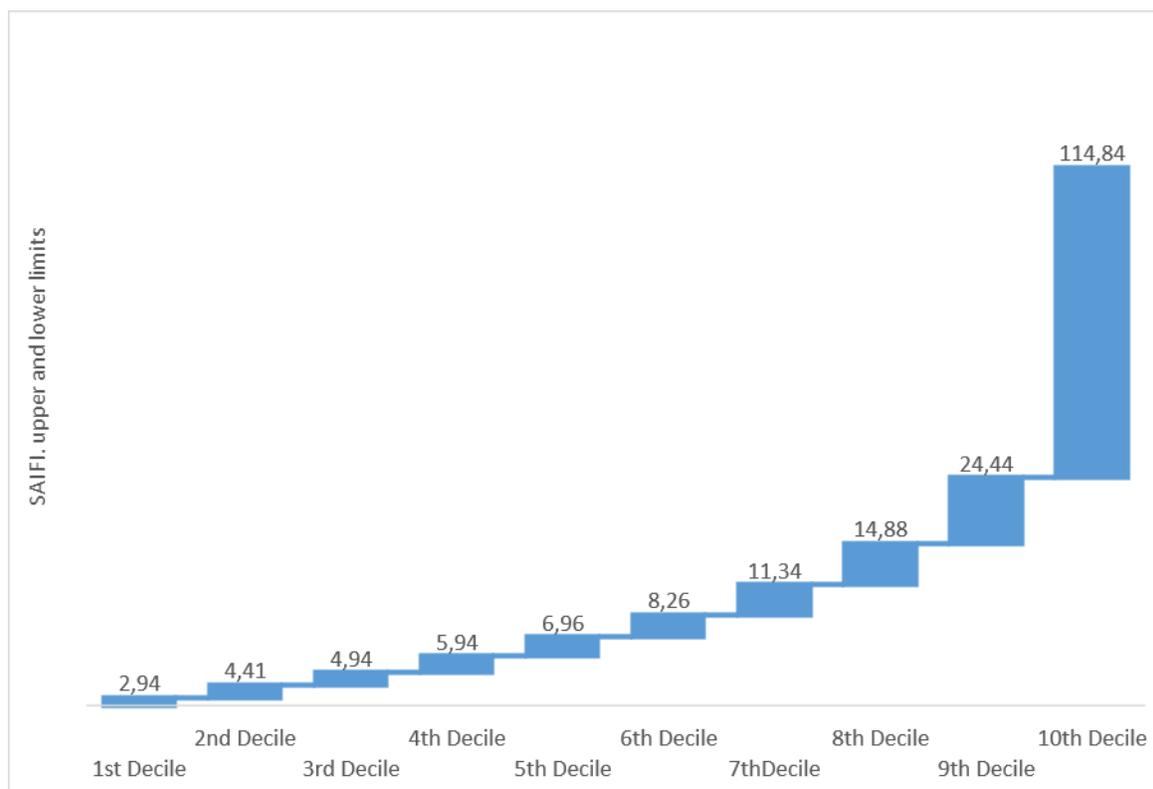
Figure 1 SAIDI Distributors Electricity per Deciles (in hours per customer in 2019)



Source: Own elaboration with IDB data

The above figure shows that distribution companies' decile with the best SAIDI indicators had a maximum of 4.5 hours of outages per client per year in 2019. The decile with the worst results had SAIDI varying between 40.83 and 166 hours of outages per client per year. Therefore, in terms of SAIDI variation, the company with the worst performance had an indicator almost forty times higher than the upper limit of the first decile of companies.

Figure 2 SAIFI Distributors Electricity per Deciles (in average interruptions per customer in 2019)



Source: Own elaboration with IDB data

Figure 2 shows that distributors' decile with the best SAIFI indicators had a maximum of 2.94 outages per customer in a year in 2019. The decile with the worst results had SAIFI varying between 24.44 and 114.84 outages per client per year. Therefore, in terms of SAIFI variation, the company with the worst performance had a SAIFI almost fifty times higher than the upper limit of the first decile of companies.

The previous analysis concludes that there is heterogeneity in distributors' results for both indicators among distributors' decile groups. The deciles where the worst-performing companies have a larger dispersion than those with best-performing results. It means that heterogeneity increases among companies with the worst-performing indicators in terms of continuity of electricity supply.

Evolution of SAIDI and SAIFI in LAC

SAIDI indicators for electricity distribution companies in LAC improved between 2000 and 2020, with a more explicit tendency after 2014. The SAIDI mean decreased from 20.4 in 2000 to 16.7 in 2020. The median of SAIDI also improved significantly, passing from 15.53 hours of interruption per client per year to 11.8 hours of interruption per client per year in 2020.

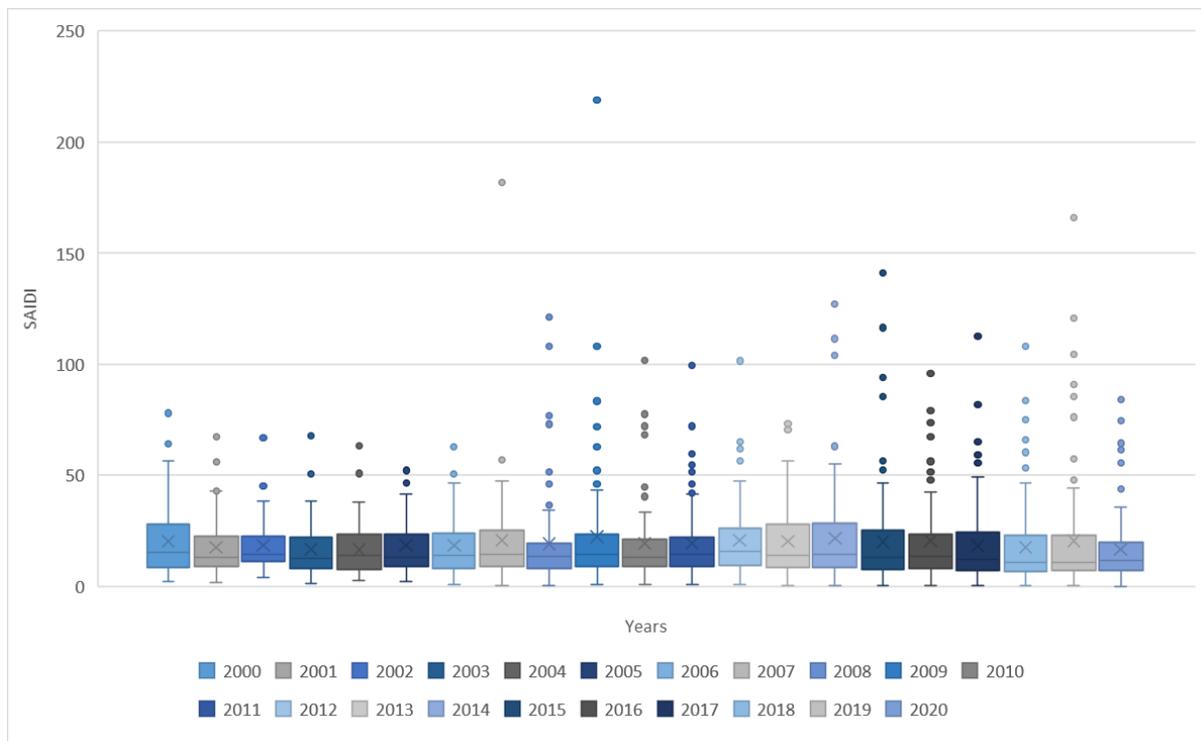
In general, the distributors' results regarding SAIDI have improved. The average value of SAIDI median over the years 2000 to 2020 for electricity distributors is approximately 13.55. Since

2014, the SAIDI median has been below 14.5, and the average of the first quartile in the same period was 8.47. For example, in 2020, the SAIDI median was 11.86, and the first quartile, 7.24.

The reduction in SAIDI values in the first quartile and the median reflect a significant improvement in the distributors' quality of service.

Despite the improvement in SAIDI results throughout the analysis, it is possible to notice outliers in every year, mainly since 2008, which points out that some distributors continued to present low efficient results, contrary to the trend of improvement in the region.

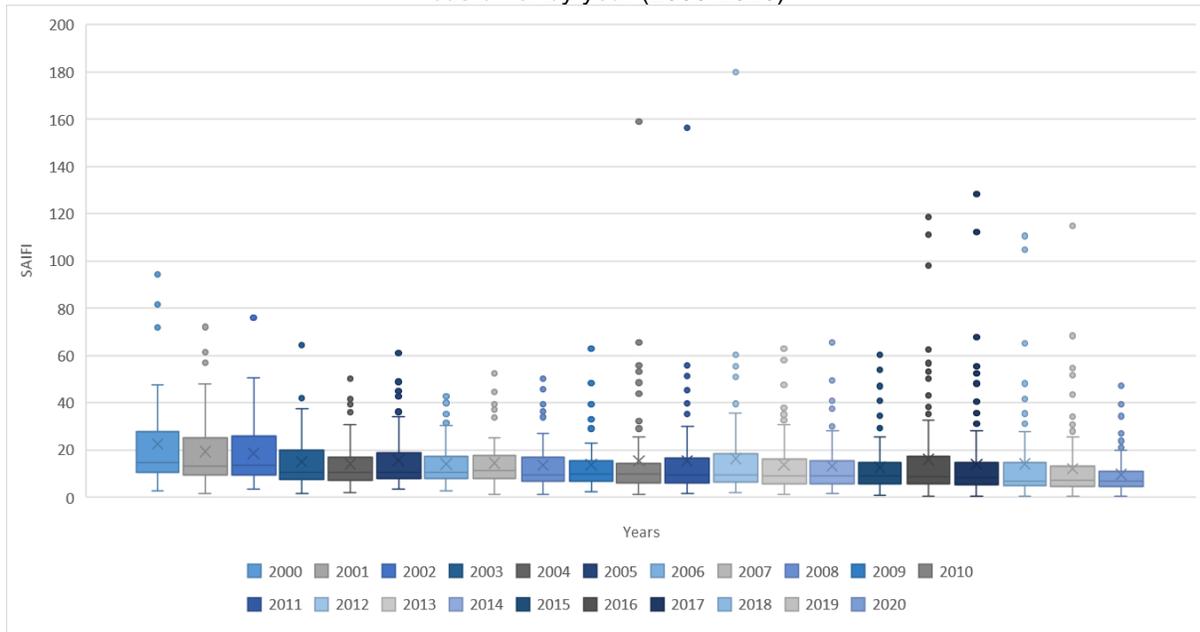
Figure 3 SAIDI Dispersion of LAC Electricity Distribution Companies - in hours per customer by year (2000-2020)



Source: Own elaboration with IDB data

In the previous figure, the rectangle boxplot contains 50% of the cases, the line that divides the rectangles are the medians, the X the means, the lines the maximum and minimum values, and the points are the outliers. Outliers are defined using the boxplot calculation formula, where the interquartile distance (third quartile - first quartile) is multiplied by 1.5 and added to the third quartile. The values above this threshold are outliers.

Figure 4 SAIFI Dispersion of LAC Electricity Distribution Companies - in average interruptions per customer by year (2000-2020)



Source: Own elaboration with IDB data

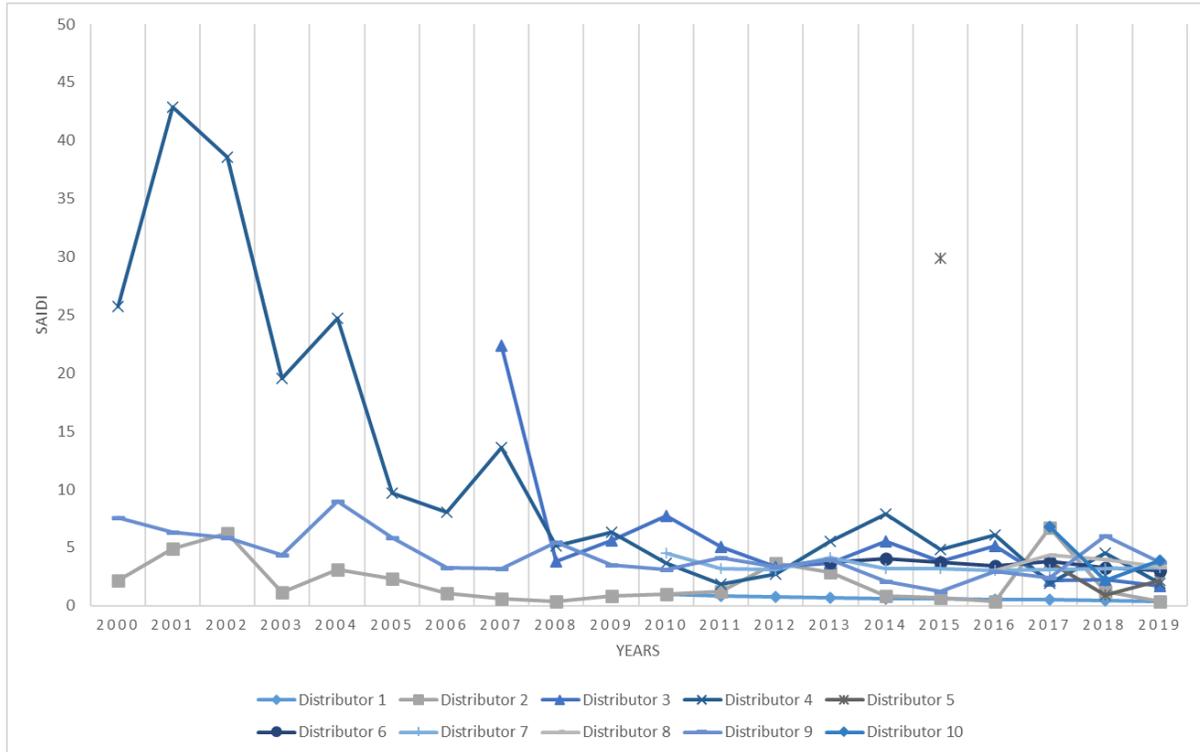
The average SAIFI also shows a continuous improvement over the years, both in terms of mean and median. The SAIFI mean decreased from 22.4 to 9.5 interruptions per client per year between 2000 and 2020. In terms of median, the improvement of SAIFI was even better, 14.78 in 2000 and 6.67 in 2020.

The average value of SAIFI between 2000 and 2020 was around 14.86 outages per client per year. However, since 2013, the average has been below this value (2020 for example had a value of 9.53). The continuous improvement of the indicator can be seen in the decreasing median and minimum values. The upper limit and the third quartile have also decreased over the years, which points to an improvement in the regional SAIFI indicators. Despite the improvement trend, an important point is an increase in maximum values since 2007, representing some companies' worsening performance indicators.

Distributors' SAIDI evolution in the first and last deciles

The 10 companies with the best results for SAIDI or/and SAIFI shows a significant improvement until 2009. In the group of companies with the 10 worst results for SAIDI or/and SAIFI, it is possible to note a significant lack of information. Due to SAIDI and SAIFI indicators' heterogeneity, it is interesting to analyze the 10 companies with the best and worst performance evolution concerning continuity of services in Figures 5 and 6

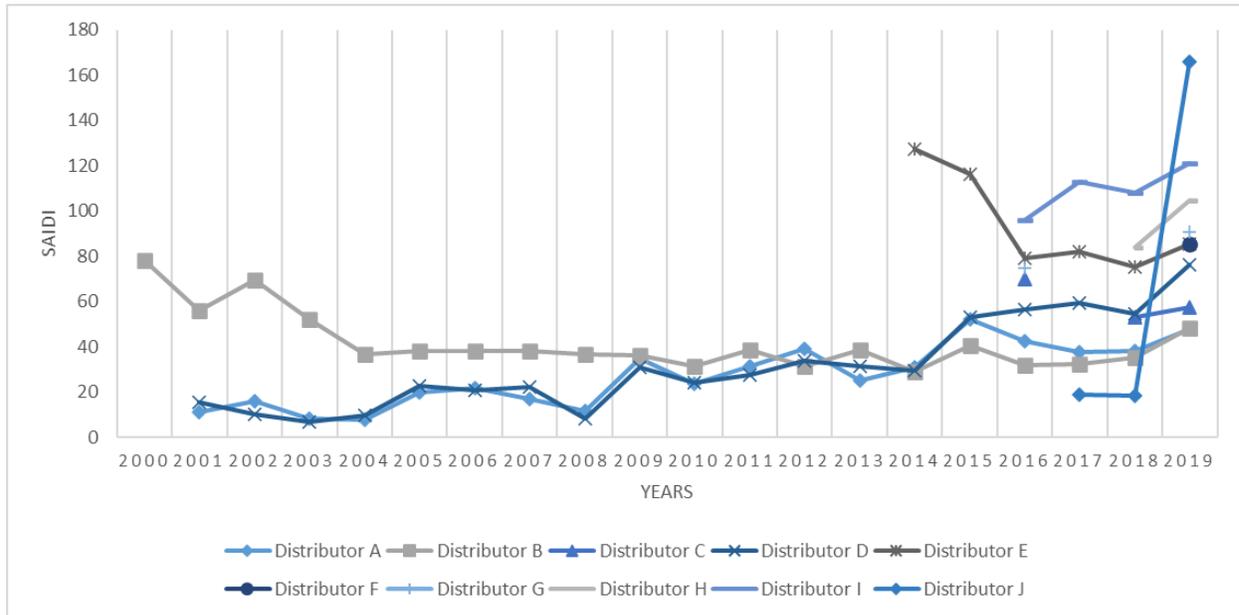
Figure 5 Evolution of SAIDI: The 10 Distribution Companies with the Best SAIDI in 2019 (Between 2000-2019)



Source: Own elaboration with IDB data

The figure above shows the SAIDI evolution for the ten companies with the best results in 2019. It is possible to see a continuous improvement trend with some notorious cases. For example, distributors 4 and 3 used to have a high SAIDI level, but over the years, they have improved to the point that in 2019 they are among the best results. These distributors can be used to illustrate the best cases, having been able to reduce the duration of outages and consequently the SAIDI indicator.

Figure 6 Evolution of SAIDI: The 10 Distribution Companies with the Worst SAIDI in 2019 (Between 2000-2019)



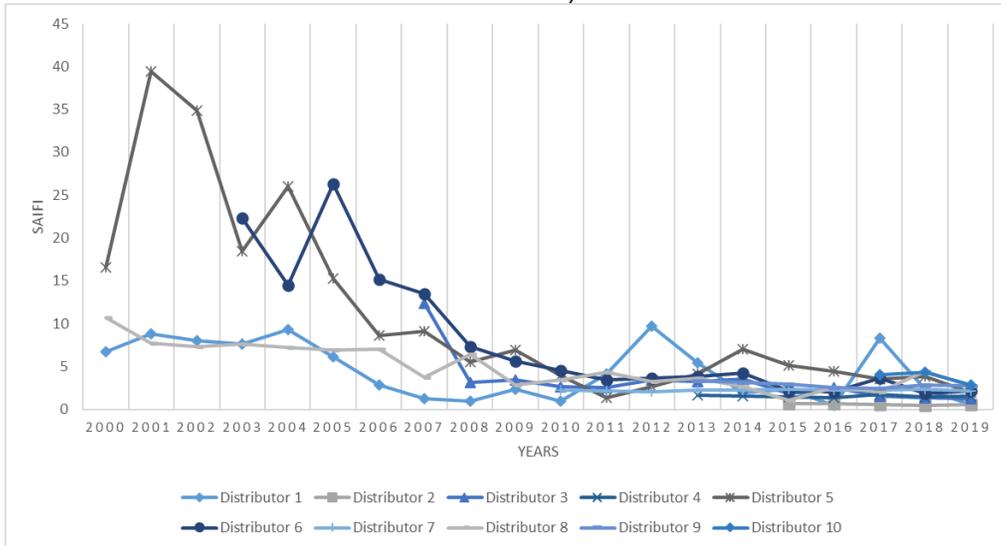
Source: Own elaboration with IDB data

Figure 6 shows the evolution of ten companies with the worst SAIDI results in 2019. Most companies in this group have worsened their SAIFI indicators during the analysis period, but at least one distributor presented an improvement over the years. The chart also exhibits the discontinuity of information for the distributors, which can be attributed to the data's non-existence, difficulty accessing the information, lack of data transparency, or lack of regulatory instruments requiring companies to measure and publicize that information.

What can be concluded is that the companies with the best results have maintained an improvement trend over the years, reaching values well below the region's average. On the other hand, the companies with the worst results retain a tendency to increase SAIDI values. In conclusion, companies can improve over time – and they have done it – as shown in the figure 5. Concerning the companies with less efficient performance, they've had – and continue to have – weak performance for a long period, with no significant improvement.

Distributors' SAIFI evolution in the first and last deciles

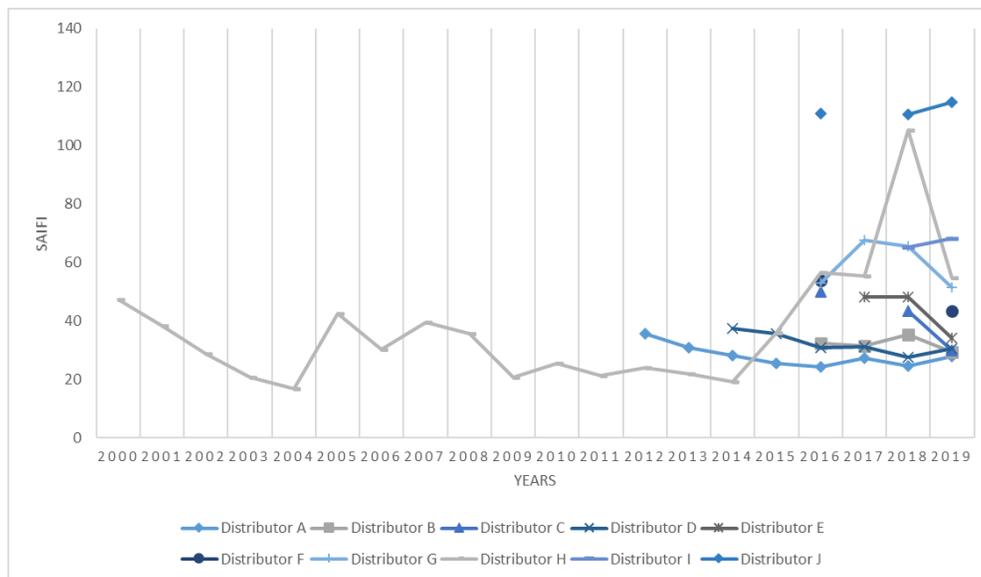
Figure 7 Evolution of SAIFI: The 10 Distribution Companies with the Best SAIFI in 2019 (Between 2000-2019)



Source: Own elaboration with IDB data

For SAIFI, in general, there are some points of similarity with SAIDI data, mainly in companies with better results in 2019, as can be seen in Figure 7 and Figure 8. Figure 7 shows that the ten distributors with the best SAIFI performance in 2019 presented a trend of improvement over time. Almost all distributors had a higher SAIFI index between 2000 and 2008, and most of them managed to reduce the indicator significantly till 2008. Between 2009 and 2019 the indicators have remained below 10 outages per client per year.

Figure 8 Evolution of SAIFI: The 10 Distribution Companies with the Highest SAIFI in 2019 (Between 2000-2019)



Source: Own elaboration with IDB data

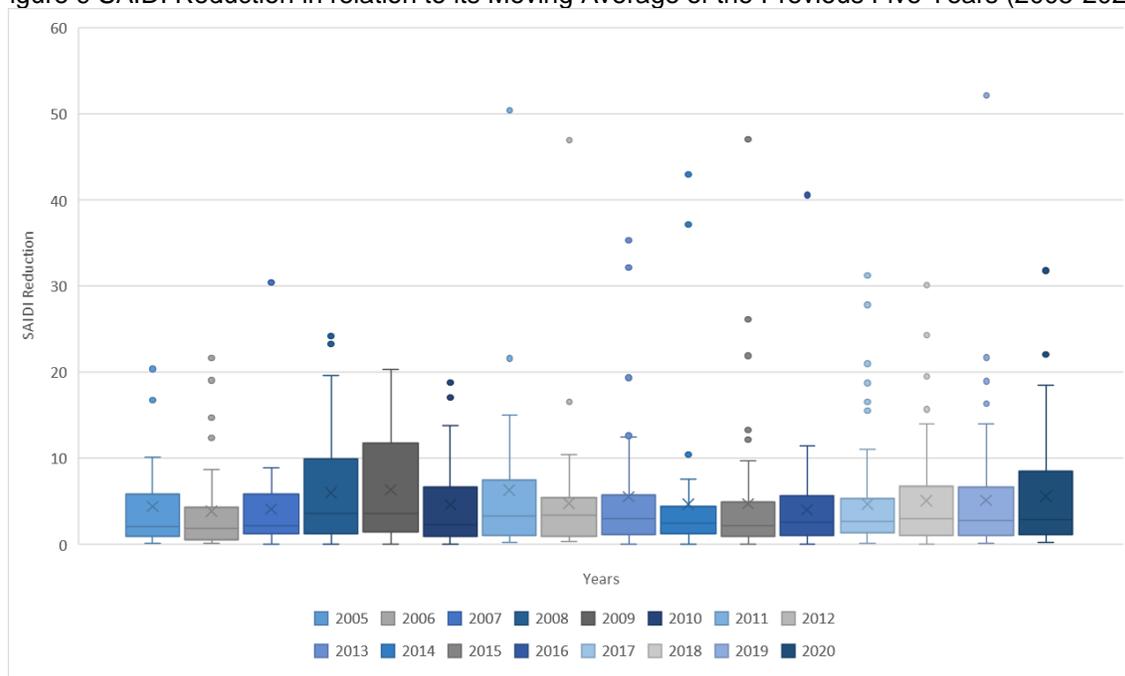
In Figure 8, it is possible to note that the distributors with the lowest SAIFI performance in 2019 did not present a clear improvement during the analysis period. As in the analysis of the SAIDI indicator, the lack of information made it difficult to analyze the evolution of the performance of companies with the worst SAIFI indicators

Evolution of improvements in the SAIDI and SAIFI indicators

The percentage of companies improving their quality has increased over the years. The distributors decreasing the duration of outages annually rose from 49% in 2005 to 74% in 2020. The number of companies that reduced the frequency of outages (comparing to the last 5 years) also increased from 67%% in 2005 to 78% in 2020.

Figure 9 shows the reduction in SAIDI of energy distributors from 2005 to 2019 in absolute values. The variation of SAIDI was calculated using the simple moving average for five years. For example, the result of 2005 is the variation of SAIDI of 2005 in relation to the average of the years 2000 to 2004. The result of 2020 refers to the variation of 2020 with regard to the average of 2015 until 2019. Only the reduction in SAIDI is shown. That is, how much was the decrease in the interruption duration of one year concerning the simple average of the previous five years. The choice to use the comparison with the average of previous years aims to reduce the impact of events that may cause significant distortions in the distributors' results, such as, for example, climatic events that result in the interruption of the electricity supply.

Figure 9 SAIDI Reduction in relation to its Moving Average of the Previous Five Years (2005-2020)



Source: Own elaboration with IDB data

The analysis of the data presented in the graph points out, that from 2005 to 2020, the average reduction in SAIDI is 4.97 hours. Also, the largest reduction in SAIDI by distributors, where more than 75% had a reduction in SAIDI below 10 hours, given that, except for a few years,

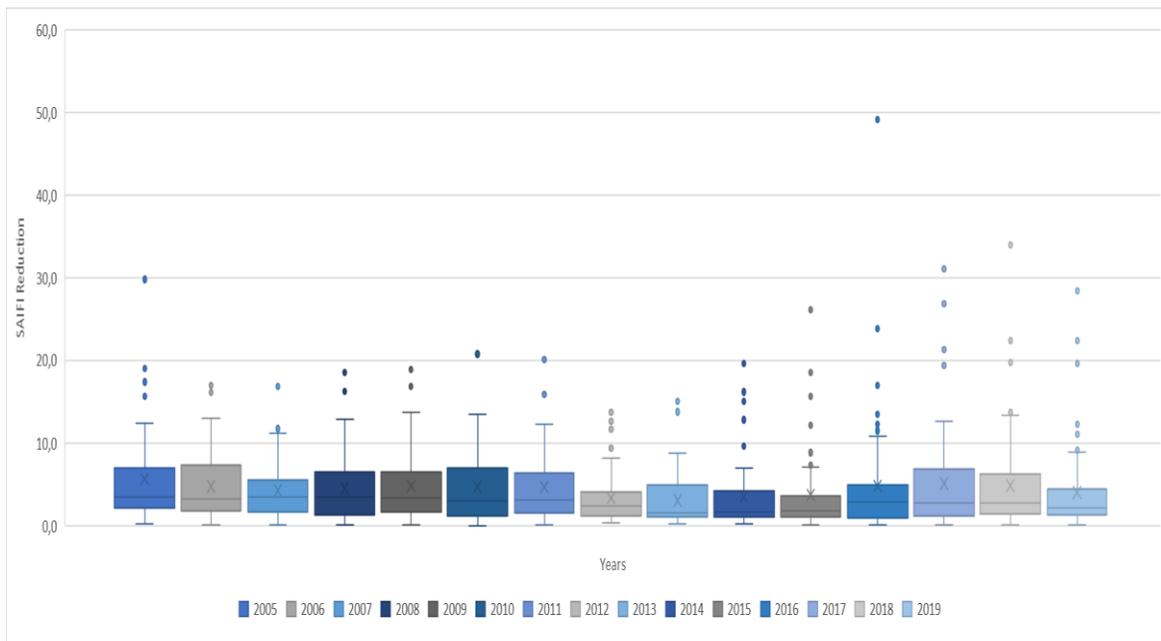
the third quartile is below that value. Although the standard behavior is a reduction of 10 hours in relation to the average of the previous five years, some distributors achieved results above this value, staying between 10 and 20 hours of reduction of the interruption, in addition to outliers that reach up to 50 hours of reduction.

In terms of percentage, it is observed is that the average reduction in SAIDI over the years was 24%. However, some companies achieved reductions with variation reaching 89%. Furthermore, it can be observed that the companies with lower SAIDI value, when having a change in the indicator, presented a high percentage of variation, even if in absolute terms this value did not seem so significant, which can induce a distortion in the interpretation of the changes.

When analyzing the electricity distributors individually, the greatest reduction achieved, in approximately 81% of the cases (from a total of 62 distributors in 2020), was between 0 and 10 hours, while 16% were between 10 and 20 hours of reduction in the interruption duration, the other results varied between 20 and 32 hours. Of the total cases under analysis, 35% of SAIDI's largest reductions were above the average reduction in distributors' interruption duration. What can be concluded is that in 97% of the cases, when the reduction of SAIDI occurs, it reached a level of reduction between 0 and 20 hours of the duration of the interruption.

The same analysis performed above is applied to the SAIFI indicator.

Figure 10 SAIFI Reduction in relation to its Moving Average of the Previous Five Years (2005-2020)



Source: Own elaboration with IDB data

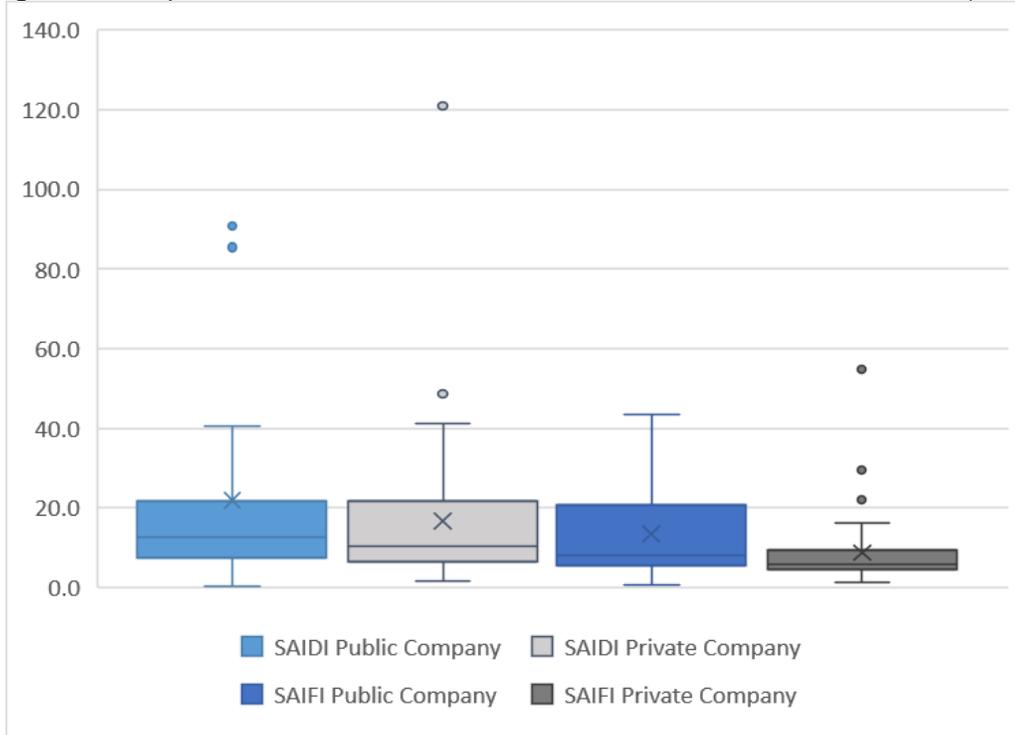
The variation of SAIFI, in absolute value, follows the same methodology used for the analysis of SAIDI. The average SAIFI variation from 2005 to 2020 was 3.56 interruptions. In all years, what is observed is, that except for outliers, the reduction in the frequency of interruption below 15 interruptions, in addition, more than 75% of the distributors, showed a reduction in SAIFI below 10 interruptions. Considering the percentage, the average reduction of SAIFI in relation to the simple moving average of the previous 5 years was around 24%, however there are distributors with a reduction of around 40% to 60%, as well as outliers reaching 91% reduction of SAIFI.

Individually, approximately 92% of the distributors, out of 62, showed a reduction in SAIFI from 0 to 10 interruptions, 6% from 10 to 20 and 2% from 20 to 42 interruptions. Of the SAIFI reduction results, 29% of the highest SAIFI reduction values were above the average SAIFI reduction for distributors between the years 2005 to 2019.

Comparison of SAIDI and SAIFI by company type

On average, private companies have better SAIDI and SAIFI indicators than public companies. To verify the existence of a difference between SAIDI and SAIFI results among public and private companies, 68 companies with SAIDI data for 2019 were used, of which 50 is private and 18 public. From a total of 65 of companies with SAIFI data available for the same year, 49 was private and 16 were public. The graph below shows the comparative SAIDI and SAIFI boxplots for public and private companies in 2019.

Figure 11 Comparison of SAIDI and SAIFI between Private and Public Distributors (2019)



Source: Own elaboration with IDB data

Table 2 Comparison of SAIDI and SAIFI between Private and Public Distributors (2019)

Type	SAIDI					SAIFI				
	Min	Mean	Median	Third Quartile	Max	Min	Mean	Median	Third Quartile	Max
Public	0.4	21.9	12.7	21.7	90.9	0.6	13.4	8.2	8.8	43.5
Private	1.7	16.7	10.4	21.8	120.9	1.2	8.8	5.8	13.4	54.7

Source: Own elaboration with IDB data

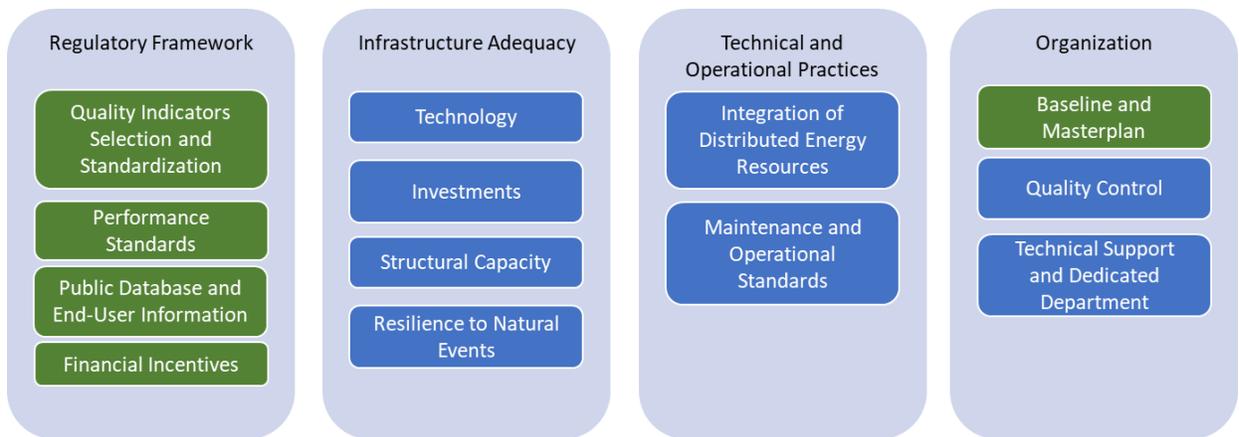
The figure and table above show that for both indicators, private companies' average and medians are better. The average of private companies was lower than that of public companies as the minimum values (except SAIFI) and the median. The difference between companies' types is more remarkable, especially when comparing SAIFI, where private companies' third quartile is close to public companies' mean.

The SAIDI average for private companies was 16.7 against 21.9 for public companies. A relevant point is the third quartile, where 75% of the companies have a value below this. In private companies, the third quartile was 21.7, and in public companies, 21.8. The average SAIFI for private companies was 8.8 against 13.4 for public companies. A point to be emphasized is that the upper limit of private companies' SAIFI has a lower value than the third quartile of public companies, respectively: 9.4 and 20.9. It means that excluding outliers, 100% of private companies have results below the third quartile of public companies for SAIFI.

C. Best practices

Multiple changes in the use of electricity are requiring the electricity systems to perform in ways and in a context for which they were not designed originally, requiring new capabilities and designs to maintain historical levels of reliability. The result is a system that is under stress from these and other factors and which requires greater flexibility, agility, and ability to dynamically optimize grid operations in time frames that are extremely fast. As consumers demand high-quality power with high reliability to support a digital economy, power disruptions have potentially greater consequences for customers. Moreover, there is a growing expectation for a resilient and responsive power grid in the face of more frequent weather events, cyber and physical attacks.

This section focuses on the utility's best practice processes as enablers to improve its quality of service using industry standards. The section does not focus on the specific parameters (e.g., voltage limits, methodology for calculating the indices, etc.) of each country in the LAC region, as these are determined by each regulator as per each country's technical norms. The utility's processes related to technical quality of service are organized in four groups:



Regulatory framework

This section illustrates the important role of the regulator (and the regulatory framework) regarding the best practices to be adopted by utilities. In this regard, it is pertinent to highlight that some of the best practices are included in other groups, for example the use of international technical standards for power and voltage, are defined by the regulator and not by the utility.

- 1. Quality indicators selection and standardization:** appropriate indicators that allow for a proper tracking and control of quality evolution over time must be defined. The commonly used indicators that have already been mentioned (SAIDI, SAIFI, etc.) serve as a reference. Even though the use of diverse quality indicators

within distributors' operation for management and planning purposes is a common practice and may already be in place, the definition of common and standardized indicators within a particular country or regulatory framework allows: (i) for benchmarking and performance comparison among peers; (ii) to incorporate specific criteria in the indicators' calculation that may be relevant within a particular context; (iii) to define mid to long term policy objectives; and (iv) to calibrate and track performance for the application of financial incentives within a common regulatory framework.

2. **Performance standards:** refers to the level of quality a company (or a group of companies) is expected and/or required to provide. The definition of performance standards must take into account conditions that are inherent to each system (i.e., topology, weather phenomena, etc.) and can sought to be achieved gradually over time.

Even though quality indicators and performance standards are most commonly reported and tracked at an aggregate or average level (i.e., annual SAIDI of a company, average SAIDI in a country, etc.), they can also be specified for groups of end users depending on their importance or prioritization. For example, a SAIDI indicator of 30 hours for a distributor means, that on average, a client will experience 30 hours of electricity supply interruptions within a year, however, the average value most probably conceals the fact that there are a set of customers that experience supply interruptions totaling way over 30 hours in the year. The previous example reveals that even though a distributor can on average improve its quality indicators, it is not necessarily making improvements for the users experiencing the worst service quality within the network.

To cope with this issue, the concepts of *individual quality* and *worst-served customer* (customers whose service quality is below a certain threshold relative to the average service quality), may be used. Performance standards can therefore be set at an individual level or for a group of customers. Service quality monitoring and analyses must consequently be done at a much lower disaggregation level (i.e., circuit level).

3. **Public database and end-user information:** It is especially important that the regulatory or control authority establishes a periodic public information system, and the obligation to inform in the monthly billing the quality that is required, as well as the one that is being supplied. This incentivizes the distributor to improve results, provide transparency and enable follow-up by consumers.
4. **Financial incentives:** distributors may receive a positive, or negative, incentive that adds, or subtracts, to their income depending on service performance. For example, performing above the required standard may allow for an increase in the distributor's remuneration. Incentives can be applied through the correct definition of quality indicators and performance standards, and their proper calibration (i.e., positive and negative incentives must be aligned with the economic impact an increase or decrease in quality may represent).

Moreover, incentives may be determined to apply and be monitored according to the average performance of a quality indicator (average performance of SAIDI, SAIFI, etc.), depending on the performance of individual quality levels (quality of the worst-served customer), or both. For example, if a distributor is making progress in its average quality of service performance, it can be subject to receive a higher income, but if at the same time the worst-served customers have not experienced an improvement in service quality, the distributor must pay an economic compensation to the worst-served customers (i.e., by charging a lower energy tariff until service quality is improved for this group of customers).

Considering that electricity supply quality may be highly dependent on external factors (i.e., weather conditions or natural events in a particular year affected grid performance), upper and lower performance standards thresholds should be considered. In this way, distributors can operate within acceptable boundaries within which no positive or negative financial incentives are triggered.

An example of an incentive-based quality scheme is the one adopted in Colombia (Resolution CREG 015 of 2018). Quality in distribution systems is measured annually in terms of two indicators SAIDI and SAIFI. Based on the improvement, or deterioration, of the average quality of the system (average of the events that affected all the users served by the distribution company during the previous year), with respect to a target established by the regulator, the distribution company will receive an annual incentive, positive or negative, which is added to or subtracted from the regulated revenues. The average quality target for both SAIDI and SAIFI is set at an annual improvement of 8%. There is a buffer of +/- 0.5% in meeting the annual target, within which, the incentive is zero. The long-term target indicators are 2 hours and 9 interruptions for SAIDI and SAIFI respectively. These indicators are calculated, recorded, and considered by the ISO, who is in charge with the monthly tariff calculations.

Infrastructure Adequacy

- 5. Technology deployment:** The implementation of new digital devices, communications and control systems can help utilities improve their quality of service. Utilities are deploying advanced technologies to plan, manage, and control electricity delivery to enable safe and reliable two-way flow of electricity and information, support growing numbers of distributed energy resources, and support customers participating in electricity markets as power suppliers and demand managers. These devices include for example phasor measurement units (PMU) and specific technology to track and record outages, such as eReliability Tracker Software or supervisory control and data acquisition (SCADA). For example, PMU technology can detect low-frequency oscillations that were missed by SCADA systems, allowing operators to act and prevent widespread disturbances.

To help the technical indicator management process, it is recommended that the utility collect and assess disaggregated interruption data, for example by voltage level and by cause, in order to better identify priorities for practices and network interventions. In the same way individual information on and verification of voltage quality upon user request is carried out at the initiative of the company. DSOs collect information on the number of customer's voltage complaints, number of resolved voltage problems and publish these on a regular basis.

Utilities should have a protocol for self-supplied electric power quality control as do records of the findings, applying criteria at least as stringent as those set by the regulations. Records are kept of operation parameters measured in all power substations. Remote control systems are available to manage processes and internal parameters of power substation, alarm thresholds exist for corrective maintenance and operation adjustment. Automatic electrical power quality monitoring stations are available at the outlets of the power substations.

6. Investments to reduce SAIDI and SAIFI. In general, new investments in power systems seek primarily to meet the increased load of customers, however it is important to seek investments that are directed exclusively at reducing the outage duration and/or number of customers affected for specific outages, such as:

- Install an additional fuse: all outages that are related to a specific location have a probability of reducing the number of customers affected.
- Install sectionalizers: It can isolate faulty portion of distribution line and return service to the circuit.
- Replace a fuse with a recloser: has a high probability of reducing the duration of all outages related to the fuse that is replaced and causes such as lightning, trees, birds, etc.
- Place short distribution lines underground: all outages on this feeder with most causes (e.g., lightning, trees, traffic accidents, etc.) are removed (the utility can select just some areas for this step)
- Add bird spikes / reflectors: all outages related to birds have a high probability of being reduced.
- Add a barrier to prevent car accidents from causing outages: outages at the location a barrier is added have a probability of being removed.
- Increase the utility spending on media outreach to improve awareness and response time: the duration of outage has a probability of being reduced.
- Install electric energy storage (EES) in rural communities or distant from urban centers, where the installation of cross connects are not economic or even feasible and so maintaining an allowable level of SAIDI.

There is no standard or cost benchmark for quality improvement plans because it depends on the particular case of each company in aspects such as topology (for

example, urban-rural topology, radial or redundant networks), network status and indicators in the different regions where service is provided. Depending on the current quality of service level, and on the type of incentives for poor or good quality, the company must carry out a financial evaluation of the investments to define the optimal strategy. For example, in certain radial networks, the definition of the optimal number of reclosers to be installed depends on this analysis.

7. **Structural capacity to verify that electricity distribution is adequate and there is redundancy.** The electric power distribution system must be able to supply all the electric power demand for the different load levels and improving system redundancy is an important enhancement to increase reliability.

Electrical power supply and distribution infrastructure design is conceived to minimize impact due to contingencies, to comply with service standards (quality and continuity) and to renew supply and distribution system elements that take into account the risk of impact on service continuity. In this way, distribution network design criteria exist that considers the quality of the supply and distribution of electrical energy. Hence, planning and operation of the infrastructure adopts criteria to prevent risk of service interruption and unintended variations in quality (voltage, frequency, capacity, and others).

In planning, the utilities must use the criterion called N-1, that is, the electricity supply must be maintained even if 1 equipment fails in the system, for some customers with high criticality, it is possible to use N-2 criteria. In the operation, with communication and metering technologies, reconfiguration, and islanding schemes of Distributed Generation (DG) are possible methods that can help implement differentiated reliability.

For new assets, protocols exist to ensure the quality of electricity when integrating the new infrastructure to the system. Sometimes these new assets require for planned interruptions, if so, it is important that customers are notified in advance to minimize the impact of power outages.

Smart meters can also provide certain quality measurements and control features, without an excessive price increase for customers, such as the capabilities of voltage quality monitoring.

8. **Electricity grid resilience facing natural events:** Natural events can lead to outages with prolonged load interruptions. Although such events are characterized by a high level of unpredictability, utilities have ways of reducing and mitigating their consequences. Some practices for each type of event can be used:
 - Lightning strokes is one of the prime factors of unplanned supply interruptions in power systems. Some classical solutions are: (i) cost-effective equipment can be installed on the distribution and transmission lines to find the path of a lightning strike; (ii) correctly use of surge arresters to reduce the induced voltages, that is,

surge arresters perform better when grounding resistance is lower, and the adjacent arresters have shorter distances; and (iii) install shielding wire to decrease the lightning stroke frequency on the power lines.

- Floods: A change identification method to map floods in urban areas using satellite images can be used to classify images near rivers and forecast where a new flood is likely to happen. The aim is to find the optimal hardening plan for the system resilience and the optimal functioning of the electric power system under the worst event. Some possible actions are: (i) pre-allocation of mobile energy generators; (ii) replan the optimal switching locations using distributed energy resource locations; and (iii) review the current power grid to feed critical clients.
- Hurricanes: These events result in a forced reduction in load because of distribution equipment damage. In this situation some solutions are: (i) invest in an operation using microgrids concepts in a distribution system to increase the self-healing ability and enable the distribution system to restore sooner during outage occurrence. Also consider the possibility of integration of distributed energy resources in microgrids; (ii) use proactive scheduling in response to imminent hurricanes in multiple energy carrier microgrid; (iii) a self-healing methodology by sectionalizing the distribution system into microgrid after the occurrence of a natural disaster can be used; and (iv) during hurricanes, develop a method to alleviate the cascading effect in transmission networks using a risk-based preventive islanding method.
- Windstorms: can cause equipment failure when hitting the power grid. To mitigate such effects, utilities must carry out customized projects for transmission and distribution lines for regions with a higher incidence of these events. In the first stage, empirical models are created based on historical and weather data. The second stage involves the real-time tracking of windstorms. During the design of new or assessing the old transmission lines, an acceptable level of compromise between cost and probability of failure must be maintained. In addition, it is possible to establish a framework for microgrids proactive management to coordinate demand-side resources, secure voltage regulation, and generation rescheduling.
- Wildfires: can cause intense temperature, leading to an explosion of transformers and changing dielectric and mechanical properties of T&D lines. Some possible solutions are to: (i) substitute oil-immersed transformers with dry types; (ii) apply real-time transmission line monitoring to identify the dynamic line rating during normal or contingency cases; (iii) use a cost-effective fire detection mechanism with different technologies; (iv) use distributed framework of multiple unmanned aerial vehicles to avoid humans from dangerous dynamic fire tracking. It reduces the operational cost, correctly tracks the fire progress, avoids in-flight crashes, and collaborate well with nearby vehicles.

Technical and Operational Practices

9. Integration of Distributed Energy Resources: The use of new distributed energy technologies (PV systems, fuel cells, energy storage, and electric vehicles) connected to the grid requires improvements in all interconnection standards to define the requirements that these technologies must need for safe and reliable integration with utility electrical networks. These standards address issues such as power quality and voltage limits and maximum power to be connected. For example, in many countries, local regulations will provide for these procedures, however when this does not occur, countries can use IEEE references such as IEEE 1366 and IEEE 1547 and technical studies.

One relevant example is the New Grid Code in Colombia (currently under revision) which considers an important integration of intermittent generation to the national system (not for DG). The study contracted by the Regulator (CREG) proposes different rules in fields like protections (fault protections), fast frequency response, and quality of the voltage waveform, for which it is proposed to update the current requirements considering the incorporation of power electronics of wind and photovoltaic farms (FACTS - Flexible AC Transmissions Systems, EES – Electrical Energy Storage, and in the future HVDC – High Voltage Direct Current).

As far as DG integration is concerned, the connection to the grid must comply with the voltage standards set by the competent authority or the utility for the transmission and distribution system, to avoid negative technical effects on the grid in aspects such as voltage regulation, power flow reversal, thermal limits, short circuit currents, protection coordination, power quality and island operation⁸.

Additionally, a generalized opinion is that the integration of distributed generation should be done in stages (such as a moderate stage for the existing grid, full integration, and development of localized markets).

In this context, best practices consist mainly of:

- Carry out specialized technical studies to determine the appropriate technical standard for system capacity availability. For example, in Colombia it was set at a maximum of 15% of the capacity of a circuit.

⁸ In this regard, please refer to the document “Autogeneración a pequeña escala y generación distribuida”, CREG-066 -2017. This document refers to international research in which similar criteria were identified for the entry of distributed generation according to the aggregate capacity limit with respect to referents, the most commonly used being: i) some percentage of the peak demand of the circuit (in 27 countries); and ii) a capacity limit in MW:

[http://apolo.creg.gov.co/Publicac.nsf/1c09d18d2d5ffb5b05256eee00709c02/b5341fbcfab96db80525819b006d42fa/\\$FILE/D-066-%20AUTOGENERACI%C3%93N%20A%20PEQUE%C3%91A%20ESCALA%20Y%20GENERACI%C3%93N%20DISTRIBUIDA.pdf](http://apolo.creg.gov.co/Publicac.nsf/1c09d18d2d5ffb5b05256eee00709c02/b5341fbcfab96db80525819b006d42fa/$FILE/D-066-%20AUTOGENERACI%C3%93N%20A%20PEQUE%C3%91A%20ESCALA%20Y%20GENERACI%C3%93N%20DISTRIBUIDA.pdf)

- Carry out periodic studies to update these standards based on the development of the grid and the incorporation of distributed generation.
 - Define and implement adequate procedures to promote the integration of distributed generation. For example, the publication and permanent update in the official Internet portal of the available capacities in each circuit and the connection requests in process, accepted and installed generation; the adoption of standardized formats to submit the connection request, the steps of the process and response time limits.
10. **Maintenance and operation standards:** The utility must have protocols and standards to perform corrective and preventive maintenance in the power substations and networks. There are safety plans for contingencies regarding the quality of the supply and distribution of electrical energy. It is also recommended that a verification of the operational status of supply and distribution system elements (for which visual inspection or operational test is possible) to be carried out at least once every 3 years, and for the strategic systems, every year.

For both corrective and preventive maintenance, the use of GIS tools is desirable to support isolation, repair, and resolution of contingencies, and to effectively track and record where the maintenance is being made (which can provide valuable planning information for deployment of new quality driven programs and investments). In systems with various alternative supply sources, operation center protocols exist to ensure supply quality on initial use of new supply sources (sources and interconnections), as well as protocols to analyze and resolve non-compliance with applicable regulations regarding supply and distribution quality.

Organization

11. **Baseline and masterplan:** It is essential to develop quality improvement or control plan, based on a diagnosis that identifies the baseline (current state of service quality according to the selected and standardized indicators), the specific factors that cause major supply interruptions, the location where supply quality is deficient (region, circuit, customer), the definition of quality objectives and goals, the definition of strategies to address each field of action, the formulation of projects, the definition of an implementation schedule, the assignment of responsibilities in the organization, the criteria for evaluating the plan, and the economic and financial evaluation of the plan.

Service quality indicators should be recorded regularly and kept consistent with the methodology used for the baseline definition in order for a proper evaluation of the results of the service quality-oriented projects.

As for the possible duration of a quality improvement plan, which may be defined at the sectoral level by distribution subareas, or at the level of the company as a whole, it depends largely on the initial situation and the quality investment effort,

which is also closely related to investment in network replacement and modernization (the general condition of the networks may affect quality to a large extent, as well as the remuneration recognized by the regulator for preventive and corrective maintenance expenses). However, taking as a reference the recent case of Colombia, which defines a gradual improvement path of 8% per year until the target is reached, a maximum period of 10 years may be reasonable for companies with deficient indicators.

- 12. Technical Support and dedicated department:** An operation center and maintenance crews should be available 24/7 to manage contingencies in distribution systems. The operation center must be available 100% of the time since the maintenance crews must respond when necessary. Specific crews should also be available to perform inspections in difficult to access zones. For all regions, there must be maintenance crews to cover the entire population served, and for areas with a higher population density.

A department within the distribution company with the task of analyzing the performance of continuity and quality indicators should be functioning. This department must provide reports to executives and help other departments to direct their actions to improve these indicators. This department should have a control methodology for calculating quality indicators with certification recognized as ISO 9000. Within the scope of this area, analyses must be carried out to identify zones at risk of not complying with electricity supply and distribution service, and, if this is the case, appropriate actions must be taken. Trends in continuity of supply and (when applicable) the economic results (periodic evaluation and revision of the continuity practices are suggested) are analyzed. Lastly, the utility should engage the regulator to discuss how investments in monitoring voltage control are recognized by the authorities on the capital investment and operational costs.

- 13. Lastly, there is a need to establish quality committee:** Maintain a quality committee with regular meetings that has the function of monitoring the performance of the electricity supply and product quality indicators, in addition to following the action plans established by the business areas. This committee should encourage and ensure that quality indicators are presented or weekly to employees at hierarchical levels (from managers to electricians). Meetings and panels are used to discuss the evolution of these indicators.

D. References

For more information regarding the quality of the technical service, please consult the following references:

Reference	Case Studies	Methodology	Technical Reference
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IEEE Guide for Electric Power Distribution Reliability Indices," in IEEE Std 1366-2012 (Revision of IEEE Std 1366-2003) , vol., no., pp.1-43, 31 May 2012, doi: 10.1109/IEEESTD.2012.6209381. https://ieeexplore.ieee.org/document/6209381			
Report on the Quality of Electricity Service - Standards and Incentives in Quality Regulation. ECRB - Energy Community Regulatory Board. https://www.energy-community.org/dam/jcr:276d8122-8939-4a48-90dd-2fd1297faae2/ECRB_report_quality.pdf			
Simple Strategies to Improve Power Reliability. Power Grid International, Issue 4, Volume 11. Author Steve Eckles (El Paso Electric Co.) https://www.power-grid.com/2006/05/01/simple-strategies-to-improve-power-reliability/#gref			
US Department of Energy. Quadrennial Technology Review - An Assessment of Energy technologies and Research Opportunities. Chapter 3: Enabling Modernization of the Electric Power System (September 2015).			

Reference	Case Studies	Methodology	Technical Reference
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<p>Procedimentos de Distribuição de Energia Elétrica no Sistema Elétrico Nacional – PRODIST Módulo 8 - Qualidade da Energia Elétrica. Agência Nacional de Energia Elétrica – ANEEL. 01/01/2018</p> <p>https://www.aneel.gov.br/modulo-8</p>			
<p>Best practices in the electric power distribution sector in Brazil promoted by ABRADÉE – Associação Brasileira de Distribuição de Energia Elétrica through its biannual seminar SENDI – Seminário Nacional de Distribuição de Energia Elétrica (Anos 2010, 2012, 2014, 2016 e 2018)</p> <p>https://www.abradee.org.br/sendii/</p>			
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<p>Norma Técnica De Calidad De Servicio Para Sistemas De Distribución. CNE. -Comisión Nacional de Energia (Chile). 2017</p> <p>https://www.cne.cl/wp-content/uploads/2015/06/Norma-T%C3%A9cnica-de-Calidad-de-Servicio-para-Sistemas-de-Distribuci%C3%B3n_vf.pdf</p>			
<p>6TH CEER Benchmarking Report On The Quality Of Electricity And Gas Supply. Council of European Energy Regulators (CEER). 2016</p> <p>https://www.ceer.eu/documents/104400/-/-/d064733a-9614-e320-a068-2086ed27be7f</p>			

Reference	Case Studies	Methodology	Technical Reference
IEEE (Institute of Electrical and Electronics Engineers). Siripha Junlakarn. Distribution System Reliability Options and Utility Liability. IEEE Transactions on Smart Grid (Volume: 5, Issue: 5, Sept. 2014). 2014 https://doi.org/10.1109/TSG.2014.2316021			
The Electricity Journal. Muhammad Waseem and Saeed D.Manshadi. Electricity grid resilience amid various natural disasters: Challenges and solutions. Volume 33, Issue 10, December 2020, 106864. 2020 https://doi.org/10.1016/j.tej.2020.106864			
IEEE (Institute of Electrical and Electronics Engineers). IEEE 1547-2018 - IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces. 2018 https://standards.ieee.org/standard/1547-2018.html			