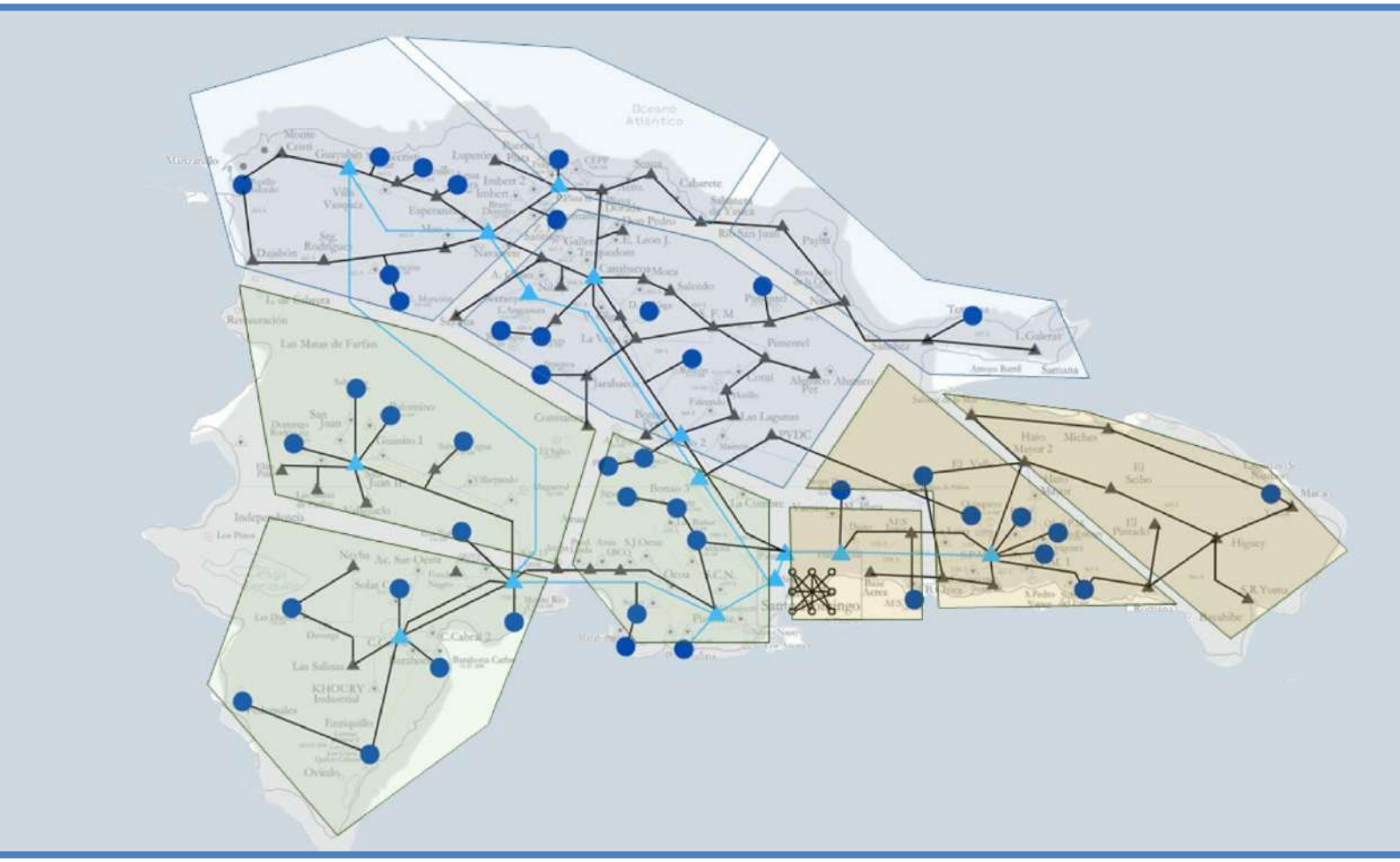
USAID
FROM THE AMERICAN PEOPLE

PUCMM
Pontificia Universidad Católica
Madre y Maestra



MICROGRID RESEARCH GROUP - PUCMM

RESILIENCY ANALYSIS FOR THE DEVELOPMENT OF MICROGRID ARCHITECTURE AGAINST CLIMATE-DRIVEN EVENTS IN THE DOMINICAN REPUBLIC'S ELECTRIC SYSTEMS

PARTNERSHIPS FOR ENHANCED ENGAGEMENT IN RESEARCH (PEER) PROGRAM - CYCLE 9

FINAL REPORT (15/04/2021 – 15/09/2023)

FOREWORD

This report is based upon work supported by the Partnerships for Enhanced Engagement in Research (PEER) Program, which is funded by the United States Agency for International Development (USAID) and implemented by National Academy of Sciences (NAS) under parent award number AID-OAA-A-11-00012. Any opinions, findings, conclusions, or recommendations expressed in this report are solely those of the authors and do not necessarily reflect the views of USAID or NAS.

This research was led by P.I Ramón Emilio De Jesús-Grullón, C.I Rafael Batista, and C.I Abraham Espinal, researchers from the Microgrid Research Group at the Pontificia Universidad Católica Madre y Maestra (PUCMM), Santiago de los Caballeros, Dominican Republic.

ACKNOWLEDGMENTS

The Microgrid Research Group of the Pontificia Universidad Católica Madre y Maestra (PUCMM) wish to thank the United States Agency for International Development (USAID) and the National Academy of Sciences (NAS) for their generous financial support of this initiative, the Empresa de Distribución Eléctrica del Norte (EDENORTE) for providing valuable technical information about their network topology and operations, as well as for the ongoing support in new research endeavors at PUCMM. In particular, Joan Núñez (Technical Distribution Management) y Saúl Azcona (Engineering Management), have been key supporters of this research. The research team would also like to thank research assistants Juan Pichardo and Justin Bueno, for the invaluable and continued support, insight, and sheer resilience while participating in this project.

EXECUTIVE SUMMARY

OVERVIEW

The rapid growth of **grid resiliency research** worldwide is enabling unprecedented opportunities for global collaboration to expand scientific knowledge and to improve the quality of life and well-being of citizens facing the dangers of climate change. This research project is building upon, and expanding on, the knowledge from our partners and academia in this key technology area with the goal of transforming the scientific findings into tools that can generate further education and employment, necessary elements underpinning the economy and improvement of the quality of life in our society.

Recent severe power outages caused by increasingly frequent climate-driven events have highlighted the urgency to improve grid resilience worldwide. Traditionally, the power industry has focused on methods that aim to restore loads by servicing the affected infrastructure and a gradual service restoration after a general blackout. However, when the distribution system is severely damaged traditional approaches cannot guarantee that energy will be supplied to much needed critical loads. Here is **where microgrids (MGs) have emerged as a tool due to the potential to recover in an effective quick manner**, providing an alternative approach to the resilience dilemma. The new paradigm presented by active MG integration to the grid required a robust modelling process and hardware testing, this research tackled both. Using the latest **real-time hardware-in-the-loop (HIL)** simulation platforms allowed for accurate representation of device integration and modeling. To the best of our knowledge, the PHIL testbed built at the Pontificia Universidad Católica Madre y Maestra (PUCMM), campus Santiago, is the first one developed in the country.

Capacity building on this topic is essential to obtain, improve and retain the skills, knowledge, tools, and resources needed to bootstrap the industry in the region and the country.

The testbed not only serves as an educational tool to promote training and learning in this key technology area, but also as a **benchmark for government agencies, communities, and industry looking to integrate Renewable Energy Sources (RES) and resilience into their decision-making process and policies**, and as a test platform for device agnostic energy storage and electric vehicle integration into the energy grid.

OBJECTIVES

The main goal of this research is to create a **hardware-in-the-loop laboratory testbed** in the PUCMM-Santiago campus, where scenario modelling and control techniques related to the improvement of resilience through microgrid formation are evaluated. The laboratory allows for the integration of real-time simulation (us/ns) with physical systems representative of the scenarios that are studied, forming a microgrid laboratory that will be used both for **research and teaching.**

Additionally, simulation strategies based on the integration of **open-source software tools** such as **OpenDSS®** (Open Distribution System Simulator) with open-source Geographic Information System **(QGIS),** are tested for the rapid modeling of real large-scale electrical distribution circuits with distributed renewable generation, with data provided by the regional energy utility (EDENORTE).

Finally, we identified the required steps the Dominican Republic's electrical system stakeholders should considered for **improving the resilience** of the electrical grid under extreme weather events, as well as other identified vulnerabilities.

METHODOLOGY

To effectively perform an analysis on the impact of Distributed Energy Resources (DERs) in the Medium Voltage (MV) and Low Voltage (LV) networks, utilities must first have in place the data necessary to build detailed models of the Distribution Network (DN) components, as well as advanced simulation tools that allow for comprehensive analysis to evaluate system performance and identify potential issues.

Distribution Network Modelling: The project takes advantage of open-source platforms (QGIS and OpenDSS) for the rapid modeling of large-scale electrical distribution circuits with distributed renewable generation. The implementation is based on the adaptation of a tool called QGIS2OpenDSS, which creates OpenDSS distribution network models directly from an open-source geographic information system, QGIS. The plugin's capabilities are demonstrated using a real distribution feeder with more than 60% penetration of renewable generation based on photovoltaic systems. These simulations are carried out using real data from a circuit provided by a Distribution Network Operator (DNO) in the Dominican Republic.

Real-Time Simulation (RTS): RTS of the electric power system are the reproduction of output (voltage/currents) waveforms, representative of the behavior of the real power system being modeled. Our Microgrid Testbed uses the Opal OP5700 Real Time Simulation System paired with RT-LAB to edit, compile, load, execute and analyze models that are fully integrated with MATLAB/Simulink®. This complete simulation system contains a powerful target computer, a high-end reconfigurable FPGA, signal conditioning for up to 256 I/O lines, and 16 high-speed fiber-optic SFP ports, which allows for Hardware-in-the-Loop (HIL) and Power Hardware-in-the-Loop (PHIL) testing for the development, validation, and integration of microgrid control and protection systems.

KEY FINDINGS

The Digitalization Curve

- EDENORTE´s network topology (including substations, distribution lines, transformers, and other assets) is well maintained using GIS. However, the underlying base maps are not georeferenced, which hinders the ability to integrate this data into another services.

- During the process of exploring the tools and processes used by energy distribution companies in the DR to conduct their network studies, the research team discovered how far behind these institutions are on their digitalization curve and how valuable these tools would be to, for example, study distribution losses, which continue to be one of the most important burdens in the sector.

The Value of Resilience

- After reviewing the worldwide effort to define and measure resilience the team found a range of different methods and frameworks, most of which estimate the avoided costs of power interruptions or propose indicators to guide cost-benefit studies prior to investment planning. However, many of these methods have been applied in academic analyses, but few have been used to directly inform state regulatory or policy decision-making.

Policies to Support Microgrid Development

- Our research showed that there is an increasing number of countries that are supporting microgrid development. In fact, our neighbors in Puerto Rico have enacted microgrid-specific legislation to provide greater certainty to developers, utilities, and state regulators. Broadly speaking, these policies take aim at common barriers to microgrid deployment, including challenges to interconnecting with the larger grid and uncertainty around how microgrids will be compensated for services they provide to a utility.

CONSIDERATIONS FOR DOMINICAN REPUBLIC´S GOVERNMENT INSTITUTIONS

NATIONAL ENERGY COMISSION (CNE), SUPERINTENDENCE OF ELECTRICITY (SIE) & MINISTRY OF ENERGY AND MINES (MEM-RD)

INCLUDE MICROGRID REGULATORY FRAMEWORKS IN THE NATIONAL ENERGY PLAN UPDATES

- Study the regulatory frameworks around microgrid development worldwide, looking at case studies for success and challenges faced by other countries in implementing and regulating microgrids.
- Establish partnerships between the government and research institutions for joint R&D initiatives on energy resilience and microgrids. This will leverage the strengths of each sector and accelerate innovation.

INTEGRATE THE DISTRIBUTED ENERGY RESOURCES CUSTOMER ADOPTION MODEL (DER-CAM) INTO THE SOFTWARE STACK AT THE CNE

- The software is strongly recommended by most US Energy Agencies when addressing the need for resilience and microgrids, as can be seen in Policy Paper: *Energy Resilience Solutions for the Puerto Rico Grid*, which the U.S Department of Energy (DOE) wrote after hurricane Irma y Maria destroyed Puerto Rico´s energy infrastructure.

CONDUCT STUDIES ON THE INTEGRATION OF AC COUPLED BATTERY ENERGY STORAGE SYSTEMS (BESS) TO PROVIDE ANCILLARY SERVICES TO THE GRID

Regulatory Framework:

- **Clear Regulatory Policies:** Define clear regulatory and tariff structures for the provision of ancillary services. This will provide incentives to investors and stakeholders.

Technology Neutrality in Policies:

- Frame policies in a way that they are neutral to specific technologies.
- Ensure subsidies, incentives, or support mechanisms are not biased towards one specific technology but rather promote desired outcomes.

EDENORTE (AND OTHER EDES)

INCORPORATE MODELING AND SIMULATION SOFTWARE IN DISTRIBUTION PLANNING

Addressing the shortfall in digitization, particularly in the use of modeling and simulation software for distribution planning, is crucial for energy distribution utilities in the age of data. To catch up with the digitization curve, utilities in the DR must embrace a comprehensive strategy that integrates modern software tools, infrastructure upgrades, and continuous skill development.

- Adopt software solutions that cater specifically to the modeling and simulation of renewable energy sources' integration into distribution circuits. Programs such as OpenDSS, GridLABD, or PSS®SINCAL are valuable tools in this domain.
- Ensure the chosen software is scalable and can accommodate the growing complexity of the grid with increased renewable penetration.

GEOREFERENCING AND GIS INTEGRATION FOR IMPROVED EFFICIENCY

EDENORTE´s network topology (including substations, transmission lines, transformers, and other assets) is well maintained using GIS. However the underlying base maps are not georeferenced, which hinders the ability to integrate this data into another sevices.

Georeference Existing Base Maps:

- Engage GIS specialists to georeference existing base maps using known coordinate systems. This process involves linking points on the digital map to known real-world geographic coordinates.
- Utilize control points, or benchmarks, that have known geographic locations to ensure accuracy during georeferencing.

Adopt Standard Coordinate Systems:

- Choose a widely recognized coordinate system (e.g., WGS 84 or UTM) based on the region and the type of projects. This ensures compatibility when integrating with external data or services.

GIS FOR VEGETATION MANAGEMENT AND IDENTIFICATION OF NON-STANDARD INFRASTRUCTURE

49.5% of the interruptions reported in EDENORTE correspond to unknown causes and only 2% to trees on lines. Now, according to the literature reviewed on outages in the utility industry, tree-related outages commonly comprise 20% to 50% of all unplanned distribution outages. So, a large percentage of unknown faults can find their origin in this cause.

Comprehensive Database Creation:

- Utilize GIS to create a comprehensive database of vegetation near all energy infrastructure. Ensure this database includes species information, growth rates, and potential hazards to the grid.

Enhanced Spatial Analysis:

- Use spatial analysis to predict areas of rapid vegetation growth based on historical data. This can guide proactive trimming and maintenance activities, ensuring potential hazards are addressed before they become critical.

Optimized Work Routes:

- Leverage GIS to create optimized routes for maintenance crews, minimizing travel time and ensuring urgent areas are addressed promptly.

INTEGRATE HARDWARE-IN-THE-LOOP (HIL) SIMULATIONS FOR NETWORK STUDIES

Integrating Hardware-in-the-Loop (PHIL) simulations can be crucial for energy utilities, especially as they seek to modernize and incorporate new technologies and systems. HIL simulations allow real-world hardware to be tested and validated against a real-time simulation environment, ensuring that new devices and systems are integrated effectively into the existing infrastructure.

EDENORTE can use the capabilities for:

- **Test Grid Modernization Equipment:** Before deploying new grid equipment, such as advanced transformers, breakers, or controllers, validate their operations through HIL simulations to ensure compatibility and performance.

- **Real-time Testing for Grid Emergencies:** Use HIL simulations to recreate potential grid emergency scenarios, such as a sudden drop in renewable energy generation or a major grid component failure. This can guide utilities in developing effective response strategies.

INVEST IN DIGITIZATION AND THE APPLICATION MACHINE LEARNING (ML) ALGORITHMS FOR MASSIVE ANALYSIS OF ENERGY BALANCE DATA FROM AREA METERS (TOTALIZERS) TO REDUCE ENERGY LOSSES

- **Invest in Tehcnology and Data Science :** Manage energy loss through data insights coming from an energy balance system using micro measurements and telemetry to administer, analyze, manage and monitor energy loss control in the basic management

units of the EDE, such as transformers, in an integrated Wide Area Network (WAN).

- **Work on the Association (client – transformer – circuit) in Geographic Information Systems (GIS):** Lack of maintenance of the circuit association field of supplies (customers), currently affect all the data of the intelligence tools acquired for monitoring and loss control.

THE COORDINATION BODY (OC)

Back in 2020, the OC published a SENI Island Operation report, for the Superintendency of Electricity and the MEM Agents, with the objective of analyzing the isolated operation of each of the SENI areas, based on the potential occurrence of an atmospheric phenomenon, and with the aim of evaluating, for example, partial system restore / black start scenarios.

- Repeat the study considerering the hypothetical scenario of having BESS with AC-coupled systems, that allow for ancilliary services from such systems.
- Repeat the study considering the hypothetical scensario of having stand alone BESS in critical subestations, those that link two or more transmission lines, through power switches that connect or disconnect the networks in conditions of failure or maintenance, for example:

DOMINICAN ELECTRICAL TRANSMISSION COMPANY (ETED)

The development of new energy generation projects, especially renewable energy, has been limited by the capacity of transmission networks to transport it to the largest points of consumption. This currently represents one of the main drawbacks when planning the development of new projects and to mark the route to follow in terms of diversification of the generation matrix.

According to the Transmission Expansion Plan (2021-2035), the budget that ETED needs to execute its expansion in the short and medium term to improve energy transmission capacity, regardless of the source of origin, totals an investment of around **800 MM USD** between now and 2030.

ETED issued no objections between 2020-2022 for the interconnection of 5,150 new megawatts, of which 3,562 correspond to renewable energy projects. In fact, 17 large renewable energy plants are under construction (September 2023); with 14 coming into operation by the end of the year. While another dozen projects are in prospective studies for the following years.

- **Developed Public Private Partnerships:** Prioritize these alliances for the design, construction, maintenance and financing of the needs of high voltage lines and substations close to areas with high wind and solar resources.
- **Update renewable penetration forecasts:** It is necessary to review and continue the expansion plans that contemplate and/or update the renewable penetration forecasts proposed by the International Renewable Energy Agency (IRENA) in 2016 for the country in the next 20 years.

MINISTRY OF ECONOMY, PLANNING, AND DEVELOPMENT (MEPYD)

INCLUDE THE DECENTRALIZATION AND THE FORMATION OF FLEXIBLE ELECTRICAL MARKETS AS A TOOL TO ADD VALUE IN THE NEXT EDITION OF THE MULTI ANNUAL PUBLIC POLICY PLAN

- **Develop Clear Indicators for Decentralization and Flexibility**
- **Capacity Building for Cooperatives:** Foster knowledge exchange programs with successful cooperatives from other countries.
- **Financial Incentives and Support:** Allocate budgetary provisions or financial incentives for cooperatives adopting innovative and green technologies.

TABLE OF CONTENT

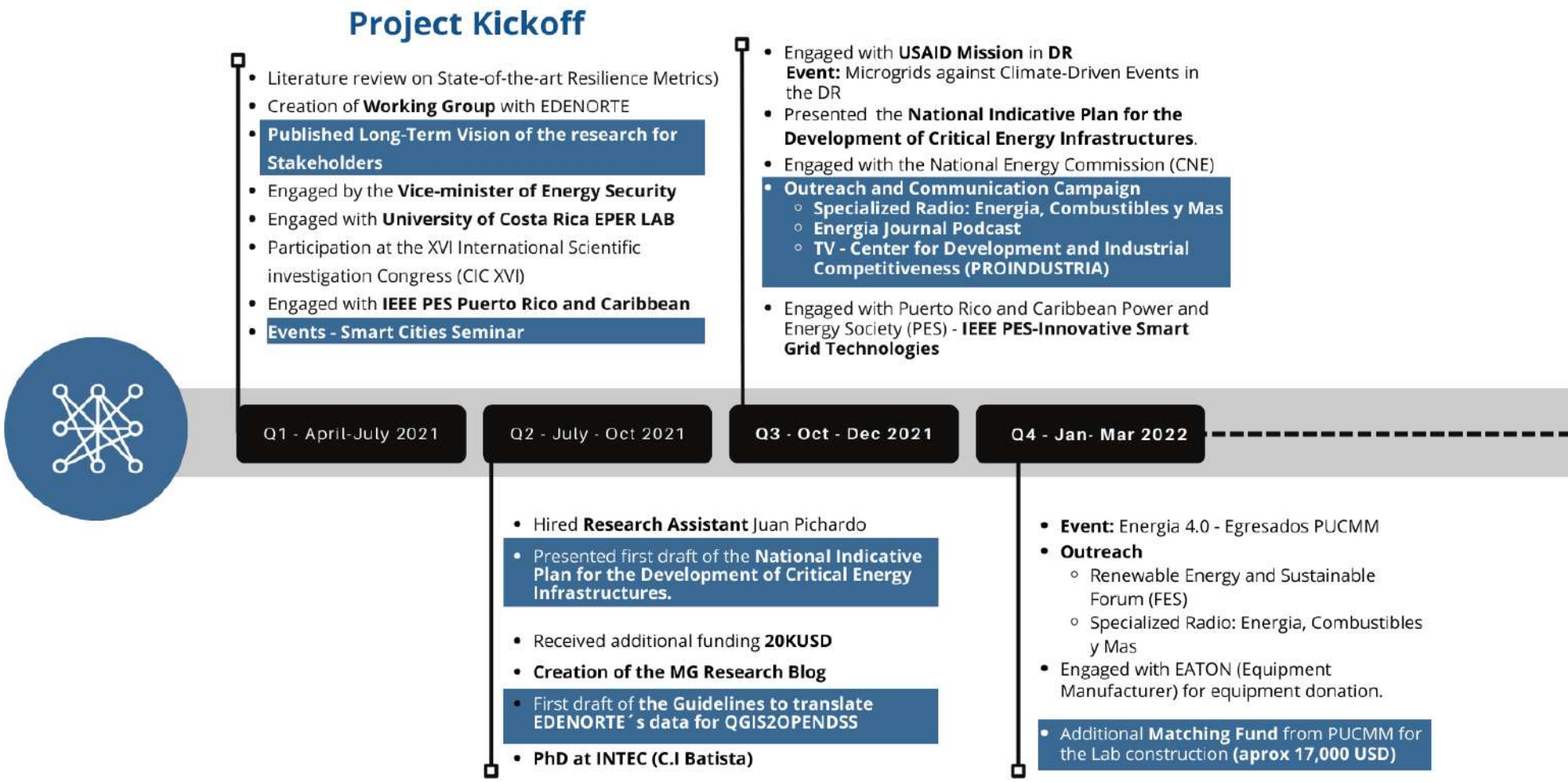
ABBREVIATIONS

ACIS	ASOCIACION DE COMERCIANTES E INDUSTRIALES DE SANTIAGO
AECID	AGENCIA ESPAÑOLA DE COOPERACIÓN INTERNACIONAL PARA EL DESARROLLO
ASOFER	ASOCIACIÓN PARA EL FOMENTO DE ENERGÍAS RENOVABLES
BEES	BATTERY ENERGY STORAGE SYSTEMS
CCIP	CARIBBEAN CLIMATE INVESTMENT PROGRAM
CECACIER	COMITÉ REGIONAL DE LA CIER PARA CENTROAMÉRICA Y EL CARIBE
CEPM	CONSORCIO ENERGÉTICO PUNTA CANA - MACAO
CEPR	COMISIÓN DE ENERGÍA DE PUERTO RICO
CNE	COMISIÓN NACIONAL DE ENERGÍA
CTPC	CENTRAL TERMOELÉCTRICA PUNTA CATALINA
DER	DISTRIBUTED ENERGY RESOURCES
DIGEPRES	DIRECCIÓN GENERAL DE PRESUPUESTO
DNO	DISTRIBUTION NETWORK OPERATOR
DOE	DEPARTMENT OF ENERGY
DSS	DISTRIBUTION SYSTEM SIMULATOR
EDE	EMPRESA DE DISTRIBUCIÓN ELECTRICA
EDEESTE	EMPRESA DE DISTRIBUCIÓN ELECTRICA DEL ESTE
EDENORTE	EMPRESA DE DISTRIBUCIÓN ELECTRICA DEL NORTE
EDESUR	EMPRESA DE DISTRIBUCIÓN ELECTRICA DEL SUR
FEMA	FEDERAL EMERGENCY MANAGEMENT AGENCY
FONDOCYT	FONDO NACIONAL DE INNOVACIÓN Y DESARROLLO CIENTÍFICO Y TECNOLÓGICO
FPR	FEEDER PROTECTION RELAYS
GW	GIGAWATTS
HIL	HARDWARE-IN-THE-LOOP
HILP	HIGHT IMPACT LOW PROBABILITY
HUT	HARWARE UNDER TEST
IEL	INGENIERIA ELECTRICA
LV	LOW VOLTAGE
MEM-RD	MINISTERIO DE ENERGIA Y MINAS
MESCYT	MINISTERIO DE EDUCACIÓN SUPERIOR, CIENCIA Y TECNOLOGÍA
MG	MICROGRIDS
ML	MACHINE LEARNING
MV	MEDIUM VOLTAGE
MW	MEGAWATTS
NARUC	NATIONAL ASSOCIATION OF REGULATORY UTILITY COMMISSIONERS
NAS	NATIONAL ACADEMY OF SCIENCE
NASEO	NATIONAL ASSOCIATION OF STATE ENERGY OFFICIALS
NCSL	NATIONAL CONFERENCE OF STATE LEGISLATURES
NMIG	NETWORKED MICROGRIDS
NOAA	NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NREL	NATIONAL RENEWABLE ENERGY LABORATORY
NWA	NON-WIRES ALTERNATIVES
OECD	ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
PCC	POINT OF COMMON COUPLING

PDA	PLATAFORMA DE DATOS ABIERTOS
PEER	PARTNERSHIP FOR ENHANCED ENGAGEMENT ON RESEARCH
PEN	PLAN ENERGÉTICO NACIONAL
PHIL	POWER-HARDWARE-IN-THE-LOOP
PI	PRINCIPAL INVESTIGATOR
POC	PROOF OF CONCEPT
PUCMM	PONTIFICIA UNIVERSIDAD CATOLICA MADRE Y MAESTRA
PV	PHOTOVOLTAICS
RMI	ROCKY MOUNTAIN INSTITUTE
RTI	RESEARCH TRINAGLE INSTITUTE
SENI	SISTEMA ELÉCTRICO NACIONAL INTERCONECTADO
SIE	SUPERINTENDENCIA DE ELECTRICIDAD
USAID	UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT
UTM	UNIVERSAL TRANSVERSAL DE MERCATOR
VOLG101	VILLA OLGA 101 FEEDER
VSEI	VICEMNISTERIO DE SEGURIDAD ENERGÉTICA E INFRAESTRUCTURA
YLAI	YOUNG LEADERS OF THE AMERICAS INITIATIVE

I KEY ACTIVITIES, IMPACTS AND OUTCOMES

SECTION 1 - SUMMARY OF KEY ACTIVITIES – TIMELINE



Q5 - April-June 2022

- Initial testing OpalRT-Simulator and Installation of **equipment in the MG Lab**
  - Solar panels
  - Wind Turbine
- Summited a project to the **Energy Shared Technology between Europe and Latin America (ESTELA).**
- Engaged German Cooperation Agency (GIZ)
- Engaged with Association for the Promotion of Renewable Energies. **Became Members**
- **Submitted (3) projects to the National Fund for Scientific and Technological Innovation and Development (FONDCOYT)**

Q6 - July - Oct 2022

- **Presented the Guidelines to translate EDENORTE´s data for QGIS2OPENDSS.**
- Presentation of Research Lines to the Association of Merchants and Industrialists (ACIS) and Innovation Cabinet.
- Furniture and final touches at the MG Lab.
- **Additional funding from FONDOCYT (around 380k USD) - Grant for 2 Projects**

Q7 - Oct - Dec 2022

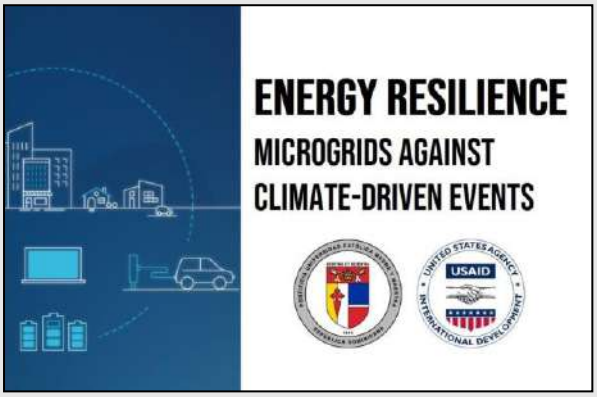
- Modelled the PV Distribution generators in the VOLG 101 circuit in OpenDSS
- **Integrated the OpenDSS-MATLAB COM Interface**
- Organized a Symposium on **Emerging Research in Electrical Power Systems, Energy Resilience and Microgrids.**
- Delivered a technical presentation to EDENORTE and presented de QGIS2OpenDSS
- **Received representatives from USAID,NAS and RTIR**

Q8 - Jan- Mar 2023

- Conducted a **Energy Resilience Indices Literature Review**
- Developed a **Fault Detection Algorithm.**
- Organized a event on the ***Applications of real-time simulation in electrical power systems***, given by Opal-RT at PUCMM.
- **Developed a Distribution Network Segmentation into Minigrids proof of Concept (POC).**
- **USAID - PEER Project success story article "Investigando sobre resiliencia energética"**

Mar-Ago 2023

- Organized a Panel in the Sustainable Energy Forum DR called> ***Energy Storage: Resilience and Energy Independence in the D***R
- Submitted a Research Paper for Peer Review: **Modeling and Simulation of Distribution Networks with High Renewable Penetration in Open-Source Software: QGIS and OPENDSS**
- **Presented several works in the XVIII International Congress for Scientific Research**
- **Successfully ran a Real-Time Simulation on a local Distribution Network Circuit (VOLG101)**



Q1 I APRIL – JUNE 2021

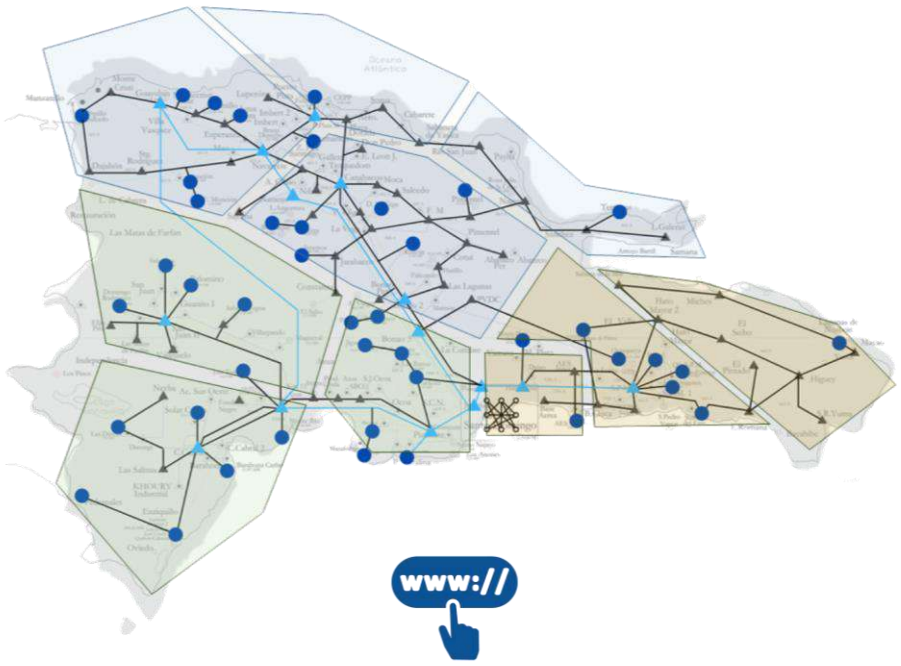
1. LONG TERM RESEARCH VISSION FOR STAKEHOLDERS: *MI(NI)CROGRIDS AND THE 3D´s OF THE ENERGY TRANSITION*

Due to the increase of extreme and disrupting climate-driven events resilience enhancement of power grids has been in the spotlight for government, industry, and energy sector researchers and engineers. Today, the existing power grid can assure service reliability during normal conditions and abnormal but foreseeable and low impact contingencies (Low-Impact High Probability events (LIHP)).

However, the continuity of service during unexpected and high-impact events (Hight-Impact Low Probability events (HILP) is still a great challenge. This is the reason why power systems are known to be ***reliable but not resilient.***

The resiliency of a system is defined as **its ability to return to equilibrium (stable operation point) after a major disruption event.** Microgrids and Minigrids have emerged as tools to deal with major power disruption events due to the potential to recover in an effective quick manner. The ability to sustain the increasing penetration of Renewable Energy Sources (RES), and serve critical loads (e.g. hospitals, military bases, water treatment plants, etc), makes them an important part of the evolution towards the Transactive Grid and the **3D´s of the energy transition: *Decarbonization, Decentralization, and Digitization.***

A VISION OF MINIGRIDS AGAINST CLIMATE-DRIVEN EVENTS



www://

GitHub

ESTABLISHED A WORKING GROUP WITH REGIONAL UTILITY (EDENORTE)

With the goal of implementing and adding the OpenDSS-Based Distribution Network Builder into EDENORTE's (main stakeholder) software stack, a working group was created within the Distribution Management and Network Studies Department and the MG Research Team. The task at hand was to create a blueprint of the processes that are necessary to obtain, clean and transform the utilities' existing GIS Data to be fed into the QGIS2OPENDSS Plugin. Several Data Dictionaries and Workflows were created to standardize and summarize the efforts that have been conducted for future use.

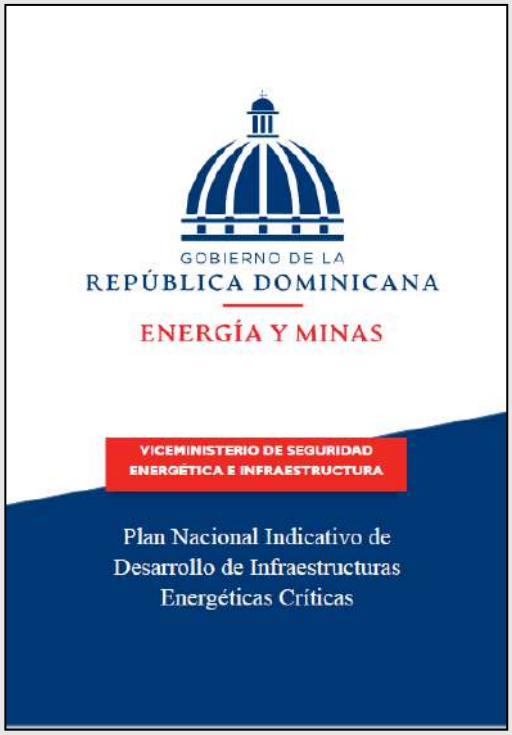
By Q6 the team delivered the guidelines to the Distribution Management and Network Studies Department in EDENORTE.

ORGANIZED A SMART CITIES SEMINAR

In collaboration with IEEE PES Dominicana and Island Innovation, the MG Research team organized a seminar series on Smart Cities, where we had the honor to have professionals and academics from across the region. The event focused on several topics regarding the importance of technology and innovation in the future of cities, and where we presented a panel on microgrids with experts from academia in the region.

We had the honor of having professionals from industry and academia that brought high level discussion and topics, such as:

- **Machine Learning Applications**: The Role of ML in Smart Cities – Guillem Duran Ballest
- **Digital Twins** – Exploring applications and opportunities Benjamin Weber – Stor Water
- **Smart Grid:** Microgrid-Based Self Healing – Dr. Hashem Nehrir



Q2 I JULY – SEPTEMBER 2021

INDICATIVE PLAN FOR CRITICAL ENERGY INFRASTRUCTURE (REPORT FOR VICE MINISTER OF SECURITY AND ENERGY INFRASTRUCTURE (VSEI)

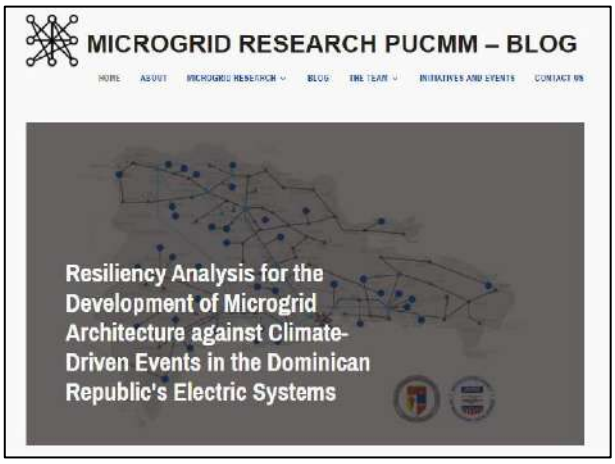
The VSEI's new administration is now mapping the Critical Energy Infrastructure in the country, creating an Indicative Plan defining how to enhance resiliency across the whole system. PI Ramón Emilio De Jesús-Grullón was the main external researcher and editor for the Plan.

The Plan is derived from an extensive investigation on the effects of Hurricanes María and Irma (2017) on the Energy Infrastructure of Puerto Rico, and draws conclusions from the recommendations made by agencies of the United States Government (e.g. US Department of Energy) and Laboratories such as Rocky Mountain Institute (RMI) to the government of Puerto Rico: PREPA (Puerto Rico Electric Power Authority) and Puerto Rico Energy Commission (PREC), as well as the vision of the Critical Infrastructure Risk Management Framework taken from the National Infrastructure Protection Plan (NIPP) of the United States Government, and of the literature in Energy Infrastructure Risk Management of U.S. Department of Energy Office of Energy Assurance.

ADDITIOAL FUNDING – ENESTAR DONATION TO MADRE Y MAESTRA FUNDATION

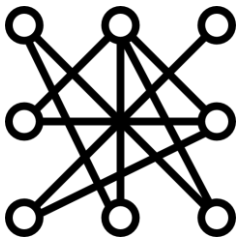
C.I Abraham Espinal, through his company (ENESTAR), has made agreements to donate scholarships and equipment to the School of Electrical and Mechanical Engineering and the Microgrid and Renewable Energy Laboratory of the University for an estimated value of USD$20,000.00.

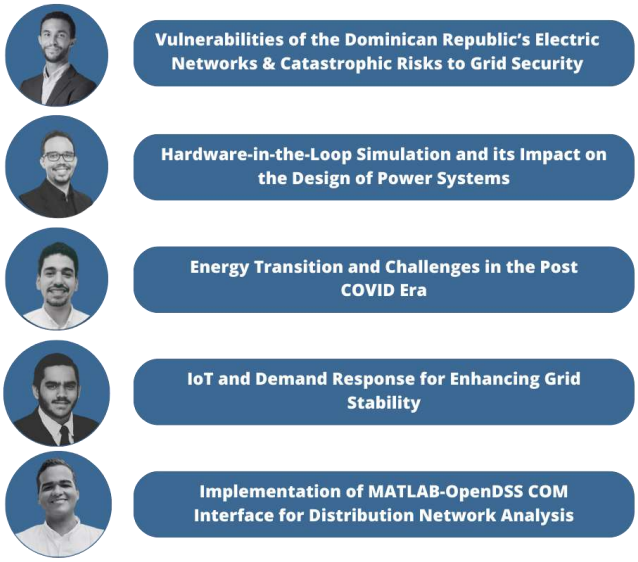
The agreement was signed by the president of the Madre y Maestra Foundation, Mercedes Carmen Capellán de Lama and the executive director Edwin Hernández, as well as the main executives of ENESTAR: Jerojainier Cerda, Abraham Espinal, Cristhofer Ozoria and Patricia Espinal.



LAUNCHED THE MICROGRID RESEARCH BLOG

The blog serves as a channel of thought and as a support to publicize the project and to attract students and collaborators, in addition to work as an excellent presentation letter and summary of the status of the investigation. It is linked to PUCMM's Vicerrectoría de Investigación (VRI) website and has a blog section that is updated regularly and is linked to social networks profiles to increase the visibility of the site and the results.





DEVELOPED CAPACITY BUILDING WORKSHOPS

The MG Research Team organized a workshop titled: "Modeling and Simulation of Electrical Distribution Networks using OpenDSS and QGIS", where the team showed an introduction to one of the main tools being developed and utilized in the research: a software add-on (plugin) that creates the OpenDSS network model directly from an open-source GIS software environment (QGIS2OpenDSS - developed by a research laboratory in the University of Costa Rica) and that exponentially reduces modeling time to simulation time.

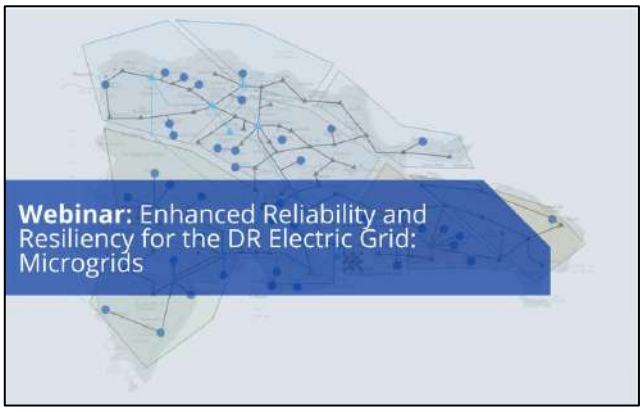
Q3 1 OCTOBER – DECEMBER 2021

LAUNCHED AN OUTREACH AND COMMUNICATION CAMPAIGN ABOUT THE RESEARCH´S VISION AND LONG-TERM GOALS

- The MG Researh Group participated in the first **Entrepreneurship and Innovation Fair** of the Center for Industrial Development and Competitiveness - ProIndustria, held in the city of Santiago de los Caballeros, Dominican Republic.

Invitation to a national radio show **Energías, Combustibles y Más**, a segment specialized in Energy and Fuels, broadcast by zol1065fm FM every Tuesday at 8.30PM. In this space, Pl De Jesús, Ben Weber (Stor Water) and Miguel Estevez (Energia Journal) talked about their trajectory, vision, and projects in development.

Invitation to **Esta Mañana**, a national tv show, with the intention of communicating the vision of not only the research project on Resiliency and Microgrids but exploring the importance and relevance of the Water-Energy Nexus for Dominican Republic.



www://

DEVELOPED CAPACITY BUILDING WORKSHOPS

The MG Research Team organized two webinars, one titled: “Enhanced Reliability and Resiliency for the DR Electric Grid: Microgrids" which was presented to the Puerto Rico and Caribbean Power and Energy Society (PES), which consists of roughly 85 members including power engineering professionals, students, and associates in the Caribbean. The presentation was designed to showcase our ongoing research, the characteristics of the testbed, the stakeholders involved, the long-term vision and to open up collaboration opportunities.

Q4 I JANUARY - MARCH 2022

DISCUSSION PANEL - ENERGY 4.0 - THE FUTURE OF ENERGY IN THE DOMINICAN REPUBLIC

The Webinar was titled: Energy 4.0 - The Future of Energy in the Dominican Republic, which was presented to an heterogenous group of professionals, students and faculty from across the DR. The Webinar was hosted by EGRESADOS PUCMM, which is a non-profit organization, committed to the growth and strengthening of the services offered by the Pontificia Universidad Católica Madre y Maestra to students.

PARTICIPATED IN THE RENEWABLE ENERGIES AND SUSTAINABILITY FORUM (FES 2022)

The MG Research Group represented the university at the **"1st Meeting for a Sustainable Energy Transformation"** forum, an activity organized by the Sustainable Energy Forum, within the framework of World Efficiency Day. This forum, held in the context of the Official Development Agenda Santiago 2030, aimed to publicize the protagonists of the Energy Transition in the country, as well as their plans, decisions and impact on the economy and the environment.

PI De Jesús Grullón and CI Batista presented the keynote: ***Interconnected Microgrids: Improving Resilience in Electrical Grids in the Dominican Republic.***

Q5 1 APRIL - JUNE 2022

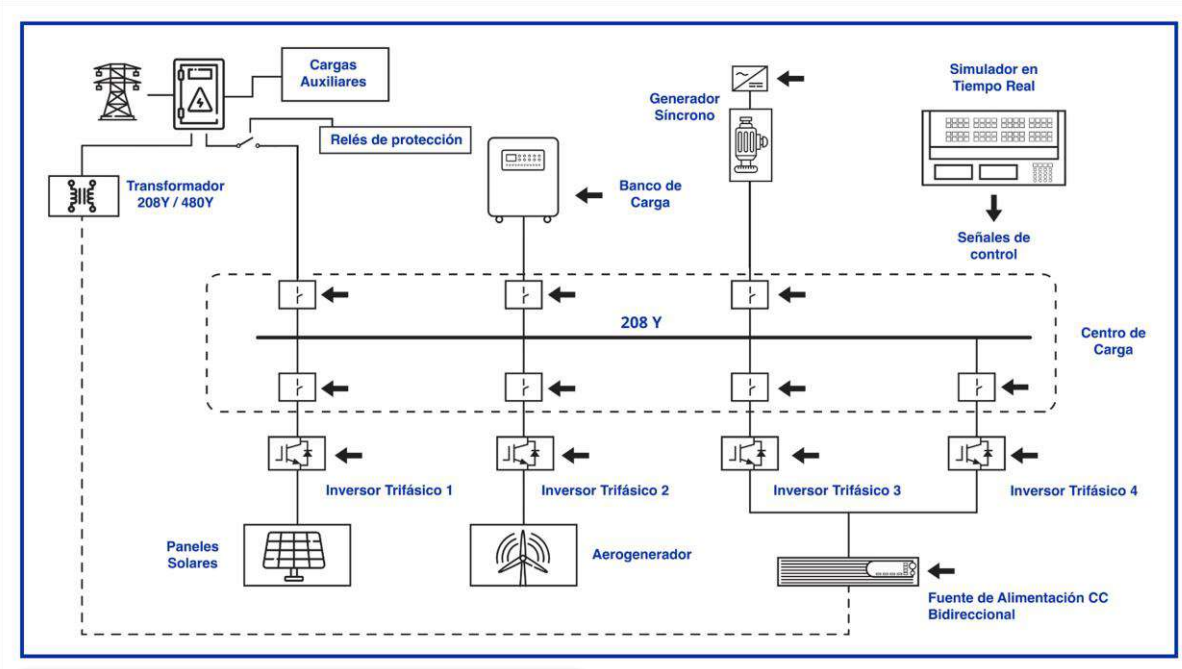
MICROGRID LABORATORY TESTBED INITIAL TESTING, FINAL SPATIAL LAYOUT, EQUIPMENT INSTALLATION AND ADDITIONAL FUNDING

A series of training were taken regarding the use of the real time simulator and its inputs/outputs interfaces. It was possible to generate reference signals and monitor them using an oscilloscope. Furthermore, real time simulation testing capabilities were conducted using power electronics circuit simulations, for the validation of the integration between Matlab/Simulink® and OpalRT-Lab®.

Various signal configurations were tested under the capability of the Opal-RT platform, this includes: Analog outputs, PWM outputs, digital outputs, analog inputs and digital inputs.

The laboratory also received an additional **17K USD** in matching funds from PUCMM for its renovation.

MICROGRID TESTBED PUCMM



ADDITIONAL FUNDING - NATIONAL FUND FOR SCIENTIFIC AND TECHNOLOGICAL INNOVATION AND DEVELOPMENT (FONDOCYT)

MESCYT announced the 2022 Call for the **National Fund for Scientific and Technological Innovation and Development (FONDOCYT**), In this FONDOCYT call, proposals for basic and applied research, Research and Development and innovation (R+D+i) or Technology Transfer will be accepted.

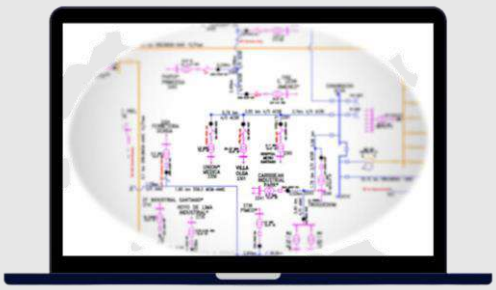
The Microgrid Research Team presented 3 proposals to FONDOCYT with the goal of expanding the research scope, increasing capacity building and involving more institutions from PUCMM and Government Agencies. Out of those 3 proposals 2 were successful, with an additional funding of **345K USD.**

Open Data Platform for Spatial Analysis of Energy and Community Resilience.

105 K USD

www://

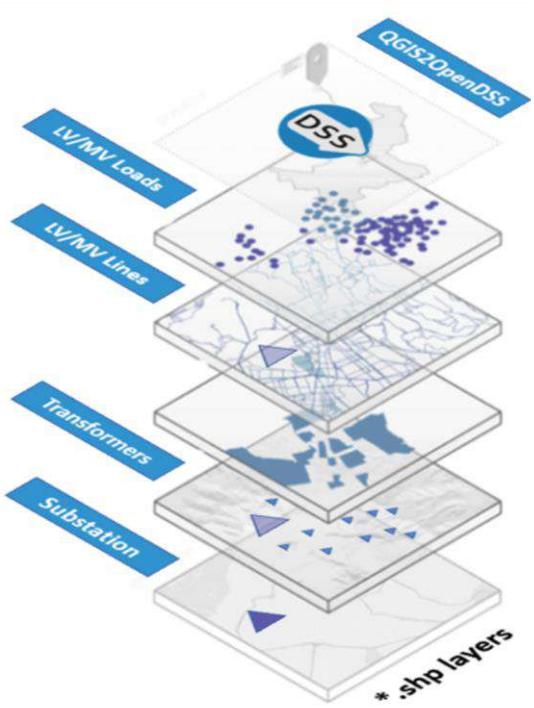
Use of Simulations with Power Hardware in the Loop for Verification Schemes of Protections against Faults in EDENORTE's Electrical Distribution Systems.



240 K USD

www://

Q6 I JULY- SEPTEMBER 2022



OPENDSS-BASED DISTRIBUTION NETWORK BUILDER IN OPEN-SOURCE GIS ENVIRONMENT IMPLEMENTATION IN EDENORTE (VOLG101)

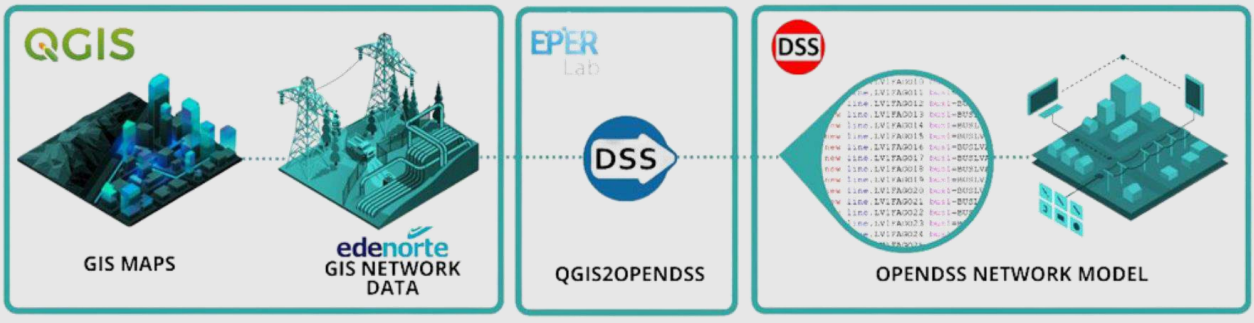
During this quarter the research group reached an important milestone with the presentation of results named **Modeling of Distribution Networks with High Renewables Penetration in Open-Source Software (OpenDSS + QGIS).**

The team completed the implementation of QGIS2OPENDSS, a plugin designed to automatically generate distribution network models for OpenDSS (*dss files), which data comes directly from an open-source Geographic Information System (GIS) software environment, QGIS. This plugin was developed by researchers at the EPER Lab in the University of Costa Rica (UCR), and it's part of a series of tools under development to help researchers and power engineers to assess the evolution of distributed generation and power systems, reducing the time from model to simulation by orders of magnitude (months to weeks).

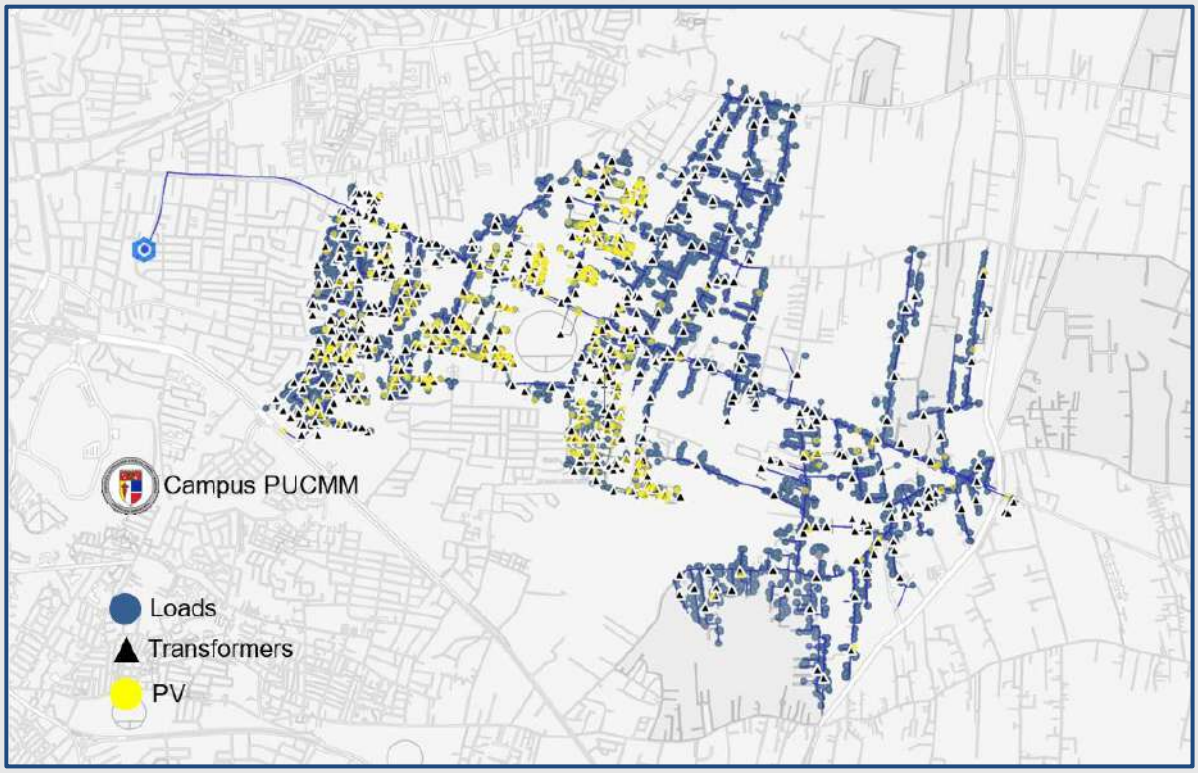
www://

PAPER PRE-PRINT

FROM GIS LAYERS TO SIMULATION

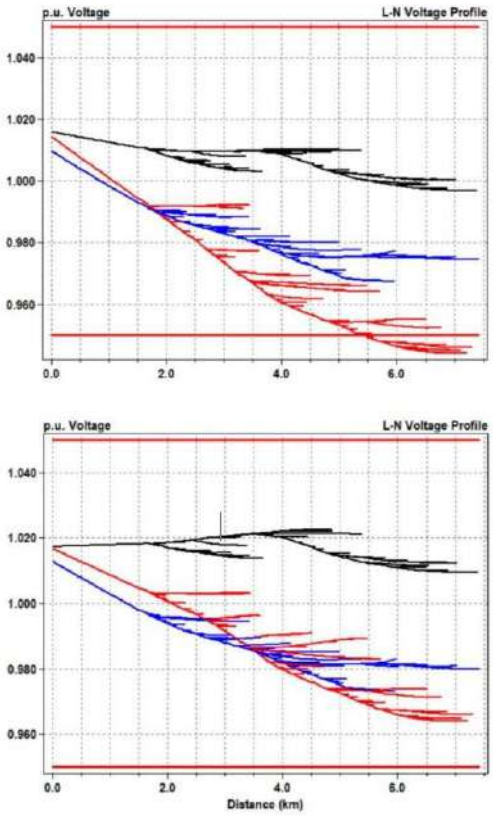


GIS Network provided by the power utility EDENORTE



QUANTIFYING THE IMPACT OF OF VARIABLE SOURCES

(Above) L-N Voltage profile (pu) without PV generation, while (below) with PV.



Heatmap of percentage of voltage rise.

The main contribution of this paper is to adapt and use **real PV penetration** data from a GIS database of a distribution network circuit, use the QGIS2OpenDSS plugin to build the DN model, and then conduct illustrative analysis on the simulations in OpenDSS.

The integration of this tool in the software stack of the DNOs in the Dominican Republic holds utmost significance. Recent studies on the issues regarding the development of DERs in the island have identified that the lack of access and capacity on specialized electrical system analysis software for DER interconnection procedures create unnecessary delays on the approval of projects and the further development of the market.

OUTREACH - ASOCIACIÓN DE COMERCIANTES E INDUSTRIALES

The research group presented the active lines of research to the directors of the Association of Merchants and Industrialists of Santiago. The event organized by the Vicerrectoría de Investigación sought to connect the business community of the city of Santiago with possible opportunities for collaboration and financing.

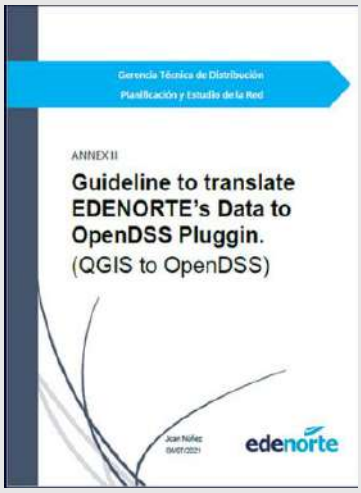
The team presented the ongoing work related to:

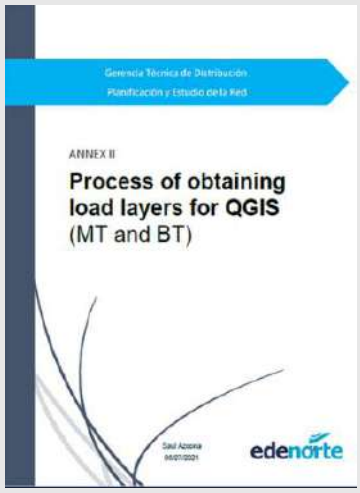
- Energy modelling and Simulation
- Microgrid Laboratory
- Optimization of MG using Swarm Algorithms

TECHNICAL PRESENTATION TO EDENORTE ON THE GUIDELINES FOR QGIS2OPENDSS

A technical presentation of results was given to our main stakeholder (EDENORTE). The main goal of the presentation was to showcase the tools we have been building and using, providing insights on how EDENORTE can use them in their internal processes, and the possibilities to use them for more in depth analysis. Professionals from various directions were present (losses, projects, information technology, communications).

GitHub





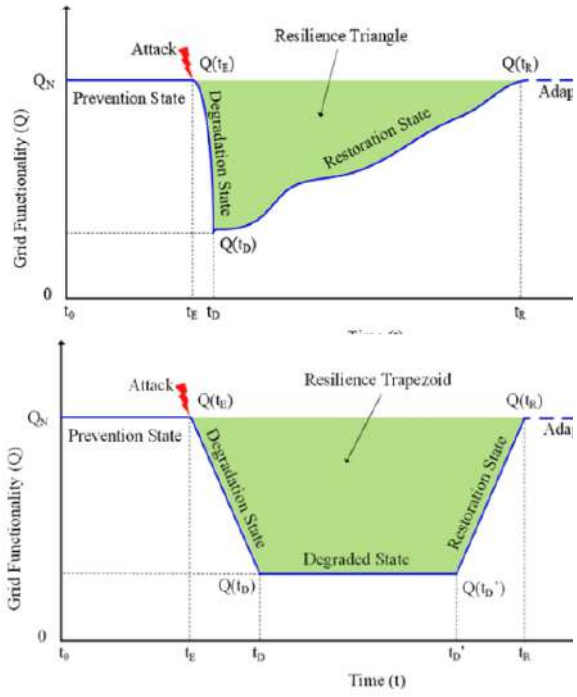
Q7 I OCTOBER – DECEMBER 2022

USAID, NAS & RTI VISIT

The MG Research Group received representatives from the United States Agency for International Development (USAID), the National Academy of Sciences (NAS) and Research Triangle Institute (RTI) for the purpose of evaluating the development of our project "Analysis of resilience for the development of microgrid architectures to face extreme weather events in the Dominican Republic". During the visit, the Research Team walked them through our development process, as well as presented our roadmap, outreach, milestones, and our capacity building.

SYMPOSIUM - EMERGING RESEARCH IN ELECTRICAL POWER SYSTEMS, ENERGY RESILIENCE AND MICROGRIDS.

The research groups at PUCMM presented the active lines of research on Electrical Power Systems, Energy Resilience and Microgrids, being conducted in both Santiago and Santo Domingo campus. The event organized by the Vicerrectoría de Investigación sought to show the active and future lines of research of the school's research groups, and to define possible routes for the students' undergraduate research projects.

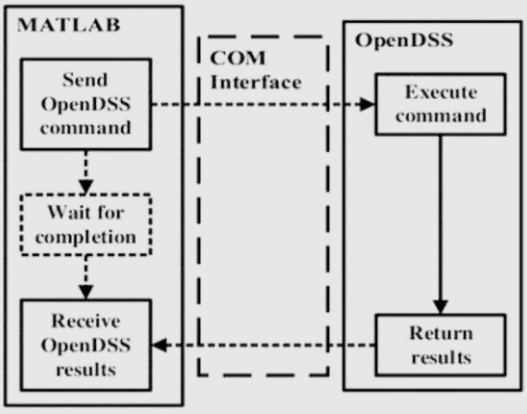


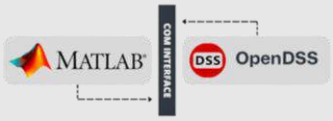
Q8 | JANUARY – MARCH 2023

ENERGY RESILIENCE INDICES LITERATURE REVIEW

One of the last objectives for the research was to conduct a review of frameworks for assessing energy resilience in power distribution networks. There is a growing body of literature on quantitative assessments of resilience that propose relevant indicators to guide not only resilience enhancement but also cost-benefit studies prior to investment planning. Our goal was to find state-of-the-art resilience frameworks to use in our resilience analysis.

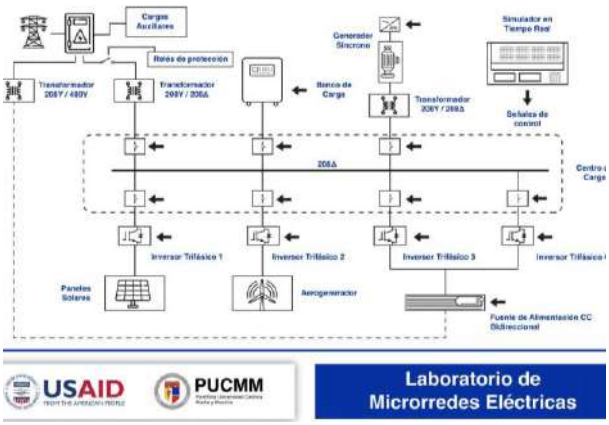
Various methodologies for quantifying the resilience index have been proposed by researchers in the field using the Resilience Trapezoid (see figure on the left). A taxonomy of resilience evaluation methods and metrics reviewed can be found in our blog.





IMPLEMENTATION OF MATLAB-OPENDSS COM INTERFACE FOR DISTRIBUTION NETWORK ANALYSIS

The MATLAB-OpenDSS COM interface comes from one of the main characteristics of the OpenDSS software; it is customizable for user-defined applications. Based on this attribute, custom processes can be modeled using modern programming languages, in which MATLAB is included. To sum it all concisely, the MATLAB-OpenDSS COM interface is a portable compilation and execution of OpenDSS commands without using the OpenDSS interface. This means that MATLAB code can interact with OpenDSS files, not only compiling and executing, but also editing them; for example, lines can be connected or disconnected without modifying the files directly.

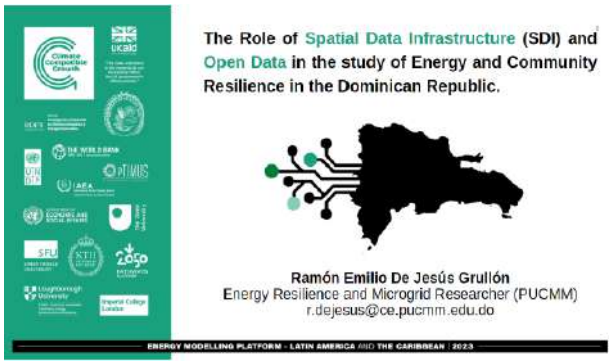


USAID - PEER PROJECT SUCCESS STORY ARTICLE "RESEARCHING FOR ENERGY SOLUTIONS."

USAID´s mission in Santo Domingo reached out to the MG research group to write a story about the context, objectives, highlights, and potential developments of the MG research project.

In the story we talked about the relevance of the research in the context of climate change, our efforts regarding capacity building and how using the laboratory as a new research platform, it has been possible to receive additional funds for future projects that will continue the vision of the team.

With the new funds the National Fund for Scientific and Technological Research (FONDOCYT), the aim is to create an open data platform on resilience and deepen the operation of the electrical distribution system. Also, this platform will help provide data on how the electrical system must change to adapt, and what effects may occur with a much more dynamic electrical grid that is susceptible to rapid and unexpected changes.



ENERGY MODELLING PLATFORM LATIN AMERICA

PI De Jesús participated of the EMP-LAC 2023 program, a 3-week hybrid program taught at the University of Costa Rica in the ONSSET software. OnSSET is a GIS-based optimization tool that has been developed to support electrification planning and decision-making for the achievement of energy access goals in currently unserved locations. During the training the research team got to interact with a wide range of professionals working on resiliency and energy access, providing avenues to capacity building in the near future.

Q8 I APRIL – JUNE 2023

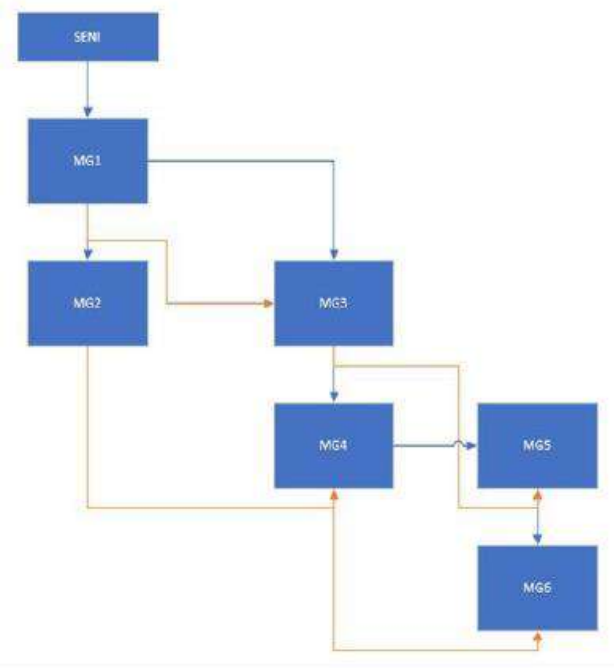
DOMINICAN WEEK OF SCIENCE AND TECHNOLOGY 2023

The MG Research group presented several ongoing works in the XVIII International Congress of Scientific Research (XVII CIC) 2023. The event held keynote and special conferences, poster exhibitions, courses, seminars, and workshops, carried out in face-to-face, virtual and hybrid modalities at the Technological Universities of Santiago (UTESA) and Open University for Adults (UAPA).

SUSTAINABLE ENERGY FORUM (FES 2023) – PANEL: ENERGY STORAGE: RESILIENCE AND ENERGY INDEPENDENCE IN THE DR

Energy storage has become an increasingly relevant topic in the discussion on the transition towards cleaner and more sustainable energy systems. In the context of island nations, such as the Dominican Republic, these technologies will play an even more crucial role in the search for resilience and energy independence.

PI De Jesús and CI Espinal were invited to moderate and participate the panel "Energy Storage: Resilience and Energy Independence in the DR" in the Sustainable Energy Forum (FES) a platform to promote the energy sector in the Dominican Republic, in which productive connections are established and they receive the most up-to-date information about energy efficiency, financing, technology, regulation, responsibility social, climate change, among other topics of interest.



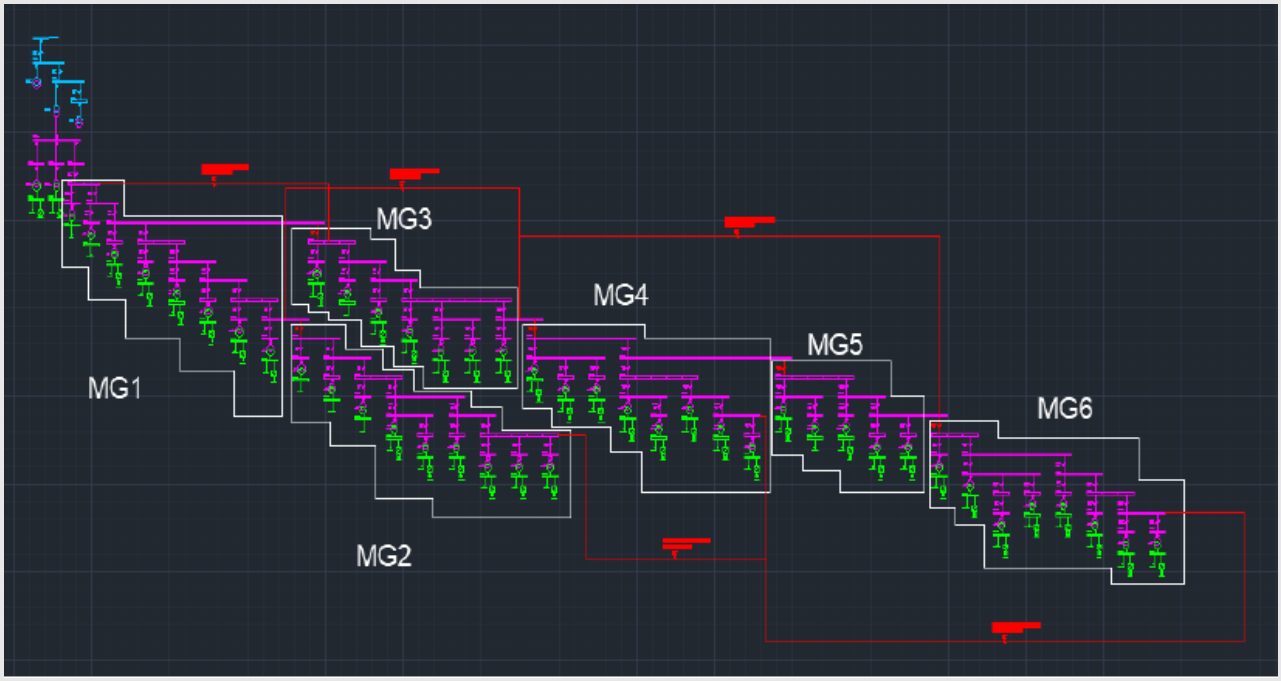
Q8 1 JULY – SEPTEMBER 2023

DISTRIBUTION NETWORK SEGMENTATION INTO MINIGRIDS – PROOF OF CONCEPT

One of the main objectives of the research is the study of simulation scenarios of MG formation (segmentation) in the local distribution network (Santiago de los Caballeros), proposing possible control strategies and an overall vision of resiliency standards and practices to the regional utility company (EDENORTE)

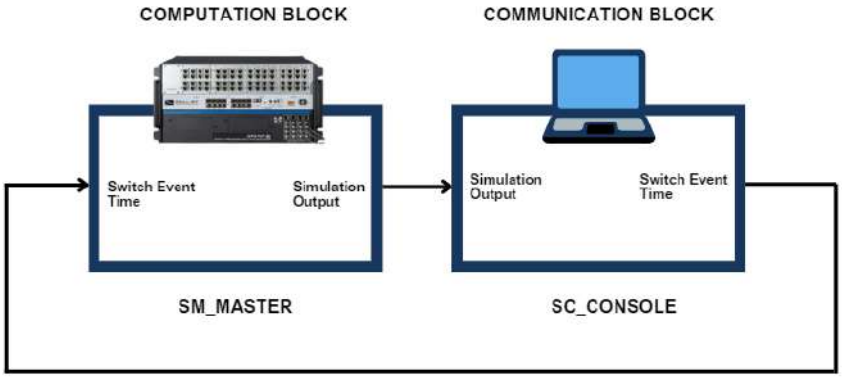
The team used the analyzed distribution circuit (VOLG101) up to the entire High Voltage Feeder from the CANABACOA HV substation, including in the simulation, the other distribution circuits from the VILLA OLGA distribution substation, as well as other HV loads (Hospitals and Industries) that are considered critical for the city of Santiago. All the elements of the distribution circuit chosen VOLG101 were simplified and modeled in OPENDSS by grouping the loads and transformers based on proximity and topology.

PROPOSED NETWORKED MICROGRID TOPOLOGY



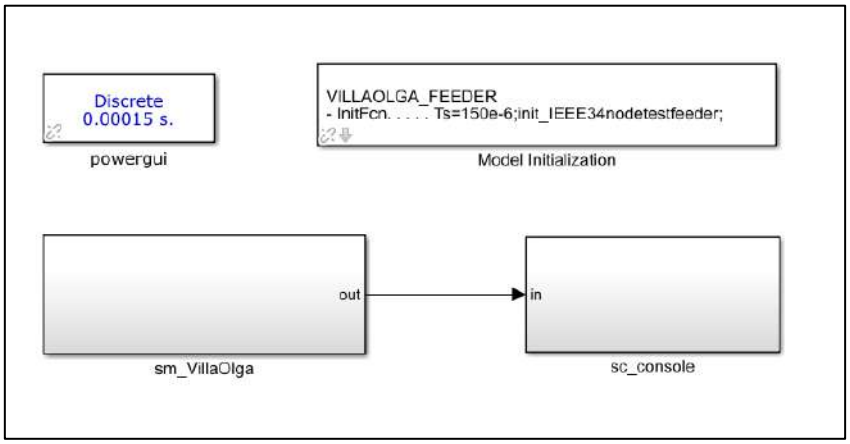
REAL TIME SIMULATION

A real time simulation process was carried out for the selected feeder. The main objective was validating the computational capability of the HIL testbed for executing this type of detailed power system simulations on a real time framework. This simulation environment is composed of the integration of RT-LAB© and Matlab/Simulink©. Our simulator (OPAL XG5707) uses the RT-LAB© software to compile and coordinate the models that are developed on Matlab/Simulink©. A specific methodology must be followed for developing this type of model and several training sessions were required for the team to learn how to use this type of technology.



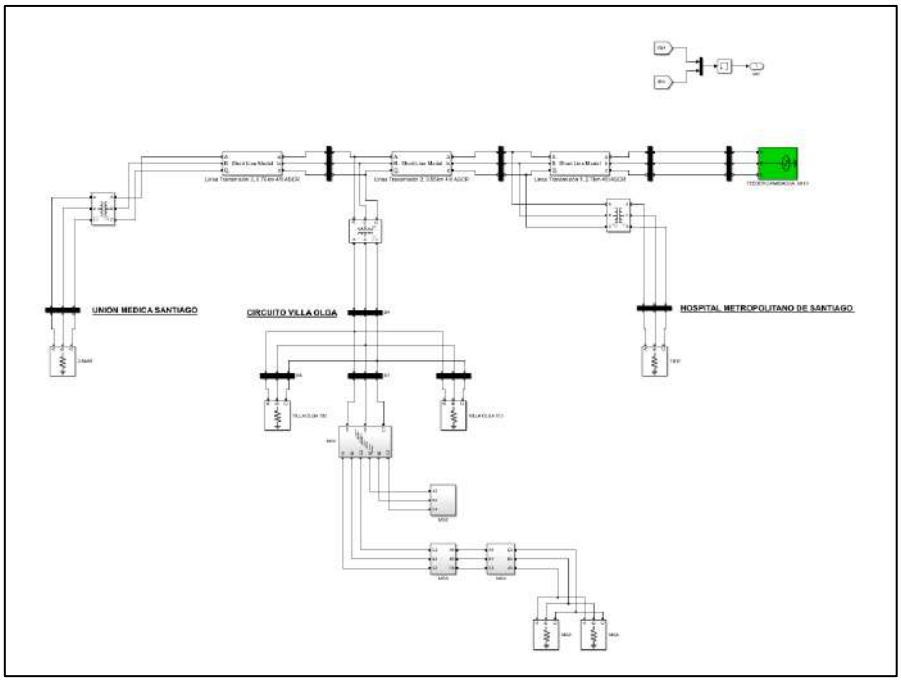
Top Level Model of OPAL-RT

The first part of this process required the reduction of the electrical distribution infrastructure using an active power aggregation rule-based methodology. For future purposes, five subdivisions (segmentations) were created within the circuit, with the objective of conducting future parallel real time simulations as our system is capable of that functionality. The presented real time simulation on this section was conducted using only one of the eight available cores. With the additional funding received from other grants to the laboratory, the team is inthe process of enabling real time simulations in up to six cores. The simulator requires a division between computation and visualization processes (see the picture above), after completing this separation, the resulting high level blocks diagram is shown in the figure below.



Simulation separation between computation and visualization.

For real time requirements, a fixed time step of 150µS was chosen, ensuring a total of 112 measurements per cycle in a 60Hz electrical system. A total of 123 electrical buses were simulated at the selected time step, furthermore, the dynamics of transmission lines and transformers were considered in the construction of each segmentation of the electrical feeder. Each segmentation was created as a separate subsystem as shown in the figure below. The selected naming for each segmentation block was MG1 to MG5.



Simulation under the SC computational node in RT LAB.

The monitoring utilities of RT LAB probed the feasibility of this real time simulation as can be seen in the figure below the number of overruns is equal to zero.

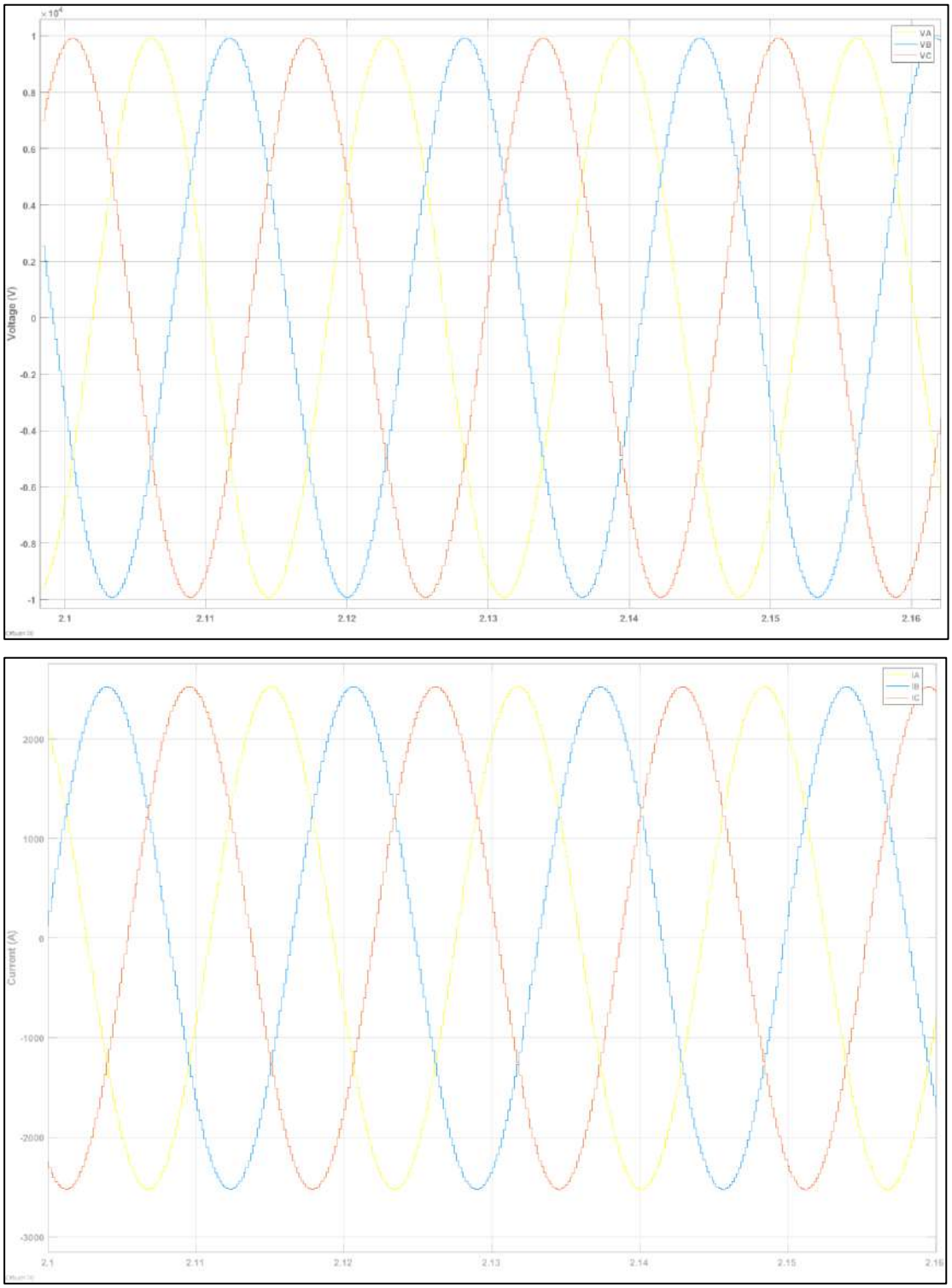
Monitoring

Model: VillaOlga_FEEDER Ts=1.5E-4[s] T=2243.7303[s] Number of overruns=0

Probes	Info				Data			
	Usage [%]	Min	Max	Mean	1	2	3	4
VillaOlga_FEEDER Ts=1.5E-4[s]	65.48%							
sm_VillaOlga T...0071246177E-4[	65.48%	dt= 97.28 [us]	dt= 98.93 [us]	dt= 98.22 [us]	dt= 97.74 [us]	dt= 98.18 [us]	dt= 98.01 [us]	dt= 98.20 [
New data acquisition	0.06%	dt= 0.02 [us]	dt= 0.15 [us]	dt= 0.08 [us]	dt= 0.06 [us]	dt= 0.07 [us]	dt= 0.14 [us]	dt= 0.05 [u
Major computation time	42.11%	dt= 62.50 [us]	dt= 63.63 [us]	dt= 63.16 [us]	dt= 62.74 [us]	dt= 63.11 [us]	dt= 62.93 [us]	dt= 63.25 [
Minor computation time	22.4%	dt= 33.13 [us]	dt= 33.83 [us]	dt= 33.61 [us]	dt= 33.45 [us]	dt= 33.51 [us]	dt= 33.52 [us]	dt= 33.56 [
Execution cycle	65.48%	dt= 97.28 [us]	dt= 98.93 [us]	dt= 98.22 [us]	dt= 97.74 [us]	dt= 98.18 [us]	dt= 98.01 [us]	dt= 98.20 [
Total step size	100.0%	dt= 149.97 [us]	dt= 150.03 [us]	dt= 150.00 [us]	dt= 150.00 [us]	dt= 149.98 [us]	dt= 150.02 [us]	dt= 149.99
Total idle	33.99%	dt= 50.26 [us]	dt= 51.91 [us]	dt= 50.99 [us]	dt= 51.63 [us]	dt= 51.24 [us]	dt= 51.40 [us]	dt= 51.05 [
Update lv panels	0.0%	dt= 0.00 [us]	dt= 0.00 [us]	dt= 0.00 [us]	dt= 0.00 [us]	dt= 0.00 [us]	dt= 0.00 [us]	dt= 0.00 [u

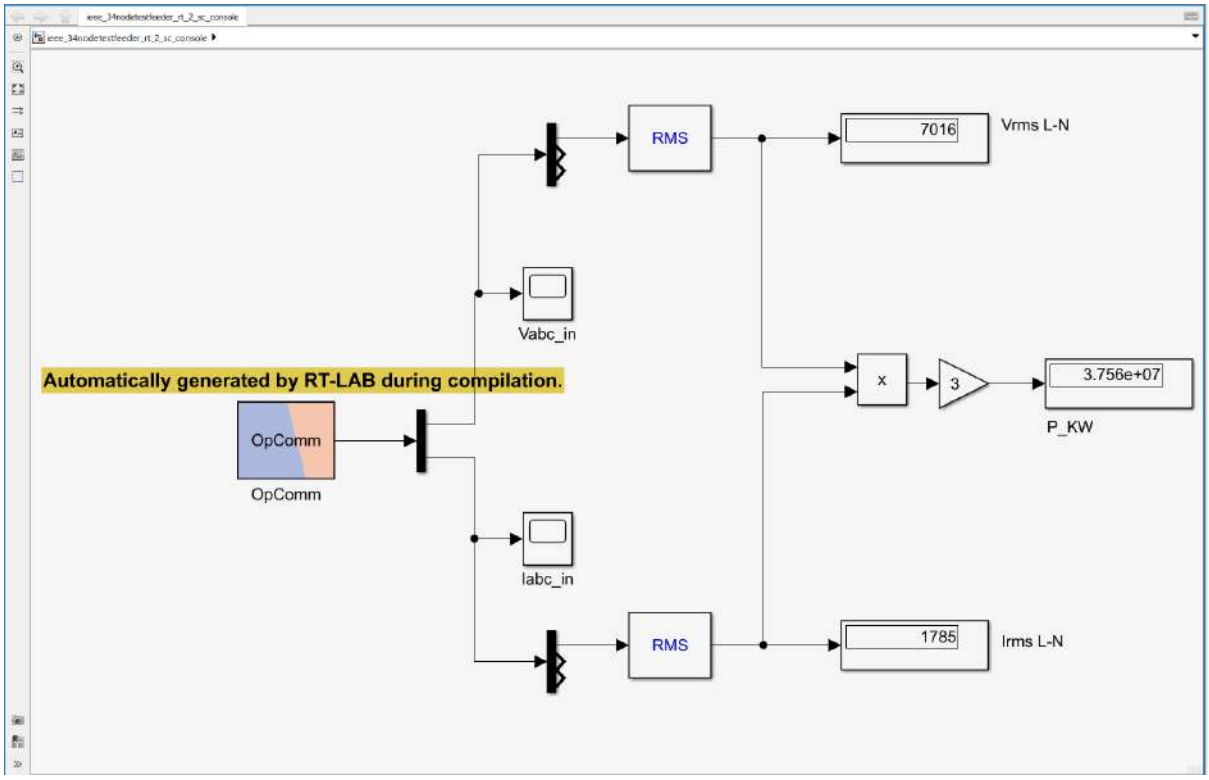
Real time simulation monitoring in RT LAB.

The resulting wave forms for the real time simulation are shown in the figure below.



Wave forms of Three Phase Voltage and Current

Finally, the figure below shows the voltage and power calculations for the complete feeder.



2 PROJECT EVENTS

STAKEHOLDER EVENTS

CONFERENCES / PANELS

SHORT CURSES

WORKSHOPS

Q1 - APR-JUN 2021

- MICROGRIDS AGAINST CLIMATIC EVENTS: ENERGY RESILIENCE IN THE DOMINICAN REPUBLIC
- SMART CITIES: PROMOTING TECHNOLOGICAL INNOVATION AND ADAPTATION IN THE DR

Q2 - JUL-SEP 2021

- SIMULATION AND MODELLING OF DISTRIBUTION NETWORKS USING OPENDSS AND QGIS
- INTRODUCTION TO MATLAB&SIMULINK FOR POWER SYSTEM ANALYSIS

Q3 - OCT-DEC 2021

- ENHANCED RELIABILITY AND RESILIENCY FOR THE DR ELECTRIC GRID: MICROGRIDS
- MICROGRIDS AGAINST CLIMATE-DRIVEN EVENTS IN THE DR

Q4 - JAN-MAR 2022

- ENERGY 4.0 - THE FUTURE OF ENERGY ON DOMINICAN REPUBIC
- NETWORKED MGS - INTERCONNECTED MICROGRIDS: IMPROVING RESILIENCE IN DR ELECTRICITY GRIDS

Q5 - APR - JUN 2022

- PRESENTATION OF PROGRESS OF THE MICROGRID RESEARCH LAB TO THE INNOVATION CABINET OF DR
- PRESENTATION OF RESEARCH LINES TO THE ASSOCIATION OF MERCHANTS AND INDUSTRIALISTS
- USAID – SEED (SUSTAINABLE ENVIRONMENT AND ECONOMIC DEVELOPMENT OFFICE)

Q6 -OCT - DEC 2022

- EMERGING RESEARCH IN ELECTRICAL POWER SYSTEMS, ENERGY RESILIENCE AND MICROGRIDS
- USAID, NAS & RTI VISIT
- PRESENTATION AT THE FETE DE LA SCIENCE

Q7 - JAN-MAR 2023

- APPLICATIONS OF REAL-TIME SIMULATION IN ELECTRICAL POWER SYSTEMS

Q8 - APR-JUN 2023

- DOMINICAN WEEK OF SCIENCE AND TECHNOLOGY 2023
- ENERGY STORAGE: RESILIENCE AND ENERGY INDEPENDENCE IN THE DR

3 RESEARCH TEAM

RESEARCHERS

Ramón Emilio De Jesús-Grullón
r.dejesus@ce.pucmm.edu.do

Rafael Omar Batista Jorge
r.batista@ce.pucmm.edu.do

Abraham Espinal Serrata
ab.espinal@ce.pucmm.edu.do

RESEARCH ASSISTANTS

Juan José Pichardo Estévez
20180427@ce.pucmm.edu.do

Justin Eladio Bueno Perez
20180748@ce.pucmm.edu.do

4 EDUCATIONAL IMPACTS

CHANGES TO EXISTING COURSE CURRICULA

With the creation of the hardware-in-the-loop (HIL) laboratory on the Santiago campus, many subjects of Electrical Engineering – (concentration Electrical Power Systems) now have new testing tools for practical and conceptual sessions.

SUBJECT	YEAR
Electrical Power Systems I	YEAR 4, 1st Period
Electrical Machines II	YEAR 4, 1st Period
Electrical Machines Laboratory II	YEAR 4, 1st Period
Power Electronics	YEAR 4, 2nd Period
Power Electronics Laboratory	YEAR 4, 2nd Period
Electrical Power Systems II	YEAR 4, 2nd Period
IEL Degree Preliminary Project	YEAR 4, 2nd Period
Photovoltaic Solar Energy	YEAR 4, 2nd Period

STUDENT LED RESEARCH - B.S UNDERGRADUATE THESIS PROJECT

Objective: To model and simulate the Nibaje circuit (NIBA103), located in Santiago de los Caballeros, Dominican Republic. In this study, extensive research was carried out on the incorporation of open-source geospatial tools and analysis of electrical distribution systems. This was demonstrated by the integration of QGIS and OpenDSS using the QGIS2OpenDSS plugin, which generated OpenDSS models from GIS.

DEVELOPMENT OF TRAINING COURSES ON OPENDSS AND MATLAB/SIMULINK

The main platforms/software to simulate the electrical grid components and interactions have been already identified by the team, and training courses on how to utilize them will be developed to build capacity among the students and professionals that interact with the project. This will serve as a platform for developing future work and investigations. The team will organize workshops on the use and capabilities of these two tools for developing Power Systems simulations and to address studies on specific electrical grid issues. The training courses and workshops will be held at PUCMM with the support of the Engineering faculty and student's committee. Furthermore, these training courses will help the integration of future students into the project as well as serving as a base for the development of the engineering curriculum of the local universities.

DEVELOPMENT OF TRAINING COURSES ON QGIS AND OPENDSS INTEGRATION

The integration of OpenDSS and QGIS has been crucial in order to have the capability to represent the existing large distribution networks and its components in the scripting language of the OpenDSS software. There are several plugins available under the QGIS stack that help correct and filter the information prior to its translation into the scripting language, therefore a course on these special plugins will be very convenient to be linked to the the previous OpenDSS course, giving it a broader applicability.

5 RESEARCH OUTPUTS

MICROGRID RESEARCH BLOG

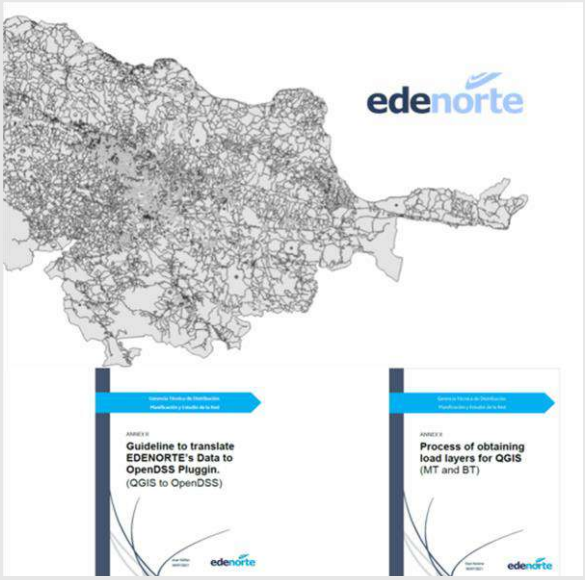
ARTICLE NAME	DATE	URL
Towards the Future: The 21st Century Electric Grid.	OCTOBER 12, 2021	
Hardware-in-the-Loop Simulation and its Impact on the Design of Power Systems.	NOVEMBER 11, 2021	
Energy Transition and Challenges in the Post COVID Era.	JANUARY 11, 2022	
Vulnerabilities of the Dominican Republic's Electric Networks & Catastrophic Risks to Grid Security.	JANUARY 31, 2022	
Networked Microgrids: Building Block of the SmartGrid.	APRIL 8, 2022	
IoT and Demand Response for Enhancing Grid Stability.	MAY 9, 2022	
Energy and Community Resiliency Studies in the Dominican Republic. Case Study: Santiago de los Caballeros City.	JULY 12, 2022	
DC Microgrids for the Integration of Vehicle to Grid Technology.	OCTOBER 17, 2022	
The role of Power Hardware-in-the-loop (HIL) Simulations in the Energy Transition.	DECEMBER 8, 2022	
Implementation of MATLAB-OpenDSS COM Interface for Distribution Network Analysis.	FEBRUARY 22, 2023	
Frameworks for Assessing Energy Resilience in Power Distribution Networks.	MARCH 30, 2023	

OPINION ARTICLES IN THE LOCAL PRESS

ARTICLE NAME	DATE	URL
¿Secuestrando al Sol? La nueva regulación al sector fotovoltaico	FEBRARY 20, 2022	
Plan Energético Nacional (PEN 2022-2036): ¿Qué es y en qué está?	OCTOBER 27, 2022	
Almacenamiento de Energía: Resiliencia e Independencia Energética en RD	JANUARY 22, 2023	
Pérdidas de Energía en Distribución: El Agujero Negro del Sector Eléctrico en República Dominicana	AUGUST 15, 2023	

TECHNICAL GUIDELINES FOR EDENORTE (MAIN STAKEHOLDER)

The objective of this guide is to support EDENORTE in the digitalization processes necessary to use cutting-edge modeling and simulation tools for its medium and low voltage networks, with the goal of increasing the distributor's ability to use the growing availability of data for its network studies such as: Impact of Distributed Generation and microgrid design, voltage profile studies for the identification of network losses, integration of electric mobility , renewable energy accommodation maps, among others.



COLLABORATION IN RESEARCH FOR POLICY MAKING

The Vice Ministry of Energy Security and Infrastructure, in keeping with its mission of establishing policies to guarantee electric power service for the Dominican population, is working on a **National Indicative Plan for the Development of Critical Energy Infrastructures**. PI Ramón Emilio De Jesús-Grullón was the main external assessor and editor for the Plan. The plan is organized as follows:

- Section 1: Executive Summary
- Section 2: Introduction
- Section 3: Overview of the Dominican Electricity Sector:
- Section 4: SENI (National Interconnected Electric System) Vulnerabilities:
- Section 5: Critical Infrastructure

RESEARCH PAPER (PRE-PRINT): MODELING AND SIMULATION OF DISTRIBUTION NETWORKS WITH HIGH RENEWABLE PENETRATION IN OPEN-SOURCE SOFTWARE: QGIS AND OPENDSS

Abstract: There are important challenges for modeling large electrical distribution circuits, even more with the presence of distributed renewable generation. This paper proposes a simulation strategy based on open-source platforms and the integration of scripting tools for the rapid modeling of large-scale electrical distribution circuits with distributed renewable generation. The implementation is based on the adaptation of a tool called QGIS2OpenDSS, which creates OpenDSS distribution network models directly from an open-source geographic information system, QGIS. The plugin's capabilities are demonstrated using a real distribution feeder with more than 60% penetration of renewable generation based on photovoltaic systems. These simulations are carried out using real data from a circuit provided by a Distribution Network Operator (DNO) in the Dominican Republic, which is used to demonstrate how this approach provides a more accessible and flexible way to simulate and assess the effect of Distributed Energy Resources (DERs) in Medium Voltage (MV) and Low Voltage (LV) networks, enabling utilities to evaluate system performance and identify potential issues.

Keywords: QGIS2OpenDSS, Distribution Network Modelling, High Renewable Penetration, Distribution Network Builder, OpenDSS

OTHER DESEMINATION PLATFORMS

PODCASTING	DATE	URL
MICROGRIDS AGAINST CLIMATE-DRIVEN EVENTS	MARCH 2021, 2022	
ENERGY SECURITY AND CRITICAL INFRASTRUCTURE IN THE DOMINICAN REPUBLIC	JULY, 2021	

TECHNICAL RESEARCH PRESENTATIONS - CONFERENCES

NAME	DATE	URL
MESCYT		
Simulation of the Application of Electrical Resiliency Index in Dominican Republic Electrical Grid	JUNE, 2021	
Plataforma de Datos Abiertos para el Análisis Espacial de la Resiliencia Energética y Comunitaria	JUNE 2023	
Validación de Esquemas de Protección de Sistemas de Potencia Eléctricos en Circuitos con Alta Penetración de Generación Distribuida	JUNE 2023	
Detección Automática de Fallos en Sistemas de Transmisión de Potencia Eléctrica Mediante el Uso de Técnicas de Aprendizaje de Máquina y Esquemas de Co-Simulación	JUNE 2023	
Sistema de Gestión Inteligente para la Integración de Generación Distribuida y Vehículos Eléctricos basado en Algoritmos de Inteligencia de Enjambre	JUNE 2023	

6 PROFESSIONAL DEVELOPMENT

SECTION 6 – PROFESSIONAL DEVELOPMENT

ADDITIONAL FUNDING/GRANTS

During the project the Microgrid Research Group received 2 additional research grants, a PHD scholarship, as well as additional funding coming from a donation of private company (ENESTAR) and matching funds coming from PUCMM.

The Significance of the PEER Grant in Securing Additional Funding

- **Enhanced Credibility and Recognition:** Being a beneficiary of the PEER grant positioned the Microgrid Research Group at PUCMM as serious players and pioneers in this field in the DR. The group demonstrated the ability to execute the objectives of the grant, which makes our subsequent proposals more attractive to other grantors and can be a strong persuasive factor for potential funders.

- **Increased Research Capacity:** PEER's emphasis on building scientific research capacity means that after being awarded the grant, we had access to enhanced resources, training, and expertise. With these advantages, our research group was better positioned to produce quality research.

- **Collaborative Networking**: Through PEER, we collaborated with U.S. government-funded researchers, broadening our network. These connections opened doors for further funding opportunities or provided valuable references and endorsements for our subsequent grant applications.

ADDITIONAL FUNDING DETAILS

ENESTAR DONATION

The renewable energy company ENESTAR and the Madre y Maestra Foundation signed a collaboration agreement in which the company would donate materials and equipment to equip the PUCMM Microgrid Laboratory, for an estimated value of USD 20,000.00.

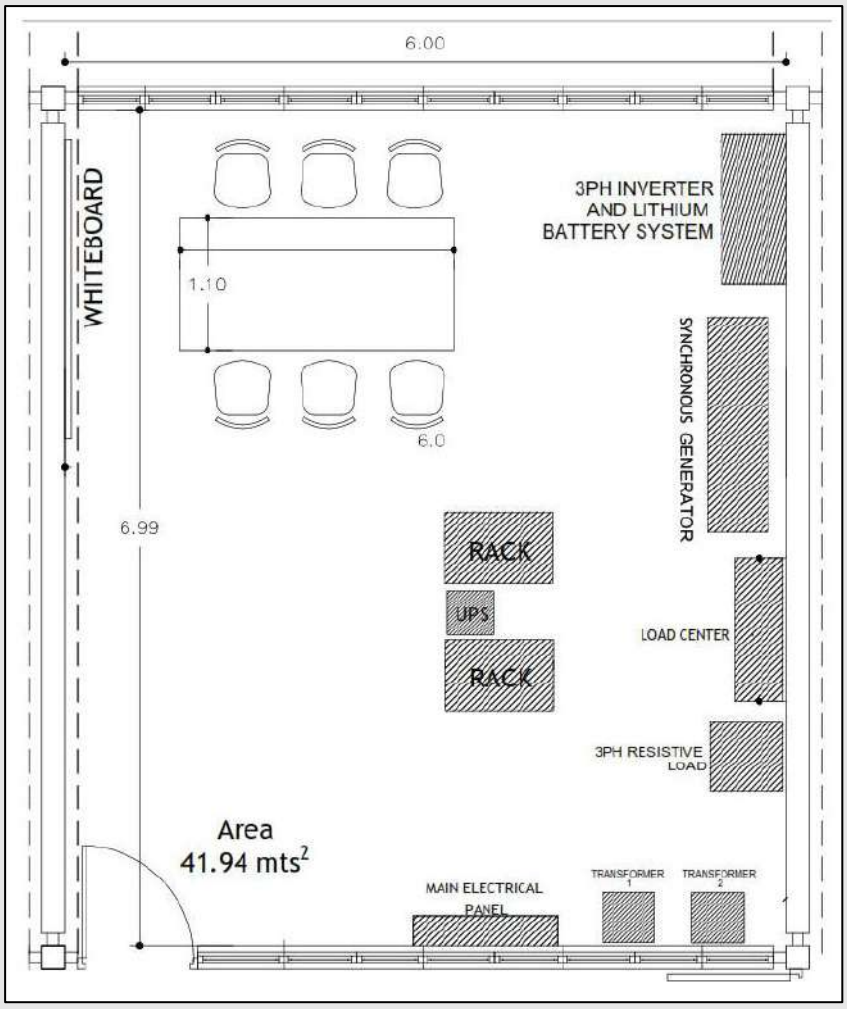
USD 20,000

PUCMM MATHING FUND FOR THE MICROGRID LAB REFURBISHIMENT

The total budget of the laboratory renovations was USD **$17,000 USD**, which came from PUCMM's matching funds. This included air conditioning, furniture and renovation of the physical plant (floors, windows), security cameras, fire alarm, secure entry system.

USD 17,000

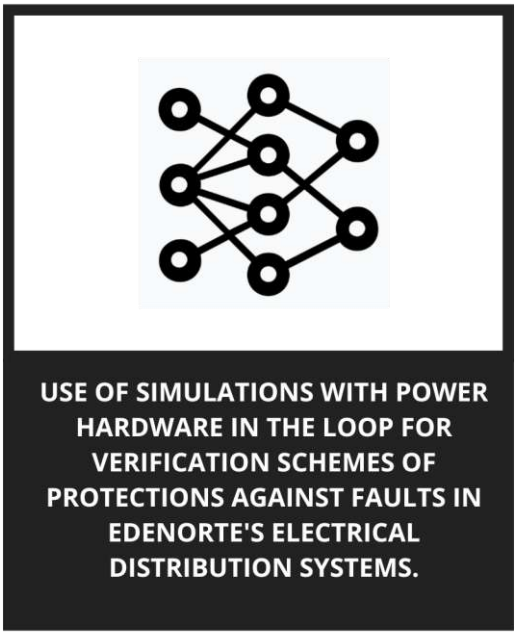
FINAL APPROVED LAYOUT OF MG LABORATORY



PHD IN ENERGY MANAGEMENT FOR SUSTAINABLE DEVELOPMENT

The MG group received an opportunity to enroll in a doctorate on Energy Management for Sustainable Development from the Instituto Tecnológico de Santo Domingo (INTEC) with a full scholarship valued at **21,500 USD**. C.I Batista is now a PhD candidate, his doctoral thesis is going to be fundamental in one of the main research branches related to electrical grid resiliency, distributed control, and the dynamic formation of microgrids under fault conditions. Furthermore, this has opened new interaction possibilities with the doctoral students of this program and the institutions involved, especially INTEC.

USD 21,500



MESCYT edenorte

USD 240K

RESEARCH GRANT – ABSTRACT

Electricity distribution companies have significant challenges when it comes to validating new projects on distribution lines, both at low voltage and medium voltage levels. This is explained in part because traditional simulation schemes have limitations to model the behavior of all the linear or non-linear characteristics that the various elements that make up an electrical power system may present. Due to this, there is an increasing number of distribution companies at a global level that use power hardware simulation strategies in the loop to validate devices under test and new infrastructures in electrical distribution networks. This allows obtaining more accurate simulation scenarios that reduce implementation and validation times when implementing new protection schemes or modifications to distribution networks. The project seeks to establish this methodology using the Microgrids laboratory of the Pontificia Universidad Católica Madre y Maestra in conjunction with the collaboration of the regional electricity distribution company EDENORTE.

Open Data Platform for Spatial Analysis of Energy and Community Resilience

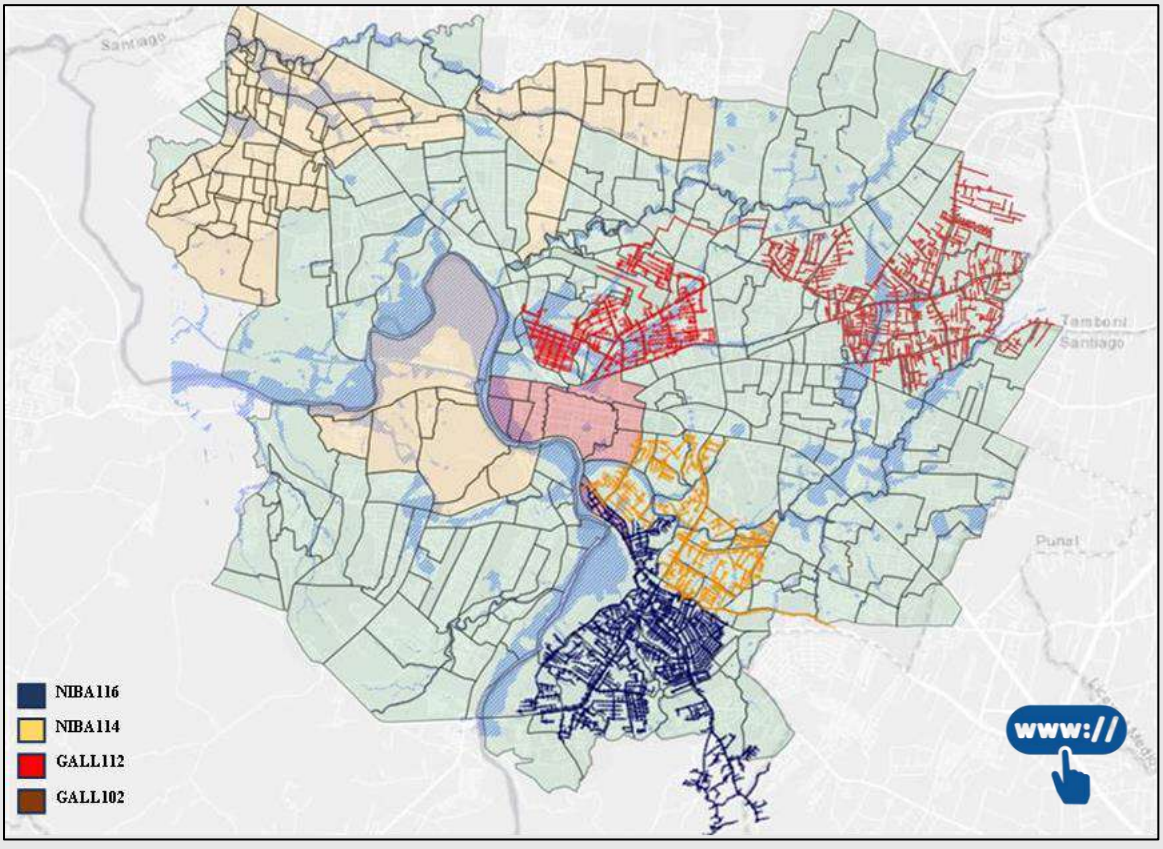
MESCYT

edenorte

USD 105 K

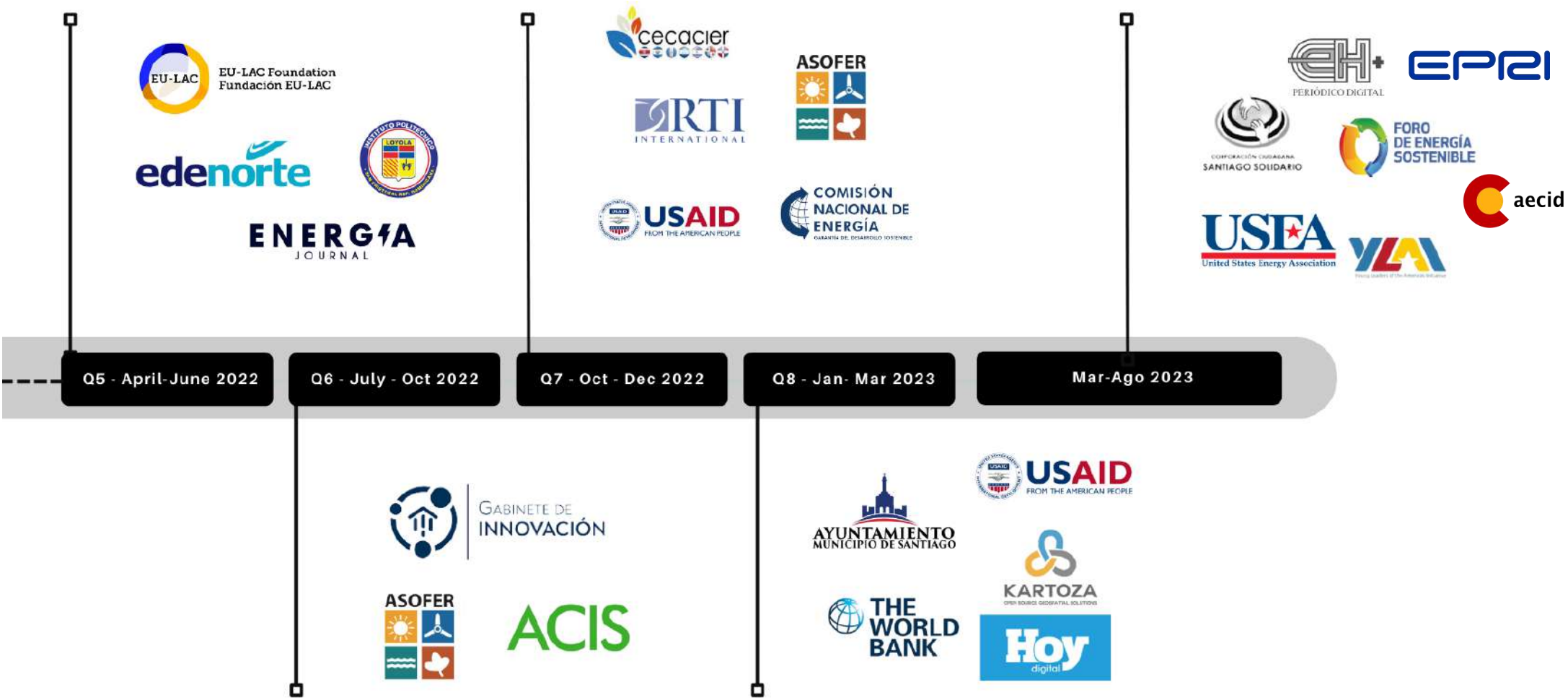
RESEARCH GRANT – ABSTRACT

This project proposes the use of Geographic Information Systems (GIS) software for the creation of an Open Data Platform for Spatial Analysis of Energy and Community Resilience, which will have the location of critical elements of the electrical network subject to being affected by natural disasters and anthropological factors. The combination of electrical system data with socioeconomic and geographic information will serve to illustrate the occurrence of high-impact, low-probability (HILP) events, which could affect said systems and the communities that inhabit it, through energy and community resilience indexes. Vulnerability maps will be created that will allow energy sector authorities and community leaders to examine the interaction of resilience indicators, locations of critical infrastructure, hazards, and estimated annualized frequency of hazards. The PUCMM Electrical Microgrids research group and the Center for Urban and Regional Studies (CEUR) participate in this project.



7 OUTREACH AND COLLABORATION

SECTION 7 - OUTREACH AND COLLABORATIONS


EU-LAC Foundation
Fundación EU-LAC
edenorte
ENERGÍA
JOURNAL
cecacier
RTI
INTERNATIONAL
ASOFER
USAID
FROM THE AMERICAN PEOPLE
COMISIÓN
NACIONAL DE
ENERGÍA
PERIÓDICO DIGITAL
EPRI
SANTIAGO SOLIDARIO
FORO
DE ENERGÍA
SOSTENIBLE
aecid
USEA
United States Energy Association
Q5 - April-June 2022
Q6 - July - Oct 2022
Q7 - Oct - Dec 2022
Q8 - Jan- Mar 2023
Mar-Ago 2023
GABINETE DE
INNOVACIÓN
ASOFER
ACIS
AYUNTAMIENTO
MUNICIPIO DE SANTIAGO
USAID
FROM THE AMERICAN PEOPLE
KARTOZA
THE
WORLD
BANK
Hoy
digital

OUTREACH AND COLLABORATIONS - HIGHLIGHTS

GOVERNMENT AGENCIES

- **EMPRESA DISTRIBUIDORA DE ELECTRICIDAD DEL NORTE (EDENORTE)**

  With the goal of implementing and adding the OpenDSS-Based Distribution Network Builder into EDENORTE's (main stakeholder) software stack, a working group was created within the Distribution Management and Network Studies Department and the MG Research Team. The task at hand was to create a blueprint of the processes that are necessary to obtain, clean and transform the utilities' existing GIS Data to be fed into the QGIS2OPENDSS Plugin. Several Data Dictionaries and Workflows were created to standardize and summarize the efforts that have been conducted for future use.

- **MINISTRY OF ENERGY AND MINES (MEM-RD) | VICE MINISTRY OF SECURITY AND ENERGY INFRAESTRUCTURE (VSEI)**

  The VSEI's is mapping the Critical Energy Infrastructure in the country, creating an Indicative Plan defining how to enhance resiliency across the whole system. PI Ramón Emilio De Jesús-Grullón was the main external researcher and editor for the Plan.

- **MINISTRY OF HIGHER EDUCATION, SCIENCE AND TECHNOLOGY (MESCYT)**

  MESCYT announced the 2022 Call for the National Fund for Scientific and Technological Innovation and Development (FONDOCYT), In this FONDOCYT call, proposals for basic and applied research, Research and Development and innovation (R+D+i) or Technology Transfer will be accepted. The Microgrid Research Team presented 3 proposals to FONDOCYT with the goal of expanding the research scope, increasing capacity building, and involving more institutions from PUCMM and Government Agencies.

- **SANTIAGO CITY COUNCIL**

  The team reached an agreement with the Territorial Planning Office (POT) of the city council of Santiago to share expertise and the data related to Geographic Information Systems (GIS) necessary to advance the research and the new research grants that extend the project life.

- **CENTER FOR INDUSTRIAL DEVELOPMENT AND COMPETITIVENESS**

  The MG Research Group was invited to participate in the first Entrepreneurship and Innovation Fair of the Center for Industrial Development and Competitiveness - ProIndustria, held in the city of Santiago de los Caballeros, Dominican Republic. An Abstract of the Microgrid Research was showcased for a heterogeneous public, including Governmental Officials (Andres Cueto, General Manager of EDENORTE) Universities (Father Secilio Espinal Espinal, recently appointed as rector of the Pontifical Catholic University Mother and Teacher (PUCMM)) and citizens.

- **EMPRESA DISTRIBUIDORA DE ELECTRICIDAD DEL SUR (EDESUR)**

  Under the umbrella of the RTI´s Energy Sector Reform project, the Microgrid Research Group at PUCMM is exploring the opportunity to extend the research line to EDESUR and Ministry of Energy and Mines (MEM). PI De Jesús presented the results of the research line on *Modeling of Distribution Networks with High Renewables Penetration in Open-Source Software (OpenDSS + QGIS)*. The personnel from EDESUR were the Development and Innovation Manager, Network Studies Coordinator, Network Studies Manager. The overall objective of the meeting and the presentation of these results is to gather support from EDESUR Dominicana and invite them to join and collaborate in the research project. EDENORTE and EDESUR are the Distribution Companies that present the greatest insertion of Photovoltaic Distributed Generation in the DR.

- **NATIONAL ENERGY COMMISSION (CNE)**

The National Energy Commission (CNE), a body of the Dominican state that is responsible for developing, coordinating, proposing and adopting policies for the proper functioning and development of the energy sector, made public through its transparency portal a study on the integration of Variable Renewable Energy and Battery Energy Storage Energy Systems (BESS), and the draft resolutions that declare these as an immediate need in order to anticipate the massive penetration of variable energy resources, and with the objective to maintain the proper functioning of the National Interconnected Electrical System (SENI). PI De Jesús wrote an article about the topic for the national press.

COMMUNITY GROUPS OR NON-GOVERNMENTAL ORGANIZATIONS

- **ISLAND INNOVATION'S VIRTUAL ISLAND SUMMIT**

Island Innovation team helped with the organization of the Smart Cities seminar, as well as invited PI De Jesús to join a network of 10,000 islanders from around the world as a speaker and ambassador at the Virtual Island Summit from Island Innovation. Under Unite Behind The SC1.5NCE – an Intergenerational Dialogue on the Future of Islands, PI De Jesús shared his experience as a researcher as well as in the Island Innovation network and Ambassador program, and how he thinks it shaped and helped create change on the island, as well as how it influenced Ramon and his colleague Miguel H. Estévez S. to create Embajadores de Energia at Energía Journal RD.

- **ENERGÍA JOURNAL RD**

The MG research group, PI Ramón Emilio De. Jesús, CI Rafael Batista, and CI Abraham Espinal were invited to participate in the Energia Journal Podcast titled: Episode 1.07: Microgrids against Climate Events in the Dominican Republic, where the team detailed the vision of the project and where they talked about how Microgrids (MG) have emerged as a tool that increases resilience due to their potential to recover quickly and effectively, providing an alternative approach to the resilience dilemma.

- **ASSOCIATION FOR THE PROMOTION OF RENEWABLE ENERGIES (ASOFER)**

As members of ASOFER (Association for the Promotion of Renewable Energies) we received an invitation to attend the presentation of the National Energy Plan (2022 – 2036), where we questioned and received feedback on the process to amend/update the plan, and how to get involved in the consultation processes.

- **ASSOCIATION OF MERCHANTS AND INDUSTRIALISTS OF SANTIAGO (ACIS)**

The research group presented the active lines of research to the directors of the Association of Merchants and Industrialists of Santiago. The event organized by the Vicerrectoría de Investigación sought to connect the business community of the city of Santiago with possible opportunities for collaboration and financing.

- **RADIO – ENERGIAS, COMBUSTIBLES Y MAS (ZOL 106.5 FM) – CONVERSATION ON THE NEW REGULATION ON DISTRIBUTED ENERGY SYSTEMS**

The regulator of the electricity sector of the Dominican Republic, the Superintendence of Electricity, published the regulations for the approval, interconnection, and operation of distributed generation systems, holding a public hearing on Tuesday, December 13 2022 to discuss the content of the regulation. In this radio capsule researchers De Jesús and Espinal, which both are part of ASOFER as well, chat about how this new regulation supports the movement towards the energy transition or hinders it.

- **CECACIER – SMART GRIDS FORUM**

The Regional Committee for Central America and the Caribbean - CECACIER, invited PI De Jesús to present a topic at the SMART ELECTRICAL GRIDS VIRTUAL WORKSHOP. The engine of the update that the electricity sector of the region requires to face the current and future challenges. PI De Jesús presented the vision of the Microgrid Research Project at PUCMM, as well as some of the hypothesis behind decentralization, energy independencies and resiliency.

- **YOUNG LEADERS OF THE AMERICAS INITIATIVE (YLAI) FELLOWSHIP PROGRAM**

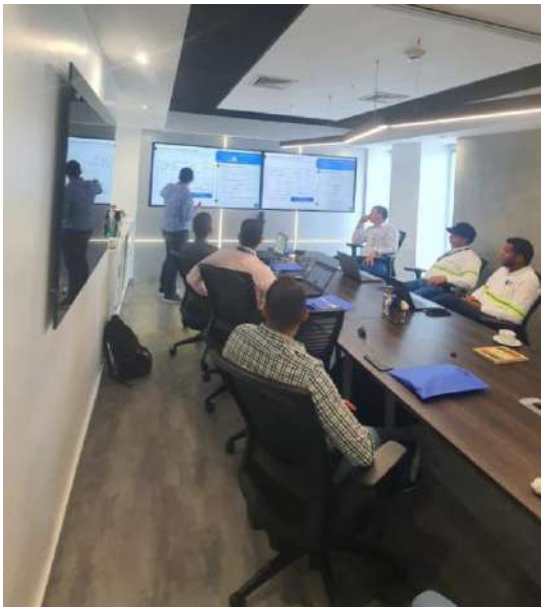
CI Abraham participated in the U.S. Department of State's Young Leaders of the Americas Initiative (YLAI) Fellowship Program empowers emerging entrepreneurs from the Western Hemisphere to enable the full economic potential of the region's citizens. YLAI promotes U.S. business models, increases trade, encourages job creation, and builds lasting and sustainable networks of young entrepreneurs and business and social leaders across Latin America, the Caribbean, Canada, and the United States.

- **SPECIALIZED LOCAL PRESS – EH PLUS - PLATFORM SPECIALIZED IN ENERGY INFORMATION**

PI De Jesus was invited to write opinion articles on topics related to the development of the Dominican Republic's energy sector for the specialized platform EHPLUS. The first one was on the topic of Energy Losses in the distribution sector. Thesis: The electrical sector of the Dominican Republic has historically been a great burden for the sustainable economic development of the nation and a great headache for its citizens. In trying to unmask the main source of its ills, we will find many years of mismanagement of public administration, a growing digital divide, deficient production capacity, dysfunctional subsidies, and at the center of the black hole, the stratospheric amount of energy that loses in distribution.

- **CONSORCIO ENERGÉTICO PUNTA CANA-MACAO (CEPM)**

As part of our outreaching efforts the MG Research Group visited CEPM, a leading energy group in the electricity sector in the Dominican Republic that generates, transmits, distributes, and markets energy, and that promotes technological innovation and the development of research projects and initiatives within its business strategy with the aim of improving the efficiency of its processes and increase the safety of its operations. The goal was to promote technical and intellectual cooperation in the design of joint research proposals that are in line with the strategic objectives of the microgrid research, exchanging good practices and methodologies; as well as studies, surveys, and material from the sector, to identify possible areas of collaboration.



CEPM

- **ELECTRIC POWER RESEARCH INSTITUTE**

The MG Research team was invited to participate in the EPRI's 2023 OpenDSS Virtual Training and User Applications. The EPRI's Open-source Distribution System Simulator, OpenDSS, 2023 webinar will provide an overview of available training materials, updates on new features, and a tool demonstration. Additionally, external user applications and presentations will showcase real-world examples. Attendees will receive an overview of the available training materials, updates on new features and functionality, a tool demonstration, and user applications and presentations. They will have the opportunity to learn, ask questions, and gain a deeper understanding of OpenDSS.

- **SPANISH AGENCY FOR INTERNATIONAL DEVELOPMENT COOPERATION (AECID) & CENTER FOR ENERGY, ENVIRONMENTAL AND TECHNOLOGICAL RESEARCH**

The Microgrid Research Group is participating in this course aimed at technical personnel who work on issues related to renewable energies in the public and private sphere linked to the energy sector in general, industry, environment. Content | **Module 1:** Introduction to Microgrids, **Module 2:** Generation, storage and demand in electrical Microgrids, **Module 3**: Microgrid Management: Communications, monitoring and control and **Module 4:** Electrical Microgrids and rural environments and Pilot experiences. During the course, practical exercises, self-assessments and synchronous sessions will be presented for exchange and clarification of doubts.

aecid Ciemat

- **JUDICIAL GAZETTE – LA REVISTA JURIDICA**

PI De Jesús was invited to a be lecturer in this course that offers an overview of the legal, technical and economic principles that govern current discussions on energy policy and sustainable development, as well as a practical understanding of the legal and regulatory framework of the electricity industry with a special emphasis on the new challenges imposed by the climate change. PI De Jesús will talk about the Energy transition and climate resilience. Renewable energies from the perspective of the Dominican State: progress, projections, limitations. Storage Systems (SAEB). Technical and regulatory challenges. Risks and challenges posed by climate change for the electricity sector and the deployment of renewables, and microgrids.

Gaceta Judicial

LOCAL USAID MISSION

- **USAID SD, NAS AND RTI VISIT**

The MG Research Group received representatives from the United States Agency for International Development (USAID), the National Academy of Sciences (NAS) and Research Triangle Institute (RTI) for the purpose of evaluating the development of our project "Analysis of resilience for the development of microgrid architectures to face extreme weather events in the Dominican Republic". During the visit, the Research Team walked them through our development process, as well as presented our roadmap, outreach, milestones, and our capacity building.

- **USAID – SEED (SUSTAINABLE ENVIRONMENT AND ECONOMIC DEVELOPMENT OFFICE)**

The MG Research Group met with the USAID´s Sustainable Environment and Economic Development Office (SEED) to present the PEER project updates, discuss the upcoming USAID/DC site visit and receive information on the USAID Energy Sector Reform (ESR) and other potential collaboration opportunities.

During the meeting the USAID team shared with us several opportunities, like the Fulbright Scholar program, the GRID (Green Recovery Investment Platform) and the Annual Program Statement (APS), that we will explore in the next coming months. From this meeting also emerged the opportunity to write an article on the research progress.

- **RTI – USAID – ENERGY SECTOR REFORM**

Representatives from RTI in the Dominican Republic, presented to the MG Research Group the Energy Sector Reform project, in which USAID provides technical assistance for energy reform to utilities, ministries, and regulators in the host countries, to develop policies, laws, regulations, tools and processes for the design and operation of more resilient and modern energy systems. By supporting the development, reform, and promotion of sustainable policies in the energy sector, this activity facilitates the harmonization of islands' policies, thereby creating a larger market for the expansion of clean and renewable energy generation.
The Research Group submitted to RIT several proposals, as we are evaluation how we can leverage on this project to showcase our capacity building by offering consulting, workshops or a development project to a utility, within the project objectives.

- **USAID – RTI – FORUM ON CYBERSECURITY IN THE ENERGY SECTOR**

The MG Research team was invited to Forum on Cybersecurity in the Energy Sector organized by the USAID Project for the Reform of the Energy Sector in the Caribbean. The main panels of the event were: Cybersecurity trends and their relationship with the resilience of the energy sector, Energy transition and challenges associated with cybersecurity and Cybersecurity and Supply Chain of the Energy Sector.

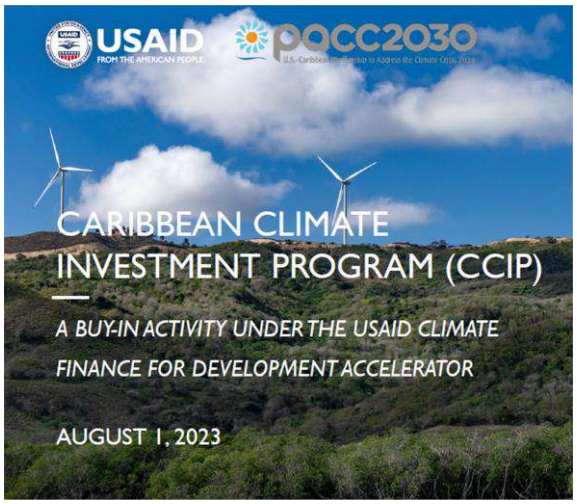
- **UNITED STATES ENERGY ASSOCIATION: IMPROVING CYBERSECURITY AND DIGITIZATION FOR THE ENERGY SECTOR IN THE CARIBBEAN AND LATIN AMERICA**

The United States Energy Association (USEA), in collaboration with the United States Agency for International Development (USAID), invited PI DE Jesús to participate in the free online course "Improving Cybersecurity and Digitization for the Energy Sector in the Caribbean and Latin America. The course consisted of 15 lessons, lasting approximately 50 minutes each, for a total of 15 hours of self-paced instruction, in which experts from around the world discuss cybersecurity and its important role in the energy sector. During the course, the USEA hosted three live, online virtual sessions with an expert who answered the questions and worked with the attendees to develop an action plan to implement cybersecurity best practices in your organization.

- **USAID – CARIBBEAN CLIMATE INVESTMENT PROGRAM (CCIP)**

The MG Research Group met with the USAID´s Project Manager Specialist Katerine Ramirez, regarding the launching of the Caribbean Climate Investment Program (CIIP). The team pitched the idea of building a Microgrid in PUCMM's Santiago Campus.

The Pontificia Universidad Católica Madre y Maestra (PUCMM) is an epicenter of education and research. But what if it could also be a benchmark in sustainability, resilience, and adaptation to climate change? The implementation of a microgrid at PUCMM will not only be an energy solution, but a model of how institutions can adapt to the changing world, reducing their carbon footprint and ensuring resilience in adverse situations.

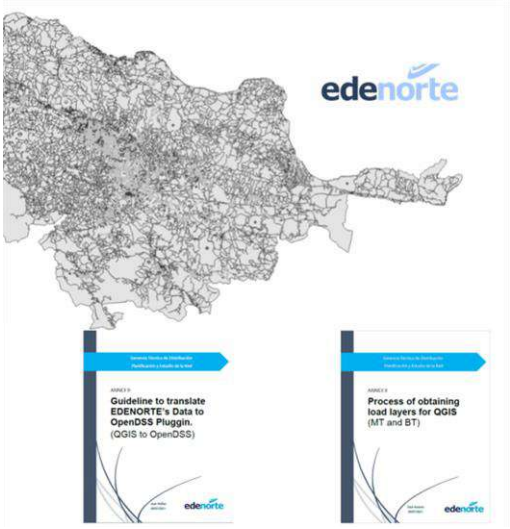


POTENTIAL DEVELOPMENT IMPACTS (EVIDENCE TO ACTION)

- **USE OF DEVELOPED TOOLS BY EDENORTE**

The research tools being developed alongside the utility personnel will be applied immediately by the Technical Management of Distribution Network Planning and Study in their daily operations. The knowledge derived from this experience will help us to create the conceptual and information maps necessary to interact with the other distribution utilities in the country, thus reducing the learning curve and barriers to entry.

Joint training activities are being planned between EDENORTE's technical team and MG Research Team to teach students the tools that the regional utility uses to carry out network studies.



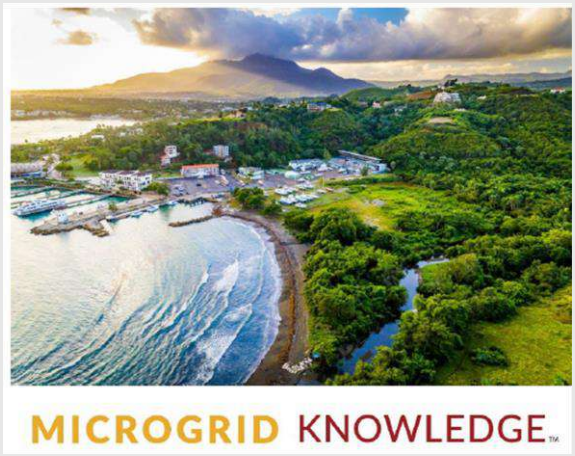
- **INDICATIVE PLAN FOR CRITICAL ENERGY INFRASTRUCTURE - POLICY DOCUMENT DEVELOPED BASED ON OUR RESEARCH**

The Vice Ministry of Energy Security and Infrastructure, in keeping with its mission of establishing policies to guarantee electric power service for the Dominican population, is working on a National Indicative Plan for the Development of Critical Energy Infrastructures. PI Ramón Emilio De Jesús-Grullón was the main external assessor and editor for the Plan. The plan is organized as follows:

- Section 1: Executive Summary
- Section 2: Introduction
- Section 3: Overview of the Dominican Electricity Sector:
- Section 4: SENI (National Interconnected Electric System) Vulnerabilities:
- Section 5: Critical Infrastructure Risk Management Framework
- Section 6: Recommendations

- **MICROGRID DEVELOPMENT IN THE DOMINICAN REPUBLIC**

CI Abraham Espinal, was interview for a Microgrid Knowledge Article about a project to electrify a Dominican Republic´s countryside village with solar microgrids. Abraham is chief of engineering at ENESTAR SRL, which designed and is helping deploy a solar microgrid that will serve about 50 families in the village.

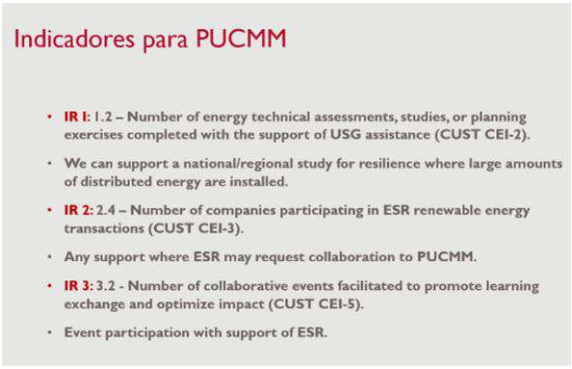


- **ENERGY SECTOR REFORM PROJECT PROPOSAL**

Several project proposals were submitted to RTI Energy Sector Reform project.

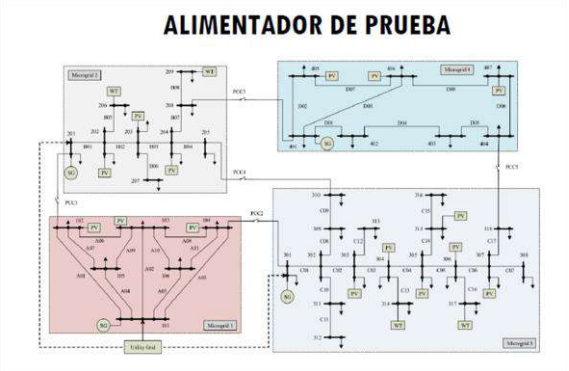
The proposals were tailored looking to synergized with the current lines of research and the main goals on the ESR Project.

- **Proposal #1:** Technical Assistance in the implementation of Geographical Information System (GIS) Distribution Network Infrastructure in EDESUR.
- **Proposal #2:** Technical Workshops on Hardware-the-Loop (HIL) Simulation for network studies and Distribution Network Modelling and Simulation (QGIS and OpenDSS)
- **Proposal #3:** Study of distribution circuit protection scheme parameters using real time simulation for safely reaching high renewable energy penetration distribution circuits.
- **Proposal #4:** Study on electrical load disaggregation using machine learning techniques for early detection of electricity theft.



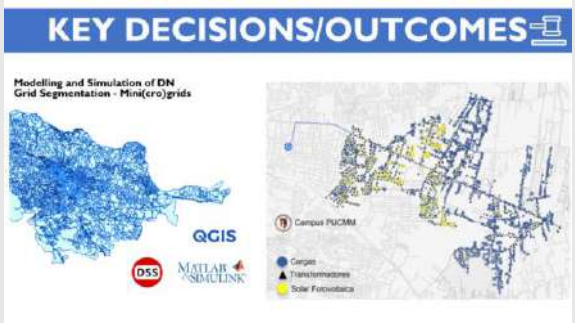
- **CAPACITY BUILDING IN RESEARCH**

As part of his PhD Research, CI Rafael Batista is conducting research on the use of biological inspired optimization techniques for the consensus making on the formation of networked microgrids in order to enhance resiliency and operational characteristics of the electrical grid. Swarm Intelligence (SI) is being explored with the particle swarm optimization algorithm (PSO) and validated using a simulation of an IEEE benchmark system for the testing of networked microgrids, presented in (Alam et al., 2020).
This work will be the fundamental part for the reconfiguration ability for improved resiliency proposed by this project.

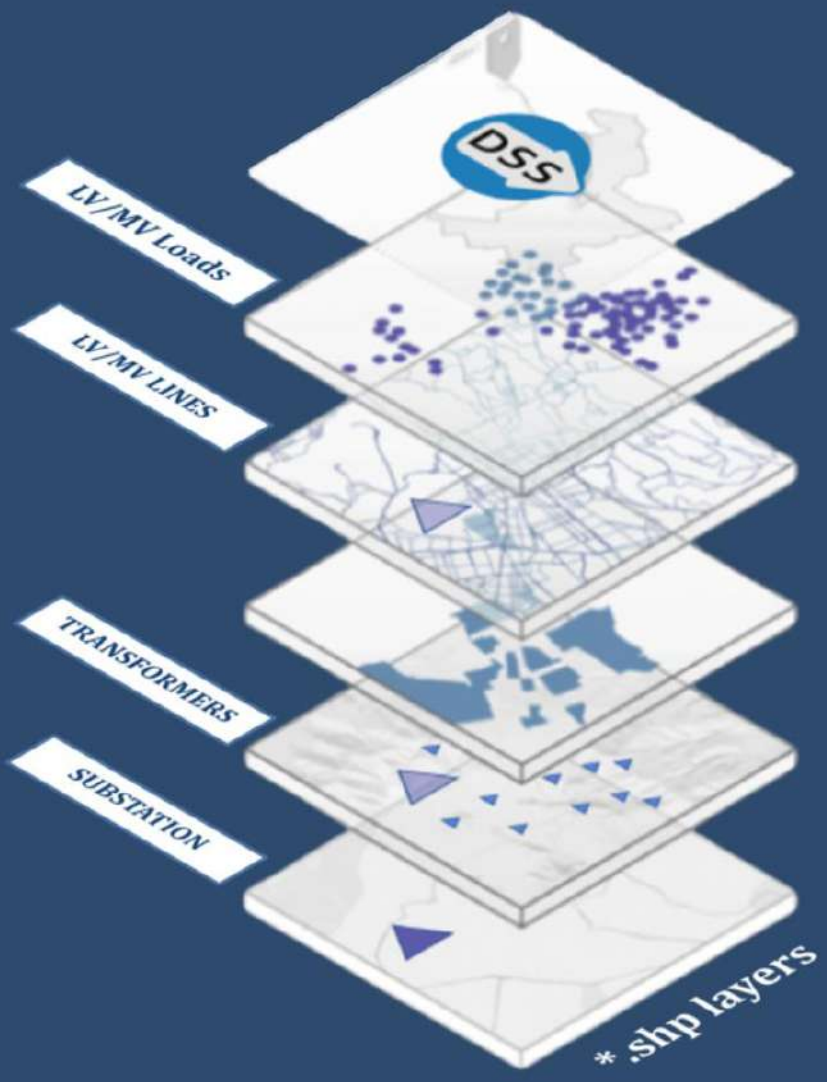


- **USAID'S ENVIRONMENTAL OFFICERS CONFERENCE**

During the Environmental Officers Conference in Colombia, Erick Conde, Project Management Specialist, SEED Office Santo Domingo, shared with USAID LAC team our potential development impacts with EDENORTE, as well as the capacity building the team is creating in the university with the construction of the first microgrid laboratory on the island.



8 OPEN DATA INITIATIVE

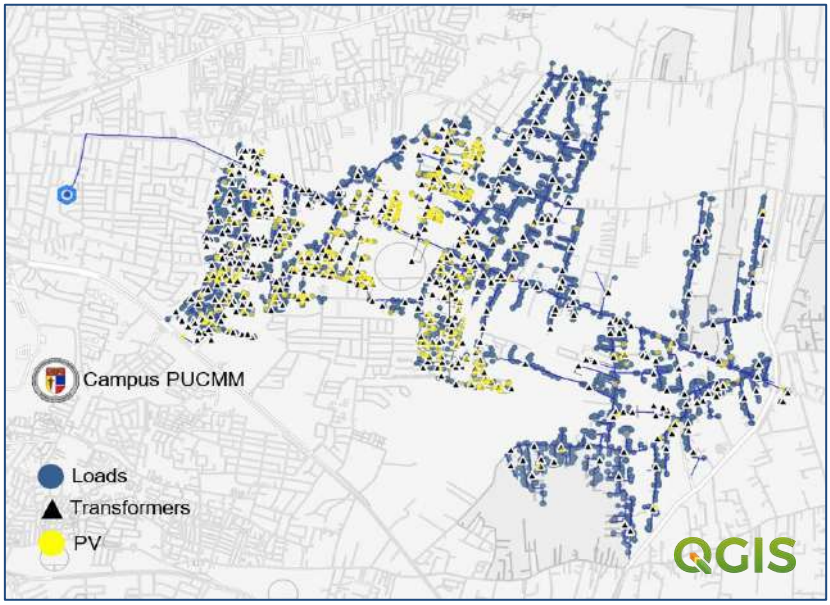


OPEN DATA PLATFORM

With the aim of laying the building blocks of an **open data platform** for Distribution Network studies in the Dominican Republic, the team created a **GitHub repository** with the Geographic Information System (GIS) and Distribution Network data, along with the OpenDSS network models created during this research. Data dictionaries, limitations and considerations are documented. This will serve as a platform to develop future work and research. The team will also organize workshops on the use and capabilities of these two tools for stakeholders, specifically aimed at Energy Distribution professionals in DR.

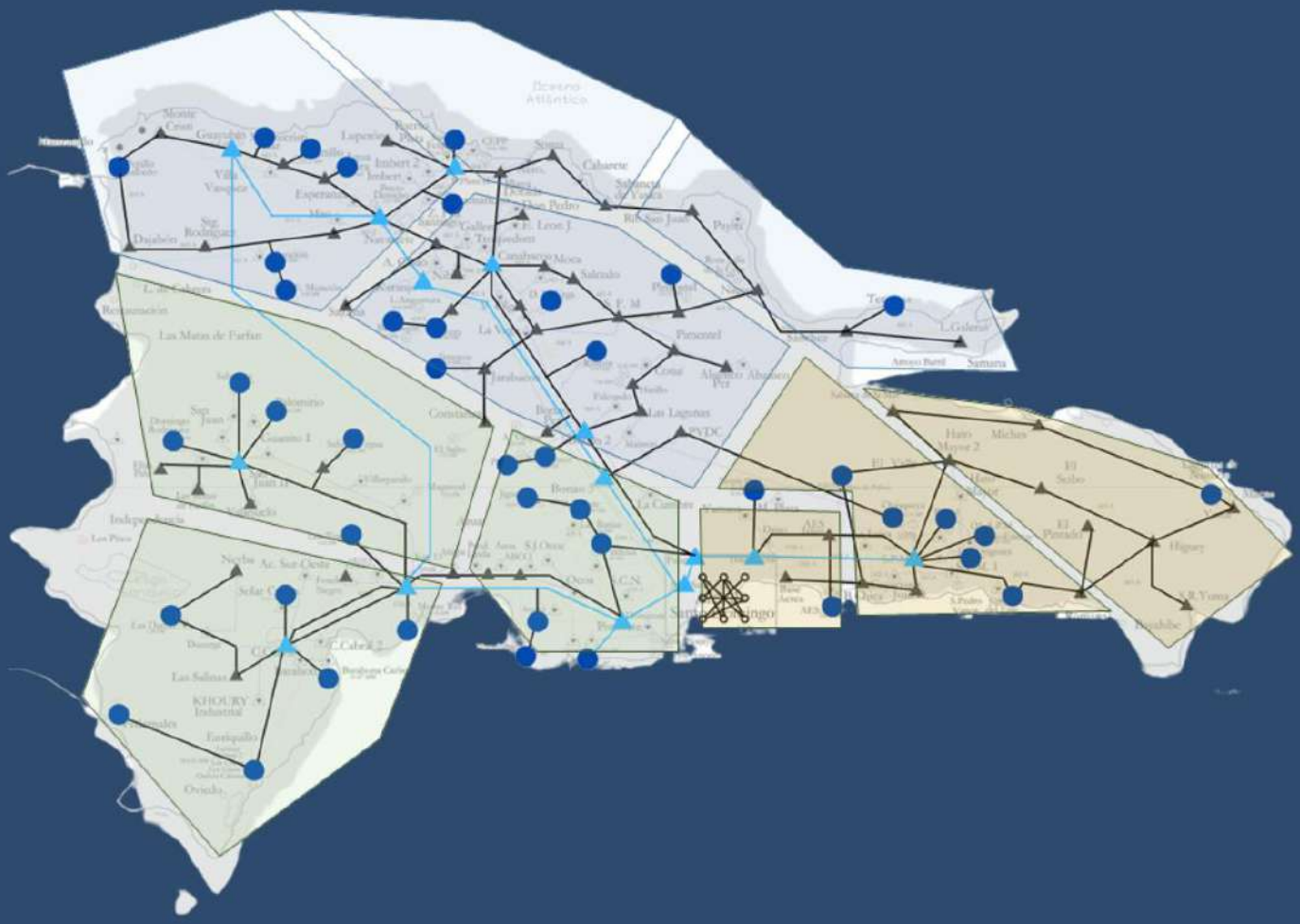
GIS NETWORK DATA AND OPENDSS NETWORK MODELS

NETWORK DATA	
Circuit Alias	VOLG101
System Voltage (kV):	12.47
Number of customers:	7,428
Sub transmission Voltage (kV):	69
Circuit MV lines (kM):	78
Circuit LV and Services lines (kM):	145
Number of transformers:	578
Number of PV Installations:	394
Reported Technical Losses (2021)	6.4%
Renewable Penetration:	60%




```
TestCircuit-VOLG101/
├── DG.dss
├── MVLines.dss
├── LVLines.dss
├── LVLoads.dss
├── MVLoads.dss
├── Loadshapes.dss
├── Substation.dss
├── Transformers.dss
└── Library
    ├── Wiredata.dss
    └── ConfigLInes
        ├── LineSpacing
        ├── LineGeometry
        └── LineCode
```

9 FUTURE PLANS



ONGOIG RESEARCH LINES

The Microgrid Research Group received 2 additional research grants with projects that are building upon and expanding the original objectives of the PEER project:

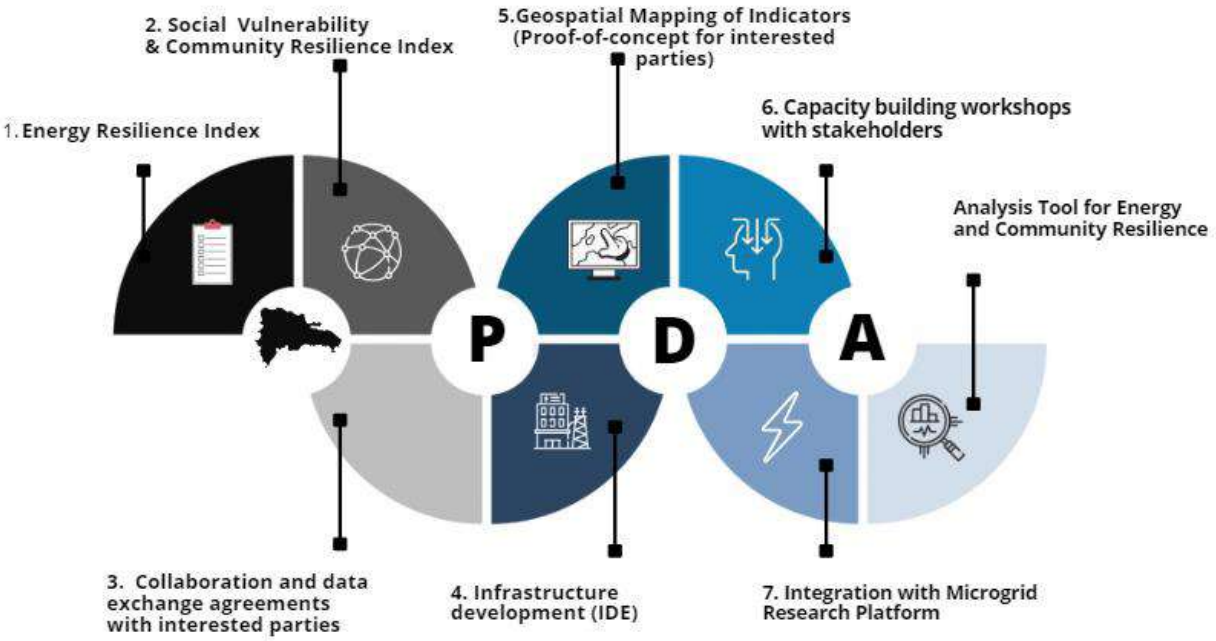
1. **Open Data Platform for Spatial Analysis of Energy and Community Resilience**
2. **Use of Simulations with Power Hardware-in-the-Loop for Verification Schemes Protections Against Faults in EDENORTE's Electrical Distribution Systems**

OPEN DATA PLATFORM FOR SPATIAL ANALYSIS OF ENERGY AND COMMUNITY RESILIENCE

The **Open Data Platform (PDA)** for Spatial Analysis of Energy and Community Resilience is a data aggregator and online tool based on Geographic Information Systems (GIS) and Spatial Data Infrastructure (SDI).

The main objective of the tool is the **creation of vulnerability maps** based on the intersection of climate risks, the city's critical energy infrastructure and social vulnerabilities in the communities.

The combination of infrastructure data with socioeconomic and geographic information will serve to illustrate the possible occurrence of high impact, low probability (HILP) events, which could affect these systems and the communities that inhabit them.

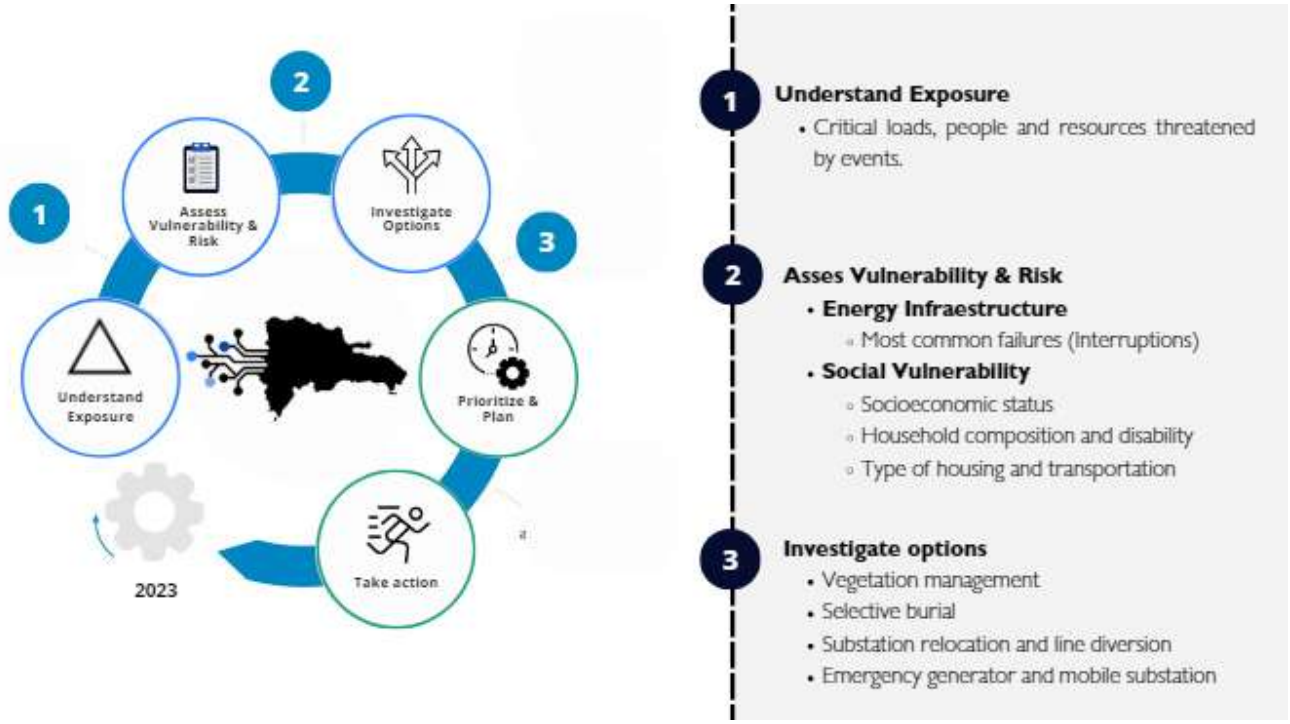


Overview of objectives in a timeline

METHODOLOGY

Useful tools for climate resilience planning have proliferated widely over the past decade. An important source of information for the methodology of this research was the **U.S. Climate Resilience Toolkit**, which is an interagency web repository initiative led by the National Oceanic and Atmospheric Administration (NOAA) and containing more than 200 tools to help communities build resilience, among many the **US Climate Resilience Map** and the **Social Vulnerability Index** (SVI) used by FEMA.

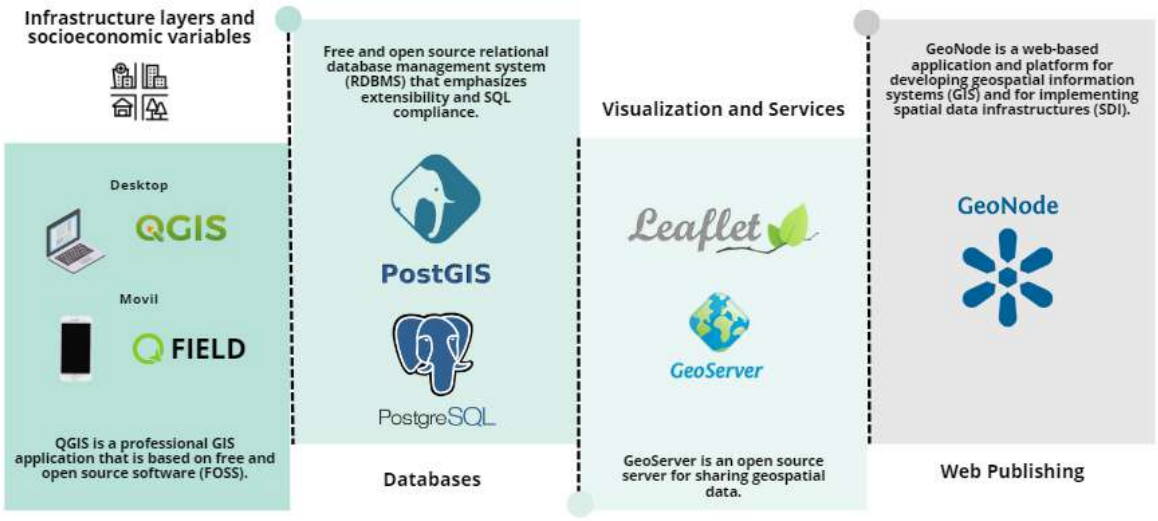
This research is building upon the **Steps to Resilience Framework:**



Steps to Resilience - Based on U.S. Federal Government, U.S. Climate Resilience Toolkit, (n.d.). https://toolkit.climate.gov/tools (accessed June 14, 2022).

OPEN-SOURCE ETHOS

This project is being developed following the open-source ethos. We believe that the tools and the knowledge we create should be shared openly for the greater benefit of society. We are also striving to leverage on the open-source community for our software stack, using mostly open-source tools such as QGIS, Leaflet, POSTGIS, Geoserver and Geonode for the development of our application.



Tools being used for the development of the PDA

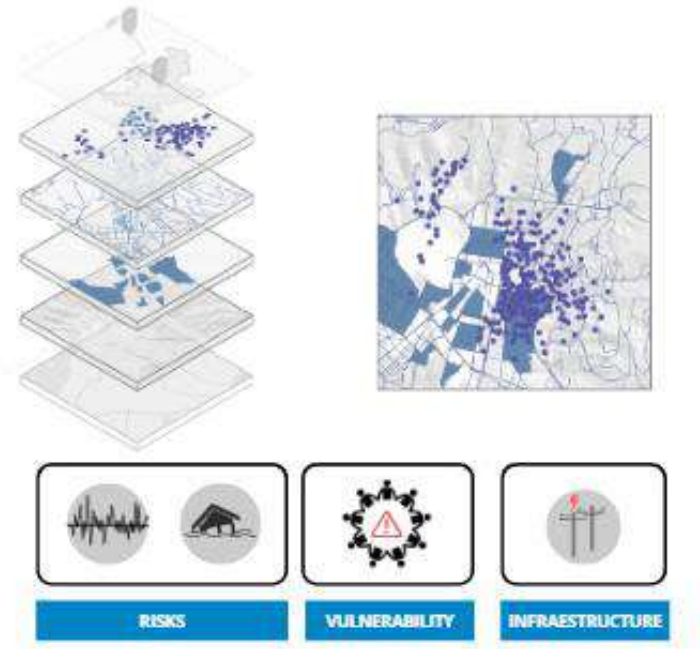
MAPPING RESILIENCE

The data layers will be organized into three (3) categories:

- (1) risks (flood, earthquakes)
- (2) social vulnerabilities
- (3) infrastructure vulnerabilities.

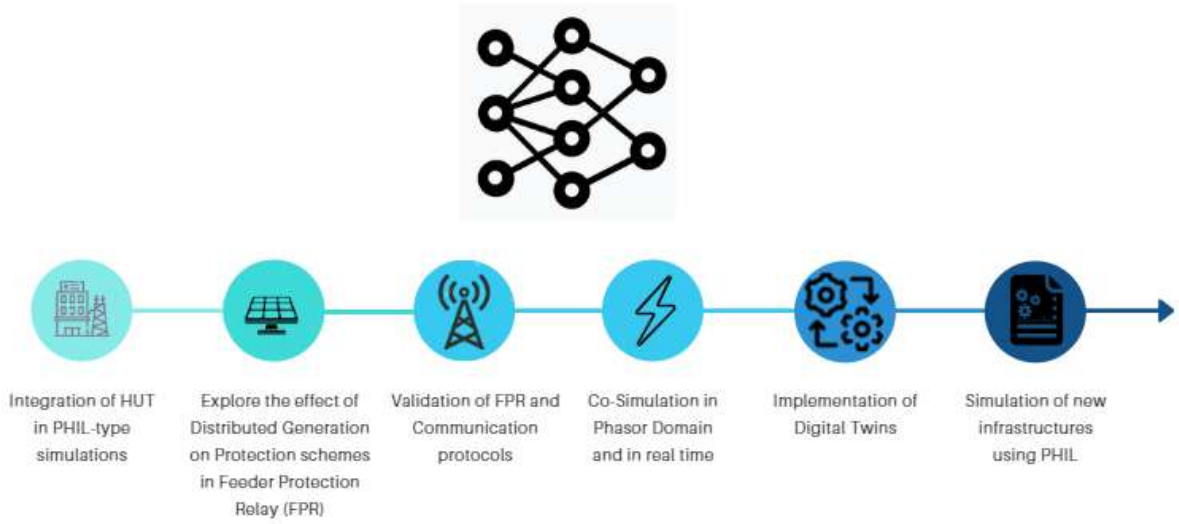
The social vulnerability layers will include layers grouped into sublayers and three main layers:

- (1) Socioeconomic status
- (2) Household composition
- (3) Type of housing and transportation



USE OF SIMULATIONS WITH POWER HARDWARE-IN-THE-LOOP FOR VERIFICATION SCHEMES PROTECTIONS AGAINST FAULTS IN EDENORTE'S ELECTRICAL DISTRIBUTION SYSTEMS

The main goal of this research is to design a methodology for the use of Power Hardware-in-the-Loop simulations for the validation of protection schemes in EDENORTE's distribution networks in the Dominican Republic.

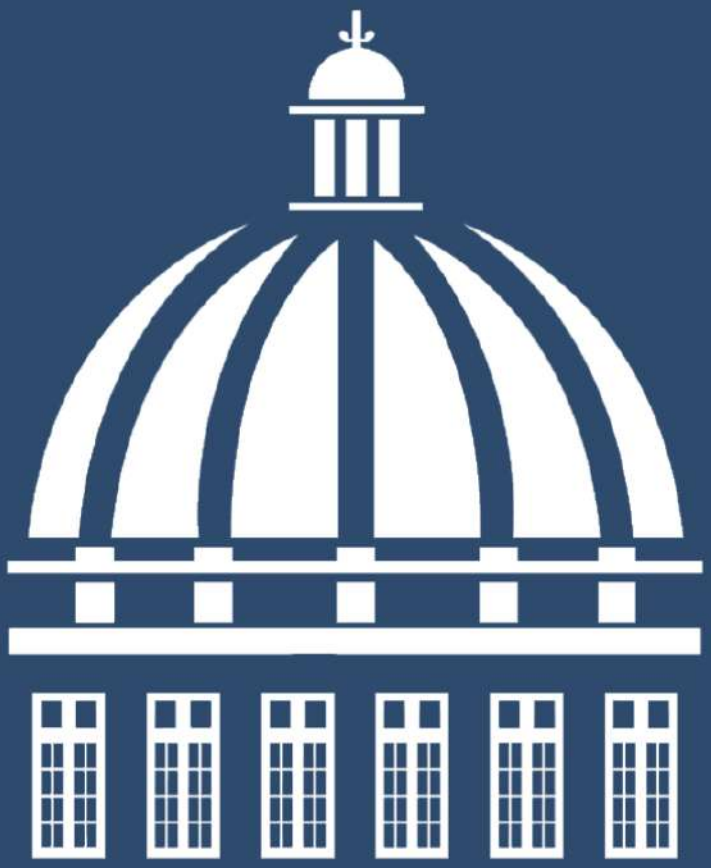


Overview of main objectives

METHODOLOGY

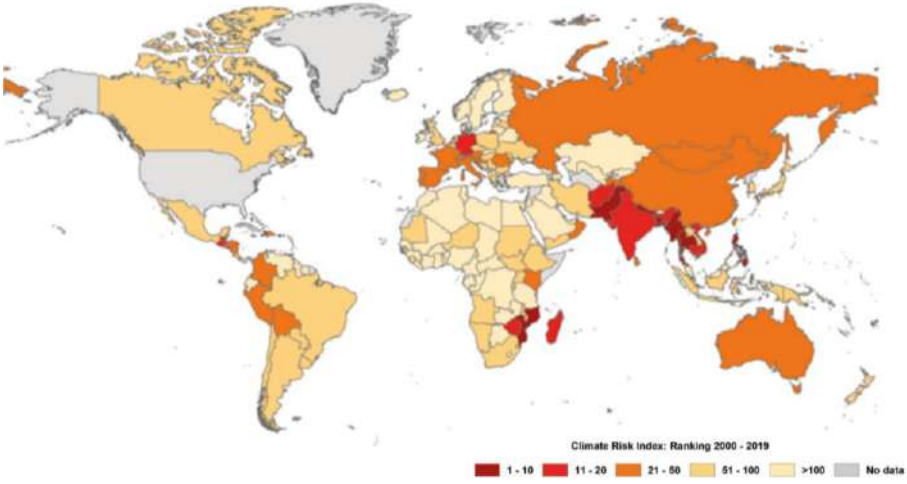
- Establish synchronization strategies for PHIL type simulations that allow including Hardware Under Test (HUT) through the use of power interfaces for validation processes of its operation.
- Create scenarios that allow exploring the effect of the integration of distributed generation with renewable energy resources in the protection schemes established for distribution networks through the use of Feeder Protection Relays (FPR).
- Validate the operation of fault protection relays under different scenarios using PHIL type simulations and interacting through communication protocols with these devices.
- Implement co-simulation methods that combine numerical simulations in the phasor domain with PHIL-type simulations with electromagnetic transient characteristics.
- Integrate digital twins into operation processes to explore the effect of failures in electrical distribution infrastructure on protection systems.
- Define a methodology to follow for the validation of infrastructures of new projects that allow the validation of critical components in a PHIL-type simulation scenarios.

10 CONSIDERATIONS FOR DOMINICAN REPUBLIC´S GOVERNMENT INSTITUTIONS



INTRODUCTION AND CONTEXT: CLIMATE VULNERABILITY OF THE DOMINICAN REPUBLIC.

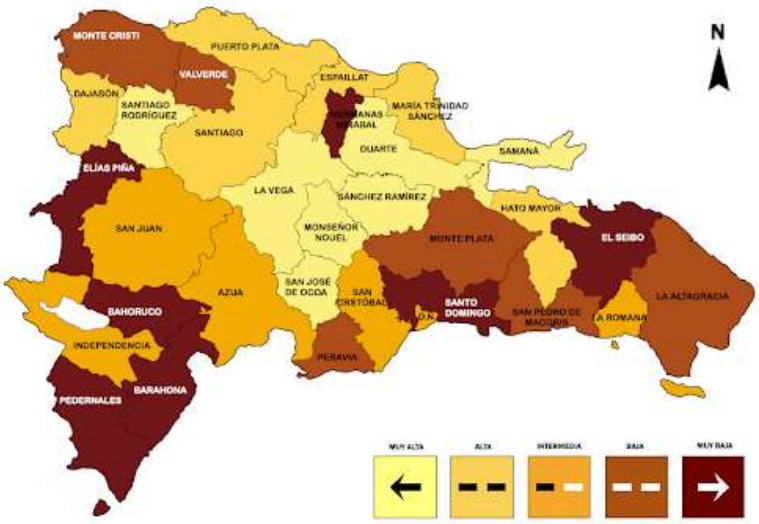
The Dominican Republic is one of the most vulnerable countries in the world to climate change. According to the Global Climate Risk Index 2021 [1] (Long-Term Climate Risk Index-CRI), that measures to what extent countries have been affected by the impacts of weather-related loss events (storms, floods, heat waves etc.), the DR is ranked 50th. In fact, Puerto Rico (a close neighbor), and Haiti (which shares the same island) have been identified as the most affected countries in the world in the last 20 years, placing the island and the region as one of the most affected globally.



Countries most affected by extreme weather events (2000-2019)	
1	*Puerto Rico*
2	*Myanmar*
3	Haiti
4	Philippines
4	Mozambique
6	The Bahamas
7	Bangladesh
8	Pakistan
9	Thailand

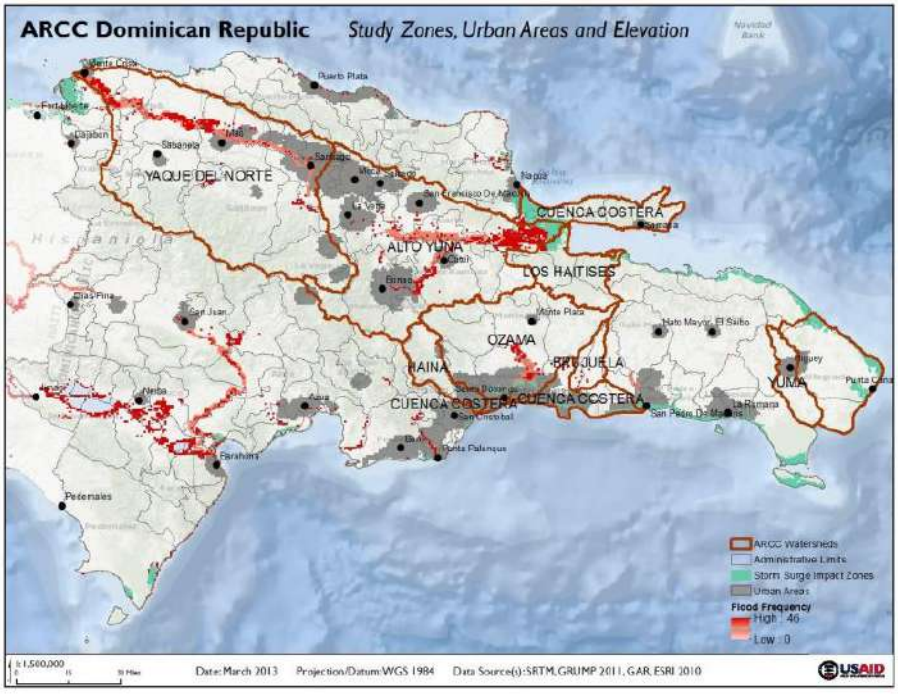
World Map of the Global Climate Risk Index 2000 – 2019. **Source**: Germanwatch and Munich Re NatCatSERVICE [1]

The analysis of the *Critical Points of Vulnerability to climate change in the Dominican Republic* [2] shows that 13 provinces (around 40% of the country) present levels of vulnerability from high to very high (see Figure below). The country's geographic location, coupled with historical social, demographic, and economic factors, and the fact that the republic shares the island with the poorest country in the hemisphere, exacerbate risky conditions. Population growth and changes in demographic and economic patterns have favored uncontrolled urbanization. This, together with the widespread poverty of some of these communities, has forced large groups of the population to live in disaster-prone areas, which translates into the obligation to live in areas exposed to high pollution or high risk of receiving negative effects from meteo-climatic or geomorphological events such as floods, landslides, rise in sea level, among others. Added to this equation is the impossibility of accessing quality public services, such as access to a resilient and stable energy service and drinking water, with important consequences for the health of the communities.



Map of Critical Points of Vulnerability in the Dominican Republic. **Source:** Puntos críticos para la vulnerabilidad a la variabilidad y al cambio climático en la República Dominicana y su adaptación al mismo.

Not surprisingly, climate change will have a significant impact on the electricity sector. Rising temperatures, the growing number and severity of extreme events, changing precipitation patterns, and rising sea levels all affect energy production, supply, and demand. Although the focus of the action plans of the electricity sector of the Republic has focused on financial sustainability in recent years, the priority should also be **adaptation and increased resilience to the impacts of climate change.**



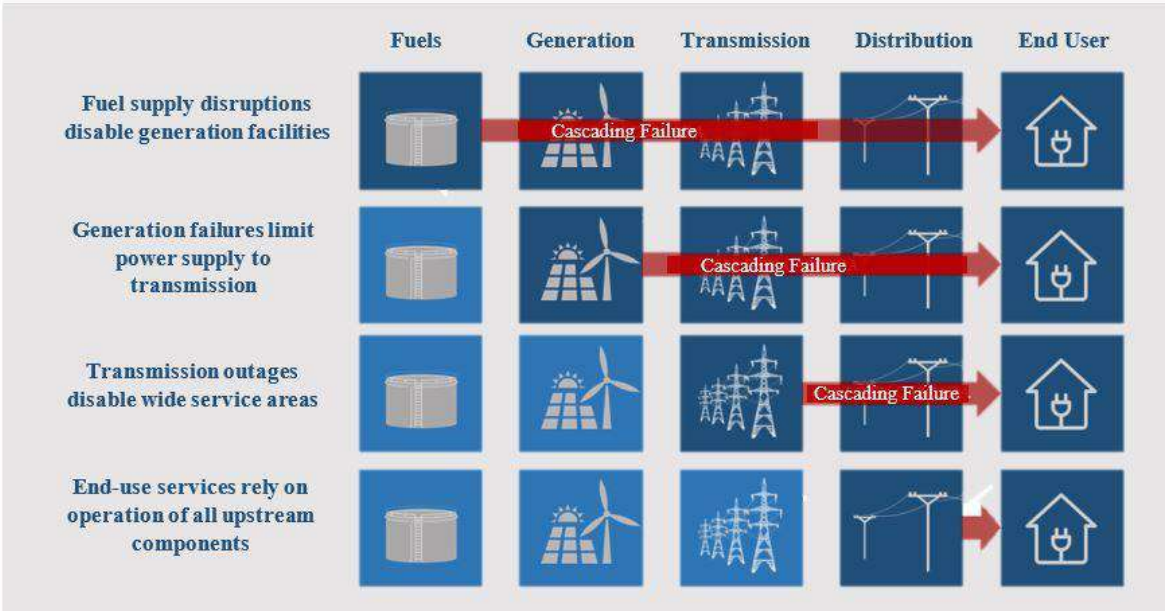
Spatial analysis: flooding, land use, population centers, and primary physical characteristics. Dominican Republic flood frequency analysis and climate sensitive hotspots. **Source:** Dominican Republic climate change vulnerability assessment report [3]

THE VULNERABILITY: ENERGY VALUE CHAIN AND THE RISK OF CASCADING FAILURE

Unfortunately, the electricity grid in the Dominican Republic, as in most of the world, was designed and planned to function like a well-oiled centralized machine, characterized by a unidirectional flow of electricity, as well as economic value, from generators to final customers, developed in an era dominated by the economies of scale of fossil fuel power plants.

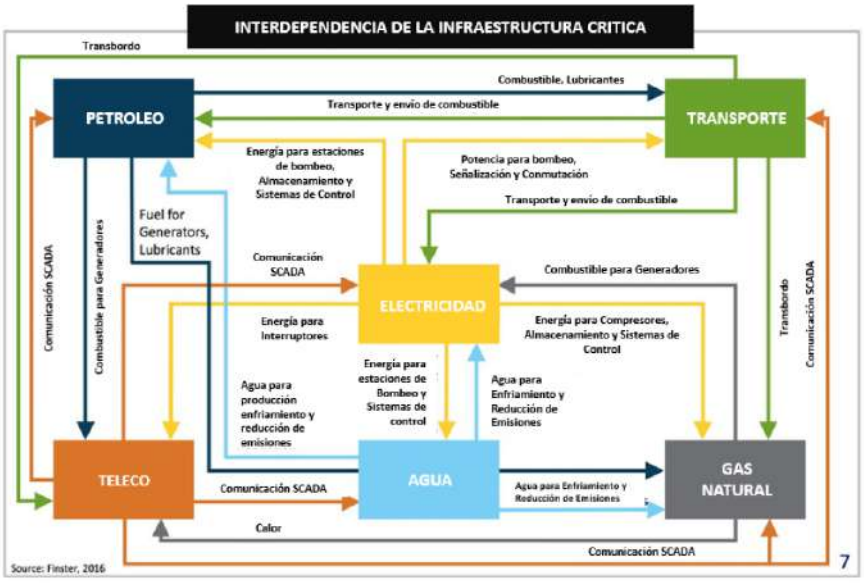
Due to its intrinsic characteristics, this architecture is increasingly exposed to rapidly evolving threats, be it malicious attacks, as well as the increasing frequency of natural disasters.

Network planners and operators have long managed this inherent vulnerability through the redundancy and hardening of critical energy infrastructure, but they cannot completely avoid the risks of outages when High Impact Low Probability (HILP) events (i.e hurricanes, cyberattacks, earthquakes, etc) show up in the equation. The figure below illustrates the components of the network value chain and in particular the reliance on access to electricity for end-users, from fuel supply to generation, transmission, and distribution. If any of the elements of this chain goes down, end-users face outages. [4].



Energy value chain and the risk of cascading failure. Source: Adapted from Reimagining Grid Resilience, RMI [5]

Therefore, to make efficient investments that effectively mitigate risk and increase the resilience of the Dominican Republic, capital planning decisions must address the need for resilience and the value chain, but also the interdependencies between the electric power system and other critical infrastructure that provides much-needed services, such as hospitals, water treatment plants, wastewater, telecommunications, and transportation, to counteract the cascading effects of energy losses. A better understanding of the complex interactions between critical energy infrastructure will help the Dominican Republic prepare for, respond to, and recover from future disasters [6].



Critical Infrastructure Interdependencies - **Source:** Adapted from Phillips, J., M. Finster, J. Pillon, F. Petit, and J. Trail, 2016, State Energy Resilience Framework, Argonne National Laboratory [7]

AN ALL-ECOMPASSING SOLUTION – MI(NI/CRO)GRIDS

Recent severe power outages caused by increasingly frequent climate-driven events have highlighted the urgency to improve grid resilience worldwide. The massive damage caused by Hurricanes Maria and Irma in the Caribbean in 2017, with an estimated damage of $90 billion dollars to the economy of the Island of Puerto Rico, offered the international community and the energy industry a rare and powerful opportunity to analyze the aftermath of such a powerful event in the electrical infrastructure, and the challenge of finding solutions to mitigate its effects. [8]

Traditionally, the power industry has focused on methods that aims to restore loads after a fault by altering the topological structure of the distribution network, effectively isolating the fault and restoring as much load as possible after the general blackout. However, when the distribution system is severely damaged traditional approaches cannot guarantee that energy will be supplied to much needed critical loads. Here is where mi(ni/cro)grids (MGs) have emerged as a tool due to the potential to recover in an effective quick manner, providing an alternative approach to the resilience dilemma [9].

A **microgrid** is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.

COMPONENTS OF A MICROGRID

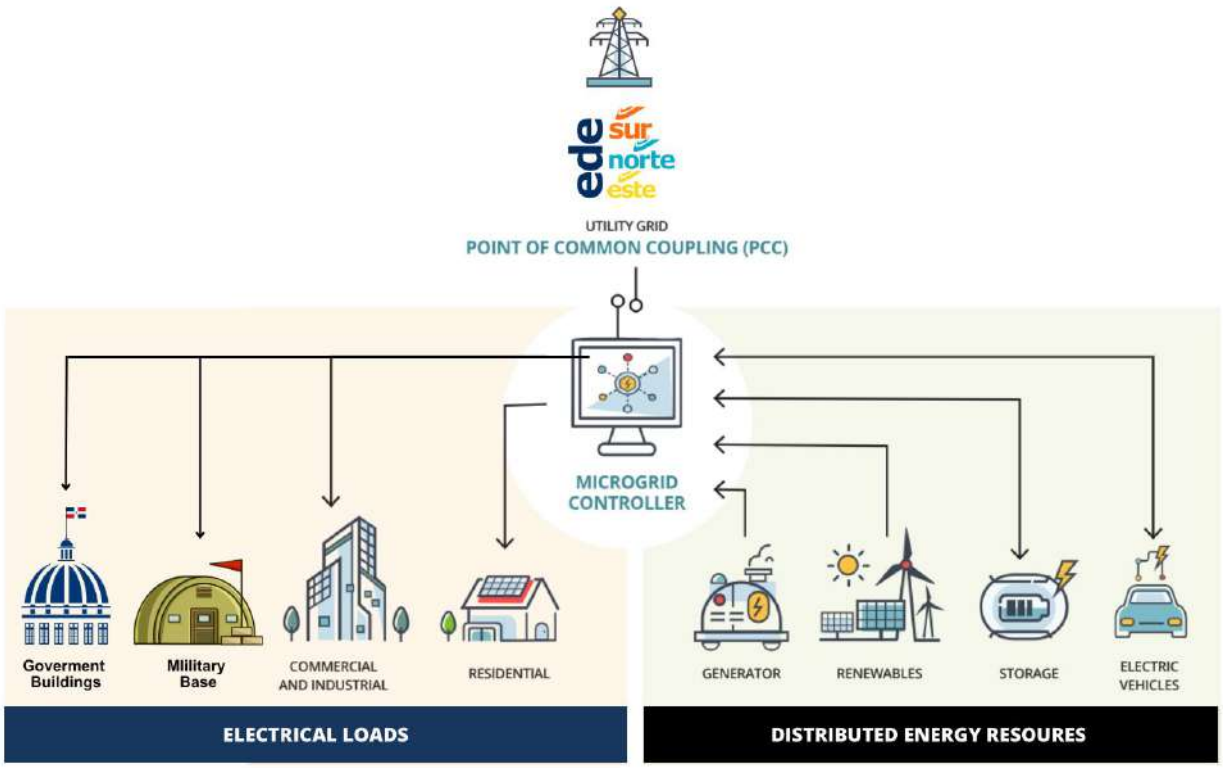
A microgrid involves four distinct components [10]:

1. **Load(s):** The consumer(s) of electricity. Load can be designated as critical, high-priority, or low-priority. Critical load is uninterruptible, meaning that any disruption of electric service, regardless of duration, is highly costly or may impact human life and safety.

2. **Distributed energy resources (DERs):** The supply of electricity. DERs are generation, storage, and load control (i.e., energy efficiency or demand response) technologies located at the distribution system. DERs can be powered by a range of fuels including diesel, natural gas, and solar power.

3. **Controls:** The management system of the microgrid. A microgrid controller performs multiple functions, including: (a) identifying when and how to connect and disconnect from the grid; (b) maintaining real and reactive power balance when the microgrid is disconnected and operating in islanded mode, and (c) dispatching DERs to support load.

4. **Interconnection/point of common coupling (PCC):** The point at which the microgrid connects to the distribution network. It is at this point that the microgrid controller connects and disconnects to the larger grid.



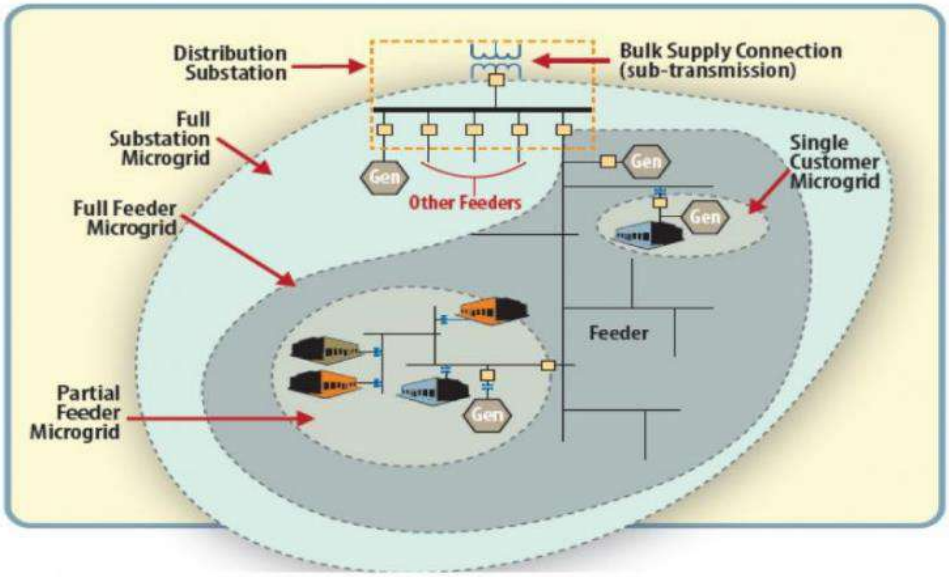
Components of a microgrid **Source:** Adapted from D. Shea, Microgrids: State Policies To Bolster Energy Resilience, 2021, National Conference of State Legislatures (NCSL) [11]

Microgrids can involve single or multiple facilities, DERs, and customers (meters). The New Jersey Board of Utilities (NJ BPU) developed one system for microgrids according to the number of customers (NJ BPU)[12]:

- **Level 1 or single customer:** serving one customer through one meter.

- **Level 2 or single customer/campus setting (partial feeder microgrid):** serving multiple facilities, controlled by one meter at the PCC.

- **Level 3 or multiple customers (advanced or full feeder microgrid):** serving multiple facilities/customers on multiple meters. The DER(s) may be located on a different site from the facilities/customers. While the advanced microgrid has one PCC, the individual facilities/customers within the advanced microgrid may have their own individual connections to the distribution grid.



Types of Microgrids. **Source:** Microgrids for Resilient Municipalities, What they are, Why you may want one, & What resources are available, 2021, U.S Department of Energy (DOE) [13]

BENEFITS OF MICROCRIDS

- RESILIENCE AND RELIABILITY

Resiliency is defined as *"the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions"* [14]. The concept of resilience represents a departure from the traditional approach to reliability, which focuses on the frequency and duration of failures event-agnostically and situational awareness and diagnosis, resilience seeks to track the dynamics, and incorporates reactive actions against contingencies, such as launching restoration operations and ensuring the continued functionality of critical loads [15]. The U.S National Renewable Energy Laboratory (NREL) considers the main resilience benefits of microgrids to be providing energy security and survivability [16].

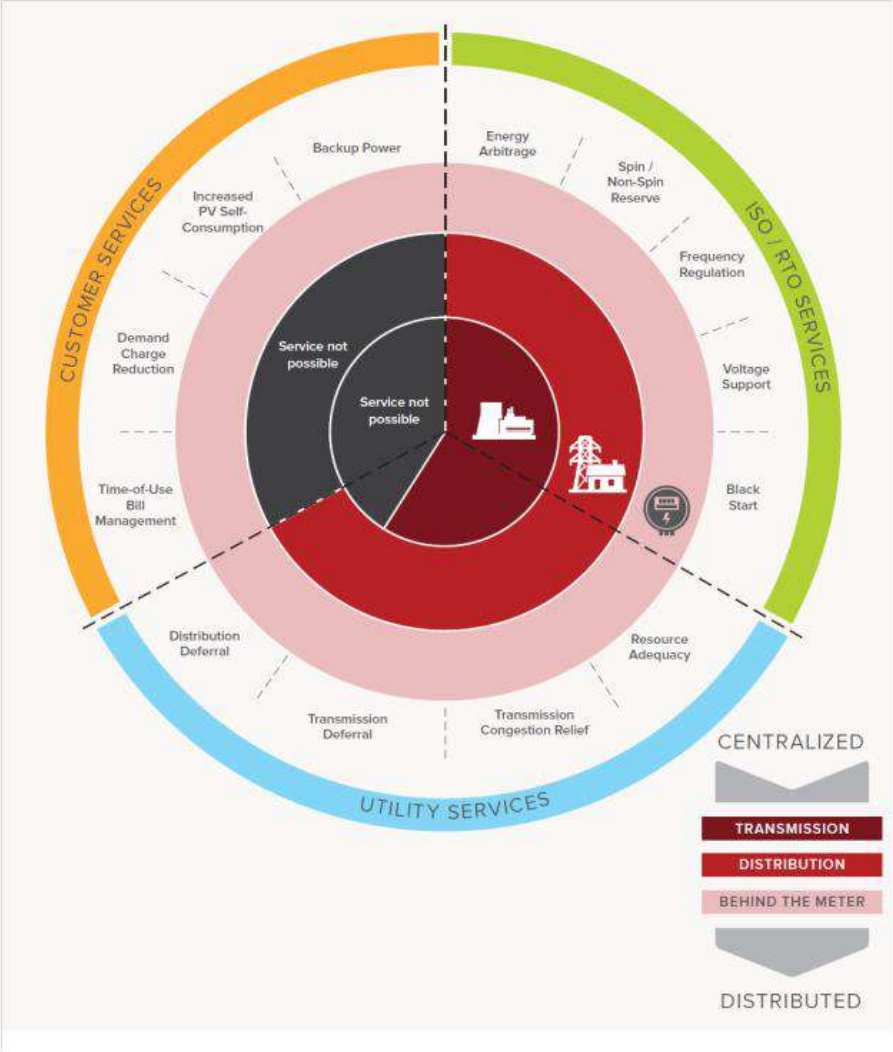
When there is a disruption or blackout, microgrids can island themselves from the main electric grid and continue providing power. During blue sky conditions, microgrids stay connected to the grid. Having a secure and steady source of back-up power is crucial, particularly at critical infrastructure locations such as wastewater treatment plants, emergency shelters, and hospitals [17].

- DECARBONIZATION

While the majority of microgrids currently are powered by fossil fuels such as diesel and natural gas, over the next five years, a surge in microgrid development is anticipated, with capacity doubling, particularly from solar generation [18]. Locations with limited fuel storage capacity may wish to rely on delivered fuels or a resource that does not require a fuel source to run, such as wind, solar, or energy storage. In fact, facilities in dense urban areas or in locations prone to flooding or natural disasters may find the costs of fuel storage to be prohibitively expensive. So, it is expected that long duration battery storage will also allow for a more complete transition away from other fossil fuel back-up resources, reducing the costs and enhancing their long-term resilience.

- GRID SERVICES AND T&D DEFFERAL

In many instances, grid connected microgrids can deliver additional grid resilience through various services, such as voltage regulation and demand response, thus making the resilience benefits bidirectional. When a microgrid is installed together with a renewable energy system and battery energy storage systems (BEES), the overall system more efficient, this is because according to a study carried out by the Rocky Mountain Institute (RMI) laboratory, BESS have the unique potential to provide thirteen basic services to electrical systems, at all levels of the network: generation, transmission, distribution or directly to the end user [19].

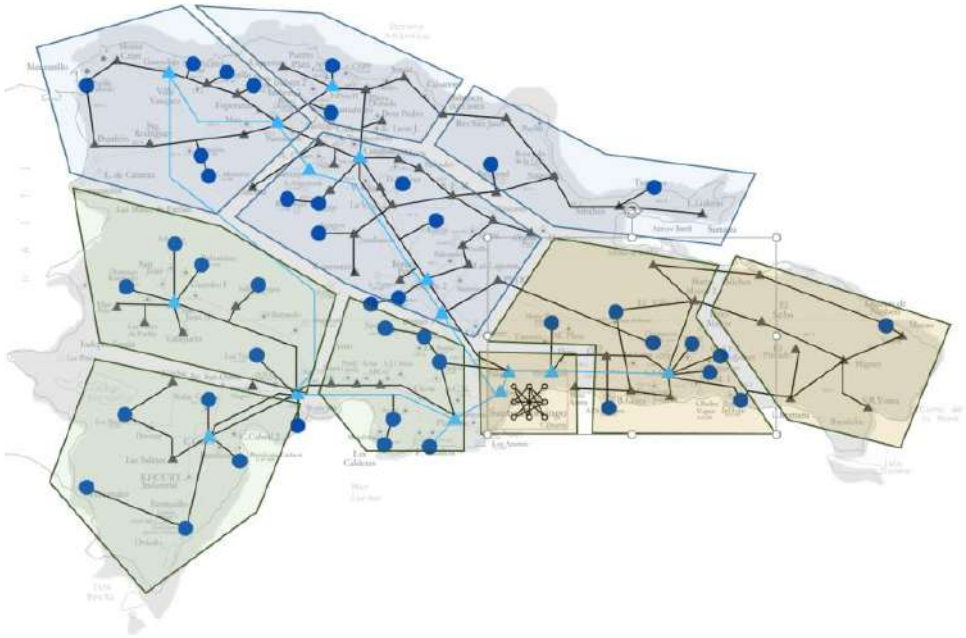


13 different services that batteries can provide to the grid **Source:** The Economics of Battery Energy Storage: How Multi-use, Customer-sited Batteries Deliver the Most Services and Value to Customers and the Grid, 2020, RMI.

Microgrids may also be considered as non-wires alternatives (NWAs) in a utility's resource portfolio. if demand in a particular neighborhood or region on the distribution grid is forecasted to increase to a degree that necessitates a feeder or substation upgrade, a microgrid either owned or procured by the utility could be a more cost-effective way to meet those needs than a capital-intensive infrastructure improvement [20].

A VISION OF MINIGRIDS: SELECTIVE SEGMENTATION IN TRANSMISSION AND DISTRIBUTION

A **minigrid** involves the separation of the existing grid distribution infrastructure into **pockets of critical loads** served by distributed energy resources and designed to operate in both grid-connected and island mode, being distinguished from microgrids in that they utilize existing distribution infrastructure and can be sized much larger than typical microgrids. [50]



A vision of Minigrids against Climate-Driven Events in Dominican Republic. **Source:** Towards the Future: The 21st Century Electric Grid, 2021, Microgrid Research Group PUCMM. [21]

To better enable system recovery in an extreme weather event and/or black start restoration, there may be operational benefits in segmenting the transmission and distribution system into smaller portions (Mini-Grids). While this would be done out of necessity after a large-scale event, there could be some advantages to preselecting which segments are likely to survive a future event and proactively planning transmission system segmentation accordingly.

These parts of the system would be identified to include a combination of generation assets, including units with black start capability, along with an appropriately sized load, so that when the distribution system is under restoration activities, there is sufficient load present to constitute the minimum generation, the stable parts of the system could be energized and maintained before the longer transmission lines are repaired and energized. These parts of the system could re-energize each other later in the restoration process.

CONSIDERATIONS FOR THE NATIONAL ENERGY COMISSION (CNE), SUPERENTENDECE OF ELECTRICITY (SIE) & THE MINISTRY OF ENERGY AND MINES (MEM-RD)

Microgrids are poised to play a large role in the future of energy resilience in the world's energy systems. However, these technologies and systems face high **regulatory barriers** tied to the legacy of the 20th-century model of centralized, top-down electricity grid dispatch, so contemporary energy policies and regulations may not fully account for or be tailored to these systems in mind.

These considerations are addressed to 1) **National Energy Commission (CNE),** the body of the Dominican state that is responsible to prepare and coordinate legal and regulatory projects; propose and adopt policies and standards; prepare indicative plans for the proper functioning and development of the energy sector, and propose them to the Executive Branch and ensure their compliance; promote investment decisions in accordance with said plans and advise the Executive Branch on all matters related to the sector [22], 2) **Superintendence of Electricity (SIE),** an autonomous body whose main function is to be the regulatory entity of the Electrical Subsector [22], and 3) **Ministry of Energy and Mines (MEM-RD)**[23], body of the Public Administration dependent on the Executive Branch, in charge of the formulation and administration of the national energy and metallic and non-metallic mining policy.

1. INCLUDE MICROGRID REGULATORY FRAMEWORKS IN THE NATIONAL ENERGY PLAN UPDATES

The National Energy Comission (CNE) recently published the National Energy Plan (2022-2036). The objective of the plan is to present the current condition of the Dominican energy sector, while outlining its future development, based on the vision of energy policies coming from both the public and private sectors, in favor of an optimal energy system at a technical level. and above all economical. [24]

Within the plan one can read how energy officials in the island have identified the need to "*establish schemes for constant monitoring of emerging technologies, such as battery storage, that allow greater incorporation of wind and solar plants*". In fact, months after its publication, the CNE made public through its transparency portal a study on the Integration of Variable Renewable Energies and Battery Energy Storage Energy Systems (BESS) [25], and resolutions [26] that declare these as an immediate need in order to to anticipate the massive penetration of variable energy resources, and with the objective of maintaining the proper functioning of the National Interconnected Electrical System (SENI).

Recommendations:

Regulatory review:

- Study the regulatory frameworks around microgrid development worldwide, looking at case studies for success and challenges faced by other countries in implementing and regulating microgrids.

Foster Research and Development Partnerships:

- Establish partnerships between the government and research institutions for joint R&D initiatives on energy resilience and microgrids. This will leverage the strengths of each sector and accelerate innovation.

INSIGHT BUBBLE

On May 16, 2018, the Puerto Rico Energy Commission adopted the final Regulation on Microgrid Development Regulation. [51]

Three (3) main types of Microgrids will be recognized under the Regulation:

- **Personal Microgrids**, which will be owned by not more than two Persons (a natural person, and any legal entity, municipality, or government entity, other than the Puerto Rico Electric Power Authority, or PREPA*)) and for which there are generally no requirements under the Regulation.
- **Cooperative Microgrids**, which need not be organized pursuant to the Puerto Rico General Cooperative Associations Act and which are to be constituted by Members (the persons sharing ownership interest in the microgrid and receiving its services); and
- **Third-Party Microgrids**, which are owned or operated by any Person for the primary purpose of selling Energy Services (electricity service) or Grid Services (ancillary services, demand response, etc.) to Customers (Microgrid customers).

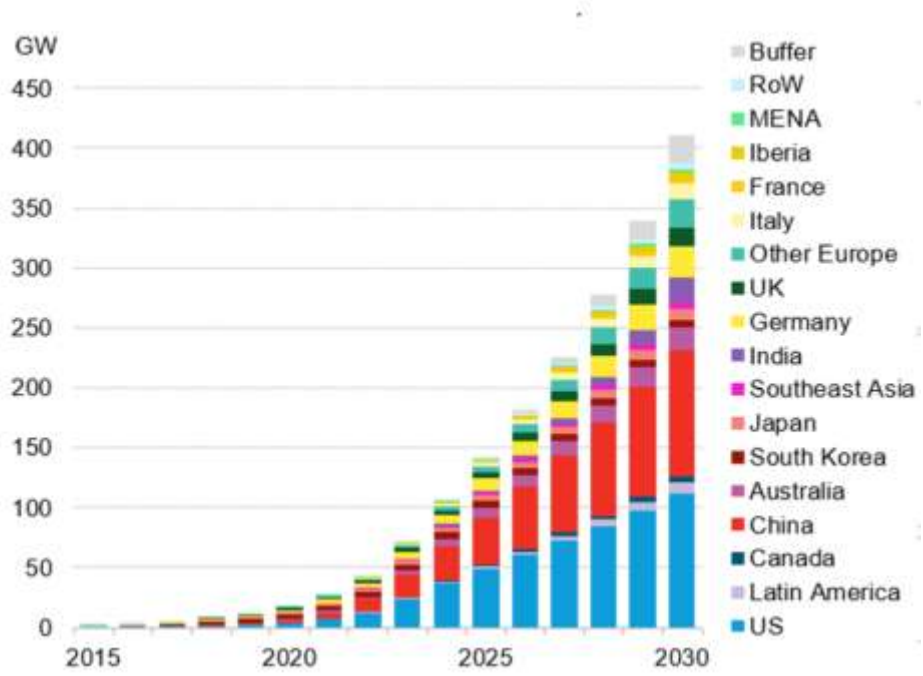
Renewable microgrid capacity in Puerto Rico is expected to grow from nearly 8 MW in 2021 to more than 140 MW by 2030. [52]

** In June 2020 AEE/PPEMA signed a contract with LUMA Energy that would give the company control of the AEE/PREPA electric grid for 15 years.*

2. CONDUCT STUDIES ON THE INTEGRATION OF AC COUPLED BATTERY ENERGY STORAGE SYSTEMS (BESS) TO PROVIDE ANCILLARY SERVICES TO THE GRID

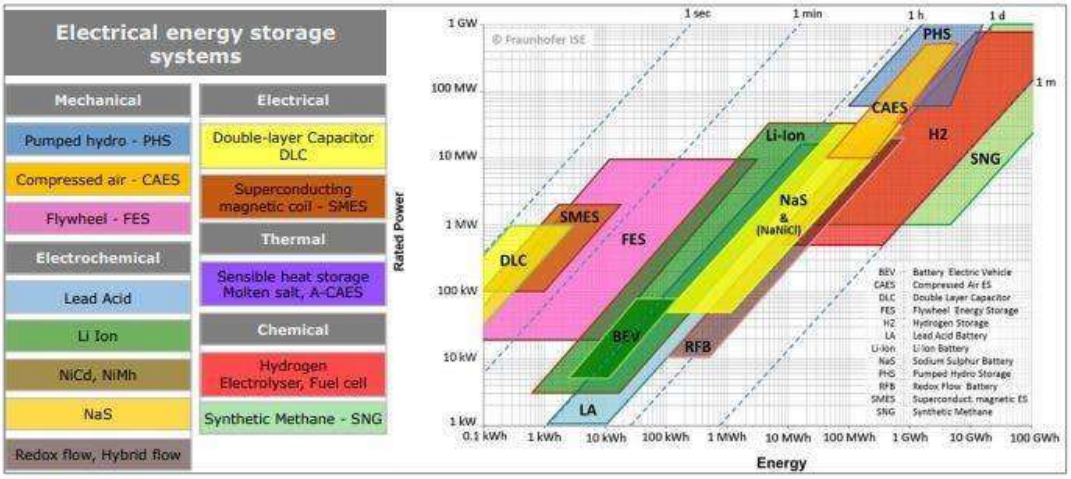
To enjoy the benefits of large-scale energy storage at its fullest, it is necessary to have BESS that can provide ancillary services to the grid. The study of the integration of BESS in different points of the network would shed light on the importance and opportunity that the use of these systems can foster to improve resilience of the network, avoid the famous *duck curve* and help pave the way towards a sustainable energy transition and on a larger scale.

According to the latest forecast from market research firm BloombergNEF (BNEF), energy storage installations worldwide are projected to reach 411 cumulative gigawatts (or 1,194 gigawatt-hours) by the end of 2030. That's 15 times the 27 GW/56 GWh of storage was online at the end of 2021 [27].



Cumulative BESS 2015-2030 **Source:** Bloomberg NEF (2022)

Due to the very different dynamics, performance characteristics and timing of those services, market evolution is driven by a wide range of different storage technologies. Some services will require high power for short periods (frequency regulation), while others will require power for longer periods (capacity firming). These differences imply different charge/discharge cycles. In some cases, uniform cycles will be the standard (power arbitrage), while in other variable patterns they might be the norm (voltage support). Therefore, a diverse group of storage technologies is likely to flourish [28].



Comparison of rated power, energy content and discharge time of different energy storage technologies. **Source:** Electrical Energy Storage, IEC, 2011 [29]

Recommendations:

Regulatory Framework:

- **Clear Regulatory Policies:** Define clear regulatory and tariff structures for the provision of ancillary services. This will incentivize investors and stakeholders.

Technology Neutrality in Policies:

- Frame policies in a way that they are neutral to specific technologies.
- Ensure subsidies, incentives, or support mechanisms are not biased towards one specific technology but rather promote desired outcomes.

Evaluation and Benchmarking:

- Establish a technology-neutral evaluation mechanism to benchmark different BESS solutions based on performance, safety, environmental impact, and cost. This can guide future procurements and ensure that the best technologies are chosen based on merit, not brand or hype.

Strategic locations

- **Location:** Strategically locate the BESS close to areas with renewable integration challenges or grid congestion to optimize its benefits.

3. INTEGRATE THE DISTRIBUTED ENERGY RESOURCES CUSTOMER ADOPTION MODEL (DER-CAM) INTO THE SOFTWARE STACK AT THE CNE

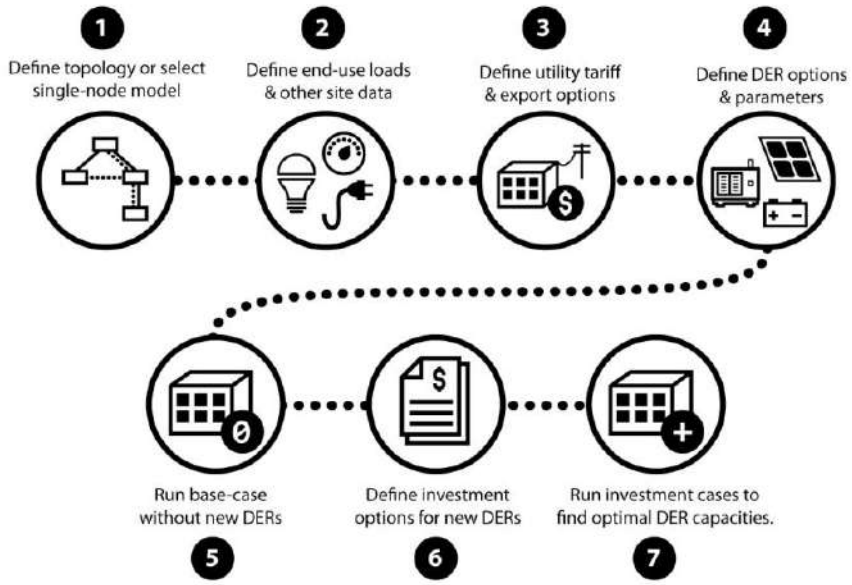
The CNE uses software tools such as DigSilent Power Factory, Stochastic Dual Dynamic Programming (SDDP) and Time Series Lab (TSL) for the elaboration of the National Energy Plan.

Recommendations:

- DER-CAM, a powerful and comprehensive decision support tool that primarily serves the purpose of finding optimal distributed energy resource (DER) investments in the context of either buildings or multi-energy microgrids, should be integrated into CNE´s software stack.

  Technically mature and extensively peer-reviewed, DER-CAM has been developed by researchers at Lawrence Berkeley National Laboratory (Berkeley Lab) since 2000, and can be used to find the optimal portfolio, sizing, placement, and dispatch of a wide range of DER, while co-optimizing multiple stacked value streams that include load shifting, peak shaving, power export agreements, or participation in ancillary service markets. [30].

  The software is strongly recommended by most US Energy Agencies when addressing the need for resilience and microgrids, as can be seen in Policy Paper: Energy Resilience Solutions for the Puerto Rico Grid, which the U.S Department of Energy (DOE) wrote after hurricane Irma y Maria destroyed Puerto Rico´s energy infrastructure. [31]



DER-CAM Workflow. **Source:** Modeling Workflow Completing a DER-CAM analysis in 7 steps, 2018, Lawrence Berkeley National Laboratory (Berkeley Lab) [32]

CONSIDERATIONS FOR EDENORTE (AND OTHER EDE´S)

These considerations are addressed to the **EDENORTE** (*main stakeholder*). The *Empresa Distribuidora de Electricidad del Norte S.A.* (EDENORTE Dominicana S.A.), has the concession for the commercialization and distribution of electrical energy in the 14 provinces of the Northern Zone of the Dominican Republic. Nevertheless, these considerations apply for the two other regional energy utilities **EDESUR and EDEESTE**.

1. INCORPORATE MODELING AND SIMULATION SOFTWARE IN DISTRIBUTION PLANNING

Addressing the shortfall in digitization, particularly in the use of modeling and simulation software for distribution planning, is crucial for energy distribution utilities in the age of data. To catch up with the digitization curve, utilities in the DR must embrace a comprehensive strategy that integrates modern software tools, infrastructure upgrades, and continuous skill development.

Recommendations:

- Adopt software solutions that cater specifically to the modeling and simulation of renewable energy sources' integration into distribution circuits. Programs such as OpenDSS, GridLABD, or PSS®SINCAL are valuable tools in this domain.

- Ensure the chosen software is scalable and can accommodate the growing complexity of the grid with increased renewable penetration.

INSIGHT BUBBLE

To assess and study the impact of Distributed Generation (DG), and the design of Microgrid Architecture in the Medium Voltage (MV) and Low Voltage (LV) networks, it is necessary to have advanced simulation tools and detailed models of the Distribution Network and its components. In order to make these simulations more accessible, open-source software tools such as **OpenDSS** (Open Distribution System Simulator) are now frequently used by Utilities and Research Laboratories across the globe. [53]

EDENORTE can build upon the existing knowledge derived by the collaboration within this research project, and invest in training and development for the staff in the Network Study Department. This will ensure the continuation of the capacity building.

The Electric Power Research Institute (the OpenDSS have professional development hours that can be a great long term investment to developed this skills.

2. GEOREFERENCING AND GIS INTEGRATION FOR IMPROVED EFFICIENCY

EDENORTE´s network topology (including substations, transmission lines, transformers, and other assets) is well maintained using GIS. However the underlying base maps are not georeferenced, which hinders the ability to integrate this data into another sevices.

Recommendations:

Georeference Existing Base Maps:

- Engage GIS specialists to georeference existing base maps using known coordinate systems. This process involves linking points on the digital map to known real-world geographic coordinates.
- Utilize control points, or benchmarks, that have known geographic locations to ensure accuracy during georeferencing.

Adopt Standard Coordinate Systems:

- Choose a widely recognized coordinate system (e.g., WGS 84 or UTM) based on the region and the type of projects. This ensures compatibility when integrating with external data or services.

Integrate with External Services:

- Once georeferenced, explore opportunities to integrate the GIS data with other external services, such Vegetation Management and Distribution Network Maintanence Department. This can enhance decision-making processes and operational efficiency.

3. GIS FOR VEGETATION MANAGEMENT AND IDENTIFICATION OF NON-STANDARD INFRASTRUCTURE

By effectively implementing and leveraging GIS for vegetation management, EDENORTE and other energy distribution utilities in the Dominican Republic can enhance grid reliability, improve operational efficiency, and ensure the safety of both their infrastructure and the communities they serve.

There is currently a Proof-of-Concept (POC) for a GIS for vegetation management and identification of non-standard infrastructure, being developed under the umbrella of the Open Data Platform (PDA) for Spatial Analysis of Energy and Community Resilience at PUCMM. The project entails the mapping and classification of trees nearby the energy infraestructure, as well as infraestructure that is outside the norm, and visualize it at Spatial Data Infraestructure.

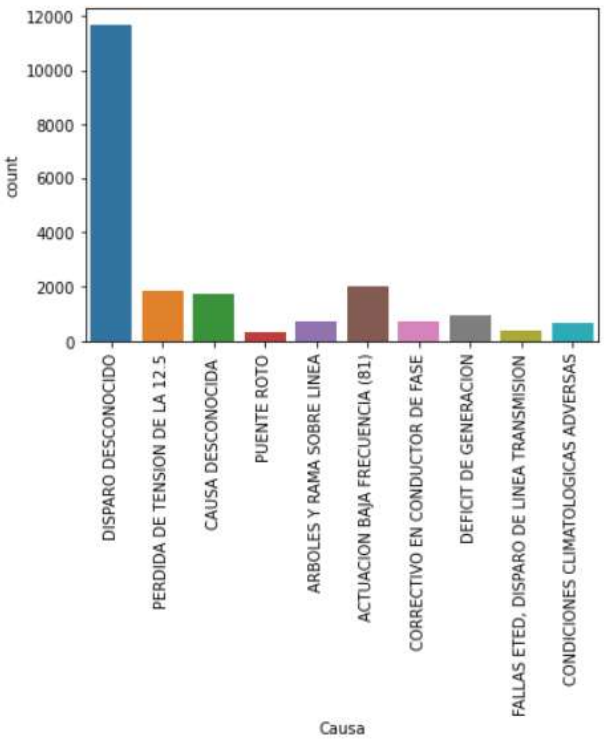
Vegetation Proximity and Growth Rate:

- Trees and vegetation growing near power lines and other infrastructure can lead to outages, fires, or safety hazards. It's crucial to monitor and manage this vegetation to prevent disruptions and damage.

Non-Standard Infrastructure Challenges:

- Infrastructure that doesn't conform to established standards can pose reliability and safety risks. It might not perform optimally under stress, and in some cases, it could be more susceptible to damage or failure.

This spinoff in the project came after reviewing data coming for the Maintencance Management at EDENORTE, it was determined that 49.5% of the interruptions reported in EDENORTE correspond to unknown causes and only 2% to trees on lines. Now, according to the literature reviewed on outages in the utility industry, tree-related outages commonly comprise 20% to 50% of all unplanned distribution outages[33]. So a large percentage of unknown faults can find their origin in this cause. Likewise, this data is relevant, since according to the Superintendency of Electricity [34] a typical company in the Dominican Republic experiences 15 blackouts per month, compared to only 1.8 in Latin America and 5.7 in around the world, according to data from the World Bank [35]. So reducing this gap is of great importance, which is why this objective has been prioritized for the project.



Distribution of the causes of interruptions in EDENORTE networks **Source:** Gerencia de Mantenimiento (EDENORTE)

Proof of concept for the GIS Vegenetation Non-Standard Infrastructure Management Tool **Source:** Microgrid Research Group (PUCMM)

The main goals of these application will be:

Comprehensive Database Creation:

- Utilize GIS to create a comprehensive database of vegetation near all energy infrastructure. Ensure this database includes species information, growth rates, and potential hazards to the grid.

Enhanced Spatial Analysis:

- Use spatial analysis to predict areas of rapid vegetation growth based on historical data. This can guide proactive trimming and maintenance activities, ensuring potential hazards are addressed before they become critical.

Optimized Work Routes:

- Leverage GIS to create optimized routes for maintenance crews, minimizing travel time and ensuring urgent areas are addressed promptly.

Pilot Testing::

- EDENORTE should propose a pilot phase where the GIS tool is implemented in select regions under EDENORTE's jurisdiction. This hands-on testing can provide valuable insights for tool refinement after the initial development.

4. INTEGRATE HARDWARE-IN-THE-LOOP (HIL) SIMULATIONS FOR NETWORK STUDIES

Integrating Hardware-in-the-Loop (PHIL) simulations can be crucial for energy utilities, especially as they seek to modernize and incorporate new technologies and systems. HIL simulations allow real-world hardware to be tested and validated against a real-time simulation environment, ensuring that new devices and systems are integrated effectively into the existing infrastructure.

PUCMM's Microgrid Laboratory has been designed to implement the latest technology in HIL simulations. Using the latest OPAL-RT's hardware combined with flexible three-phase inverters configurations, the possibility of creating various simulation scenarios has been created. This laboratory aims to become a reference for the evaluation of control strategies, focused on improving the resiliency and the operational efficiency of Dominican Republic's electrical grid system. Furthermore, recent trends like Networked Microgrids (NMIG) and distributed storage systems required the testing of coordination and dynamic formation of distributed agents, being this an excellent use case for PHIL in the validation of these advanced control algorithms [36].

Recommendations:

EDENORTE can use the capabilities for:

- **Test Grid Modernization Equipment:** Before deploying new grid equipment, such as advanced transformers, breakers, or controllers, validate their operations through HIL simulations to ensure compatibility and performance.

- **Real-time Testing for Grid Emergencies:** Use HIL simulations to recreate potential grid emergency scenarios, such as a sudden drop in renewable energy generation or a major grid component failure. This can guide utilities in developing effective response strategies.

- **Training and Skill Development**: Provide training sessions for utility personnel on the intricacies of HIL simulations, ensuring they can effectively set up, run, and interpret the tests.

- **Regulatory Engagement:** Engage with regulatory bodies, informing them of the benefits of HIL simulations and the insights gained. This can be valuable in shaping future energy policies and standards.

INSIGHT BUBBLE

EDENORTE can leverage on the opportunities provided by the Energy Sector Reform project, in which USAID provides technical assistance for energy reform to utilities, ministries, and regulators in the host countries, to develop policies, laws, regulations, tools and processes for the design and operation of more resilient and modern energy systems. [54]

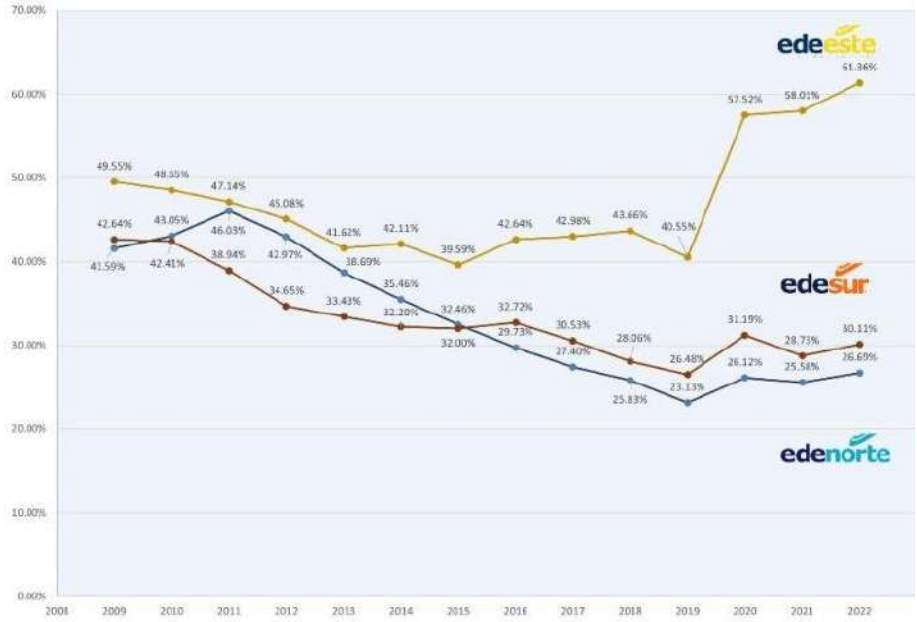
Objective 3 of the project reads: Energy Sector Resilience Enhanced Through Regional Mechanisms

- Strengthen regional entities, networks, and mechanisms to advance energy sector resilience.
- Support donor coordination to optimize sector impacts.
- Accelerate the exchange of lessons learned for energy sector modernization and resilience.
- This objective includes study tours to promote RE/energy efficiency (EE) integration and grid modernization, regional webinars to promote RE/EE, and training sessions for commercial banks to assess RE/EE projects.

EDENORTE can support the further development of the synergy with the Microgrid Research Group at PUCMM by requesting funds to support the development of training activities and the use of the infraestructure of the PHIL Laboratory for its personnel.

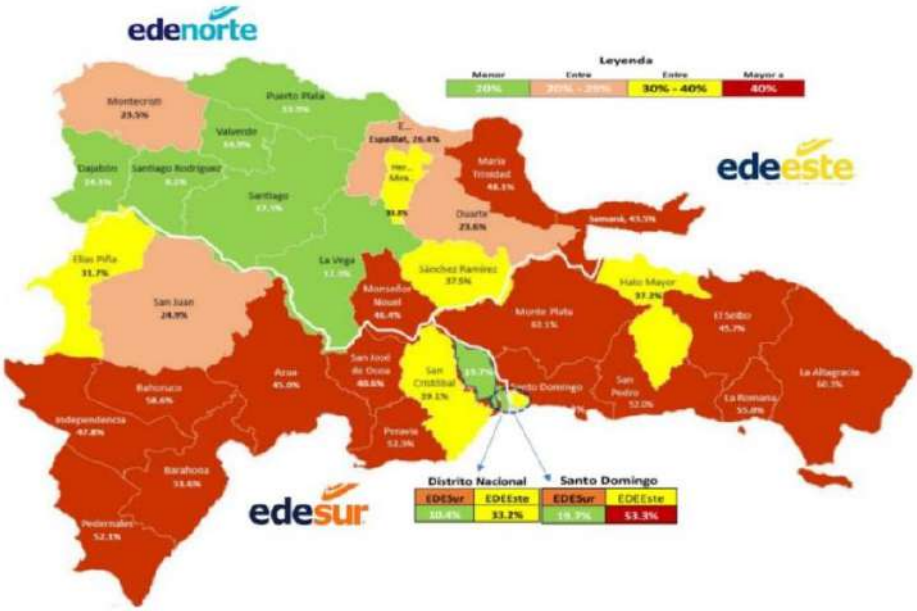
5. INVEST IN DIGITIZATION AND THE APPLICATION MACHINE LEARNING (ML) ALGORITHMS FOR MASSIVE ANALYSIS OF ENERGY BALANCE DATA FROM AREA METERS (TOTALIZERS) TO REDUCE ENERGY LOSSES

Despite the investment and the efforts made to improve the performance of the electricity sector, the levels of electricity losses in the Dominican Republic have remained above international reference standards for several decades [37]. According to data from the Superintendencia de Electricidd (SIE), electricity losses in the distribution sector (around 39.2% in 2023) are, on average, higher than in the group of low-income countries and comparable to the levels presented in the United States of America in 1929. As a reference, electricity losses in high-income countries of the Organization for Economic Cooperation and Development (OECD) have fluctuated on average between 6% and 8% and are mainly of a technical nature, result of energy transport in relatively efficient systems [38].



Total energy losses of each distributor (2022). **Source**: Prepared with data from the sector performance report (March 2023), Ministry of Energy and Mines (MEM-RD) [39]

All of this translates into a growing financial deficit, which by 2022 reached US$1,802.7 MM (RD$99,315 MM), an increase of 77% of what was originally budgeted and 82% more than what was allocated for the same purposes in the year 2021 (US$959.1 MM) [39], according to figures from the General Budget Directorate (DIGEPRES) [40].



Map of energy losses in the geography of the Dominican Republic. **Source:** Fuente: Plan Integral de Reducción de Pérdidas 2022-2028 [41]

One way to give an alternative dimension to such losses, and put them in context, is to compare the generation capacity or installed power represented by the 5,494 GWh of energy lost in 2022. The Punta Catalina thermoelectric plant (CTPC), the jewel in the crown of the country's electricity sector, it has an installed capacity of 752 MW and had a net generation in 2022 of 4,701 GWh [42], that is, 1.17 times the generation of this plant is needed just to cover the sector's losses.

Historical data reveal that the majority of electricity losses originate in informal circuits, in which customer identification, the absence of measurements and the normalization of unauthorized consumption have historically not been carried out. Less than a quarter of the total losses arise from rehabilitated circuits that have uninterrupted electricity service 24 hours a day. This finding indicates the existence of two specific elements in the problem of electricity losses: (1) relatively sophisticated fraud and corruption in wealthy areas (circuits A and B), where an adequate quality of service is observed; and (2) opportunistic fraud and non-payment in the most disadvantaged areas that have informal networks (circuits C and D), where the quality of electrical service is poor [43].

Recommendations

- **Invest in Tehcnology and Data Science :** Manage energy loss through data insights coming from an energy balance system using micro measurements and telemetry to administer, analyze, manage and monitor energy loss control in the basic management units of the EDE, such as transformers, in an integrated Wide Area Network (WAN).

- **Unified techonology schemes:** Going forward EDE´s should unify the smart metering, remote cutting and prepayment network schemes.

Sistema de medición	Tecnología de Comunicación	EDESur	EDEEste	EDENorte	TOTAL	%
		Cantidad	Cantidad	Cantidad		
Telemedida	RF	12,586	30,500	106,020	149,106	6%
	GPRS	193,218	3,114	7,461	203,793	8%
	PLC TWACS	441,899	98,000	349,760	889,659	36%
	PLC - 3G		2,000		2,000	0%
Convencional	N/A	186,139	498,665	576,274	1,261,078	50%
Total con medición		833,842	632,279	1,039,515	2,505,636	100%

Numbers of clients by type of connection and measurement technology. **Source:** : Plan Integral de Reducción de Pérdidas 2022-2028 [41]

- **Work on the Association (client – transformer – circuit) in Geographic Information Systems (GIS):** Lack of maintenance of the circuit association field of supplies (customers), currently affect all the data of the intelligence tools acquired for monitoring and loss control.

INSIGHT BUBBLE

The Microgrid Resarch Group at PUCMM submitted a research proposal called: ***Design of machine learning models for the detection of non-technical losses and failures in electrical distribution networks,*** *to the* National Fund for Scientific and Technological Innovation and Development (FONDOCYT).

The main goal is to develop an automatic system for the location and detection of non-technical losses and/or failures in the electrical distribution circuits of the city of Santiago de los Caballeros using machine learning algorithms for the massive analysis of energy balance data of measurements in real time.

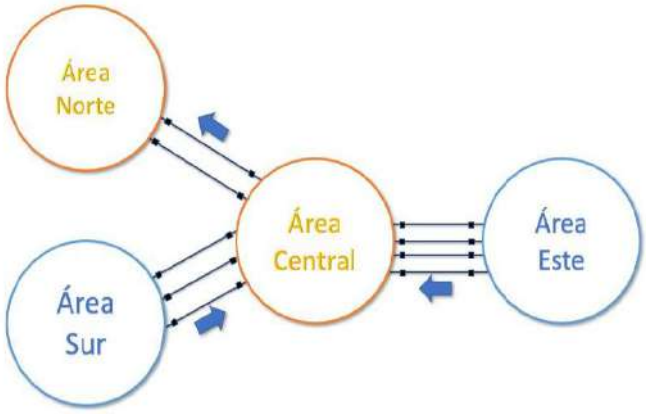
If successful, the team will need:

- **Expert Insights:** Access to engineers and experts at EDENORTE who have deep domain knowledge about the distribution network, its vulnerabilities, and operational challenges.
- **Historical Data:** Access to historical power consumption data, incident reports, and maintenance records. This would help in training the machine learning models.
- **Stakeholder Engagemen**: Regular meetings between PUCMM researchers and EDENORTE leadership to discuss progress, challenges, and refinements.

CONSIDERATIONS FOR THE COORDINATION BODY (OC)

These considerations are addressed to Coordinating Body (OC, acronym in SPANISH) of the National Interconnected Electricity System (SENI) of the Dominican Republic. A non-profit association, whose objective is to coordinate the operation of the facilities of the electricity generation, transmission and distribution companies that belong to the SENI.

Back in 2020, the OC published a SENI Island Operation report, for the Superintendency of Electricity and the MEM Agents, with the objective of analyzing **the isolated operation of each of the SENI areas**, based on the potential occurrence of an atmospheric phenomenon, and with the aim of evaluating, for example, partial system restore / black start scenarios [44].



Interconnection of different areas of the SENI. **Source:** Operación en Isla del Seni, 2020, Organismo Coordinador

The methodology used to carry out the study was the following:

- **Definition of demand scenarios:** Minimum demand scenario extracted from the June 2020 medium-term report.
- **Definition of generation scenarios:** Twelve generation scenarios are contemplated to supply the defined demand scenario, for each particular area. The definition of the scenarios is carried out based on the generation park required to keep the isolated area operating in a stable manner.
- **Simulation tool:** Power Factory DigSilent version 19 electrical power systems simulation software.
    - Studies in Transient Regime: Frequency and angle stability
    - Studies in Stable Stage: Demand and Generation

Main findings

- The demand of the South, East and North area is satisfied in its entirety through the generation installed in said area**.**
- The voltage levels are within the quality range established by the regulations; when verifying the loadability levels of the lines in the area, there are no flow violations for each of the elements that are in operation. Consequently, under the simulated

scenarios, in a steady state, in isolation, without contingencies, the island operation is safe.

- Transcient studies:
    - **East:** For the transient analysis, an eigenvector with a positive real part is presented, so the area is unstable.
    - **South and North:** For the transient analysis there are no unstable eigenvectors so the multimachine is stable for small variations in the generation or demand signals.
- One of the main recommendations of the study is to avoid the dispatch of renewable generation units (solar or wind technologies), due to the limited control over thedispatch of these types of technologies.

Recommendations:

- Repeat the study considerering the hypothetical scenario of having BESS with AC-coupled systems, that allow for ancilliary services from such systems.
- Repeat the study considering the hypothetical scensario of having stand alone BESS in critical subestations, those that link two or more transmission lines, through power switches that connect or disconnect the networks in conditions of failure or maintenance, for example:

SUBESTATION	TYPE OF SS
Subestación Eléctrica Julio Sauri	Conmutación
Subestación Eléctrica El Naranjo	Conmutación
Subestación Eléctrica Palamara	Mixta
Subestación Eléctrica Canabacoa	Mixta
Subestación Eléctrica Bonao 2	Conmutación
Subestación Eléctrica Puerto Plata II	Mixta
Subestación Eléctrica Cruce De Cabral	Conmutación
Subestación Eléctrica 15 de Azua	Mixta
Subestación Eléctrica S.P.M. 2	Mixta

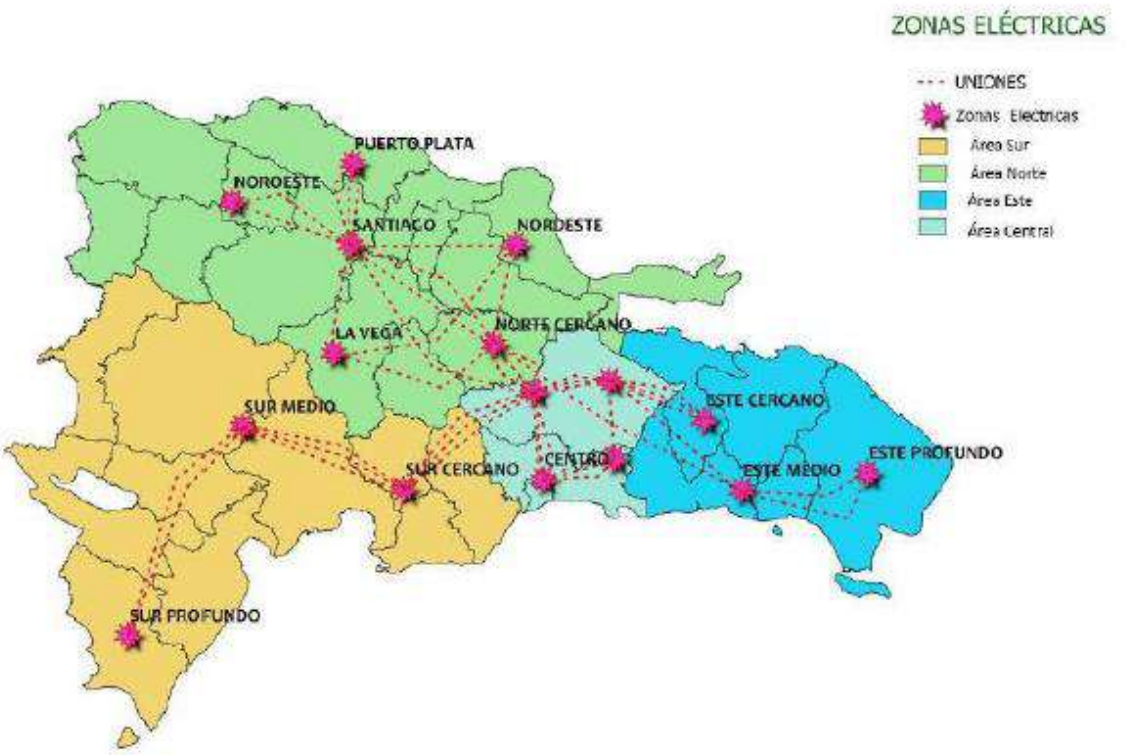
The scenarios could build upon the existing study carried out by the CNE in [25], wheresubstations of the Dominican Electric Transmission Company (ETED) with a capacity of 300 MW/1200MWh, where added to the SENI in a staggered manner, with capacities of 50, 100 and 150 in the years 2023, 2024 and 2025 and with a duration of four (4) hours [25].

CONSIDERATIONS FOR THE DOMINICAN ELECTRICAL TRANSMISSION COMPANY (ETED)

These considerations are addressed to ETED, a company owned by the Dominican State that arises from the segmentation of the electricity sector as a result of the capitalization of the Dominican Electricity Corporation through the General Law of Public Company Reform No. 141-97 dated June 24 of the year 1997, having its legal framework in the General Electricity Law No. 125-01 dated July 26, 2001 [22], which regulates all aspects related to the production, transmission, distribution and commercialization of electrical energy in Dominican Republic.

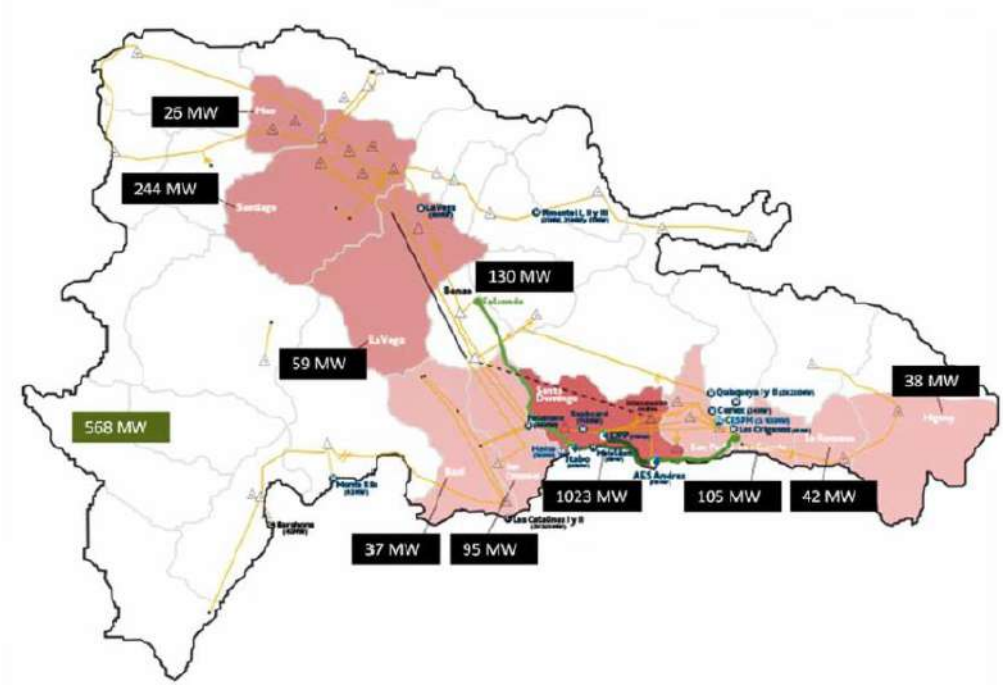
The transmission system of Dominican Republic is characterized by four electrical areas interconnected with each other through links at 69 kV, 138 kV, 345 kV and 230 kV and operated by the Energy Control Center. The current network topology is weakly meshed, with rings existing within areas. The 138 kV rings are operated in a meshed fashion, while some of the meshed configurations in the 69 kV network are operated in a radial fashion [45].

The 138 kV network connects, through the substations: Palamara – Bonao II – Canabacoa and Julio Sauri-Piedra Blanca, Julio Sauri-El Naranjo, the two main consumption centers of Santo Domingo and Santiago.



Electrical Zones and Interconnections **Source**: Plan de Expansión: Sistema de Transmisión Eléctrico (2021-2035) [45]

The SENI demand is concentrated in greater Santo Domingo (Santo Domingo East, North and West) and the National District with 47%. The Northern Zone accumulates 33% of the demand (Santiago, La Vega and Puerto Plata), the remaining 20% being distributed in the Eastern and Southern regions (see figure below).



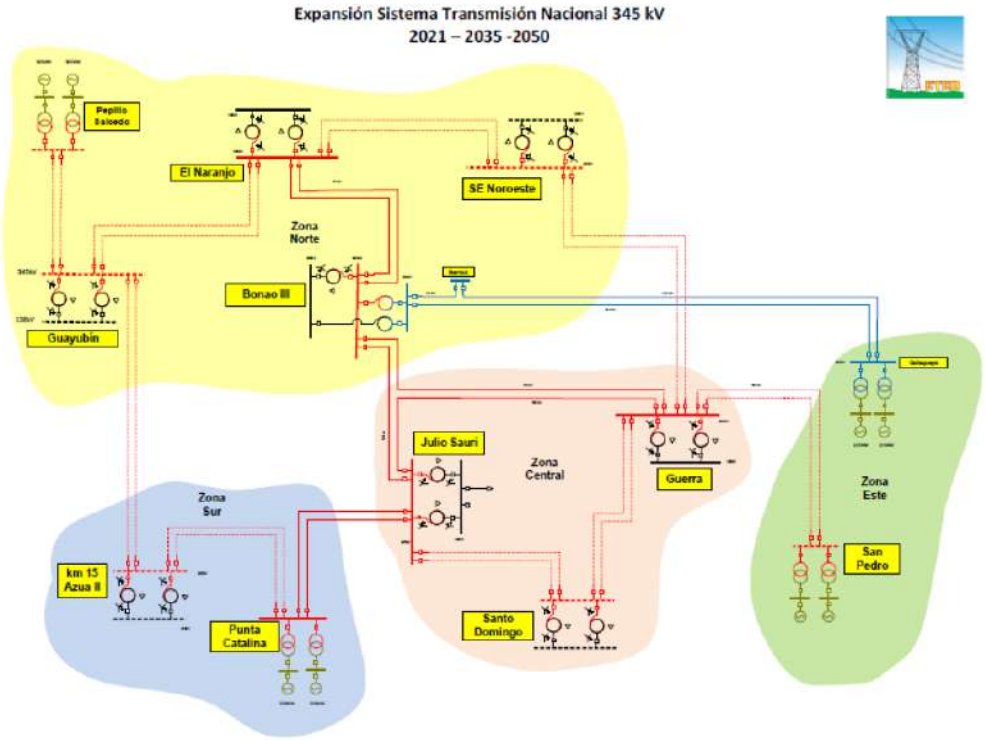
Regional Energy Demand in the Dominican Republic **Source:** La Seguridad Energética, una Estrategia para el Desarrollo Sostenido del SENI (2021)

There are risks associated with various components throughout the transmission network. Large power transformers are easily identified and difficult to protect from physical attacks. They have long waiting times for replacement (5-20 months) due to their specialization and dependence on third parties and/or offshore manufacturers. Transmission towers and lines are also vulnerable, due to their accessibility and lack of monitoring, but most can be restored quickly. Transmission system control centers and/or control equipment can also be targets of cyber-attacks.

According to information available from the monthly event reports in the SENI in 2019, 86 relevant events associated with the transmission system were recorded, which involved loss of voltage in substations, tripping of lines transmission and/or autotransformers. It is estimated that the cost of shortages associated with these events was (in total) approximately RD DOP $24,158,287.74 [45].

Taking into consideration the demand and generation projections, the rise of non-conventional renewable energy, the needs for the construction of new distribution substations, reactive compensations, and transmission works, ETED published the Expansion Plan for the Electric Transmission System 2021-2035 (see figure below), several investment projects are derived from this plan, among which it highlights:

- System expansion to 345KV
- Undergrounding of the new networks of greater Santo Domingo and the reconfiguration of existing networks
- Reactive power compensation
- New delivery lines from the main substations, towards Santo Domingo and Santiago.



345KV National Transmission System Expansion 2021-2035-2050 **Source:** Plan de Expansión: Sistema de Transmisión Eléctrico (2021-2035) [45]

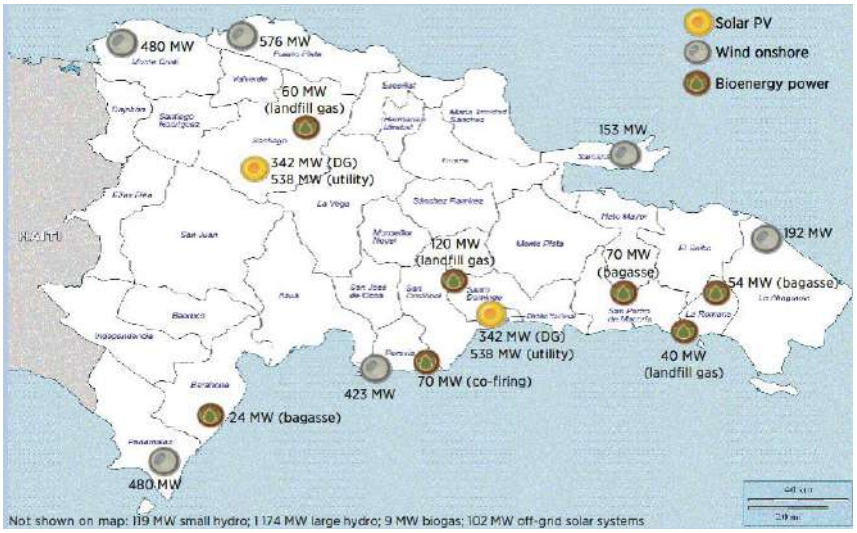
According to the Transmission Expansion Plan (2021-2035), the budget that ETED needs to execute its expansion in the short and medium term to improve energy transmission capacity, regardless of the source of origin, totals an investment of around 800 MM USD between now and 2030.

ETED issued no objections between 2020-2022 for the interconnection of 5,150 new megawatts, of which 3,562 correspond to renewable energy projects. In fact, 17 large renewable energy plants are under construction (September 2023); with 14 coming into operation by the end of the year. While another dozen projects are in prospective studies for the following years.

Recommendations:

- **Developed Public Private Partnerships:** Prioritize these alliances for the design, construction, maintenance and financing of the needs of high voltage lines and substations close to areas with high wind and solar resources.

- **Update renewable penetration forecasts:** It is necessary to review and continue the expansion plans that contemplate and/or update the renewable penetration forecasts proposed by the International Renewable Energy Agency (IRENA) in 2016 for the country in the next 20 years [46].



Location of renewable power generation capacity in 2030 under Remap. Source: Renewable Energy Prospects: Dominican Republic (2026) [46]

It is necessary to priotize the expansion of the 345kV transmission system towards areas with a high energy profile; this will allow the expansion of the generation park, based on the renewable resources available in those areas, without network restrictions.

- **345kV El Naranjo – Guayubín** transmission line will increase the availability of the wind and solar plants in the northwest area, in addition to transport energy from the Manzanillo Thermoelectric Plant.

CONSIDERATION FOR THE MINISTRY OF ECONOMY, PLANNING, AND DEVELOPMENT (MEPYD)

Microgrids are becoming a critical consideration for future governmental policies related to the enhancement of energy system reliability and resilience. The Ministry of Economy, Planning, And Development (MEPyD), as the governing body of Dominican Republic's national system for planning and public investment, should considered the importance of the transition to a decentralized electrical distribution system due to its improved reliability and fault recovering capacity under the occurrence of extreme weather events.

1. INCLUDE THE DECENTRALIZATION AND THE FORMATION OF FLEXIBLE ELECTRICAL MARKETS AS A TOOL TO ADD VALUE IN THE NEXT EDITION OF THE MULTI ANNUAL PUBLIC POLICY PLAN

The MEPyD in its Multi Annual Public Policy [47] plan for the years 2021-2024 added a section dedicated to energy. This section focused on the permanent and quality access to energy sources, with two recommendations pointing to the decentralization and flexibilization of Dominican Republic's electrical energy sector by means of modifying regulations for the creation of electrical cooperative organizations. Nevertheless, in the proposed indicators for measuring the advancement of the proposed plan, there is no indicators for measuring the added flexibility, resiliency capability, and robustness in the operation of Dominican Republic electrical grid.

Recommendation:

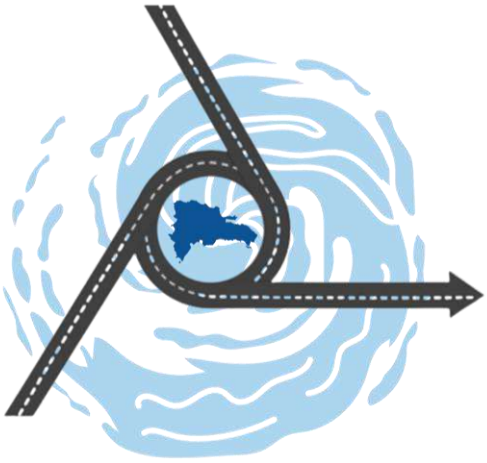
- **Develop Clear Indicators for Decentralization and Flexibility**
- **Capacity Building for Cooperatives:** Foster knowledge exchange programs with successful cooperatives from other countries.
- **Financial Incentives and Support:** Allocate budgetary provisions or financial incentives for cooperatives adopting innovative and green technologies.
- **Promote Public-Private Partnerships:**Encourage partnerships between the public sector, private enterprises, and the cooperatives to facilitate technology transfer, knowledge sharing, and financial support

CONCLUSION

It is well known that a reliable electrical grid is the **backbone of modern society**. It plays a key role in all economic activity and ensures the wellbeing of its citizens. This is especially true for nations like the Dominican Republic, which faces the challengse of geographic isolation and the need for self-sufficiency. Given this context, it is important that the managers, policy makers and regulators of our nation's energy infrastructure explore the technological tools and innovations that allow not only to increase our ability to plan, make decisions and increase the level of resilience of our infrastructure in the face of these types of events, but also have **the technical knowledge to integrate the technologies that will make it possible.**

Drawing on Nassim Nicholas Taleb's ideas about 'Black Swans' (*a metaphor that describes an event that comes as a surprise, has a devastating effect and is often inappropriately rationalized in retrospect*)[48], we argue that to be prepared for the new realities of climate change, the dominican state should priortize a **vision towards resilience** in infraestructure. When talking about resilience in infrastructure, it's important to recognize that we're talking about **systems,** and one way to think of a system is to see it as groups of relationships. A city is a system of relationships between people, businesses, institutions, and infrastructure. So, when a city that has been devastated by a hurricane recovers, no one really care if the power grids, buildings, and bridges are rebuilt in exactly the same way. What matters is whether **the key relationships within the city system remain intact**. *Can the essential people and institutions that made up that system be recovered? Can residents remain in their neighborhoods or are they forced to leave because basic services (**energy, water, communication**) have been affected? Can shops and factories reopen, or are contracts and supply lines broken beyond repair?* [49].

Increased demand for **reliability and resilience** in the shadow of climate change**,** combined with falling Battery Energy Storage Systems (BESS) costs, and the affordability of solar PV, are driving microgrid development across the world. Grasping and understanding these trends is essential for trackling the regulatory barriers and policy needs of microgrids, but even more important, pivotal for the vision towards the energy transition and it´s 3D´s: **Digitalization, Decarbonization and Decentralization.**



BIBLIOGRAPHY

[1] D. Eckstein, V. Künzel, L. Schäfer, Global climate risk index 2021: who suffers most from extreme weather events? Weather-related loss events in 2019 and 2000–2019, 2021. http://germanwatch.org/en/download/8551.pdf.

[2] M. Izzo, L. Rathe, D. Arias, Puntos Críticos para la Vulnerabilidad a la Variabilidad y Cambio Climático en la República Dominicana y su Adaptación al mismo, 2012. http://pdf.usaid.gov/pdf_docs/PA00JJ3J.pdf.

[3] USAID, Dominican Republic Climate Change Vulnerability Assessment: Executive summary, (2013) 8. https://www.climatelinks.org/resources/dominican-republic-climate-change-vulnerability-assessment-executive-summary.

[4] R.E. De Jesús-Grullón, Vulnerabilities of the Dominican Republic's Electric Networks & Catastrophic Risks to Grid Security, (2022). https://microgrid.pucmm.edu.do/vulnerabilities-of-the-dominican-republics-electric-networks-and-catastrophic-risks-to-grid-security/.

[5] M. Dyson, B. Li, Reimagining Grid Resilience, 2020. https://rmi.org/wp-content/uploads/2020/07/reimagining_grid_resilience.pdf.

[6] Viceministerio de Seguridad Energetica y Infraestructura, Plan Nacional Indicativo de Desarrollo de Infraestructuras Energéticas Críticas, 2021. https://microgrid.pucmm.edu.do/wp-content/uploads/2022/10/PIEC_v20-12-2021.pdf.

[7] D. Verner, K. Kim, F. Petit, Incorporating Prioritization in Critical Infrastructure Security and Resilience Programs, (2017).

[8] R.E. De Jesús Grullón, Microgrid Research PUCMM, (2021). https://microgrid.pucmm.edu.do/about/.

[9] D. Ton, M. Smith, The U.S. Department of Energy's Microgrid Initiative, Electr. J. (2012). http://dx.doi.org/10.1016/j.tej.2012.09.013.

[10] National Association of State Energy Officials (NASEO), National Association of Regulatory Utility Commissioners (NARUC), User Objectives and Design Approaches for Microgrids: Options for Delivering Reliability and Resilience , Clean Energy , Energy Savings , and Other Priorities, 2021. https://www.nj.gov/bpu/about/divisions/opp/microgrid.html.

[11] D. Shea, Microgrids: State Policies To Bolster Energy Resilience, 2022. https://www.ncsl.org/energy/microgrids-state-policies-to-bolster-energy-resilience.

[12] State of New Jersey Board of Public Utilities, Microgrid, (n.d.).

[13] U.S Deparment of Energy (DOE), Microgrids for Resilient Municipalities, 2021. https://energy.ri.gov/sites/g/files/xkgbur741/files/documents/SRP/Microgrids-for-Municipalities-Slides-FINAL.pdf.

[14] Presidential Policy Directive -- Critical Infrastructure Security and Resilience | whitehouse.gov, (n.d.). https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil (accessed March 28, 2023).

[15] R.E. De Jesús Grullón, Frameworks for Assessing Energy Resilience in Power Distribution Networks, (2023). https://microgrid.pucmm.edu.do/frameworks-for-assessing-energy-

resilience-in-power-distribution-networks/.

[16] S. Booth, J. Reilly, R. Butt, M. Wasco, R. Monohan, S. Booth, J. Reilly, R. Butt, M. Wasco, R. Monohan, Microgrids for Energy Resilience : A Guide to Conceptual Design and Lessons from Defense Projects Microgrids for Energy Resilience, (2020). https://www.nrel.gov/docs/fy19osti/72586.pdf.

[17] K. Verclas, K. Jones, Clean Energy Microgrids : Considerations for State Energy Offices and Public Utility Commissions to Increase Resilience, 2023.

[18] ABB, Integrating High Levels of Renewables into Microgrids: Opportunities, Challenges, and Strategies, n.d. https://www.slideshare.net/tswittrig/abb-whitepaper-final-022316-integrating-renewables-into-microgrids.

[19] Rocky Mountain Institute (RMI), The Economics of Battery Energy Storage: How Multi-use, Customer-sited Batteries Deliver the Most Services and Value to Customers and the Grid, Colorado, 2020. https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf.

[20] Schneider Electric, Non-Wires Alternatives: A 21st-Century Approach to Today's Power Challenges, (n.d.). https://www.sandc.com/en/solutions/non-wires-alternatives/.

[21] R.E. De Jesús Grullón, Towards the Future: The 21st Century Electric Grid, (2021). https://microgrid.pucmm.edu.do/towards-the-future-the-21st-century-electric-grid/.

[22] Congreso Nacional de República Dominicana, Ley no. 125-01 - Ley General de Electricidad, (2001) 1–23. https://www.sie.gob.do/images/sie-documentos-pdf/leyes/LeyGeneraldeElecctricidadNo.125-01.pdf.

[23] Congreso Nacional de República Dominicana, Ley No. 100-13 - MINISTERIO DE ENERGÍA Y MINAS, 2013. https://mem.gob.do/wp-content/uploads/2019/01/Ley-No.-100-13-que-crea-el-Ministerio-de-Energía-y-Minas-de-la-República-Dominicana.pdf.

[24] Comisión Nacional de Energía, Plan Energético Nacional República Dominicana 2022 – 2036, 2022.

[25] Comisión Nacional de Energía (CNE), INTEGRACIÓN DE ENERGÍAS RENOVABLES VARIABLES Y SISTEMAS DE ALMACENAMIENTO DE ENERGÍA POR BATERÍAS, Santo Domingo, 2022. https://www.cne.gob.do/transparencia/consultas-publicas-procesos-consultas-abiertas-2022/.

[26] Comisión Nacional de Energía, Resolución número CNE-AD-0004-2023, Santo Domingo, 2023. https://www.cne.gob.do/transparencia/consultas-publicas-procesos-consultas-abiertas-2022/.

[27] IRENA, Electricity storage and renewables: Costs and markets to 2030, 2017. http://irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets%0Ahttps://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf.

[28] R.E. De Jesús Grullón, Almacenamiento de Energía: Resiliencia e Independencia Energética en RD, (2020) 1–23. https://hoy.com.do/almacenamiento-energia-resiliencia-e-independencia-en-rd/.

[29] IEC, Electrical energy storage white paper. Tech report; 2011., 2010. https://www.iec.ch/basecamp/electrical-energy-storage.

[30] Lawrence Berkeley National Laboratory (Berkeley Lab), The Distributed Energy Resources Customer Adoption Model (DER-CAM), (n.d.). https://gridintegration.lbl.gov/der-cam#:~:text=Technically mature and extensively peer,multiple stacked value streams that.

[31] United States Department of Energy, Energy Resilience Solutions for the Puerto Rico Grid, (2018) 24.

[32] Berkeley Lab, DER-CAM Modeling Workflow, (2018) 1–37. https://gridintegration.lbl.gov/sites/default/files/DER-CAM Workflow.pdf.

[33] S. Guggenmoos, Managing Tree-caused Electric Service Interruptions, 29 (2003).

[34] Superintendencia de Eléctricidad, INDICADORES CALIDAD DISTRIBUIDORAS MARZO 2023, (2023). https://sie.gob.do/indicadores-calidad-distribuidoras-marzo-2023/.

[35] World Bank, Power outages in firms in a typical month (number) - Dominican Republic, World, Latin America & Caribbean, (2021). https://data.worldbank.org/indicator/IC.ELC.OUTG?end=2021&locations=DO-1W-ZJ&name_desc=true&start=2010&view=chart&year=2020.

[36] United States Agency for International Development, Investigando sobre resiliencia energética, (2023). https://www.usaid.gov/dominican-republic/news/investigando-sobre-resiliencia-energetica.

[37] Inter-American Development Bank, Privatization , Institutional Reform , and Performance in the Latin American Electricity Sector, (2013).

[38] Banco Interamericano de Desarrollo (IADB), Dimensionando las pérdidas de electricidad en los sistemas de transmisión y distribución en América Latina y el Caribe, 2014. https://publications.iadb.org/es/publicacion/16883/electricidad-perdida-dimensionando-las-perdidas-de-electricidad-en-los-sistemas.

[39] R.E. De Jesús-Grullón, Pérdidas de Energía en Distribución: El Agujero Negro del Sector Eléctrico en República Dominicana, (2023). https://ehplus.do/perdidas-de-energia-en-distribucion-el-agujero-negro-del-sector-electrico-en-republica-dominicana/.

[40] Dirección General de Presupuesto (DIGEPRES), Informes de Ejecución Presupuestaria, Santo Domingo, n.d. https://www.digepres.gob.do/publicaciones/informes/.

[41] Consejo Unificado de las Empresas Distribuidoras, Plan Integral de Reducción de Pérdidas 2022-2028, 2022. https://edeeste.com.do/transparencia/index.php/plan-integral-de-reduccion-de-perdidas-2022-2028/.

[42] Dirección Comercial CTPC, Balance de Energía Central Termoeléctrica Punta Catalina 2022, 2022. https://puntacatalina.cdeee.gob.do/estadisticas/.

[43] Economist Intelligence Unit, El futuro del sector eléctrico en la República Dominicana Contenido, Econ. (2015). https://www.ces.org.do/images/2015/FunglodeElectricitySectorReportSpanishFINAL.pdf.

[44] Organismo Coordinador (OC), Operación en Isla del SENI, 2020. https://www.oc.org.do/DesktopModules/Bring2mind/DMX/API/Entries/Download?Command

=Core_Download&EntryId=159365&language=es-ES&PortalId=0&TabId=188.

[45] Empresa de Transmisión Eléctrica Dominicana (ETED), Plan de Expansión: Sistema de Transmisión Eléctrico 2021-2035, Santo Domingo, 2020. https://eted.gov.do/transparencia/index.php/publicaciones-oficiales/file/38193-plan-de-expansin-2021-2035-eted1.

[46] IRENA, Renewable Energy Prospects: Dominican Republic, REmap 2030. (2016). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_REmap_Dominican_Republic_report_2016.pdf (accessed October 3, 2023).

[47] Ministerio de Economía Planificación y Desarrollo, Plan Nacional Plurianual del Sector Público (2021-2024), 2021. https://mepyd.gob.do/publicaciones/plan-nacional-plurianual-del-sector-publico-2021-2024/.

[48] N.N. Taleb, The Black Swan: The Impact of the Highly Improbable, Psychol. Rec. (2007). https://doi.org/10.1007/BF03395631.

[49] Post Carbon Institute, Think Resilience, 2022.

[50] Siemens Industry, Resilient by Design: Enhanced Reliability and Resiliency for Puerto Rico's Electric Grid Executive Summary, Siemens Ind. Inc. (2018) 26.

[51] Comisión de Energía de Puerto Rico (CEPR), Regulation on Microgrid Development (Proposed Rules), n.d. https://energia.pr.gov/wp-content/uploads/sites/7/2018/05/Resolution-Adoptation-of-Microgrid-Regulation.pdfhttps://energia.pr.gov/wp-content/uploads/sites/7/2018/05/Resolution-Adoptation-of-Microgrid-Regulation.pdf.

[52] Civil Society Institute, The Renewable Energy Economic Benefits of Microgrids, (2021).

[53] R.E. De Jesús, R. Batista Jorge, A. Espinal Serrata, J. Eladio Bueno, J. José Pichardo, N. Francisco Guerrero, Modeling and Simulation of Distribution Networks with High Renewable Penetration in Open-Source Software: QGIS and OpenDSS, (2023). https://ssrn.com/abstract=4523911.

[54] USAID, ENERGY SECTOR REFORM PROJECT, Santo Domingo, 2022. https://pdf.usaid.gov/pdf_docs/PA00ZM3B.pdf.