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DIGITALIZATION AND AUTOMATION OF POWER DISTRIBUTION

DRIVERS AND INTERNATIONAL GOOD PRACTICES

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INTRODUCTION

The digitalization and automation of electricity distribution systems are radically transforming the way energy infrastructure is managed and operated globally. In an increasingly interconnected world, where the demand for electricity continues to increase and consumer expectations evolve towards more efficient, sustainable and personalized services, the modernization of distribution networks has become an imperative necessity.

In this context, Latin America faces a unique challenge. The region presents a diverse landscape, with countries that are at different stages of economic and technological development. However, they all share the need to improve the resilience, efficiency, and sustainability of their power distribution systems. The integration of renewable energy sources, the reduction of technical and non-technical losses, and the improvement in the quality of service are some of the objectives that digitalization and automation can help to achieve.

The purpose of this document is to provide a general review of the opportunities and challenges that digitalization and automation present for power distribution systems in Latin America. It explores global trends in the implementation of advanced technologies, such as smart grids, Internet of Things (IoT), and artificial intelligence (AI), which are redefining traditional paradigms of electricity distribution. In addition, the current panorama in the region is discussed, highlighting the advances and limitations that characterize the different countries.

One of the key aspects is the identification of the fundamental drivers of this transformation, with a particular focus on the regulatory framework and public policies. In many cases, the lack of an appropriate regulatory environment has been a significant obstacle to the adoption of innovative technologies. Therefore, this document also seeks to offer recommendations on how governments, regulators and companies can foster an enabling environment for the digitalization and automation of electricity distribution.

In addition, some international success stories that can serve as a reference for Latin America are presented. These examples demonstrate how the successful implementation of digital technologies in other contexts can be adapted to address the specific challenges of the region, emphasizing the need to adapt these solutions to local realities, considering factors such as existing infrastructure, technological capabilities, and socioeconomic conditions.

Finally, this document provides practical and strategic recommendations for the implementation of digitalization and automation technologies in the region, with the aim of overcoming existing technological and economic barriers.

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GLOBAL TRENDS, NEW TECHNOLOGIES AND EMERGING SOLUTIONS

The Digitalization and Automation (D&A) of electrical distribution systems represent one of the most transformative trends in energy infrastructure globally. In recent decades, the rapid evolution of advanced technologies has made electricity distribution networks more efficient, resilient and adaptable to growing energy demands and the integration of renewable energy sources. This modernization process has redefined the traditional paradigms of electricity operation, with a focus on digital interconnection, real-time optimization, and the ability to adapt to an ever-changing energy environment. In addition, the integration of artificial intelligence (AI) and big data is improving the management of power grids in real time, as they can predict demand, optimize distribution and minimize interruptions, which generates a multiplier effect in the generation of value for distribution companies and users. Below are some technologies and solutions in networks and equipment, IT/OT systems, analytics tools, and communication and data services.

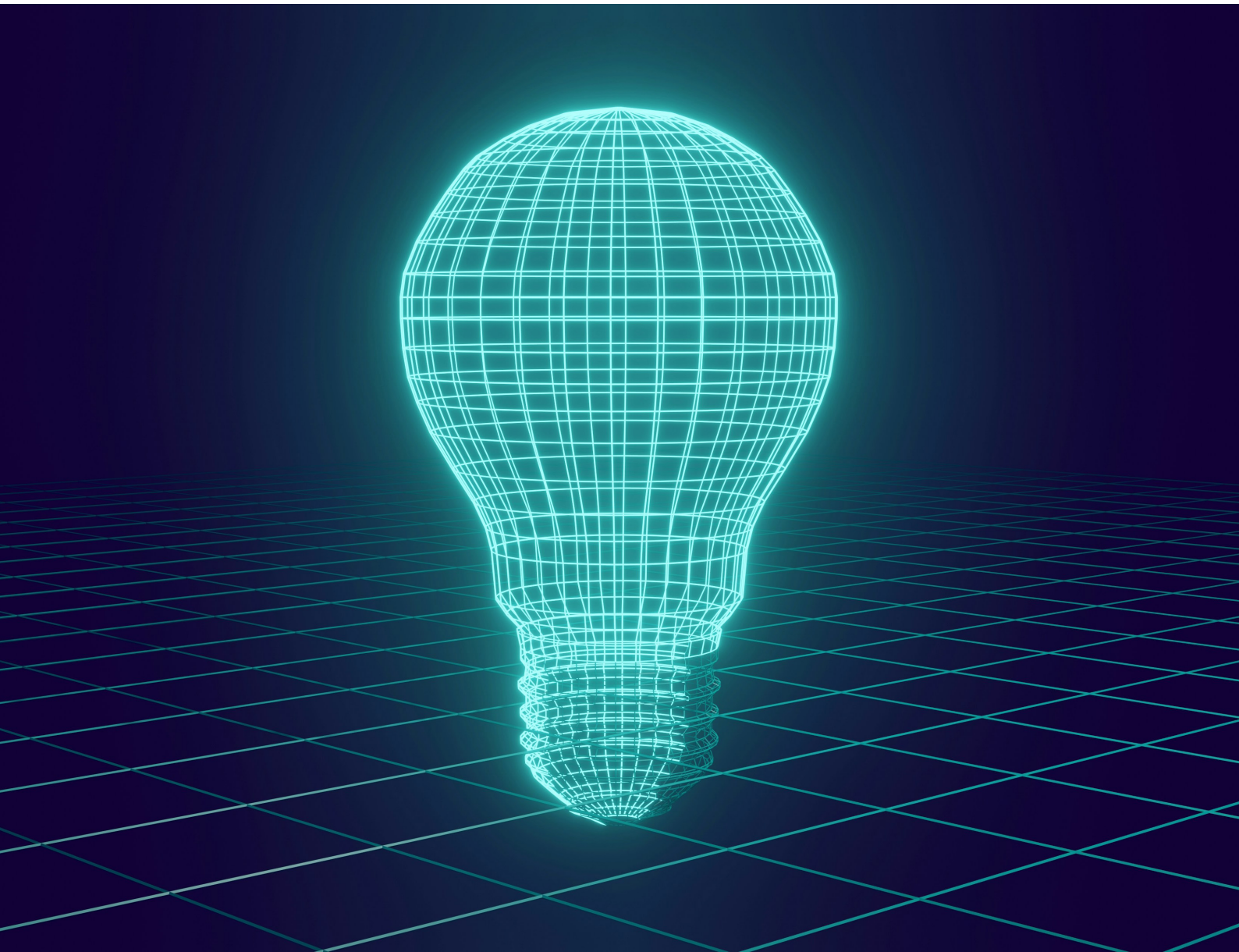
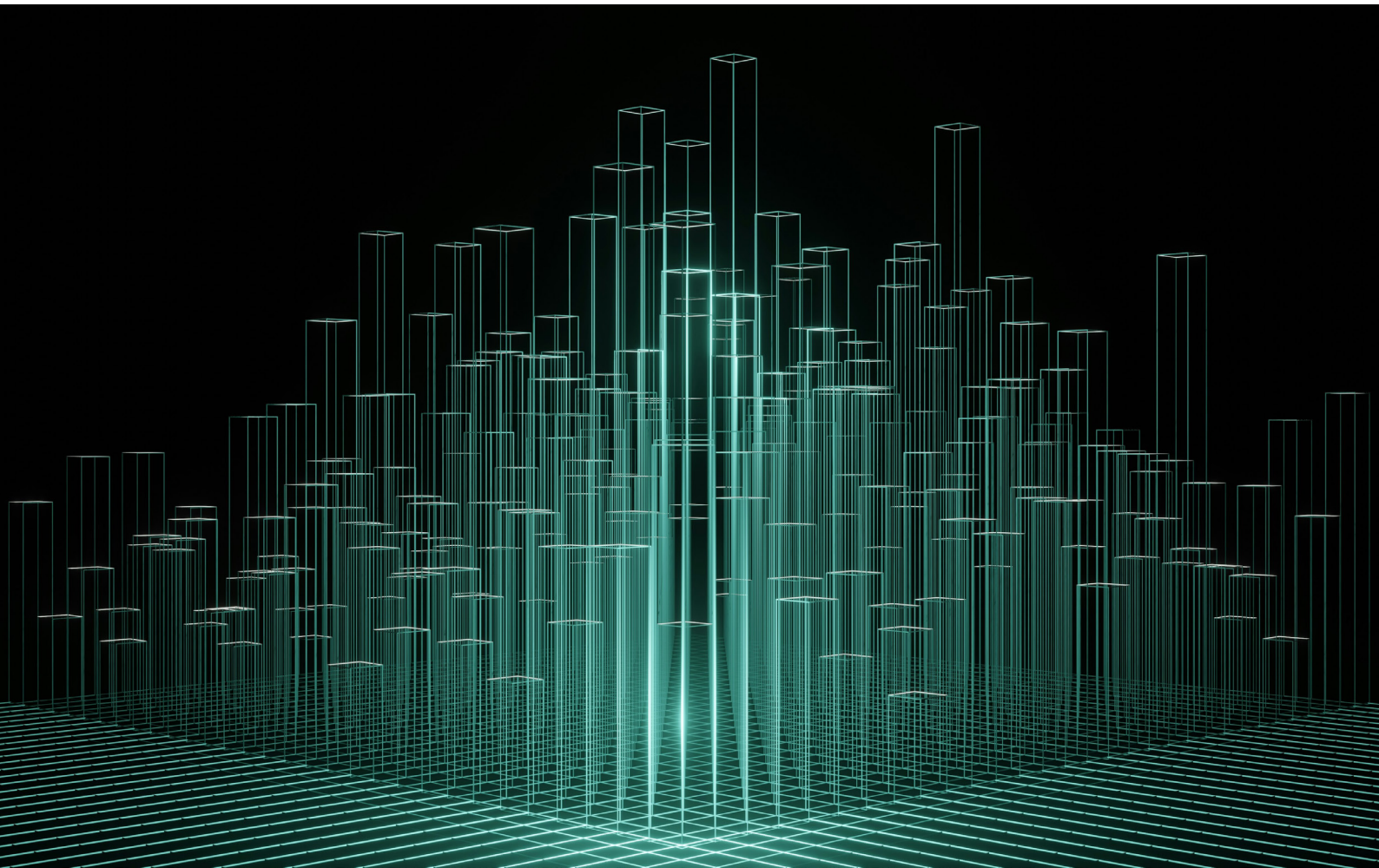


Table 1. Some D&A technologies for electrical distribution

Category	Smart Grid Technologies
Networks & Equipment	Smart Sensors & Fuses
	Substation Automation
	Advanced Metering Infrastructure (AMI)
	Drones equipped with LIDAR and other technologies
	Battery storage systems
IT/OT Systems	Supervisory Control and Data Acquisition (SCADA)
	Advanced Distribution Management Systems (ADMS)
	Geographic Information Systems (GIS)
	Measurement Data Management Systems (MDMS)
	Distributed Energy Resources Management Systems (DERMS)
	Outage Management Systems (OMS)
	Distribution system modeling, analysis and planning platforms
	Energy Management and Optimization Systems (EMOS)
	Commercial management and customer relationship platforms
Analytics Tools	Data Lakes
	Predictive analytics and big data platforms
	Artificial Intelligence (AI) and Machine Learning (ML)
Communication and data services	Advanced communication networks
	Cloud Computing
	Cybersecurity Solutions



NETWORKS & EQUIPMENT

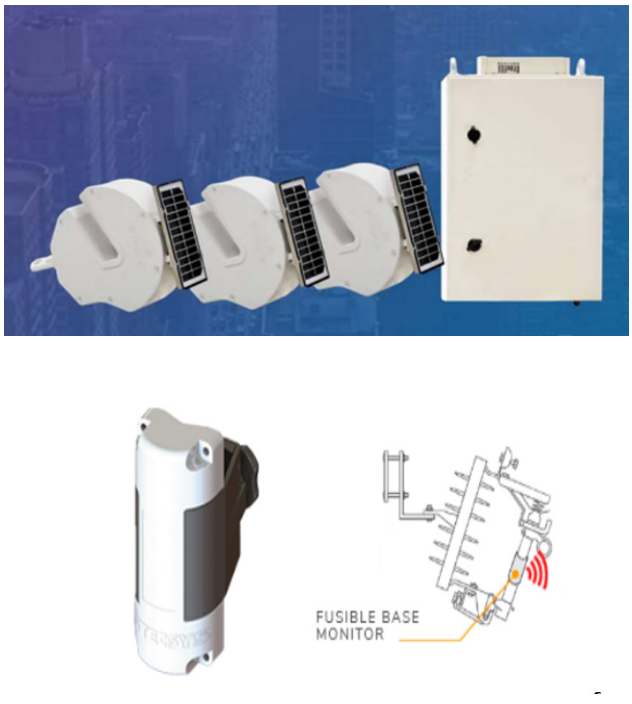
One of the fundamental pillars in the modernization of power distribution networks is the implementation of **Smart Grids**. Unlike conventional grids, which operate in a unidirectional manner, Smart Grids allow bidirectional communication between the grid, consumers and Distribution Companies. This transformation is driven by the incorporation of advanced sensors, connected devices, and real-time monitoring systems, which give grid operators the ability to manage supply and demand more efficiently and flexibly. Some of these equipment and systems are described in this section.

Advanced Metering Infrastructure (AMI) is a key technology in the process of digitizing electricity distribution networks, providing a more direct interaction between grid operators and end-users. Smart meters are the fundamental component of AMI, capable of recording detailed data on electricity consumption, such as the amount of energy used, peak demand, and consumption behavior over time. These meters send this information through secure communication networks to the management centers of the distribution companies. The key advantage of these meters is their ability to take real-time readings, eliminating the need for manual readings and facilitating automatic and accurate billing.

AMI enables dynamic demand management, which means that grid operators can adjust power distribution based on actual system conditions and consumer needs. During peak demand, distributors can apply demand response mechanisms, encouraging users to reduce their consumption through incentives or differentiated tariffs. This ability to manage demand in real time is essential to maintain grid stability, especially at times of high load, and to improve the integration of renewable energy sources, the generation of which can be intermittent. Additionally, the implementation of AMI allows the capture of historical data for a more accurate estimation of future demand so that the grid operator can make more efficient use of it.

One of the key technologies in this trend is **smart sensors**, which monitor medium and low voltage power grid conditions and consumption in real time. These devices not only help detect faults or overloads immediately, but also allow for better planning and management of the system, providing valuable data that can be used to optimize network operation and foresee potential problems before they occur. Grid protection equipment can also include **smart fuses**, which incorporate sensors that can monitor other important grid conditions, such as conductor current and temperature, allowing for more detailed, real-time diagnosis of line conditions. This information enables network operators to improve proactive maintenance management, by detecting overload conditions or intermittent faults before a total outage occurs.

Figure 1. Smart Sensors & Fuses



Source: Energy Markets Group.

Advances in **substation automation** are equally important. These technologies allow substations to operate with minimal human intervention through the use of sensors, actuators, and remote control systems. With automation, it is possible to improve the reliability of the power supply, reduce downtimes, and improve the ability of substations to adapt to changing conditions, such as increases in demand or fluctuations in renewable generation. These automated substations not only improve operational efficiency, but also significantly reduce downtime associated with maintenance or fault correction. By integrating advanced diagnostic systems, substations can detect potential problems before they become serious failures, allowing for more efficient maintenance planning.

make it possible to improve the supervision, monitoring and maintenance of power grids. LIDAR (Light Detection and Ranging) technology allows the creation of detailed three-dimensional maps, which facilitates inspection and preventive monitoring in hard-to-reach areas, allowing to accurately identify faults, assess the condition of assets and optimize maintenance planning. Drones are also used in visual and thermal inspections, using high-resolution cameras and thermal cameras to identify problems such as hot spots, overloads in lines, or failures in transformers and other components. Thermography is particularly useful for detecting potential failures before they become critical problems, allowing preventive maintenance to be performed.

Other relevant applications of drones are the hydrowashing of insulators and network components in high voltage, and the pruning of trees that interfere with power lines. Instead of using work at height equipment, drones can cut branches with precision, minimizing risks to personnel and reducing intervention time in affected areas. This is especially important in wooded or hard-to-reach areas, where vegetation can cause service interruptions if not properly controlled.

Finally, the adoption of energy **storage systems**, such as high-capacity batteries, has also been a disruptive advancement in grid automation. These technologies allow energy to be stored during periods of low demand or when renewable generation is abundant, and then released when demand is higher. This not only contributes to grid stability, but also reduces the need to rely on conventional generation sources at times of high demand.

SISTEMAS IT/OT

Network automation and control systems have radically transformed the way utilities manage and operate their electrical infrastructure, improving operational efficiency, reducing costs, and increasing system resilience. IT/OT systems allow power grids to operate more independently, efficiently, and safely, which is crucial in an environment of increased energy demand and increased penetration of renewable energy sources. To this end, platforms have been developed that integrate various control and management functions to optimize the use of energy resources, improve interaction with consumers and facilitate asset management.

SCADA (Supervisory Control and Data Acquisition) platforms have played a crucial role in the more efficient and secure operation of distribution networks. These platforms allow real-time monitoring and control of network equipment, facilitating a rapid response to emergencies, failures or fluctuations in demand. SCADA enable remote access to distributed devices, such as switches, transformers, and other critical network components, improving contingency responsiveness. A key advantage of these systems is the reduction of human intervention in critical situations. By automating certain functions, such as fault detection and automatic reconnection, response times are minimized, resulting in fewer interruptions and an overall improvement in service quality.

Advanced Distribution Management Systems (ADMS) are more advanced tools that allow network operators to monitor, man-

age and optimize the operation of distribution networks in real time. ADMS provide a detailed view of the grid, allowing for more accurate and agile decision-making, improving system reliability and efficiency. With the ability to integrate data from a variety of sources, such as smart meters, sensors, and devices distributed throughout the network, ADMS help operators manage outages, optimize power flow, and balance load in real time. In addition, it allows for the proactive identification of problem areas, improving the ability to avoid or mitigate disruptions and failures. In practice, an ADMS allows utilities to move from manual processes and siloed software to real-time data, automated processes, and integrated systems.

Distribution **system modeling, analysis, and planning platforms**, such as CyME, ETAP, PowerFactory, and PSS®E, are essential for utilities to optimize the design and operation of their power grids. These platforms allow to create detailed models of distribution networks, including all key components such as distributed lines, transformers, loads, and generators, for accurate and complex simulations. Through these models, operators can evaluate the behavior of the grid under different conditions, analyze demand, foresee operational problems, and perform load flow studies, short circuits, power quality analysis, and voltage stability, among others. These platforms also make it possible to analyze the integration of distributed energy resources and plan their impact on the grid, and make it easier to identify areas where losses can be reduced and operational efficiency improved.

The use of **Geographic Information Systems (GIS)** has revolutionized the way electricity distribution infrastructure is managed. GIS allows operators to visualize and manage the grid in a geospatial environment, offering accurate mapping of every component, from power lines and substations to meters and transformers. This visualization capability is essential for optimizing network design, operation, and maintenance. Advanced GIS integrates real-time data from SCADA and ADMS systems, allowing operators to more easily detect faults and locate points of interest in the network, such as outages or areas in need of maintenance. In addition, GIS allows for more accurate planning of network expansions, identifying areas with higher demand growth or areas where infrastructure improvements are required.

Another emerging technology in this area is the **Distributed Energy Resources Management System (DERMS)**, which allows the integration and optimization of distributed energy resources, such as generation from renewable sources, energy storage systems, and controllable loads. These systems are critical to ensure that intermittent renewable energy, such as solar and wind, can be managed effectively.

Outage Management Systems (OMS) are designed to manage and automate the response to power outages. OMS enables utilities to detect, manage, and resolve grid faults more efficiently, integrating data from multiple sources to quickly identify the location of faults, coordinate service restoration, and keep customers informed. Their ability to automate critical processes and improve response to failures places them within this key category for the modern operation of electricity grids.

Metering Data Management Systems (MDMS) manage and store large volumes of data from smart meters (AMI) and other devices, allowing utilities to analyze energy consumption, optimize billing, and improve grid management in real-time. MDMS systems facilitate the aggregation, validation and analysis of consumption data that can be shared with the end customer through apps or personal accounts, making them a key tool for the digitization and automation of electricity grids, supporting both the efficient operation and the improvement of commercial services.

Energy Management and Optimization Systems (EMS) are technological platforms designed to monitor, manage and optimize the use of energy in electrical grids, buildings, industries or any other facility that con-

sumes or generates energy. These systems integrate data from multiple sources, such as advanced metering devices, sensors, and SCADA systems, to provide a comprehensive view of energy consumption and enable more efficient and sustainable resource management. This makes it possible to identify consumption patterns and detect anomalies or inefficiencies instantly, reduce costs, minimize losses, improve the performance of distributed generation systems and actively manage energy demand.

Commercial management and customer relationship platforms, such as CRM and CMS, are another key component of ICT in electricity distribution networks. These platforms allow for comprehensive management of customer interactions, billing, account management, and analysis of consumption data, all directly linked to the operation of the network. By integrating data from smart meters and other sources of information, these platforms offer a detailed view of consumer behavior, facilitating more accurate billing and the implementation of energy efficiency policies. Commercial management platforms also play an important role in optimizing the relationship between distribution companies and customers. By allowing users to access their consumption data in real-time, the platforms encourage greater consumer participation in the management of their energy consumption. In addition, these tools allow the customization of tariffs, the implementation of demand response programs and the adoption of distributed renewable energies, promoting a more flexible and competitive energy market.

ANALYTICS TOOLS

These technologies allow utilities to collect, analyze, and manage large amounts of data in real-time, improving network efficiency, responsiveness, and reliability. Advanced data analytics platforms play an essential role in the modern operation of power grids.

Big Data-based predictive analytics platforms are transforming the way power grids collect and use data. These platforms process large volumes of information from smart meters, sensors, and other devices distributed throughout the network, allowing utilities to detect consumption patterns, predict trends, and anticipate problems before they occur.

One of the key elements in this evolution is the integration of **Data Lakes**, high-capacity data repositories where massive amounts of information are stored in their original form. Data lakes allow utilities to consolidate structured and unstructured data from a variety of sources, improving access to critical information and providing more robust support for advanced analytics. By using data lakes, enterprises can leverage large volumes of real-time and historical data to improve decision-making, optimize network management, and develop more accurate long-term strategies.

Artificial Intelligence (AI) and **Machine Learning (ML)** make it possible to optimize the operation of networks and improve decision-making, based on the analysis of large volumes of data. There are two key approaches within AI that are especially relevant to the industry: generative AI and adaptive AI. Generative AI is used to create new solutions and predictive models based on previous data. In the context of power distribution, it is useful for scenario simulation and demand forecasting. Adaptive AI, on the other hand, has the ability to adjust its behavior in real time, based on the data it continuously receives. This is especially relevant in dynamic load optimization and demand management. Additionally, machine learning algorithms can identify patterns in consumer behavior and automatically adjust power distribution to maximize efficiency, reduce operating costs, and improve system sustainability. For example, in times of high demand, systems can intelligently redistribute the load to avoid overloads, improve service quality, and reduce losses in the network.

In addition, AI and ML are also critical for automated network management. Through the analysis of satellite imagery and drones

equipped with advanced sensors, AI algorithms can identify anomalous structures, such as faulty components, and perform vegetation control processes accurately. These solutions allow for more efficient preventive maintenance, minimizing service interruptions and reducing environmental risks. This approach also contributes to sustainability, as it reduces human intervention in hard-to-reach areas and minimizes the impact of operations on the natural environment.

Another application is the integration of AI into customer experience solutions, to automate and improve customer service processes, optimizing interactions and improving user perception. AI algorithms can automatically respond to frequent queries, handle complaints faster, and offer personalized solutions based on each customer's consumption habits. This customization not only improves user satisfaction, but also creates operational efficiencies by reducing the workload on care and support centers.

COMMUNICATION & DATA SERVICES

Advanced **communication networks** are an essential component to ensure the safe, efficient and fast operation of electricity distribution networks. These networks allow data transmission between different devices, such as smart meters, sensors, protective equipment, and control centers, with reduced latency, which is crucial for real-time operation. The technologies used include fiber optics, advanced wireless networks, power line communication (PLC) systems, and more recently, 5G networks.

In many networks today, protection and maneuvering equipment is equipped with 3G and 4G LTE communication technology, which, while offering connectivity, have high levels of latency. Low latency allows signals between devices and the control center to be transmitted and processed in fractions of a second, which is essential for the network to react immediately to failures or overloads. For example, in situations where a short circuit or overload is detected, the network must be able to quickly isolate the affected segment and restore service to the remaining users. The widespread adoption of these low-latency networks will improve the efficiency of power distribution systems, as it will enable the integration of advanced technologies such as the Internet of Things (IoT), distributed sensor networks, and automated remote management, creating an interconnected ecosystem for the automated management of electrical distribution.

Cloud computing services, such as AWS, Azure or Google Cloud, play a fundamental role in the digitization and automation of electricity distribution, providing a flexible, scalable and secure infrastructure to store, process and analyze large volumes of data. As power grids adopt advanced technologies such as smart metering, real-time data analytics, and automated demand management, cloud platforms offer scalable storage solutions that allow this data to be managed efficiently and without the need for expensive infrastructure. Cloud solutions allow distributors to integrate and automate multiple systems and processes centrally. This is key to implementing smart grids that can automatically adjust power distribution, manage load, and reduce consumption at times of high demand, improving operational efficiency.

The use of the cloud allows electricity distribution companies to adopt an architecture based on microservices, allowing them to develop, implement and scale new functionalities in an agile way, such as demand management tools or network control systems. Additionally, it allows for easy collaboration and data sharing, which is key in an environment where distributed grids can benefit from integration with other players, such as renewable generation operators or energy storage providers.

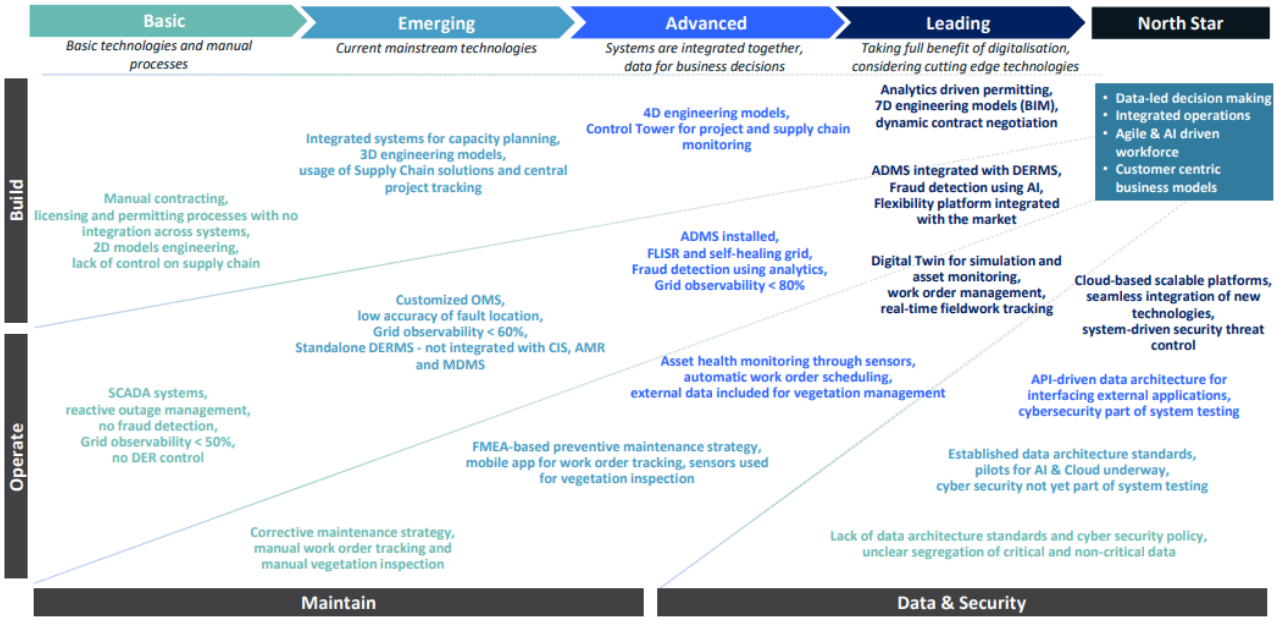
Finally, **cybersecurity** solutions are essential to protect the digital infrastructure of power distribution networks, ensuring the integrity, confidentiality and availability of the data and systems that manage the operation and

automation of the network. Cybersecurity in power grids is responsible for protecting SCADA systems, AMIs, business management platforms, and other critical components that rely on digital interconnection. Since modern networks rely on constant communication between devices and platforms, cybersecurity solutions are critical to ensuring that these communications are secure and not vulnerable to cyberattacks.

A study prepared by Eurelectric and Accenture (2024), summarizes the maturity stages of the digitalization and automation of electricity distribution, which can be classified into four levels: Basic, Emerging, Advanced and Leader, according to their progress in four key dimensions: construction, operation, maintenance, and data and safety, as illustrated below. This maturity model allows Operating Systems Distributors (DSOs) to gradually develop digital capabilities, from conventional technologies to advanced digitalization, where efficiency is maximized and the integration of renewable energies is facilitated.

> The Digitalization and Automation (D&A) of electrical distribution systems represent one of the most transformative trends in energy infrastructure globally

Figura 1. Etapas de madurez de la digitalización y automatización



Fuente: Eurelectric (2024).

In conclusion, global trends in digitalization and automation of power distribution are redefining the way energy infrastructure is managed. New technologies and emerging solutions are not only improving the operational efficiency and resilience of grids, but are also enabling the integration of renewable energy, the reduction of operating costs, and the development of more sustainable and adaptable power grids. For Latin America, the adoption of these technologies is a key opportunity to modernize its grids and prepare for a cleaner, more efficient, and more reliable energy future.

> In recent decades, the rapid evolution of advanced technologies has made electricity distribution networks more efficient, resilient and adaptable to growing energy demands and the integration of renewable energy sources

03

BENEFITS OF DIGITALIZATION AND AUTOMATION

The digitalization and automation of electricity distribution systems offer a wide range of benefits that significantly impact the operational, economic, social and environmental aspects of the energy sector. As distribution networks evolve toward smarter, more interconnected systems, utilities and governments can leverage these technologies to improve efficiency, reduce costs, increase grid resilience, and at the same time contribute to sustainability goals. This chapter explores the most prominent benefits of digitalization and automation in power distribution, highlighting how these technologies can positively transform the energy future.

Table 2. Benefits of Digitalization and Automation of Electrical Distribution

Proceeds Operating	Economic Benefits	Proceeds Social	Environmental Benefits
Reduction of Technical and Non-Technical Losses	New business models	More equitable and reliable access to energy	Lower energy consumption due to grid optimization
Improved quality of service	Improving competitiveness in industry	Improved identification and targeting of vulnerable users	GHG emissions reduction
Reduction of OPEX due to inspections and interventions	Reduction in residential user bill	Improvement in proximity management and user relations	Lower environmental impact of infrastructure
Optimizing infrastructure investment	Reduction of uncollectibles and unrecorded consumption	Job creation in the green economy and training in new technologies	Contribution to the circular economy
Improved asset management through data analytics			
Reduced customer service and digital engagement expenses			

OPERATIONAL BENEFITS

One of the main benefits of the digitalization and automation of electrical distribution systems is the considerable improvement in operational efficiency. Emerging technologies such as Smart Grids, ADMS systems, AMI and management systems enable operators to monitor and manage networks in real-time, resulting in a number of key operational advantages.

Reduction of technical and non-technical losses

The operation of distribution networks has faced the challenge of energy losses, both for technical reasons (losses inherent to the infrastructure) and for non-technical reasons (energy theft, billing errors). Digital technologies allow for more accurate detection of the areas of the network where these losses are most significant, allowing for proactive interventions. Smart meters and advanced sensors monitor the flow of energy, making

it easier to identify energy leaks, fraud, and billing errors in real-time, substantially reducing non-technical losses.

Improved quality of service

The digitalisation and automation of electricity networks allow greater control and optimisation of service quality indicators. Advanced technologies allow for faster and more efficient response to incidents, minimizing downtime. One of the key functionalities offered by these systems is the ability to carry out automated load transfers, which allow the electrical load to be automatically redistributed through other routes in the network when an interruption occurs, significantly minimizing disconnection times. This ensures that only a small portion of users are affected by the initial outage, while the rest can continue to receive power. In addition, digitalization facilitates the creation of island operations or microgrids, using distributed generation resources in each area.

Energy storage systems also contribute to quality by serving as small reserves that help the stability of the frequency at times of high demand and when there are fluctuations in a power system, as long as the operator is trained and authorized to operate the batteries that are connected to the grid.

Thus, by reducing downtimes and leveraging local resources, operators can more effectively comply with regulatory standards and improve their performance in terms of SAIDI and SAIFI, while minimizing penalties and costs related to service interruptions.

Reduction of operating expenses for inspection and intervention tasks

One of the main benefits of automation is the ability to monitor the network in real-time, eliminating the need for frequent manual inspections. With the installation of advanced sensors and technologies such as ADMS systems and advanced measurement infrastructure (AMI), constant monitoring can be performed without human intervention. This reduces the costs related to periodic inspections, improving efficiency and optimization of resources. Additionally, D&A allows for automatic or remote fault correction, without the need for physical intervention in many cases. Technologies such as smart fuses, condition monitoring systems and predictive analytics can prevent failures before they occur, which decreases the frequency of field interventions, resulting in a considerable reduction in operating costs.

Optimizing infrastructure investment

Digitalization technologies allow utilities to optimize their infrastructure investment decisions. Predictive analytics and the use of real-time data allow for more accurate planning of future network needs, meaning investments can be made in a more efficient and targeted manner. For example, instead of making massive investments in infrastructure expansion to meet peak demand, companies can use demand management solutions that optimize the use of the existing network, avoiding costly unnecessary expansions.

Improved asset management through data analytics

Thanks to the vast amount of data that advanced technologies, sensors, and monitoring systems can collect, distribution companies can optimize asset management. By applying appropriate analysis tools, operational data makes it possible to identify deficiencies in asset design, detect inadequate operations, recognize patterns of insufficient maintenance, and observe the effects of external events on the infrastructure, among other technical factors. This analysis offers distribution companies a deeper understanding of the condition and performance of each asset, allowing them to improve both technical specifications and operating criteria. In addition, this information facilitates the planning and optimization of preventive and predictive maintenance, ensuring that assets have a long service life and better performance. Ultimately, operational data analytics helps improve future projects and fine-tune asset management

throughout their entire lifecycle, with a focus on efficiency and long-term cost reduction.

Reduced customer service and digital engagement expenses

Automation also improves customer service, as information on network status and energy consumption is available in real-time to users. Digital platforms make it possible to manage complaints, notifications of interruptions or queries more efficiently, reducing the need for direct interaction and the costs associated with customer service. In addition, the increase in digital relationships between users and distribution companies improves the customer experience, fostering loyalty and reducing response times to queries or problems.

ECONOMIC BENEFITS

The digitalisation and automation of electricity distribution networks also generate significant economic benefits, both for distribution companies and for end consumers. These technologies not only reduce operating costs, but also generate new business models, improve competitiveness and allow for better optimization of energy use.

New business models

The digitalization of power grids opens the door to the development of new business models for DSOs. By having a digitalized infrastructure, distribution companies can offer additional services such as energy management for industrial and commercial customers, advice to improve energy efficiency or the possibility of operating as aggregators in distributed energy markets. In addition, greater visibility and control of the grid allows opportunities to be explored in areas such as energy storage, demand response or distributed energy asset management (DER), which diversifies revenue streams and improves the competitiveness of distribution companies.

Improving competitiveness in industry

Reducing operating and capital costs through automation not only benefits utilities, but also has a positive effect on the competitiveness of the industry as a whole. By optimizing grid usage and reducing energy losses, companies' operating costs are minimized, resulting in more competitive pricing for end-users. This is particularly important in energy-intensive industrial markets, where a reduction in energy costs can improve the overall competitiveness of the country's productive sectors.

Reduction in residential user bill

Digitalisation also allows a reduction in the bill paid by residential users for their total energy consumption. By improving network efficiency and reducing losses, utilities can offer more competitive rates to their customers. In addition, the implementation of energy efficiency programs and the adoption of technologies such as smart meters allow end consumers to optimize their energy use, which in turn reduces their consumption and final bill. Access to digital tools that allow real-time monitoring of electricity consumption offers residential users more control over their energy use, incentivizing more efficient consumption behaviors.

Reduction of uncollectibles and unrecorded consumption

The digitalisation of electricity networks contributes to the reduction of uncollectibles and consumption not recorded in billing, generating a positive impact on the financial sustainability of distribution companies. By having accurate and real-time data on consumption, companies can invoice more accurately, reducing estimated billing cases and adjusting charges to the real values of consumption. This improved control over the recording of consumption allows for a significant reduction in the costs associated with bad debts, thus increasing liquidity and improving operational efficiency. In addition, the ability to identify unregistered consumption facilitates proactive management of

users in a situation of non-payment, allowing companies to implement regularization programs or personalized payment agreements.

SOCIAL BENEFITS

The digitalisation and automation of electricity distribution networks not only bring operational and economic benefits, but also generate significant social impacts, especially in terms of accessibility, equity and improvement in the quality of life of users. The implementation of advanced technologies facilitates a more equitable distribution of energy resources, improves the management of services to users and allows for closer and more efficient service.

More equitable and reliable access to energy

The digitalization of power grids facilitates equitable access to energy, especially in rural or remote areas, where traditional infrastructure may be limited. With the integration of technologies such as microgrids and remote monitoring systems, utilities can offer a more reliable supply in these areas, including as a support or back-up to the traditional grid, ensuring that more communities, even in remote areas, have access to quality electricity. In addition, automation allows for more efficient management of energy resources in areas with lower generation capacity, optimising the use of available energy and avoiding prolonged outages. This equitable access contributes to improving living conditions in the most vulnerable communities and supports social and economic development in underserved areas.

Improved identification and targeting of vulnerable users

One of the key benefits of digitalisation is the improved identification and targeting of vulnerable users, allowing for a more efficient allocation of energy subsidies. Through the use of commercial management platforms integrated with advanced metering technologies (AMI), utilities and governments can obtain detailed information on user consumption and detect those households that require support. This accurate information facilitates the implementation of targeted subsidy policies, ensuring that resources efficiently reach those who need them most, contributing to greater equity in energy access. In addition, digitalisation allows continuous and real-time monitoring of the consumption of these users, avoiding fraud or errors in the application of subsidies and ensuring that aid is maintained where it is needed.

Improvement in proximity management and user relations

The automation of distribution systems also drives an improvement in proximity management, i.e. the ability of distribution companies to interact more closely and efficiently with their users. Through the use of digital technologies, such as mobile applications and web portals, users can easily access their consumption data, manage invoices and make claims or queries without having to travel to physical offices. This fosters a more direct relationship between the company and the customer, improving satisfaction and facilitating problem solving. In addition, digital platforms make it possible to simulate the behaviour of the grid under different extreme conditions (weather events or overloads), anticipating possible incidents and user needs, assessing and mitigating risks in the most vulnerable areas, offering personalised services and preventive alerts in the event of scheduled interruptions or supply problems. This greater capacity for foresight, early action, communication and transparency improves the customer experience and strengthens the bond between users and the distribution company.

Job creation in the green economy and training in new technologies

The implementation of digitized and automated networks creates a demand for technical jobs specialized in network management systems, digital technologies, clean energy, advanced data analysis and pro-

cessing, decision-making support systems and algorithms, etc. This generates opportunities for specialized employment at the local level and in vulnerable environments, improving training in the operation and maintenance of digital networks, promoting territorial economic development and preparing the population for the transition to a green economy.

ENVIRONMENTAL BENEFITS

The digitalisation and automation of electricity distribution networks have a significant impact on environmental sustainability, as they allow a more efficient use of energy resources and reduce greenhouse gas (GHG) emissions. Advanced technologies optimize grid operation, minimize energy losses, and facilitate the integration of renewable sources, directly contributing to reducing the environmental impact of the electricity system.

Reduction of energy consumption due to network optimization

One of the most prominent benefits of digitalization and automation is the reduction of energy consumption through the operational optimization of the grid. Advanced technologies, such as advanced distribution management systems (ADMS) and smart meters, enable more efficient operation by detecting and correcting inefficiencies in real-time. The ability to adjust the power distribution according to demand and the current capacity of the system reduces technical and non-technical losses, resulting in lower energy consumption across the grid. This optimization not only generates energy savings, but also relieves pressure on generation sources, especially at times of high demand, contributing to a more sustainable operation of the electricity system as a whole.

Reduction of Greenhouse Gas (GHG) emissions

The reduction of greenhouse gas (GHG) emissions is one of the most outstanding benefits of the digitalisation and automation of electricity distribution networks, as these technologies make it possible to improve energy efficiency, optimise the grid and facilitate greater integration of DERs. By reducing energy consumption and losses during distribution, the need for additional generation, particularly from fossil sources, decreases. Digitalisation also facilitates the greater integration of renewable sources, such as solar and wind energy, as automated systems make it possible to manage the variability of these sources more efficiently. As more DERs are integrated into the grid, energy production becomes more sustainable, further decreasing the carbon footprint of the electricity system.

In addition, automation contributes to the electrification of final consumption, which drives a transition towards cleaner energy sources in sectors such as heating, industry and transport. The latter is particularly important, as the digitized and automated grid can enable more EVs to charge efficiently. As more consumers adopt electric vehicles, dependence on fossil fuels will decrease, contributing significantly to reducing emissions in the transportation sector.

Lower environmental impact of infrastructure

Grid automation and digitalization also allow for optimized infrastructure usage through flexibility solutions, reducing the need to build new electrical facilities, such as distribution lines and substations. By optimizing the use of existing assets, a greater number of users can be served without the need for physical expansion of the network, reducing the environmental impact associated with the construction and maintenance of new infrastructure. In addition, the implementation of technologies such as drones with LIDAR for remote inspection reduces the need for physical interventions in natural areas, protecting local ecosystems and reducing the environmental impact of maintenance operations.

Contribution to the circular economy

The digitalisation of networks also promotes more efficient management of resources, contributing to the concept of circular economy. By extending the life of assets through the use of predictive analytics and preventative maintenance, the need for frequent equipment replacement is minimized. This not only reduces operating costs, but also decreases the amount of materials that must be produced, transported and discarded, which has a positive impact on the life cycle of products and the efficient use of natural resources, also reducing the emissions associated with the manufacture and disposal of new equipment and technologies.

In summary, the digitalization and automation of electrical distribution systems provide a wide range of operational, economic, social, and environmental benefits. From improving operational efficiency and reducing costs to creating new business models and contributing to sustainability goals, these technologies have the potential to significantly transform the electricity sector. For Latin America, the adoption of these solutions represents a strategic opportunity to improve service quality, reduce its environmental impact, and build more resilient and sustainable power grids for the future.

> The digitalization and automation of electricity distribution systems offer a wide range of benefits that significantly impact the operational, economic, social and environmental aspects of the energy sector

04

OVERVIEW OF DIGITALIZATION AND AUTOMATION OF DISTRIBUTION IN LATIN AMERICA

The digitalization and automation of electricity distribution systems have begun to gain traction in Latin America, driven by the growing need to modernize electricity infrastructure, integrate renewable energies, and improve the efficiency and reliability of supply. However, the degree of progress varies significantly among countries in the region due to differences in regulatory frameworks, investment levels, government priorities, and the technological maturity of distribution companies. An example of this is the deployment of smart metering, which varies from values close to 1% for Argentina, Brazil and Peru, to 54% for Costa Rica.

Table 2. AMI deployment by country

Country	Percentage
Argentina	1,0%
Brazil	0,5%
Chile	8,8%
Colombia	3,9%
Costa Rica	54,0%
Ecuador	3,1%
Guatemala	8,4%
Peru	1,3%

Source: ADELAT (2024), IDB (2023), ICE.

Despite the challenges, several countries in Latin America have launched innovative initiatives to digitize and automate their electricity distribution systems. This chapter highlights the most relevant ones, the challenges faced by the countries represented in ADELAT, the progress made and the success stories that mark the path towards a more digitized and automated future.

ARGENTINA

In Argentina, the digitalization of electricity distribution networks has faced significant challenges due to economic conditions and a regulatory framework that has made it difficult to develop large-scale projects. However, in recent years, distribution companies such as Edenor and Edesur have begun to lead initiatives to modernize distribution infrastructure, particularly in metropolitan areas such as Buenos Aires.

One of the key projects in Argentina has been the implementation of smart meters, which has progressed gradually. In Buenos Aires, Edesur and Edenor have started pilot programs in their concession areas. Through ENRE Resolution No. 522/2024, the National Electricity Regulatory Entity established the financing criteria for the Smart Metering Program, to be implemented in the Metropolitan Area of Buenos Aires.

In addition, Argentina is beginning to implement substation automation and improve predictive network management through the use of technologies. For example, in 2019, Edenor began automating medium-voltage substations and feeders, which has allowed it to improve control and fault detection.

Despite these advances, regulatory and economic challenges continue to limit the expansion of these initiatives. Access to finance remains a major obstacle to accelerating grid modernization, and the current regulatory framework does not sufficiently

incentivize long-term investments in digitalization. The authorities have recognized the need to review the regulatory framework to include incentives that promote investment in advanced technologies and the digital transformation of the electricity system.

BRAZIL

Brazil has established itself as a leader in the adoption of smart grid technologies in Latin America, driven by its large electricity market and the need to modernize its grids to integrate renewable energy.

Enel has recently invested in a fuse-based IoT sensor, with integration between the SCADA system and the OMS, which opens automatic commands to report on customers who have run out of power. It has also invested in expanding automatic reclosers, reducing the size of customer blocks per switching section. Another implementation of great impact has been the so-called FDIR (Fault Detection Isolation and Recovery) which allows, through reclosers and automatic switches, to identify where there is a possible fault, isolate the section and restore it as soon as possible. This algorithm prevented more than 10 million customers from losing power in 2023.

In the regulatory field, there is no specific mechanism for recognising investments in digitalisation and automation technologies. However, the regulator considers these solutions as assets, and investments are recognised according to the WACC index, the percentage of which varies according to each distributor.

CHILE

Chile, pionero en la integración de energías renovables en su matriz de generación eléctrica, también ha avanzado en la digitalización de sus redes de distribución. La alta penetración de estas fuentes de energía

Chile, a pioneer in the integration of renewable energies in its electricity generation matrix, has also made progress in the digitalization of its distribution networks. The high penetration of these intermittent energy sources has prompted utilities to adopt advanced technologies, such as distributed energy management systems (DERMS) and energy storage, which enable better integration of renewable energy resources. However, in the distribution segment, the integration of renewable sources is not contemplated in the current remuneration model, which is based on the model company.

The Technical Quality of Service Standard for Distribution Systems requires the installation of smart meters at the outputs of all distribution transformers (Management and Quality System - QMS), no later than January 1, 2027, to keep the distribution network monitored with respect to power flows in the four quadrants. voltage, current and different events and alarms due to product quality or supply interruptions. In addition, it establishes the requirement to install smart metering units in electrodependent customers, critical consumption (hospitals, prisons, cell phone service antennas, pumping and distribution systems of drinking water and gas) and customers with residential electricity generation equipment, within different established deadlines.

However, the decision to install smart meters at customers' energy supply points has been left to their will, due to controversies in the population. Starting in 2018, the attempt to install smart meters nationwide generated rejection from some consumers, who criticized the lack of transparency in the process and questioned the perceived benefits compared to the associated costs. Many consumers resisted the installation, arguing that they would not receive tangible compensation for the change, while the investment would fall directly on them. As a result, the Chilean authorities had to stop the project of massive deployment of smart meters. This situation underscored the importance of better communicating the benefits of these technologies and properly managing public expectations.

Despite the challenges, some companies such as Enel Distribución in Santiago have pressed ahead with digitalization projects, implementing advanced metering infrastructure (AMI) and real-time monitoring systems to optimize demand management and improve supply reliability. In addition, Enel has implemented an automated MV failed section identification and isolation system that acts within 3 minutes, improving resilience and immediate response to network failures.

The electric cooperatives associated with FENACOPEL have begun the installation of the Measurement, Monitoring and Control Systems in the distribution transformers to monitor the electricity grids, and they plan to begin the installation of smart meters for electro-dependent customers, critical consumption and customers with electricity generation equipment in 2025. In addition, the installation of an MDM system is planned to allow different operations to be carried out in an automated way (billing, energy balances, identification of electricity losses and theft, interaction with customers), along with allowing the activation of an app for end customers and a website, where they will be able to monitor daily consumption and their electrical installations every 15 minutes. In addition, all FENACOPEL cooperatives have a SCADA system that allows them to monitor and manage reclosers in the distribution networks, which allows them to carry out automated or manual load transfers.

COLOMBIA

From the point of view of public policies, no digitalization roadmap has been defined for the electricity sector, beyond CONPES documents or the digital plan of government entities. From a regulatory perspective, the Energy and Gas Regulatory Commission (CREG) included in the electricity distribution remuneration methodology (Resolution 015 of 2018) a mechanism to remunerate assets with differential conditions from conventional devices. Thus, when there are assets with technical characteristics different from those of the established construction units, grid operators may request the CREG to create “special construction units” to be included in their investment plans, which may include advanced technologies for automation, digitalization and network monitoring, among others. The application must be accompanied by the technical considerations that justify its creation, the detailed cost of each piece of equipment that composes it and the associated installation costs. This mechanism, and the orientation towards annual service quality goals, allows distribution companies to integrate new technological solutions more easily and receive a tariff remuneration for these investments.

Regarding advanced metering, Resolution 40072 of 2018 of the Ministry of Mines and Energy established guidelines and technical requirements for advanced metering infrastructure, and established a goal of coverage of AMI meters of 75% by 2030. The CREG, through Resolution 101 001 of 2022, defined that network operators can submit AMI deployment plans in their areas of operation, the costs of which can be assumed by the company or the customer. Additionally, it created the figure of Independent Data and Information Manager (GIDI).

The country has launched several smart grid pilot programs in cities such as Bogotá and Medellín. In Bogota, Enel Colombia has carried out a pilot since 2016 that includes the installation of smart meters allowing detailed monitoring of energy consumption and a greater capacity to manage peaks in demand, based on the company’s international experience, in countries such as Italy and Spain. As of June 2024, advanced meters have been installed for 76,473 customers.

Other projects developed by Enel Colombia are:

Digital-EnelfleX Platform: The main objective of this pilot is to automate and digitize the distribution network, combining technologies, systems and customers, to identify,

prevent and resolve network congestion and eventual overload failures in an area of the northern savannah of Bogotá. The pilot will solve congestions that can affect the energy supply to more than 322 thousand customers.

ToGo: It consists of the construction of a virtual replica of the electrical grid, which works as a digitized, updated and accurate infrastructure of the physical network, using technologies such as terrestrial and aerial LiDAR, 360° photography, photogrammetry, rectangular photography, among others, with which areas with vehicular access, pedestrian areas, indoor spaces are scanned (such as substations or buildings), as well as rural areas. This digital twin, complemented by technologies such as Data Driven, artificial intelligence, BIM, augmented reality, IoT, among others, will allow obtaining a central coordination platform with agile organization and online information flows to leverage the operation and digital development of the system. To date, nearly 29,000 km of Cundinamarca's road network have been traveled, 300 MV circuits have been digitized, 4000 km of the LV network has been inspected and 12,400 transformers have been updated.

In addition, since 2021, Enel Colombia has been developing an ambitious plan to improve communications reliability, expanding its fiber optic network to the substations and operating equipment of the medium-voltage electricity grid, which in addition to improving the reliability of the links and strengthening the supervision of its electrical assets, It paves the way for the next phase of the automation program, corresponding to the self-recovery of the network in the event of failures, within the ADA (Advanced Distribution Automation) concept.

COSTA RICA

In Costa Rica, D&A penetration is at an intermediate level, with marked differences between electricity distribution companies. However, the country is one of the leaders in the region in smart metering deployment, with coverage of more than 50%.

Companies that have invested more in technology have modernized their SCADA systems and implemented some DMS applications. The Costa Rican Institute of Electricity (ICE) is in the implementation phase of a six-year project that encompasses a new SCADA system, OMS module and full DMS functionalities. In addition to the above, a part of the medium voltage network is being modernized with equipment that can be integrated with ADMS, such as reclosers, voltage regulators and sensors. In addition, advanced measurement equipment (AMI) is being integrated.

In addition, ICE acquired CyME software as the tool for electrical studies of distribution, distributed generation, hosting and coordination of protections. The main objective is to comply with the provisions of current national regulations.

ECUADOR

In Ecuador, the digitalization of electricity distribution networks has gained momentum in recent years, driven by the need to improve operational efficiency and reduce energy losses in the grid. The National Electricity Corporation (CNEL) and other local distributors have begun implementing digital technologies to modernize their electricity infrastructure, including automation projects and advanced grid management. One of the most important milestones in Ecuador has been the implementation of smart meters in several cities. In 2020, CNEL began installing more than 150,000 smart meters in Guayaquil and other urban areas. For its part,

in 2024 Centrosur signed a technological cooperation agreement with Gridspertise, with the aim of carrying out actions for the implementation of smart metering initiatives, advanced infrastructure, modernization and digitalization of the distribution network.

In the regulatory sphere, discussions have begun to update the regulatory framework in order to encourage investments in advanced technologies and ensure that distributors have the necessary resources to carry out the modernization of the network. The Agency for the Regulation and Control of Energy and Non-Renewable Natural Resources (ARCERNNR) has begun exploring options to facilitate the implementation of smart grid technologies.

GUATEMALA

In Guatemala, there is a lag in digitalization and automation, mainly derived from low investment in telecommunications services, which limits the growth of technology that can be managed remotely. For the Guatemalan market, the implementation of digitalization and automation is of great relevance since requests for distributed generation connection have grown considerably during the last year, so it is important to promote regulatory changes that encourage an acceleration of the penetration of smart metering, which currently reaches 8.4% of its market.

Guatemalan regulation allows for the recognition of investments in technology made by distributors in two different ways. The first, when the tariff study is carried out that defines the Distribution Value Added (VAD) assigned to the distributors and which is in force for five years. The second, when the investment is capitalized and the tangible or intangible asset generated comes into operation. This involves notifying the regulator about the investment made so that it is recognized and the VAD is adjusted. However, there are investments such as those made in smart meters that are not recognized by the regulator.

Starting in 2019, companies such as Energuate began digital transformation processes that seek to update the technological platforms that support the distribution operation. These projects include the implementation of the GIS platform, the Utility Network module for the geographical management of the distribution network, the implementation of an OMS system and the updating of the SCADA platform. Energuate already has 37% of remotely controlled equipment, and is the first electricity distribution company in the country to implement a SCADA in the AWS cloud.

PERU

In Peru, the digitalization of distribution networks is also advancing, albeit gradually. Smart meter pilot projects have already been implemented in the country, with a focus on improving measurement accuracy and reducing non-technical losses, for which the regulator has defined the technical characteristics that the meters must have. For example, Pluz Energía has installed 22,663 smart meters in the low-voltage network. In terms of network automation, 30% of the medium-voltage feeders of the same company have remote control and fault location equipment. However, regulation does not currently recognize these assets as mandatory planning equipment.

The regulatory process for determining Distribution Value Added Costs (VAD) in Peru allows for the incorporation of additional charges for technological innovation, energy efficiency and replacement of smart metering systems. Additionally, it includes incentives to improve the quality of service. However, these incentives are designed for one-off projects that serve as an initial test, but not for the digitization and automation of the network. In addition, Peruvian regulation follows the model company scheme, which does not recognize the real investments made by distributors.

05

DRIVERS OF DIGITALIZATION AND AUTOMATION

Despite progress in some countries, the digitalization of distribution networks in Latin America faces a series of barriers that have limited its large-scale adoption. These barriers include the lack of adequate financing, the need to upgrade existing infrastructure, and the absence of clear regulatory frameworks that incentivize long-term investments. However, there are also significant opportunities to advance digitalization across the region.

Latin America faces a unique set of challenges in the digitalization of its electricity distribution networks, derived from its economic, social and geographical heterogeneity. In many countries, distribution networks are still obsolete and require significant investment to modernize. In addition, the technological gap between urban and rural areas is considerable, making it difficult to implement digital solutions in some regions.

The digital transformation of electricity distribution networks in Latin America will be driven by a number of key factors that enable, facilitate and encourage the adoption of advanced technologies. These drivers include both external elements, such as regulatory frameworks and access to financing, and internal elements, related to the strategies of distribution companies and the development of technical capacities.

PUBLIC POLICIES AND REGULATORY FRAMEWORKS

Governments and regulators play a central role in designing policies that facilitate grid modernization, while protecting consumer interests and promoting competitiveness in the electricity sector. In Latin America, regulatory frameworks have been, in many cases, slow to adapt to the needs of digitalization and automation of electricity grids. In many countries, regulations do not incentivize utilities to invest in advanced technologies, as remuneration schemes are not aligned with the costs associated with infrastructure modernization. Creating digitalization roadmaps for the electricity sector should be a priority for governments, as they provide a clear vision of the steps to be taken to modernize distribution networks. These roadmaps can include specific goals, timelines, and detailed planning for the implementation of digital technologies. In addition, it is necessary for these policies to include regulatory guidelines for the evaluation of the benefits of digitalization, establishing a methodology for the economic and technical assessment of the projects that are implemented. This can include key indicators such as improvement in service quality indicators, impact on operational efficiency, and the integration of renewable energy.

Another key aspect is the creation of a framework for assessing the digital maturity of the electricity sector. Regulators must have tools that allow them to evaluate the current state of digitalization of distribution companies, comparing it with international standards and establishing goals for improvement over time. This type of assessment can help identify gaps in infrastructure, technical capabilities, and areas where greater regulatory support or financial incentives are needed.

Some Latin American countries are introducing reforms to remuneration schemes to incentivize investment in advanced digitalization technologies. However, one of the most common approaches, based on the model enterprise, has significant disadvan-

tages that can limit investment in digitalization and automation. Under this mechanism, the remuneration of distribution companies is set ex ante, that is, it is based on the estimated costs of an "ideal company" that operates efficiently. In this scheme, any savings in the company's real costs translate into higher profits. Thus, companies tend to delay their improvement plans and do not have adequate incentives to make long-term investments in advanced technologies, such as digitalization and automation of networks. Because compensation is not adjusted to reflect the actual costs incurred by the company in implementing new technologies, utilities may be less motivated to undertake investments that, while necessary to modernize infrastructure and improve efficiency in the future, do not immediately translate into financial benefits.

To avoid this behavior, regulators should design schemes that incentivize companies to invest in a sustained manner over time, with a more immediate compensation system, preferably on an annual basis. The state of the art and modern regulations suggest that a good remuneration scheme should consider both the recognition of real costs and incentive schemes that encourage efficiency and continuous improvement in performance indicators. A more balanced approach is to move towards schemes based on real costs, complemented by incentives for efficiency. This type of scheme would ensure that distribution companies are fairly compensated for their investments in digitalization, while remaining motivated to continuously improve their performance. Another effective approach is to allow distribution companies to submit investment plans that include special unconventional assets, such as those related to advanced technologies, including physical and digital assets (software), with agile time ranges for approval. In addition, passthrough schemes can be implemented, based on the presentation of real costs together with control mechanisms, such as generic catalogs of assets related to the energy transition, but which can be detailed for each technological project.

Finally, the adoption of technological norms and standards is essential to guarantee the interoperability of digital systems and the security of electricity grids. In many countries, regulators have begun to define standards for the implementation of advanced metering technologies, distributed energy management systems (DERMS), and real-time monitoring platforms. These standards will not only ensure interoperability between different systems and technologies, but will also provide distribution companies with the necessary certainty to plan their long-term investments.

ECONOMIC INCENTIVES AND ACCESS TO FINANCING

Investments in smart grids, sensors, advanced meters, and automation systems are costly. Financing is one of the main barriers to the digitalization of distribution networks in Latin America. The upfront costs of implementing advanced technologies, such as smart meters and automation systems, are high, and utilities often face difficulties in accessing affordable financing. Since initial investments in advanced technologies are often high, distribution companies in Latin America rely on various sources of financing to carry out these projects.

In addition to remuneration schemes, some countries have begun to offer tax incentives and financial support programmes for companies investing in the modernisation of their distribution networks. These incentives may include tax breaks, subsidies for the implementation of advanced technologies, and access to preferential financing. Multilateral financial institutions also play a crucial role in providing financing for grid modernization projects in Latin America. These institutions not only offer loans at preferential rates, but also provide technical assistance and support for capacity building in distribution companies, and promote the development of regulatory regulations that facilitate access to financing for digitalization projects.

Collaboration between the public and private sectors is another key factor driving the digitalization and automation of electricity grids in Latin America. Public-private partnerships allow utilities to access private financing for modernization projects, while governments provide incentives and regulatory guarantees that reduce risk for private investors.

TRAINING AND CAPACITY BUILDING

One of the key drivers of the digitalisation and automation of electricity distribution networks is training and capacity building both within distribution companies and in the general population. The adoption of advanced technologies requires technical staff to be highly trained in areas such as data analysis, digital systems management, cybersecurity, and automated network operation.

In addition to technical training, it is crucial to communicate and educate the population about the operation and advantages of new technologies, such as smart meters. Many times, the lack of information about how these technologies work or about the benefits they bring can generate mistrust or resistance among users. To maximize the success of digitalization, it is essential that utilities and governments launch awareness campaigns that explain, in a clear and accessible way, how these tools improve the efficiency of the electricity system, optimize energy consumption, and enable more accurate monitoring.

Specifically, in the case of smart meters, users should be informed that these devices not only allow for more accurate billing, but also give them the ability to better manage their energy consumption in real-time, which can translate into significant savings. By understanding the benefits, such as the ability to identify consumption patterns and adjust energy use to reduce costs, users will be more inclined to embrace these technologies and actively participate in energy efficiency programs. In addition, compensation mechanisms or incentives could be considered for users affected by the transition to new technologies, thus mitigating the perceived economic impact and encouraging wider acceptance.

The effort to educate the population not only favors a better adoption of technologies, but also fosters trust between users and distribution companies, improving the customer-company relationship. This, in turn, facilitates the implementation of future technological advances in the network and ensures that the modernization process is perceived as a common benefit.

TELECOMMUNICATIONS INFRASTRUCTURE

One of the biggest challenges for the digitalization and automation of electricity grids in Latin America is telecommunications infrastructure, especially in rural and isolated areas. Digitalization requires robust communication networks that enable the transmission of large volumes of data in real time, from distributed sensors and smart meters to centralized control systems.

In urban areas, these networks are usually well-developed, but in remote areas, limited connectivity can slow down the deployment of advanced technologies. The lack of adequate telecommunications infrastructure in rural areas prevents the deployment of smart grids and the integration of technologies such as advanced metering and substation automation. In these areas, where the quality of the electricity supply is most vulnerable, the implementation of telecommunication solutions, such as advanced wireless, satellite or even 5G networks, is essential to ensure that networks can operate efficiently and reliably. This would allow for better management of local energy resources and improve service to rural users.

To overcome these challenges, greater investment in rural-specific telecommunications infrastructure is required. Governments and regulators should promote projects that

include the expansion of communication networks, both to ensure connectivity and to enable the integration of digital technologies in these areas. The adoption of solutions such as mesh networks and the combination of satellite technologies with 5G could offer wider and more affordable coverage in remote regions.

RESEARCH, DEVELOPMENT AND INNOVATION (R+D+I)

The promotion of the digitalisation and automation of distribution networks also depends to a large extent on investment in research, development and innovation (R+D+i). The creation of new technologies and the adaptation of advanced solutions to the particularities of Latin American markets are essential for the success of digital transformation.

International collaboration also plays an important role in driving innovation in Latin America. Open innovation programs, which allow the transfer of knowledge and technologies between different countries and companies, are helping to accelerate the development of digital solutions in the region. Latin American companies and governments are working with international partners to adopt and adapt advanced technologies developed in other parts of the world.

In conclusion, the drivers of the digitalization and automation of electricity distribution networks in Latin America are multiple and complex. Regulatory frameworks and economic incentives are critical to encouraging utilities to adopt new technologies. Access to financing, both public and private, also plays a key role in the implementation of network modernization projects. In addition, investment in research and development, technical capacity building, and cooperation between the public and private sectors are essential to ensure the success of digital transformation in the region. While the challenges are considerable, the benefits of digitalization and automation are clear and represent an opportunity for Latin America to modernize its electricity infrastructure and build more efficient, resilient, and sustainable grids for the future.

> “Despite progress in some countries, the digitalization of distribution networks in Latin America faces a series of barriers that have limited its large-scale adoption

06

INTERNATIONAL BEST PRACTICES IN DIGITALIZATION AND AUTOMATION

Around the world, many regions and countries have made significant progress in modernizing their electricity grids, implementing advanced technologies that enable more efficient, resilient, and flexible management. International experiences offer valuable lessons and good practices that can be adapted to local contexts in Latin America, providing a point of reference for the development of effective strategies in the region.

UNITED STATES

The United States has been one of the main references in the implementation of Smart Grids, thanks to its combination of favorable public policies, robust financing and a focus on innovation. The federal government has played a crucial role since 2009 through the American Recovery and Reinvestment Act (ARRA). Under this law, the Department of Energy and the electric industry have invested in 99 projects involving more than 200 utilities and other organizations to modernize the electric grid, interoperability, and collect an unprecedented level of data on smart grid operations and benefits, including initiatives such as the Smart Grid Investment Grant (SGIG) and the Smart Grid Demonstration Program (SGDP), which have provided funding for a wide range of grid modernisation projects.

The success of digitalization in the United States is also due to its flexible regulatory framework. The Federal Energy Regulatory Commission (FERC) and state commissions have adopted an incentive approach, where utilities can recoup some of their investments in advanced technologies through tariffs.

In California, one of the most advanced and automated electric grids in the world has been developed by Pacific Gas and Electric (PG&E), which has pioneered the implementation of an automated distribution grid that uses advanced sensor and software technologies to improve service reliability, optimize grid performance and significantly reduce power outages. One of the key systems in PG&E's automated network is the Distribution Management System (DMS), which combines substation automation technologies with a centralized control system. The DMS enables optimized demand management, ensuring that energy distribution is efficient and that critical loads can be prioritized in emergency or high-demand situations. This is especially important in California, where heat waves can lead to spikes in energy consumption, making it crucial that the grid is able to adjust dynamically.

PG&E has also implemented advanced energy storage systems, such as high-capacity batteries, that allow energy supply and demand to be balanced more efficiently. These storage systems are managed through the automated platform, which ensures that the use of energy resources is optimal and that renewable energy is used to the maximum. This has helped to improve grid stability and reduce reliance on more polluting energy sources during times of peak demand. The implementation of these technologies has had a significant impact on the reliability of electric service in PG&E's area of operation. Service interruptions have been reduced by more than 40% in areas where advanced network automation has been deployed.

Southern California Edison (SCE) launched a project that integrates data analysis software and automated control technologies, such as Fault Management Devices (FLISRs) to reduce service interruption times. These devices can automatically recognize faults and redistribute electricity autonomously, improving grid reliability.

Another example is Consolidated Edison's (Con Edison) Smart Grid project in New York, which leverages a combination of software and hardware technologies to make the grid more resilient and flexible. With the adoption of remote automation devices and smart sensors, Con Edison is able to monitor and control the grid in real time, optimizing power distribution and integrating a growing number of renewable sources.

EUROPEAN UNION

The Grid4EU project is one of the most advanced initiatives in the European Union for the digitalisation of electricity distribution networks, demonstrating the feasibility of advanced grid management solutions to enable active energy distribution. This project involves six leading electricity distributors from Europe: Enedis (France), Endesa (Spain), Enel Distribuzione (Italy), RWE (Germany), Vattenfall (Sweden) and CEZ (Czech Republic), each with a particular focus on the implementation of digital technologies and automation.

Grid4EU started in 2011, is co-funded by the European Commission, and has been a key platform for testing and validating new technologies that enable utilities to transform the way they manage and distribute energy. The impact of the Grid4EU project has been significant, not only for the technical results obtained, but also for its ability to lay the foundations for future regulatory and operational frameworks that allow a faster transition to smart grids in Europe. In addition, it has provided valuable insights on how to design and implement advanced electrical infrastructures that can be replicated and adapted in other countries and regulatory contexts. Grid4EU has also contributed to the development of common standards and best practices across the European Union, facilitating interoperability between different technologies and systems implemented by distribution operators.

More recently, the EU has continued to fund, through the Horizon Europe project, initiatives aimed at the development of advanced projects and functionalities of distribution networks. Finally, EU support for distributors through the creation of specific working groups and partnerships is crucial, for example:

The Smart Grids Task Force is a working group of the European Commission dedicated to the development of smart grids. Since 2009, it has brought together distributors, operators and regulators to discuss key issues such as interoperability, cybersecurity and demand management. It promotes common standards to facilitate the integration of renewable energy and improve the resilience of grids in Europe. Their work is essential for the transition to a sustainable and digital energy system, aligned with the European Green Deal.

E.DSO (European Distribution System Operators) is a European association that brings together the main operators of electricity distribution networks to promote the development of smart grids. E.DSO works in key areas such as digitalization, cybersecurity and integration of renewable energies, encouraging the adoption of advanced technologies and innovative practices in distribution networks. Through collaborations and joint projects, E.DSO facilitates knowledge sharing and sets common standards to improve the resilience and efficiency of networks in Europe. It aims to support Europe's energy transition towards a sustainable and consumer-oriented system.

Italy has established itself as one of the leaders in digitalization in Europe, thanks to its focus on the implementation of stable and high-speed communications technolo-

gies, as well as the development of smaller network topologies and an optimized infrastructure for rapid action in the event of failures. This model has allowed the country to reduce unavailability times and improve the quality of service. According to data from the national electricity operator, Terna, average interruptions have been reduced to less than 50 minutes per year per user in urban areas in recent years, a figure well below the European average

One of the greatest successes in the digitalisation of Italian networks has been the implementation of the Telegestore project, which began in 2001 with the introduction of smart meters by Enel Distribuzione, covering more than 35 million users. This system was a pioneer in Europe, allowing real-time monitoring and management of consumption, resulting in a drastic improvement in fault detection and resolution. The system uses a high-speed communications network to manage the distribution infrastructure and ensure real-time data availability, optimizing response to any contingency.

One of the most important achievements of digitalization in Italy has been the reduction of deviations in the quality of supply, such as variations in voltage or frequency of supply. Thanks to the use of advanced control technologies and constant monitoring of the grid, Italy has managed to minimize these variations and maintain a more stable and reliable electricity supply. This has been made possible in large part by the use of automation systems that allow grid operators to make real-time adjustments to load balance and maintain system stability.

One of e-distribuzione's most recent projects is the **Network Digital Twin**. This project creates a digital replica of the electricity distribution network, enabling real-time monitoring and predictive analysis of energy flows. With this technology, e-distribuzione can anticipate failures, optimize grid management and facilitate the integration of renewable energies. The Digital Twin improves grid resilience and efficiency, supporting the energy transition in Italy. The digital replica of the network also includes the ability to scan airlines with drones and secondary and primary cabins with ground-based lasers. The software analyzes this data to detect anomalies and optimize maintenance activities, preventing critical problems.

In Spain. E-distribución leads the digitalization of electricity grids with several innovative projects. Network digitalization includes the use of a Digital Twin to simulate and optimize asset behavior in real time, improving efficiency. Projects such as Aerial-Core, which uses drones to inspect and manipulate elements of the network, and Smart5Grid, which implements 5G to ensure the safety of operators and optimize infrastructure automation. Other projects include Resisto, which increases resilience to weather events, and LEO Satellite, which allows remote control of the grid in remote areas. In addition, E-distribución has carried out proofs of concept with start-ups in areas such as the supervision of power lines and waste management near overhead networks. It is also investigating grid flexibility through projects such as Coordinet and BeFlexible, which seek to improve stability using underutilized resources and electric mobility.

UNITED KINGDOM

The UK has been one of the pioneers in creating innovative energy markets, driven by digitalisation and automation of electricity distribution. One of the most prominent initiatives in the UK is the creation of flexibility markets, where businesses and consumers can offer demand matching and distributed generation services to stabilise the grid. This has been facilitated by the digitalization of power grids and the adoption of technologies such as advanced metering infrastructure (AMI) and demand management platforms. Companies such as UK Power Networks have implemented pilot projects in London and other cities to better manage peak demand and reduce the need for investments in new infrastructure.

The UK has also made progress in grid automation to facilitate the integration of renewables. In Scotland, Scottish Power has developed projects that include substation automation and the use of AI to optimize the flow of renewable energy into the grid. This has made it possible to increase the share of wind energy in the country's electricity grid without compromising the stability of the system.

The UK's electricity sector regulator, Ofgem, has been a key player in promoting digitalisation by introducing regulatory frameworks that encourage innovation. Through its RIIO (Revenue = Incentives + Innovation + Outputs) regulatory model, Ofgem has provided financial incentives to utilities that adopt advanced technologies to improve grid efficiency and reliability. In RIIO 3, distribution companies receive a "quota" of resources specifically allocated for technological innovation, which allows them to make investments in new technologies and digital solutions without relying exclusively on the revenues generated by traditional tariffs. This approach is relevant for Latin America, where the inclusion of a regulated "quota" for innovation in national regulatory frameworks could accelerate the digital transformation of the electricity sector.

JAPAN

Japan is a benchmark in network automation, especially after the devastating earthquake and tsunami of 2011, which exposed the vulnerability of electrical infrastructure. Since then, Japan has implemented a number of initiatives to improve the resilience of its network through digital technologies and advanced automation. One of the major developments in Japan has been the adoption of smart microgrids, particularly in areas prone to natural disasters. The Sendai microgrid in the Tohoku region is a prominent example. This network has been equipped with automation systems that allow the microgrid to operate independently in the event of disconnection from the main grid, guaranteeing the electricity supply during emergencies. In addition, the integration of energy storage and distributed generation has enabled the microgrid to effectively manage local supply and contribute to the stability of the main system.

Japan has also led the way in implementing advanced distribution management systems (ADMS), which enable utilities to anticipate and manage outages more efficiently. Companies such as Tokyo Electric Power Company (TEPCO) have adopted these technologies to optimize grid operation, reduce downtime, and improve resilience against future disasters.

Japan has implemented specific regulatory policies to encourage digitalization as a key tool to improve grid resilience. The National Energy Resilience Strategy sets clear targets for the digitalisation of electricity grids, prioritising automation and the creation of more flexible distributed systems.

> Around the world, many regions and countries have made significant progress in modernizing their electricity grids, implementing advanced technologies that enable more efficient, resilient, and flexible management

COREA DEL SUR

South Korea, through its main energy company, Korea Electric Power Corporation (KEPCO), has developed one of the most advanced power grids in the world, using effective integration of information and communication technologies (ICTs) throughout the distribution system. One of the key projects within KEPCO's digitalization has been the implementation of a platform that connects more than 2 million smart meters and other IoT devices, providing constant monitoring and the ability to efficiently manage energy supply and demand.

KEPCO has also developed a data analytics platform that uses advanced machine learning algorithms to predict energy demand with high accuracy, optimize grid load, and perform simulations on grid behavior in different scenarios. In addition, KEPCO's Advanced Network Management System (ADMS) enables the company to detect cyber threats, perform vulnerability scans, and respond quickly to attempted system outages. This has made KEPCO a global benchmark in terms of cybersecurity applied to electricity grids.

> International experiences offer valuable lessons and good practices that can be adapted to local contexts in Latin America, providing a point of reference for the development of effective strategies in the region

07

CONCLUSIONES Y RECOMENDACIONES

The digitalization and automation of electricity distribution systems in Latin America represent a crucial opportunity to modernize the region's energy infrastructure, improve operational efficiency, reduce energy losses, increase grid resilience, and facilitate the integration of renewable energy. As the region moves towards a more sustainable energy future, the adoption of advanced digital technologies is critical to meeting the growing challenges of energy demand, decarbonization, and security of supply.

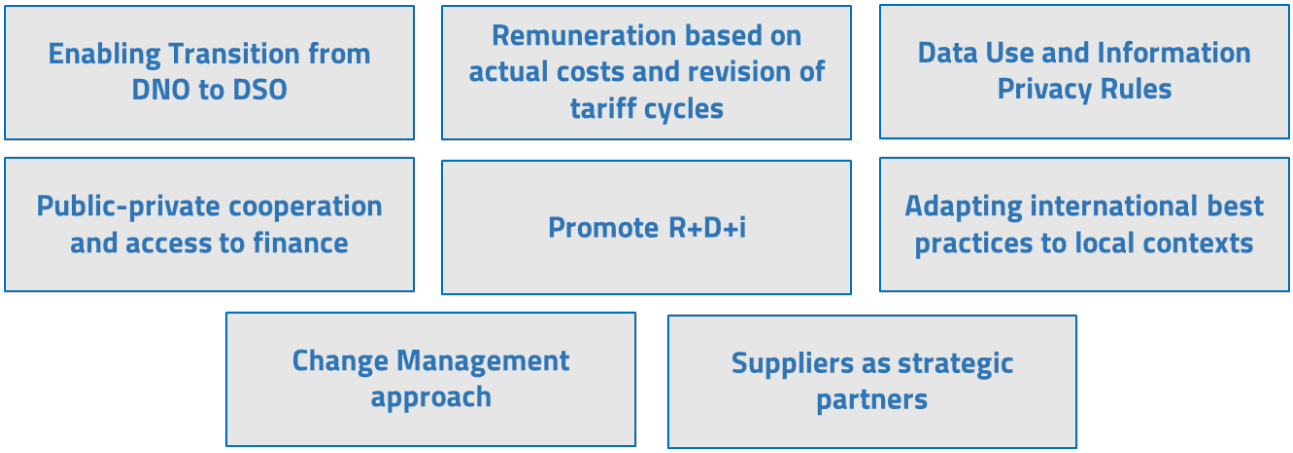
The regulatory framework plays a central role in promoting or limiting the digitalisation and automation of distribution networks. Countries that have implemented clear and consistent regulations to incentivize investment in smart grids and advanced technologies have made faster progress in modernizing their grids. On the other hand, in those countries where regulatory frameworks are ambiguous or do not include specific incentives for digitalization, distribution companies have been more reluctant to make the necessary investments.

The digital transformation of electricity distribution networks requires significant investments, which often exceed the financial capacities of utilities, especially in developing countries or countries with distressed economies. Public-private cooperation and access to affordable finance, both through multilateral banks and private initiatives, are essential to unlock the necessary investments.

The success of digitalization and automation depends not only on technology, but also on human capital and the ability of companies to adapt to these changes. The development of specialized technical capabilities in the electricity sector is crucial to ensure that investments in technology are implemented effectively. In addition, research, development and innovation (R+D+i) must be encouraged to adapt global technologies to the specific realities of the region. The creation of innovation centers, collaboration with universities and research centers, and the transfer of international knowledge are key factors in promoting the technological modernization of distribution networks in Latin America.

Based on the above conclusions, the following recommendations are proposed for Latin America to advance in the digitalization and automation of its electricity distribution networks.

Figure 3. Recommendations for advancing the D&A of electricity distribution



ENABLING THE TRANSITION TO A DSO IN DISTRIBUTION SYSTEMS

A crucial step in driving the digitalization of distribution networks is to enable the shift from the traditional distributor to a Distribution System Operator (DSO). This model allows distribution companies not only to manage the physical infrastructure of the network, but also to facilitate and encourage the integration of different technologies and platforms for monitoring, digitalization and automation. The DSO acts as an enabler for the incorporation of distributed renewables, energy storage, demand management systems and electric vehicles, promoting a more flexible and efficient grid. The adoption of the DSO model also helps to define more clearly the responsibilities and rights of the different actors using the distribution network, such as distributed generators, energy market operators and consumers. This more structured framework is key for digitalization technologies to be able to work in an integrated and efficient manner, maximizing the benefits for both operators and end-users.

REMUNERATION BASED ON ACTUAL COSTS AND REVISION OF TARIFF CYCLES

One of the biggest obstacles to encouraging investment in digitalisation and automation in the electricity distribution sector is the remuneration mechanism based on the model company. In this scheme, the remuneration of distributors is set ex ante, taking as a reference the costs of an ideal company. This means that any cost savings that a real company achieves translates into higher profitability, but it does not directly incentivize the adoption of innovative technologies such as digitization or automation. Thus, while this system can foster operational efficiency, it does not create the right incentives for investment in technological modernization in the long term.

Therefore, it is essential to review both the remuneration method and the investment recognition periods. A more favourable approach would be to move towards a cost-based pricing method, which more immediately recognises investments in digitalisation, together with a package of efficiency incentives. This blended scheme would ensure that distributors are fairly compensated for their modernization efforts while also promoting continuous improvements in service quality and operational efficiency. In addition, reducing the periods of recognition of investments would provide greater certainty to companies, incentivizing them to make early investments in advanced technologies that benefit the entire electricity system.

DATA USE AND INFORMATION PRIVACY RULES

In the digitalization process, it is essential to develop clear rules on data use and information privacy. Digitized distribution networks generate large volumes of data on energy consumption and network status, posing significant challenges in terms of information security and protection of consumer privacy. Regulations should be put in place that authorize the active participation of Distribution System Operators (DSOs) in data management, but with strict safeguards that ensure that information is used ethically and with the appropriate consent of users. These standards should include cybersecurity protocols, ensuring that digitized networks are not vulnerable to cyberattacks and that data is handled securely and responsibly.

PUBLIC-PRIVATE COOPERATION AND ACCESS TO FINANCE

Cooperation between the public and private sectors is essential to mobilise the investments needed for the digitalisation and automation of distribution networks. Investments in these technologies, while essential, can be substantial and put pressure on rates if not properly managed. To minimize this impact, governments can facilitate access to preferential financing and innovative mechanisms that ensure that investments are distributed in a more balanced manner and without significantly affecting costs for consumers.

One solution is to promote alliances with multilateral banks, financial institutions and private actors, which allow capital to be mobilized under conditions accessible to distribution companies. The creation of national or regional funds for the modernization of electricity infrastructure, with preferential conditions for digitalization and automation projects, could also reduce investment costs, which would avoid a direct increase in tariffs. These funds can prioritize projects that modernize infrastructure, improve efficiency, and generate long-term benefits, offsetting part of the investment through operational improvements and the reduction of energy losses.

In addition, the implementation of risk mitigation mechanisms, such as government guarantees, can attract the participation of the private sector, reducing the perception of risk and, consequently, the costs associated with financing. This is particularly relevant in emerging markets or rural and isolated areas, where telecommunications and energy infrastructure is more limited. By reducing the cost of capital and sharing risk between the public and private sectors, these strategies not only ensure the viability of projects, but also help mitigate the impact on rates.

PROMOTE RESEARCH, DEVELOPMENT AND INNOVATION (R+D+I)

Research, development and innovation (R+D+i) is essential to adapt emerging technologies to local particularities, ensuring that solutions are suitable for their energy, economic and climate realities. Governments can play a crucial role in this process by providing incentives and creating programmes that encourage innovation in companies, universities and research centres. In addition, innovation labs and pilot platforms can be established, where emerging technologies are tested and validated in controlled environments before their large-scale implementation.

Countries in Latin America can also take advantage of the knowledge and best practices of countries that have already made progress in digitizing their networks, such as the United States and European countries. Establishing joint projects and participating in global energy innovation initiatives can accelerate the adoption of proven technologies and facilitate knowledge transfer. In addition, it is important to promote an open innovation model, in which distribution companies, universities, research centers, and technology providers collaborate closely to develop technological solutions that re-

spond to the specific challenges of the electricity sector in the region. This cooperation can generate synergies that maximize results and accelerate the process of modernizing electricity grids.

ADAPTING INTERNATIONAL BEST PRACTICES TO LOCAL CONTEXTS

Latin America can learn from the experiences of leading countries in digitalization. However, it is critical that technological and regulatory solutions are tailored to the specific realities of each country in the region. Governments and utilities should evaluate international best practices and adjust their implementation according to the particularities of their networks, infrastructure, and energy demand. In addition, it is recommended that regulators promote smart grid pilot projects in different parts of the region, adapted to urban and rural contexts, to test technological solutions and obtain learnings that can be scaled later.

CHANGE MANAGEMENT APPROACH TO D&A

Digitalization and automation are not simply technological projects; represent a strategic initiative that fundamentally transforms the way an electricity distribution company operates. For these initiatives to be successful, it is crucial that they are supported by the highest level of the organization and are fully aligned with its long-term vision. This means that the digitalization process should be seen as a strategic priority and not just as a one-off operational improvement. Senior management must be firmly committed to leading and promoting this change, as it will affect all areas of the company, from technical operation to customer management.

The transition to digitized and automated networks involves profound organizational changes, which require not only the implementation of new technologies, but also the acquisition of new skills and the adaptation of operational and management processes. This requires the creation of a dedicated, cross-functional team that includes experts in technology, operations, finance, customer service, and other key areas.

In addition, the financial justification for digitization and automation must be approached from a different perspective than the traditional cost-benefit analysis. Not only should tangible savings in operating costs, such as reduced outages or decreased maintenance costs, be considered, but also intangible savings that may be more difficult to quantify but have a significant long-term impact. These include improved customer satisfaction, increased operational resilience, and the ability to integrate future technologies, such as renewables and electric vehicles. These intangible benefits are critical to justifying investments, as they future-proof the company and allow it to stay competitive in a rapidly evolving environment.

SUPPLIERS AS STRATEGIC PARTNERS

In the process of digitalization and automation, technology providers should not be seen simply as sellers of products or services, but as strategic partners in the transformation of the distribution company. Vendors play a crucial role in the successful implementation of advanced technologies and must be an integral part of the process from the planning phase to the execution and maintenance of technology solutions.

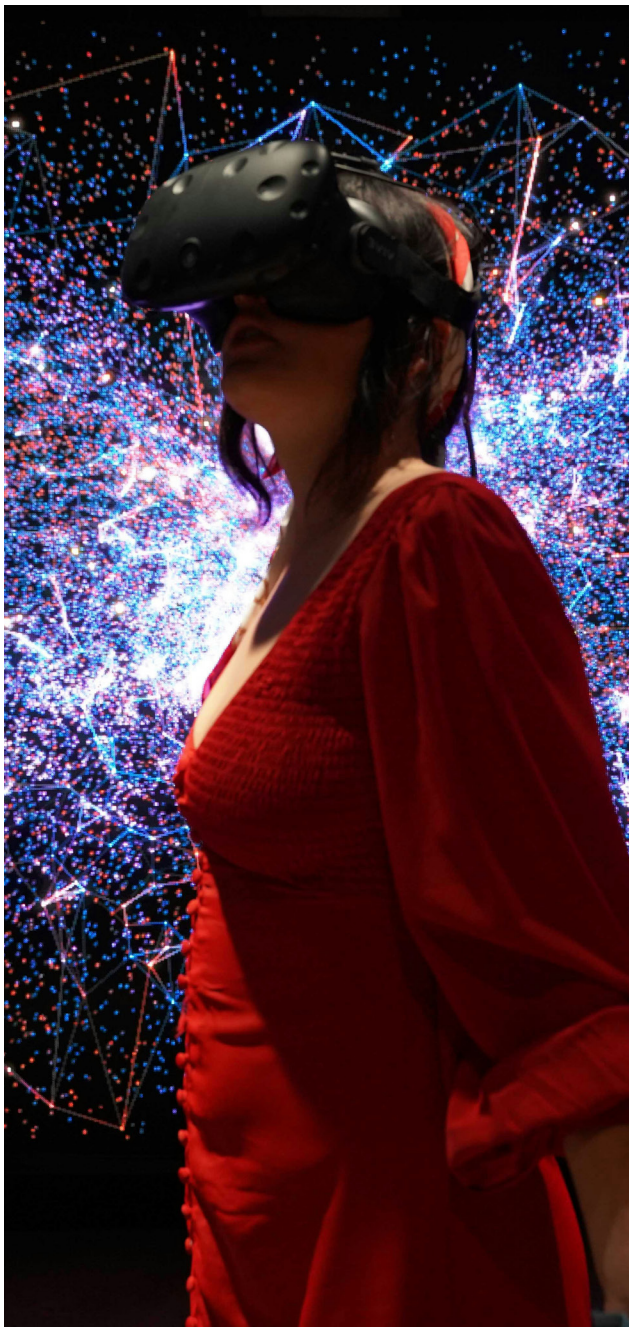
It is important to establish collaborative relationships with suppliers who understand the company's long-term goals and can adapt to their specific needs. These providers provide scalable and flexible solutions, capable of evolving along with the electricity grid as more advanced technologies are integrated, such as energy storage, distributed generation, and demand management systems.

Close collaboration with suppliers allows for a better adaptation of technological solutions, ensuring that they are aligned with the operational particularities of the distribution network. In addition, suppliers can offer

technical training and ongoing support to the distributor's staff, which is essential for the development of the capabilities needed to operate and maintain the new technologies. In this way, distribution companies can ensure that they are implementing best practices and using the most innovative technologies suitable for their needs.

The digitalization and automation of electricity distribution networks are critical steps for Latin America to achieve a more efficient, resilient, and sustainable energy future. As the region continues to face challenges related to growing energy demand, decarbonization, and the integration of renewable energy, the adoption of advanced technologies will be a critical pillar to ensure a reliable and quality electricity supply. With a clear focus on creating a favorable regulatory environment, access to financing, public-private cooperation, technical capacity building, and technological innovation, Latin America has the opportunity to advance in the modernization of its distribution networks and position itself as a benchmark in the transition to a smarter and more sustainable electricity system.

> The digitalization and automation of electricity distribution systems in Latin America represent a crucial opportunity to modernize the region's energy infrastructure



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