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Methodological Proposal: First Steps for the Implementation of Demand Management Programs in Colombia

Propuesta metodológica: primeros pasos para la implementación de programas de gestión de la demanda en Colombia

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Abstract

The electrification of isolated or rural areas brings with it technical, economic, and social challenges that differentiate the operation of these networks compared to the traditional operation of large electrical power systems, such as the dependence of air or river transport on fuel for the supply of generation plants, the absence of individual measurement and the obsolete infrastructure of the distribution networks. Therefore, this paper proposes a hybrid methodology for studying a Colombian case, analyzing the development of programs for rational electricity use and energy efficiency in isolated areas. These first steps are related to the diagnosis of the current conditions of the power network, the identification of actors that can influence the regulation of the electricity service in the area, and the proposal of mechanisms that allow promoting the rational and efficient use of the electricity.

Keywords: demand-side management; energy efficiency; isolated grids; local energy potentials; non-interconnected zones; rural electrification; sustainability; sustainable energy.

Resumen

La electrificación de áreas aisladas o rurales conlleva desafíos técnicos, económicos y sociales que diferencian la operación de estas redes en comparación con la operación tradicional de los grandes sistemas eléctricos de energía, como la dependencia del transporte aéreo o fluvial de combustible para el suministro de las plantas generadoras, la falta de medición individual y la infraestructura obsoleta de las redes de distribución. Por lo tanto, este artículo propone una metodología híbrida para el estudio de un caso colombiano analizando el desarrollo de programas para el uso racional de la electricidad y la eficiencia energética en áreas aisladas. Estos primeros pasos están relacionados con el diagnóstico de las condiciones actuales de la red eléctrica, la identificación de los actores que pueden influir en la regulación del servicio eléctrico en el área y la propuesta de mecanismos que permitan promover el uso racional y eficiente de la electricidad.

Palabras clave: generación distribuida; generación variable; análisis técnico-económico; capacidad de alojamiento; simulación técnica.

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1. Introduction

Currently, one of the greatest challenges in the world energy sector is the combination and massification of the benefits that can be abstracted from renewable generation, with a coordinated operation of all the resources immersed in the network, to have a continuous supply to all connected users [1]. This leads to active demand participation being considered as a new resource with potential benefits in the operation of the system [2], [3].

This inclusion of distributed generation resources in electrical systems and the use of demand response leads to modifications in the operation of the distribution networks, moving from a passive network with unidirectional power flows and communications to an active network (with bidirectional flows) that recognizes the importance of having real-time monitoring [1], [4], to involve all the agents related to the electricity supply chain in the operation of the system [5].

The foregoing, in addition to the potential ability of users to generate changes in consumption profiles, situates demand as a new resource with the ability to participate in the improvement of the operational conditions of the electrical power system. Therefore, demand-side management has become a complementary resource to generation, and its activities are divided into energy efficiency and demand response [6], [7], [8], [9]. Energy efficiency, due to its static nature, is not a dispatchable or controllable resource and, therefore, cannot be used to solve real-time problems that arise in the electrical system, such as the intermittency of renewable energy generation or network congestion. However, having greater efficiency on the demand side influences the release of installed capacity in the long term [6], [8].

On the other hand, the demand response is characterized by its flexibility and its ability to make changes to consumption profiles [10], [11], [12], [13] allowing the leverage of economic opportunities [10], [12], [13], [14], [15], and increasing the reliability [11], [14], [16] and the sustainability of the system [14], [16], [17]. Here, it is necessary to emphasize that demand response is the reflection of the action taken by a consumer because of financial encouragement. However, the real value of the demand response is the aggregation of impacts throughout the entire electricity supply system, providing flexibility to the network [13], [18], [19]. This flexibility allows changes in the demand curve through curtailments or load shifts, which lead to the impact of the long-term demand response being even greater [20]. This suggests that to reduce the price of electricity in the long term and to have a sustainable operation of a distribution network, it is necessary to start-up demand response programs as these are the ones that would allow to react to the real-time state of the distribution system and to make better use of the energy potentials of each region [21], [22].

However, one of the main challenges in implementing demand response in rural or isolated areas lies in the fact that it is essential to have an individual measure of the energy consumed by each of the users connected to the system [23], [24], since a rate design that encourages the use of demand response programs should make the decisions that the client makes to minimize their bill to be consistent with the actions that would be taken to minimize the system operating costs [25], [26]. Therefore, in case studies such as the electrical systems of Colombian Non-Interconnected Zones (ZNI by its Spanish initials), it is unfeasible to adopt demand response programs in the nearest future, since electricity charges from connected users, in most of these areas, are carried out considering a fixed rate for all residential and commercial users [27]. This fact lies largely in the opposition of the communities to the installation of individual metering that allows the electricity collection to be carried out equitably, in the sense that those responsible for the costs must bear their proportional burden of costs in the system.

Therefore, one of the first steps toward adopting demand response programs should consider the individual implementation of intelligent measurement technologies in the system. However, this can only be achieved if the community understands the importance of installing these devices and the benefits they provide [25], [28], [29]. It is here where the implementation of energy efficiency programs is strategic for the transition towards the use of tariff schemes with the potential to provide benefits for both the end-user and the electricity supply system [21], [26]. At the same time, these programs would make the population aware of the importance of the rational and efficient use of energy, the carbon footprint generated by the uncontrolled use of electricity, and the environmental impact that this use can bring to the region's ecosystems.

In this sense, energy management systems focused on achieving energy efficiency are one of the most important tools for addressing the global increase in demand for electricity [30], [31]. The experience developed by countries that have advanced in structuring energy efficiency programs has shown that it contributes to improving energy security, increasing the competitiveness of the economy, generating employment, increasing the reliability of energy systems, reducing vulnerability to rise and instability of energy prices and contribute to the protection of the environment.

Success in the formulation, implementation, and monitoring of programs for the rational use of electrical energy and energy efficiency, begins with an approach to the populations to understand their vital dynamics, an analysis of the territory and the context in which they live, the collection and study of data from the measurement from generation to final use of electricity and its impact on associated ecosystems [32], [33].

Considering the above mentioned, this paper presents the implemented hybrid methodology and the results of the first actions taken in the municipality of Mitú for the development of programs for the rational use of electricity and energy efficiency. These first steps are related to the diagnosis of the current conditions of the electrical network, the identification of actors that can influence the regulation of the electricity service in the area, and the proposal of mechanisms that allow promoting the rational and efficient use of the electricity in Mitú.

2. Colombian Non-Interconnected Zones a natural laboratory for the development of demand management programs

Electricity systems in Colombia are divided into two main categories: a central interconnected system and isolated microgrids. The first, which works mainly with a centralized generation and has a liberalized market since 1995, is known as the National Interconnected System - NIS, and although it supplies energy to 80% of the country's electricity demand, it only covers 48% of the national territory. The energy supply to 52% of the remaining territory is carried out by employing isolated microgrids, which are characterized by operating with distributed generation resources and having a predominantly residential demand [34], [35], [36].

The isolated microgrids in Colombia are grouped under the name of Non-Interconnected Zones - NIZ and are characterized by supplying electricity to populations located far from the large consumption centers and which are difficult to access by road [36], [37]. These areas provide electricity service to 1.769 localities located, partially, in tropical forests, deserts, mountains, and snow-capped mountains, i.e., most of the environmentally protected areas and 26 national parks are in the departments that are part of the NIZ [37], [38].

Among the 1.769 localities that belong to the NIZ, 37 are municipal seats that group a total of 201.525 users [38]. In this sense, it is possible to affirm that the electrification of these remote areas is a challenge for the companies that provide the electricity service, because of the remote location, the difficult access by road, and the unfeasible expansion from the transmission networks to many of these areas due to possible environmental impact [39]. The last makes the supply of energy to be dependent on the use of the primary resources existing in those territories, or on the use of fuel-based generation sets. Most of the localities that belong to the NIZ use diesel as their primary energy source, and only 15 localities are operating with projects that integrate renewable energy together with diesel production units to supply electricity to small communities [40], [41].

The use of fossil fuels such as diesel or ACPM for the supply of energy significantly increases the cost of generation in these territories, which in turn is aggravated by the costs involved in the logistics of transporting this fuel to the isolated areas, since the difficult access by road to these localities means that fluvial or aerial means must be used for its transport [37]. Furthermore, the use of diesel generators as the main means of energy production in these isolated microgrids increases the rate of carbon dioxide (CO2) emissions, which is the main contributor to the atmospheric concentration of greenhouse gases [42], [43].

Also, the communities belonging to the NIZ are characterized by being localities with low population density, with low payment capacity and low collection level, and an index of Unsatisfied Basic Needs - UBN greater than 70%. At the same time, in terms of energy supply, they are characterized by being areas with a low level of average consumption, high service provision costs, low level of micro-metering, and high dependence on fossil fuels [44]. Difficulties in transporting primary energy resources, together with the limited generation alternatives on-site, mean that the supply of energy in the NIZ is scarce, deficient, and of high cost, at the same time as the ability to pay for the resource is low [45].

In this sense, the energy management of these areas presents challenges in terms not only of technical sustainability, but also in matters related to economic, social, and environmental sustainability. These challenges also vary in their urgency and their implications according to the time scale in which they are analyzed, as shown in Table 1.

Table 1. Problems related to technical, economic, social, and environmental sustainability in the short, medium, and long term on the operation and planning of the supply of electricity in the NIZ in Colombia

Challenge	Time horizon		
	Short term	**Medium term**	**Long term**
Technical Sustainability	Blackouts at peak hours, due to the high concentration of residential, and ignorance of the need to make a rational use of energy.	Increase in electrical losses in the distribution networks due to massive and uncoordinated growth in demand, because of the installation of electrical appliances with reduced efficiency and energy expenses related to the adaptation of living space.	Need to expand the conventional generation capacity from fossil fuels. Need in the expansion of distribution networks.
Economic sustainability	High generation costs, fuel transportation and low profitability of the service provider companies.	Increase in the value of electricity.	Reduction in hours-of-service availability, due to the need to reduce operating costs. Need to increase government subsidies.
Social sustainability	Resistance to measurement and control projects.	Aversion to supply failures that affect the quality of life.	Increase in the social gap and reduction in social equity due to a supply of electricity with reduced quality and high volatility.
Environmental sustainability	Intervention to ecosystems with the massive burning of fossil fuels.	Changes in ambient temperature, increased greenhouse gas emissions due to generation with fossil fuels.	Permanent modifications to ecosystems protected by fuel spills, hydrocarbon-based production, and by construction of new infrastructure.

Source: Own compilation based on [46], [47], [48].

Now, although these electrification challenges may be more marked in isolated areas such as the NIZ, at distribution level, a large part of the technical, economic, and social problems are also generalizable to many of the distribution networks that make up the NIS.

On one hand, the depletion of the transmission network and the high voltage transformation capacity in most of the operating areas of the NIS mean that the supply of distribution networks requires decentralized solutions to improve reliability and continuity of electricity supply to connected users.

An example of this is the Saidi and Saifi indices published by the Superintendence of Home Public Services for the year 2018, in which it is indicated that the Caribbean region (belonging to the NIS) is above the national level of frequency and duration of interruptions of the electric power service [49]. The highest Saifi indexes, which measure the number of annual power service interruptions, for the Caribbean region are Magdalena and Córdoba with 88,42 and 80,60 interruptions respectively, followed by Sucre with 69,08 interruptions, La Guajira with 62,84, Atlantic with 60,18; Cesar with 57,09 and Bolívar with 57,06; being the national average of 37 interruptions [50]. At the same time, of the 10 municipalities with the lowest quality indicators in the electric power service in Colombia, eight (8) are in the departments of Bolívar and Magdalena.

On the other hand, from the social point of view, the Index of Unsatisfied Basic Needs in some municipalities belonging to the Caribbean area and the AntioquiaChocó Area of the NIS reach values up to 70% and 80%, as is the case of some municipalities located in departments belonging to the Caribbean operational area: Uribia - Guajira (88,26%), Clemencia - Bolivar (84,79%), Tuchín - Córdoba (77,51%), Canalete - Córdoba (75,37%), Puerto Escondido - Córdoba (73,72%), Among others [51]. These values are comparable and sometimes higher than the indices found in the NIZ. At the same time, some zones of these same NIS operating areas have been characterized by the opposition of the communities to the installation of individual measurement that allows knowing the real value of electricity consumption.

All this suggests that although the electrification of the NIZ presents marked technical, social, and cultural challenges, these are not exclusive to isolated areas. Thus, it is possible to consider NIZ like a natural laboratory where it would be feasible to analyze the effects of the integration of demand-side programs, the inclusion of distributed energy resources, and the requirements for the operation by local production units. This would provide valuable information for future implementations of demand management programs, both in the NIZ and in the NIS, and in turn, it would allow vulnerable communities to have sustainable access to electricity [35].

Therefore, the following sections will present the first steps taken towards the implementation of demand management programs in a specific case of the Colombian NIZ, where the problems previously exposed are highly visible. This to understand the dynamics of sustainable electrification in isolated areas and seeking to extract valuable information for the successful implementation of demand management programs in other vulnerable communities.

3. Case of study

Mitú is one of the 5 departmental capitals that belong to the Colombian Non-Interconnected Zones - ZNI (by its Spanish initials), being the capital of the department of Vaupés. This municipality is part of the Amazon region, it is located on the banks of the Vaupés river, and borders the Carurú municipality, with the towns of Papunahua, Pacoa, Yavaraté and is a border territory with Brazil. The department is in a transition zone between the Orinoquía plains and the Amazon rainforest and is part of the Amazon forest reserve [52]. Figure 1 shows the location of the Vaupés department and highlights the municipality of Mitú.

Mitú has a population of 31.861 inhabitants, of which 16,302 are in the municipal capital, and 15.559 in the rural areas of the municipality.

Figure 1. Colombian map, with Vaupés department highlighted, and zoom in Mitú municipality.
Source: Own elaboration.

The geographical conditions of Mitú make it a territory with high environmental wealth and population diversity.

Currently, there are 27 indigenous ethnic groups in the territory, which correspond to 80% of the population of the department; this classifies the municipality as an indigenous reservation. The remaining population is Mestizo, White, Afro-descendant, and Raizal [27], [53]. In Mitú, the index of Unsatisfied Basic Needs - NBI (by its Spanish initials) is 66,74%, while the same index for the entire department of Vaupés is near to 69% [51].

Mitú has a generation power matrix that is managed by GENSA S.A. and is mainly made up of a 6,5 MW diesel plant and a 2 MW small hydro-power unit. Additionally, the Institute for Planning and Promotion of Energy Solutions for Non-Interconnected Areas - IPSE (by its Spanish initials) has been developing projects to provide photovoltaic solutions and benefit users through investment, both of its resources and the resources from the Financial Support Fund for the Energization of NonInterconnected Areas - FAZNI (by its Spanish initials); however, these are individual photovoltaic solutions that allow energy to be taken to communities that are far from the municipal seat, mainly indigenous [54].

The average monthly consumption of electrical energy power in Mitú for the residential users is 314 kWh, while that of commercial users is 427 kWh [27]. Here it is important to highlight that the average consumption of residential users of the Colombian NIZ is up to 150 kWh/month [27], [37]. In this sense, the consumption of residential users in Mitú is about 200% of the average consumption defined by the Energy Mining Planning Unit - UPME (by its Spanish initials) for this type of user [55].

Considering the above, Mitú is one of the municipalities with the highest average consumption of the NIZ, this is due to the high presence of high-consumption equipment such as electric stoves, refrigerators, freezers, and incandescent light bulbs, among others. The use of gas for cooking is minimal, since the logistics of bringing the gas pipes to the area is complex, and on the other hand, the consumption of timber as fuel is limited since the municipality is part of the Amazon forest reserve [52]. For this reason, the use of electric stoves has become widespread, which directly increases the electricity demand.

On the other hand, the electricity supply chain in Mitú is associated with high operating costs, since the transportation of the fuels and lubricants necessary for the operation of the diesel plants must be carried out by air, since due to the location from the municipality, land access from the center of the country is impossible, and the presence of streams in the river, greatly hinders river traffic.

4. Methodology

The success of the deployment of sustainable solutions for the improvement of technical parameters of isolated distribution systems depends largely on the attitude of the customers towards it and on the effectiveness of the activities that support the expansion of these mechanisms; since the adoption of schemes that are not adapted to the technical, economic, social, and environmental characteristics of the context can lead to a reduction of the reliability indexes of the electricity supply, the increase of the non-technical losses and the system operating costs, and to a higher rate of greenhouse gases emissions [21]. This indicates the need to develop social cartographies that allow us to understand, from a holistic point of view, what are the causes of the problems related to the supply of electricity in a defined context, and at the same time, it allows establishing the mechanisms to improve the technical conditions of the system, which adequately adapt to the cultural aspects of the region.

Therefore, the methodological basis used to carry out this research is systems thinking, which has been used since the middle of the 20th century as an interdisciplinary methodology that allows going beyond scientific thought, by taking a holistic view of the problem in question [56].

The methodology of systems thinking refers to a set of conceptual and analytical methods in which it is considered that the components of a system act differently when they are isolated from the environment of the system or from other parts that make up the system. This methodology proposes to understand a system by evaluating the links and interactions between the elements that make up the set as a whole, allowing to explore interrelationships of the context, perspectives on the perception of the actors in front of a single situation, and borders to limit the scope of the proposed solutions [56], [57], [58].

This methodology is particularly useful for dealing with complex or wicked problem situations, in which problems cannot be solved by a single actor, nor can a complex system be fully understood from a single perspective [58].

Therefore, it can be understood as a rigorous way of helping to think, visualize, share and communicate the evolution of complex organizations and systems in a time horizon, to solve problems and develop robust designs that minimize the possibility of occurrence of unintended consequences, by creating roadmaps and simulation models that externalize mental models and capture the interrelationships of physical and behavioral processes, boundaries, policies, information feedback, and process delays [57].

Accordingly, to know the perception of the Mitú population about the origin of the energy problems in the municipality, a hybrid method was used that consisted of the identification of problems related to the electric power service by the community and the analysis of data from entities involved in any of the activities of electricity supply, seeking to build a map of actors to identify the level and interest of each of them in the solution of the problems, to finally propose the implementation of measures to promote the rational and efficient use of electricity in Mitú.

Therefore, as shown in Figure 2, this research is carried out using three different methods and strategies that allow evaluating each component (technical, economic, social, and environmental) of the problem to be solved, which refers to the high electricity consumption in the municipality of Mitú. The following subsections explain each of the methods addressed.

4.1. Data Driven Decisions - DDD

Decision making requires the most satisfactory solution to a decision problem to be found in a process of identifying and evaluating alternatives, and subsequently selecting the best option [59]. In this sense, the datadriven decision process is a method based on making organizational decisions depend on actual data rather than intuition or observation alone [60].

In this research, the small data was complemented with open data to perform statistical analyzes that would allow identifying the sources of the problems, the related actors, and the possible behaviors that would occur in the implementation of the proposed scenarios. Table 2 describes the phases of the research that considered the Data-Driven Decisions method.

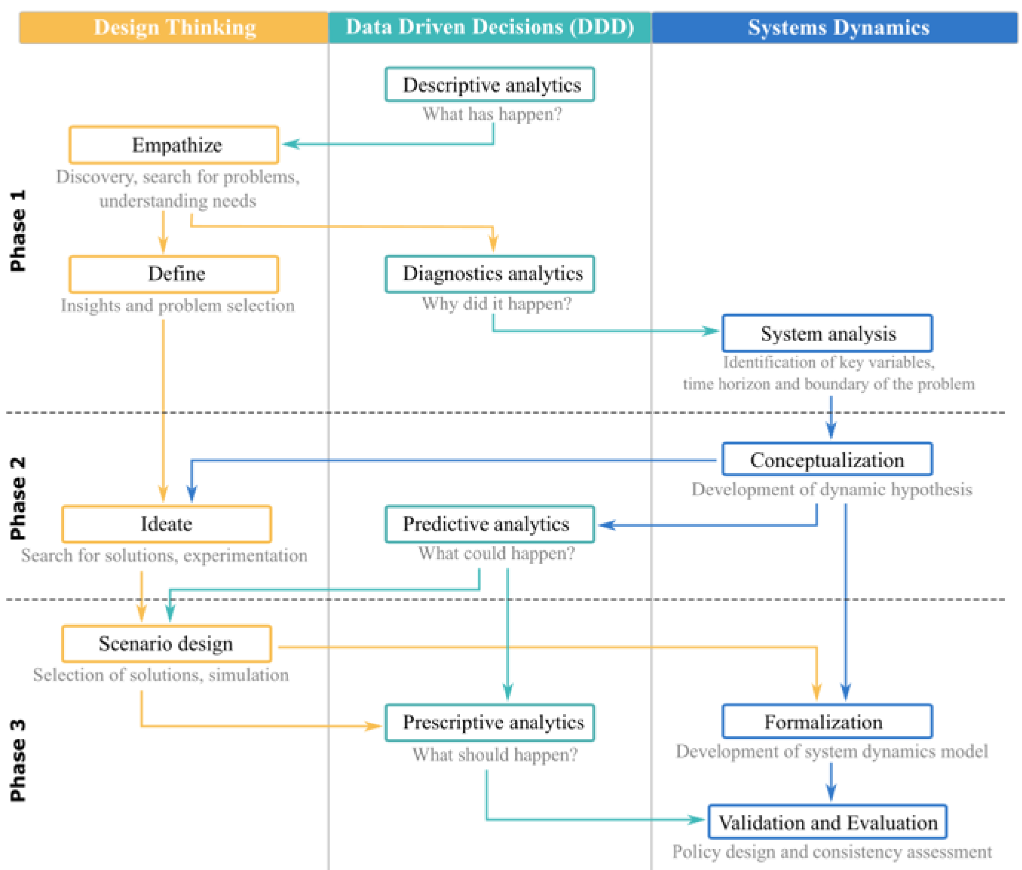

Figure 2. Methodology followed in the development of the research. Source: Own compilation.

Table 2. Phases of the project framed in data-driven decision method

Phases	Supplies/Tools	Activities developed
Descriptive analytics	Open data: data published on the websites of companies in the electricity sector (UPME, IPSE, SUI, DANE), previous degree projects.	Technological surveillance that made it possible to identify high consumption in the residential and commercial sectors of the municipality, inconsistencies between the available hours (on the generation side) and supplied hours (on the load side), and possible origin of electricity losses.
Diagnostics analytics	Information collected in the first phase of design thinking regarding - the main actors involved in the electricity supply of Mitú, and previous diagnosis resulting from the technological surveillance.	Interviews were conducted with focused groups in the community to identify the real sources of electrical losses and the reasons behind the high consumption of electricity.
Predictive analytics	Small data from the interviews that were performed with the focused groups, participatory mapping, and causal relationships between the different actors and components of the problem. Compilation of related historical data.	• Characterization of the demand with a load census and with data collected from the design thinking method workshops. • Focused workshops were held with the community to identify the main sources of electricity consumption, which led to an oversight that made it possible to identify the tripling of electricity demand from 1999, the year in which the Colombian army settled in the region after the guerrilla takeover carried out that year. • Identification of percentage of population growth due to the settlement of Venezuelan migrants and Colombian migrants from other regions.
Prescriptive analytics	Information obtained from predictive analysis; scenario design carried out in the last phase of design thinking.	• Identification of desirable scenarios linked to community awareness. • Characterization of energy management programs, modernization of the electrical infrastructure, and sustainable electrification projects, as a possible solution to the identified problems.

Source: Own compilation.

4.2. Design thinking

Design thinking is a method for generating innovative ideas that focus its effectiveness on understanding and solving the real needs of users [61]. It is a method focused on the user, on the problems that may arise, and on empathy. These two (2) concepts are closely related; it is essential to previously make a composition of the place, an analysis of the situation, be aware of where you are and what you need.

Design thinking is a method that considers five (5) differential characteristics compared to the other methods: the generation of empathy, teamwork, the prototype elaboration, playful pedagogies, great visual content.

In this research, this method was used to achieve a better approach to the community, seeking to understand the origin of energy problems, and want to identify the main actors that support or oppose the implementation of energy sustainability systems in the long term. Table 3 exposes the phases considered in this component of the project.

4.3. Systems dynamics

System dynamics is a method that allows an approach to understanding complex non-linear problems [62].

Table 3. Phases of the project framed in design thinking method

Phases	Supplies/Tools	Activities developed
Empathize	Results of the technological surveillance carried out in the descriptive-analytical stage of the DDD method. Establishment of relationships with the main governmental entities of the municipality.	• Presentation of the scope of the project before the state assembly, the municipal council, the legal authority, the mayor's office, and the departmental government to provide feedback on the information acquired in the first phase of the DDD. • Approach to representative groups of residential users and the tertiary sector to understand the needs of the users involved in the solution we are developing and their environment. • Compilation of information on the antagonistic actors and population in favor of the development of demand management programs.
Define	Brainstorming, Surveys, Cocreations with customers, Interviews, Workshops, Customer Journey, and information collected in the stage of generating empathy - with the community.	• Analysis of the information collected from comments in the empathy phase and selection of what adds value and leads us to reach new perspectives. • The main energy problems afflicting the community are filtered and identified. • Realization of a map of actors related to the implementation of demand management programs.
Ideate	Surveys, Co-creation with - customers, Interviews, Workshops, Observations, work with focused groups, - participatory mapping and information acquired from the analysis of causal relationships.	• Holding of practical workshops on safety issues in the use of electricity and raising awareness of the rational and efficient use of energy. • Creation of participatory maps planned around the rational and efficient use of the electricity, with the participation of representative groups of the affected community.
Scenario design	Characterization and information obtained from the predictive analytics stage of the DDD method, and social mapping carried out in the ideation stage.	• Establishment of strategies to reduce intensive electricity consumption and curtailment of load peaks that are not necessary for the development of production processes and comfort of residential users. • Development of education and awareness days on the rational and efficient use of energy. • Identification of government mechanisms that could leverage the development of energy efficiency programs in the area.

Source: Own compilation.

It is a necessary method to solve problems that change in the time horizon and in which the causal relationships determine the future of the system [62], [63].

Since the sixties, this method has been recognized as the means to model and understand the behavior of complex systems, their evolution over time, and their visualization from different perspectives [64].

Table 4 shows the methodological stages of the research framed in the systems dynamic’s method.

5. Results

The results obtained from the implementation of the methodology described above in the stated case study allowed us to obtain the following results, which are broken down by the previously described phasest.

Table 4. Phases of the project framed in systems dynamics method

Phases	Supplies/Tools	Activities developed
System analysis	Problems that plague the community identified in the first two stages of the design thinking method. Interviews developed in the diagnostic analysis stage of the DDD method.	• Identification of variables involved in the identified problem, time horizon, and scope of the problem. • State of the art review, taking as support the articles found in indexed databases, of international experiences adaptable to the Colombian context.
Conceptualization	Results of the identification of the problem, and the search for international solutions applicable to the context.	Development of the dynamic hypothesis, detailing the existing relationships between the technical and social dimensions involved in the provision of the electric power service in the municipality.
Formalization	Results of predictive analytics, search for solutions and scenario design (previous stages of the DDD and design thinking method).	• Development of a high-level map (system diagram) that shows the main variables and problems involved in the target system. • Simulation of the stability of the model in a defined time horizon by identifying steady state conditions.
Validation and Evaluation	Expected behaviors identified in the prescriptive analytics stage. Scenarios posed in the last phase of the design thinking method.	• Evaluation of the scenarios proposed in the previous methodological stages, which allows addressing the identified problem in different conditions of the context. To do this, key drivers of change, uncertainties, and factors that could have a significant impact on the objective contexts. • Analysis of extreme, optimistic, and pessimistic scenarios, to evaluate the coherence of the model within its external limits.

Source: Own compilation.

5.1. Phase 1: Data Driven Decisions – DDD with Design Thinking: Building the past and the present from understanding needs

The statistical analyzes carried out, based on the information provided by the electricity service provider company, the fieldwork developed, and the technical simulations implemented, show that the percentage of total electrical losses in the municipality of Mitú is higher than 40%, which are composed of the following partial forecasts:

- 10% in the generation of electrical energy in the diesel plant
- 1% in the medium-voltage network
- 20% in transformers and the low-voltage network
- 10% in the electrical installations of the endusers

Also, based on load censuses and interviews carried out with more than 500 users, the hourly utilization factor of the most used appliances in Mitú is determined. This made it possible to demonstrate the massive use of electricity to cook food and air conditioners during the day. In this sense, it is identified that electric stoves are high consumption burners, while the air conditioners and lighting used in Mitú are of low energy efficiency.

The characterization of electrical energy consumption in the area allowed obtaining the curves shown in Figures 3 and 4 as characteristic demand curves for the region. Also, the design thinking phase made it possible to develop a social mapping of the population, identifying the degree of interest of the inhabitants in the implementation of energy efficiency programs in the region.

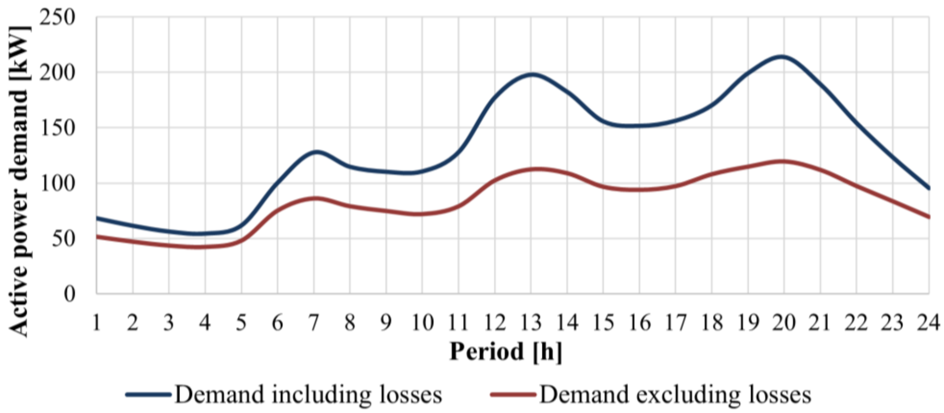

Figure 3. Typical daily demand curve for the municipality of Mitú including losses (blue line) and excluding losses (red line). Source: Own compilation.

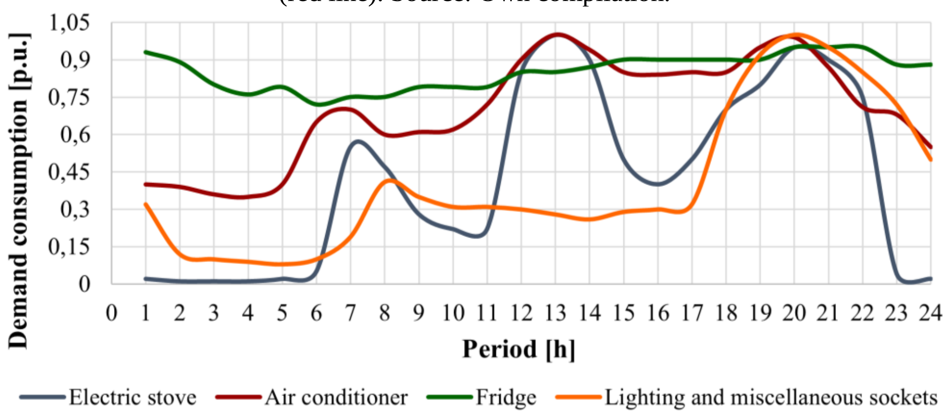

Figure 4. Daily consumption, in per unit, for different intensive use electrical appliances in the municipality of Mitú. Source: Own compilation.

Therefore, in this phase, a stakeholder map was elaborated, which allows identifying the degree of interest vs. the influence or power that the actors have concerning to promote the rational and efficient use of electrical energy in the municipality. For the elaboration of this stakeholder map, meetings were held with each actor to explain the results of the technical analysis obtained on losses and high electricity consumption.

These interviews made it possible to validate the data analysis and determine the entities with the most influence in the area, which in turn expressed interest in supporting any class of initiative related to the rational and efficient use of electricity.

The graphic representation of this stakeholders' map was carried out by assigning to each agent analyzed, a score from one (1) to one hundred (100) in interest in participating in initiatives that promote the rational and efficient use of energy and assigning another score (on the same scale) that reflects the influence or power of the agent in that area. Table 5 shows the scores obtained by each entity.

After assigning the scores to each stakeholder, it is possible to make a graphical representation of the interest versus the influence or power of each agent in the area, to classify each agent into promoters, antagonists, and multiple intermediate categories, regarding the implementation of mechanisms for the rational and efficient use of energy in the municipality. The graphical representation obtained can be seen in Figure 5.

5.2. Phase 2: Solution proposal - Investment in replacement of low - efficiency appliances and training for the population around the rationality in the use of electricity

After the construction of the stakeholders' map, we proceeded to evaluate the relevance of implementing the two proposals put forward by the same community, which were: Develop training activities on rational and efficient use of electrical power, and the replacement of high-consumption appliances with efficient ones.

Table 5. Scores awarded to the most representative agents of the community

Entity	Interest	Influence	Description
DANE	85	30	Entity responsible for the planning, collection, processing, analysis and dissemination of official statistics of Colombia.
Military forces	20	70	It is made up of 1,500 soldiers and they are located in the largest construction of the municipality.
Departmental government	95	100	Entity in charge of the operation of the distribution networks and the collection for the electricity service.
Municipal government	85	95	Entity in charge of planning the expansion of electric power generation.
Environmental agents	60	25	The Amazonian Scientific Research Institute SINCHI is a non-profit research institute of the Government of Colombia charged with carrying out scientific investigations on matters relating to the Amazon Rainforest, the Amazon River and the Amazon Region of Colombia for its better understanding and protection.
DPS	8	10	Administrative Department for Social Prosperity (DPS) is the Colombian Government Entity that heads the Social Inclusion and Reconciliation Sector.
Merchants	50	60	People dedicated to the retail sale of appliances, fast food and clothing.
Community	15	50	Residential Users.
Indigenous authorities	55	70	19 indigenous leaders representing each of the indigenous ethnic groups
SENA	75	70	Public entity of the national order that offers free training in technical, technological, and complementary programs that focus on the economic, technological, and social development of the country.
SPD oversight	90	90	Entity that supervises the provision of public services and is made up of community representatives.
ASOLECTIVA	50	33	Association of Electrical Technicians.
Ombudsman	20	20	Public entity in charge of promoting actions related to guaranteeing human rights in the territories.
University	85	50	The National University of Colombia is a public and national research university in Colombia.

Source: Own compilation.

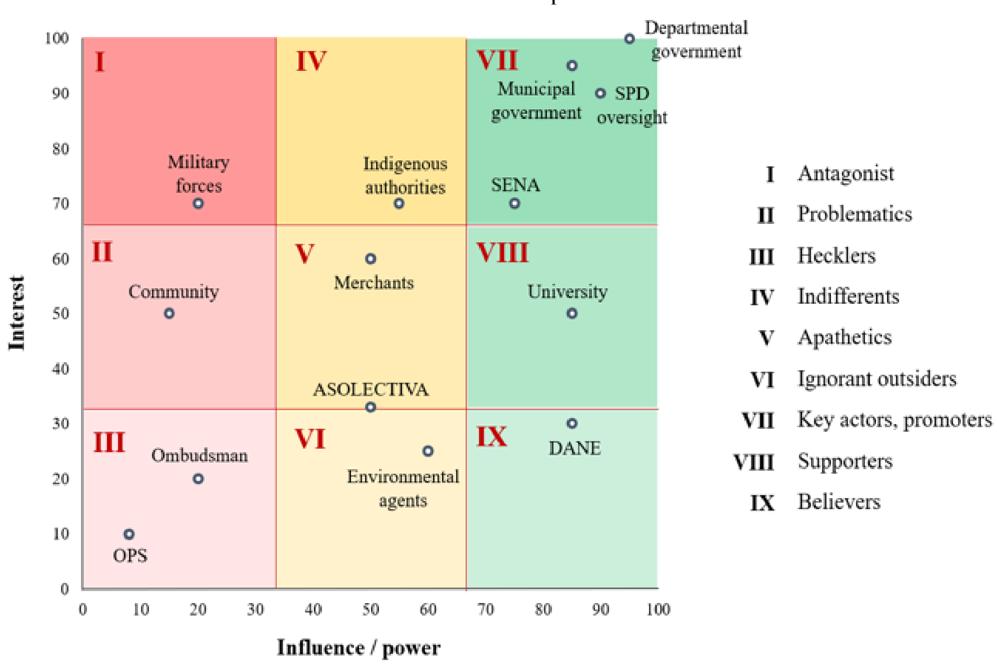

Figure 5. Stakeholder map representation. Source: Own compilation.

To achieve this, a causal diagram was elaborated to reflect the region's problems and the behavior of the proposed solution. This causal diagram, which can be seen in Figure 6, is composed of four cycles: technical, economic, social, and proposed solution that integrates the three dimensions identified above.

The technical cycle represents the current operation of the electrical provision of the area and shows the exponential growth of electricity consumption. This growth is due to the lack of entities that control the number of electrical connections to the grid, the state of the facilities, and the lack of planning for the growth of electricity demand in the short, medium, and long term. The lack of electricity meters, together with the lack of planning, makes it difficult to install and select adequate networks and equipment, so the capacity of the networks may be oversized or on the contrary be insufficient, so it is common to find overloaded circuits that present frequent disconnections, which encourages people to have multiple connections in their homes so that, in the event of disconnection, they have power from other circuits, which aggravates network congestion.

The economic cycle shows how as the energy demand increases, the consumption of diesel fuel and the energy cost increase proportionally. This relationship generates the need to increase subsidies to cover operating costs. Accordingly, the need to create strategies to reduce demand and GHG emissions and decrease consumption and dependence on diesel fuel is evident.

Then, to analyze the behavior of the model under various temporary percentage increases in investment in the monthly capital granted by the government to this area for subsidies, for the replacement of units and training of the population, a diagram of stocks and flows was drawn up, which made it possible to identify the dynamics of implementation of removable subsidies that would reduce the demand for electricity in the area in the long time horizon.

This analysis also made it possible to identify that the residential sector has the potential to reach levels of demand reduction (in the long term) of almost four (4) times the maximum possible reduction in the commercial sector.

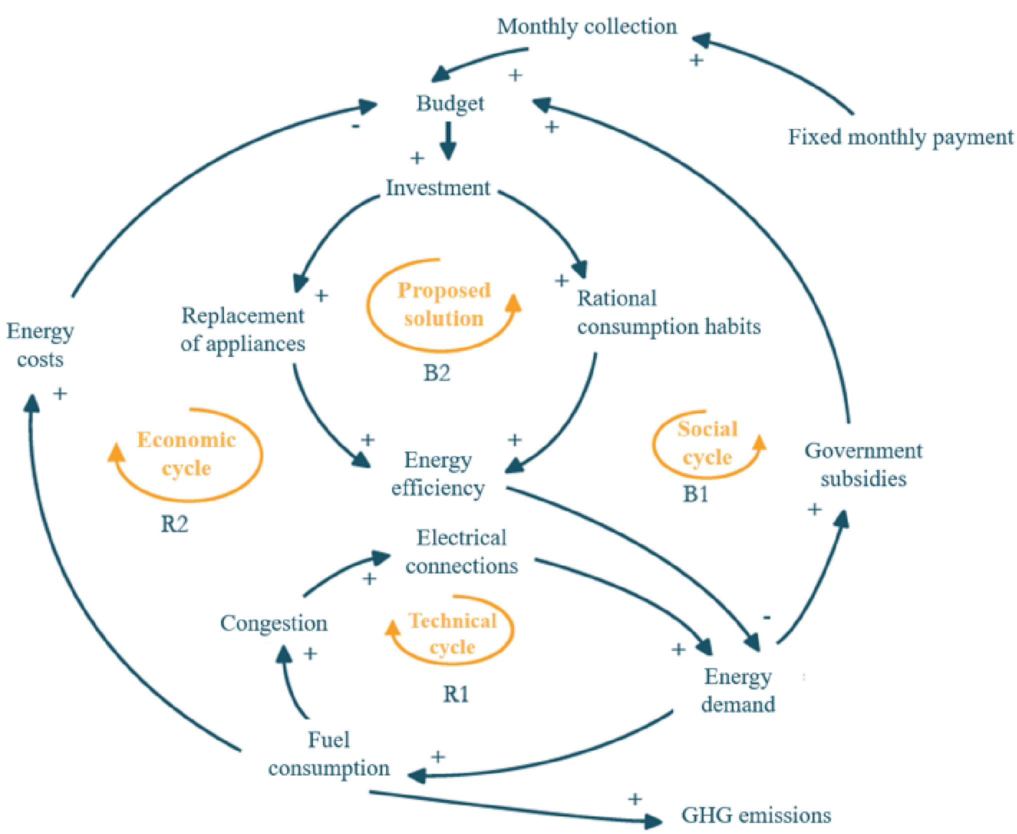

Figure 6. Causal diagram that proposes to replace electrical appliances and to generate permanent training sessions on rational and efficient use of electrical energy in Mitú. Source: Adapted from [27].

Even though the residential sector is identified as the focus of the implementation of energy efficiency programs, it is important not to rule out the other sectors, given that although they are only 11,75% of the population, they represent approximately 25% of electricity consumption.

5.3. Phase 3: Projected response of the model based on the behavior of demand and budget

The model presented above is formed by two modules, which are the most relevant for the proposed objective: demand and budget. Energy demand represents the energy consumption of the analyzed population. It is composed of residential, commercial, and official users. This energy demand is directly affected by the consumption behavior of the population and the state of the electrical appliances and electrical networks. The amount of diesel fuel used to meet this demand depends on this consumption. It is important to highlight that fuel generates a significant impact on energy costs since it is precisely this component that influences generation costs [65]; Furthermore, reducing fuel consumption has a direct impact on GHG emissions, since almost all energy in the NIZ is generated by diesel plants and these are highly polluting sources.

The budget variable represents the economic flow of the power system operation in those isolated areas. Budget income sources are the fixed monthly collection contributed by the end users and the subsidies granted by the Ministry of Mines and Energy – MME to the NIZ [64] that can be used both for investment in the area, such as to cover the costs of the required fuel [65].

The interrelation between the variables, with the rest of the main components of the system, is shown in Figure 6. This is done through a causal diagram of the proposed model, which is formed by four cycles, two of balance (B1 and B2) and two of reinforcement (R1 and R2). Boost or positive loops cause exponential growth behavior, while balance cycles, as the name implies, cause the model to stabilize at the equilibrium point.

The technical cycle R1 reflects the current operation of the area and exhibits an exponential increase in electricity consumption. The reason for the demand increase is attributed to the absence of institutions responsible for managing, controlling, and supervising the local grid, as well as the lack of implementation of energy policies that address or incentivize the reduction of electricity consumption and the implementation of energy management programs in the short, medium, and long term. These activities are typically the responsibility of the regional operator.

In the economic cycle R2, an increase in electricity costs is evident when energy consumption rises, as more fuel will be required to meet peak demand. Consequently, the community must adopt strategies that yield successful results in reducing expenses and energy demand. This approach achieves a less harmful impact on the environment and reduces dependence on fossil fuels. On the contrary, cycles B1 and B2 promote a decrease in energy demand, an increase in efficiency, and economic savings using economic incentives that allow the replacement of old or high-consumption electrical appliances and improve the state of the networks. Also, training sessions on the conscious and rational use of energy are proposed. So, it could be possible to improve operations, reduce the environmental impact, improve service conditions, decrease costs, and make the provision of energy services more profitable and efficient for both generators, distributors, and marketers, as well as for end-users.

Changes in consumption habits are the main social component since significant results can only be obtained if the population is interested in modifying their energy use habits. However, continuous monitoring must be maintained to promote the integration between the population and the educational and official agents.

The complete dynamic and mathematical modeling of the presented model can be consulted in detail in [27].

6. Concluding remarks

This paper presents the hybrid methodology implemented in the municipality of Mitú for the development of programs for rational electricity use and energy efficiency. These initial steps are related to diagnosing the current conditions of the electrical grid, identifying the actors that can influence the regulation of electricity service in the area, and proposing mechanisms that promote rational and efficient use of electricity in Mitú.

The three methods used (DDD, System Dynamics, and Design Thinking) together made it possible to obtain a social mapping of the context, identifying the main sources of problems, the agents that support and those that oppose the implementation of rational and efficient use of energy.

Also, the experience in the region made it possible to verify that a large part of the success of the deployment of programs for the rational and efficient use of energy depends on the attitude of the clients and the effectiveness of the activities that support the expansion of these mechanisms, at the same time, that the adoption of schemes that do not adapt to the technical, economic and social characteristics of the context can lead to uncontrolled consumption that compromises the reliability and continuity of supply.

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Autor Contributions

D. A. González-Sotto: Formal Analysis, Methodology, Resources, Visualization, Writing -Review and Editing. C. Arango-Lemoine: Data Curation, Project Administration, Validation. D. López-García: Conceptualization, Data Curation, Funding Acquisition, Writing Original Draft. A. Arango-Manrique: Conceptualization, Funding Acquisition, Methodology, Resources, Supervision, Writing Original Draft, Writing -Review and Editing.

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Conflicts of Interest

The authors declare no conflict of interest.

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