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Financial Evaluation of a Business Model for the Development of Advanced Measurement Electricity Infrastructure Projects in Colombia

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ABSTRACT

The Colombian government's plan aims to strengthen the electricity sector through the implementation of Advanced Measurement Infrastructure, network automation, distributed resources, and electric vehicles. These initiatives present both technological and economic challenges, given the current conditions in various Colombian municipalities, many of which will struggle to meet them. In response to this need, it is proposed to evaluate a business model to encourage the development of projects that facilitate the modernization of the distribution network, by supporting the network operator as a strategic partner. The distribution network of the municipality of San José de Guaviare in Colombia is used as a case study. The results indicate that this approach is attractive for the public service provider and demonstrate that continuous improvement in service quality indicators can be achieved without significantly impacting the local population's economy.

Keywords: Energetic Policy, Sustainable Development, Advanced Metering Infrastructure
JEL Classifications: Q41, Q48, R58

1. INTRODUCTION

Energy is an essential element for economic and human development (Embid and Martín, 2013; Salahuddin et al., 2018). Providing this service is a priority for any nation that seeks to enhance the well-being and progress of its population (Chen et al., 2019; Kaur and Luthra, 2018). It requires a robust infrastructure that facilitates the integration of new technologies for generation, transmission, and distribution (Andramuo et al., 2021; Moreno Rocha et al., 2022; Muñoz et al., 2024; Puentes, 2020; Quintero-Duran et al., 2017). The electric sector is incorporating renewable energy sources through smart grids (Masache et al., 2015) to enable their harmonious interaction with the traditional electrical system and achieve sustainable implementation (Babadi et al., 2018; Shahid, 2018). This effort necessitates government policies and private sector participation (Hassan et al., 2018; Hvelplund and Djørup, 2017; Mendoza et al., 2020). The Colombian government began its path with Law 1715 (Congreso de Colombia, 2014), which establishes regulations for the promotion, integration, development, and utilization of unconventional renewable energies within the national energy system. The aim is to achieve participation in non-interconnected zones (ZNI), reduce greenhouse gas emissions, generate sustainable economic development, and enhance energy security.

To achieve this interaction, the Ministry of Mines and Energy (MME) issued Resolution 40072, which established the mechanisms for implementing Advanced Measurement Infrastructure (AMI) in the public electricity service. The resolution set goals projecting that by 2030, 95% of urban users and 50% of users in populated centers and rural areas should be included in the implementation of AMI (MME, 2018). It also emphasizes the promotion of efficient energy management, encompassing both energy efficiency and demand response.

The environmental impacts associated with energy development have significant implications, primarily related to the generation of pollutant emissions such as CO_2 (Belaïd and Zrelli, 2019), social issues such as social equity (Grover and Daniels, 2017; Guerrero et al., 2021) and universal access to energy services (Łapniewska, 2019), as well as economic factors related to purchasing power and business opportunities for private investors (Lekavičius et al., 2019). Integrating renewable energy technologies and energy efficiency positively affects environmental impacts (Belaïd and Zrelli, 2019). However, ensuring economic viability and network access for less advantaged users remains the greatest challenge for this transition (Grover and Daniels, 2017; Łapniewska, 2019).

Developing business models that address these gaps is crucial for sustainable development and achieving government objectives (França et al., 2017; Shomali and Pinkse, 2016). To this end, a business model is proposed to provide a solution for network operators to meet the goals set by the national government. The distribution network of San José del Guaviare, a municipality in Colombia, is used as a case study. This model will improve the current loss indicators, enhance service reliability for end users, and integrate Advanced Measurement Infrastructure and Distributed Energy Resources without disrupting the economic models established by network operators.

2. METHODOLOGY

This research is of a propositional nature, as it presents a business model aimed at generating benefits for three stakeholders (Investor - Service Provider - User). The research is conducted in three stages.

The study begins with an overview of regulatory entities and the regulatory and normative framework relevant to Advanced Measurement Infrastructure technology. It then moves to the first phase, which involves characterizing the end users and providing a one-line diagram of the electrical infrastructure installed in San José del Guaviare.

The second stage proposes a technical-operational structure, defining the resources and services needed for connecting generation systems and AMI infrastructure to the grid. This phase also establishes the scope of the business model, the pricing scheme, and the investment recovery strategy.

The third stage presents a financial analysis of the viability and profitability of implementing the business model, based on the defined scope, the selected technological conversion, and the integration of AMI infrastructure. The economic results are presented in local currency (COP) and in USD, utilizing a representative exchange rate (TRM) of 4,000 COP/USD.

3. COLOMBIAN INSTITUTIONAL FRAMEWORK FOR THE ADVANCED METERING INFRASTRUCTURE SECTOR

The Colombian State owns the subsurface and non-renewable natural resources, as well as the preservation and management of renewable natural resources (Presidencia Colombia, 1974). To ensure proper development and utilization, it designates entities responsible for these tasks. Figure 1 illustrates an organizational chart of the entities involved in the Colombian electrical sector.

The Ministry of Mines and Energy (MME) is responsible for managing non-renewable natural resources and ensuring energy security. To achieve this, it delegates various tasks to specific entities: the Mining-Energy Planning Unit (UPME) handles the planning, formulation, and coordination processes for the mining-energy sector; the Energy and Gas Regulatory Commission (CREG) is responsible for formulating technical-legal standards to regulate and standardize methodologies and practices due to technological advancements in the sector; and the Public Services Superintendence (SSPD) oversees the provision of electric power services. Table 1 presents the regulatory background in chronological order for Advanced Measurement Infrastructure (AMI) technology, which has facilitated its integration and expansion plans.

These regulations have enabled the growth of measurement projects, and due to the integration of new technologies and evolving needs, they have been updated to form the basis of the AMI regulatory framework. Figure 2 illustrates this legal framework.

The integration of AMI technology enhances the reliability of electricity service and thus serves as a collective benefit or interest (Téllez Gutiérrez et al., 2018). However, the expansion of smart grids requires monitoring and information on user behavior, which involves personal and sensitive data. Starting with Law 1715, resolutions have been implemented to achieve Colombia's objectives (UPME, 2016). In the context of AMI technology, the goal is to facilitate implementation, ensure reliability and security, achieve efficient loss management, and maximize the number of users.

To achieve efficient implementation, investment is needed across various sectors of the electricity market chain, with

Figure 1: Institutional organization chart of the electrical sector for advanced metering infrastructure technology

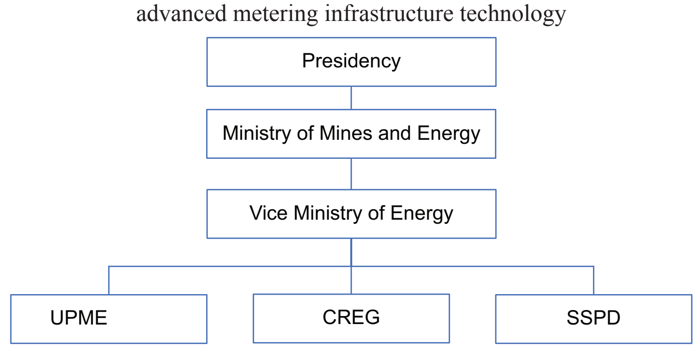
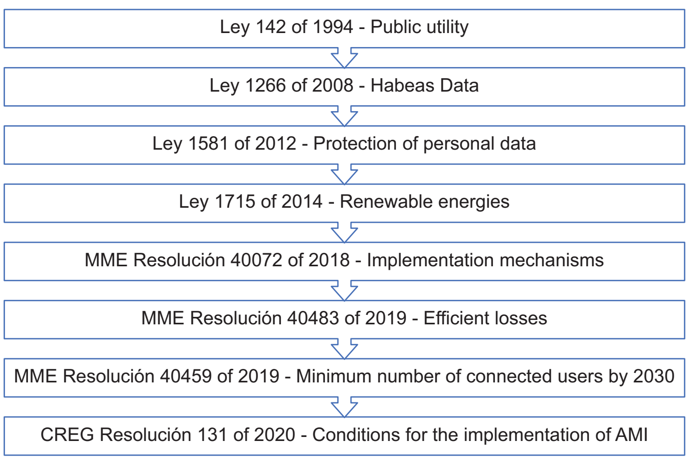


Table 1: Regulatory and regulatory background of smart metering

Regulations	Note
Ley 142 de 1994	Chapter IV. Art. 144-145: Instruments for measuring consumption.
CREG 025 de 1995	Network operation code.
NTC 2288	Requirements. Electromechanical active energy meters
NTC 5226	General requirements, tests and test conditions
NTC 4052	Requirements. Static active energy meters
NTC 4440	Data exchange for meter reading, tariff and load control.
CREG 106	Connection procedures and requirements.
NTC 5019	Selection of components of the electrical energy measurement system.
NTC 4856	Initial and subsequent verification of electric energy meters.
CREG 38 de 2014	Modification of the Measurement Code.
NTC 6079	Requirements for advanced metering infrastructure (AMI) systems in electric power distribution networks.
RETIE	Update for the inclusion of photovoltaic systems.
SIC	Metrological regulations for Electric Energy meters
CREG 077 de 2018	AMI Challenges
Acuerdo 1043 de 2018	Minimum security and integrity conditions for the transmission of readings from the meters to the Measurement Management Center, and between the latter and the ASIC.
NTC 6079	Requirements for advanced metering infrastructure (AMI) systems in electric power distribution networks.

Figure 2: Legal and regulatory framework for advanced metering infrastructure



a focus on distribution networks and residential users. This approach aims to reduce energy losses, lower network administration costs, improve service quality, facilitate self-generation, and optimize investments and network usage (Bahmanyar et al., 2016; Giaconi et al., 2018). This is the primary objective of the research.

4. ELECTRICAL POWER SYSTEM OF SAN JOSÉ DE GUAVIARE

The San José de Guaviare system functions as a radial system. Figure 3 illustrates the single-line diagram of the power system. It comprises a sole power supply via a transmission line at voltage level IV (115kV), predominantly utilizing 15-m concrete poles. These poles traverse extensive savannahs, wetland regions, dense vegetation, and are susceptible to significant climatic factors, including atmospheric discharges and gales. The transmission line extends for 187 km, connecting the Granada substation (Meta) to the San José substation (Guaviare).

The San José substation houses an operational and maneuvering center, equipped with two three-winding power transformers, each possessing a capacity of 12 MVA. These transformers provide electrical power service to four circuits operating at voltage level II, in addition to two circuits operating at voltage level III. The latter circuits feed the *El Retorno* and *Calamar* substations, with plans to extend service to the upcoming *El Capricho* substation. In turn, these substations supply three, four, and two circuits at voltage level II, respectively. The total load availability for distribution amounts to 24 MVA. The specifications of the available substations are as follows:

- *San José del Guaviare* substation features two power transformers with a capacity of 10/12 MVA and a transformation ratio of 115 kV/34.5 kV/13.8 kV. It has two output lines at 34.5 kV, secured by reclosers, which feed into the *El Retorno* and *Calamar* substations; the latter is currently under construction and not yet operational.
- *El Retorno* substation is outfitted with two installed power transformers of 1.6 MVA, possessing a transformation ratio of 34.5 kV/13.8 kV. It includes two 13.8 kV busbars with a coupling cell between the buses, as well as four 13.28 kV circuits, which are protected by indoor-type cells.
- *Calamar* substation comprises two power transformers rated at 2 MVA with a transformation ratio of 34.5 kV/13.8 kV, and it operates four output circuits at 13.8 kV.

5. CHARACTERIZATION OF END USERS

Table 2 shows the number of users, and the amount of electricity consumed in 1 month, according to the categories established by the grid operator.

The results indicate that the three largest energy consumption segments are from the Urban Commercial sector (24%), and the Urban Residential sectors, with Stratum 2 at 23.8% and Stratum 1 at 21%, accounting for a total of 68.8%. In the Rural area, Residential users in Stratum 1 make up 5.4% of the total energy consumption. When considering only the consumption of Residential users, 26.4% belongs to Stratum 1 and 24% to Stratum 2. This implies that there should be subsidies for electricity covering at least 50% of the kWh price for the first 173 kWh each month for these users (Guerrero et al.,

Figure 3: Single line diagram of the municipality of San José de Guaviare

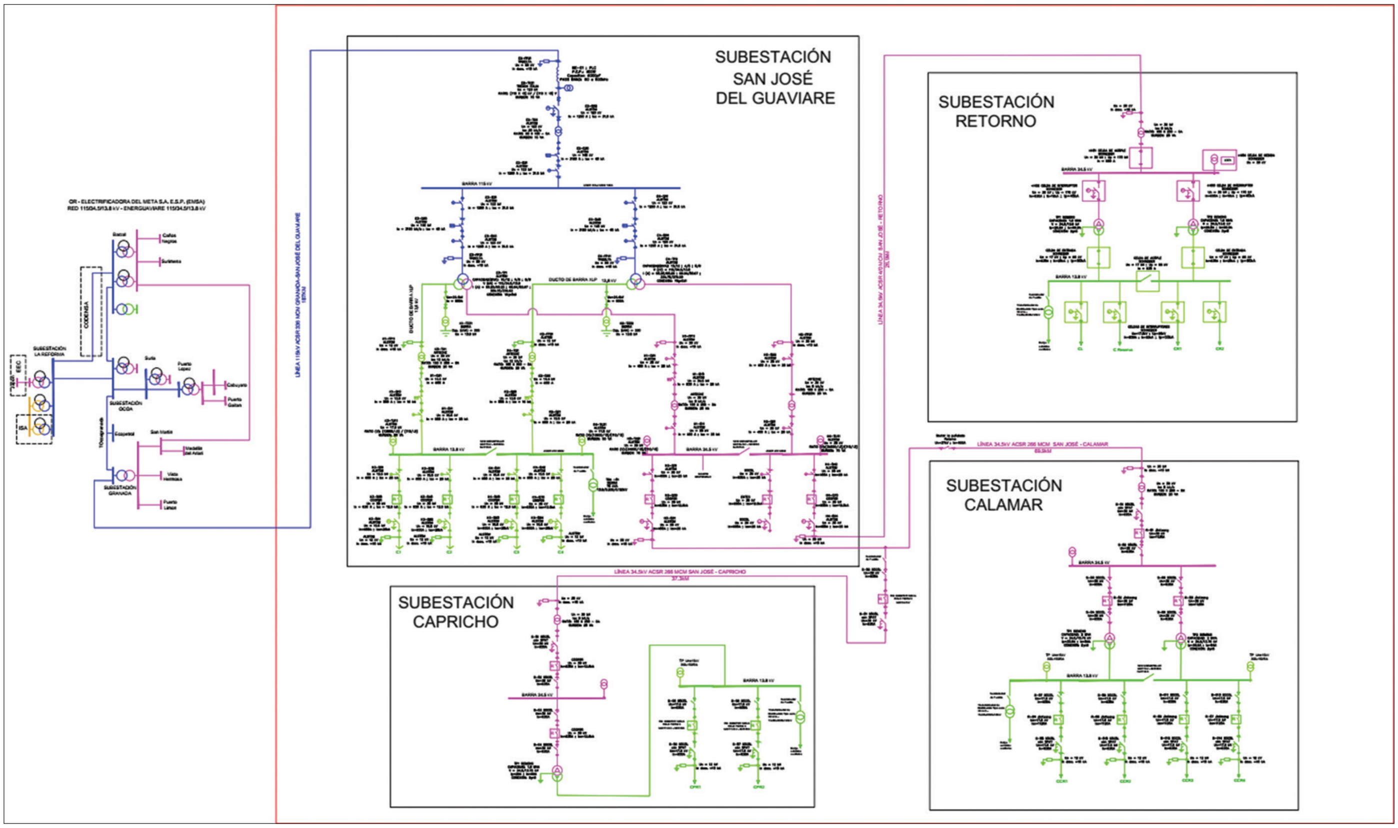


Table 2: Electricity consumption behavior by category

Location	User type	Stratum	Users	kWh	%	kWh	kWh
Rural	Water pumping	2	2	201	0.0	201	204.086
	Tenancy	1	2	3.313	0.1	3.313	
	Residential	1	3.191	174.411	5.4	181.108	
	Residential	2	68	6.697	0.2		
	Residential	3	1	0	0.0		
	Official OF	1	1	0	0.0	2.515	
	Official OF	2	30	2.515	0.1		
	Commercial	1	1	12	0.0	16.949	
	Commercial	2	49	16.937	0.5		
	Industrial Without Contribution	2	1	0	0.0	0	
Urban	Water pumping	2	8	14.005	0.4	14.005	3.020.187
	Tenancy	1	12	29.865	0.9	29.865	
	Residential	1	8.487	675.985	21.0	1.675.289	
	Residential	2	6.031	767.626	23.8		
	Residential	3	1.299	228.106	7.1		
	Residential	4	17	3.572	0.1		
	Official OF	2	300	506.503	15.7	506.503	
	Special	2	15	1.987	0.1	1.987	
	Commercial	1	3	841	0.0	774.349	
	Commercial	2	2.137	773.508	24.0		
	Industrial without contribution	2	12	18.189	0.6	18.189	

Table 3: Number of users and consumption according to the meter

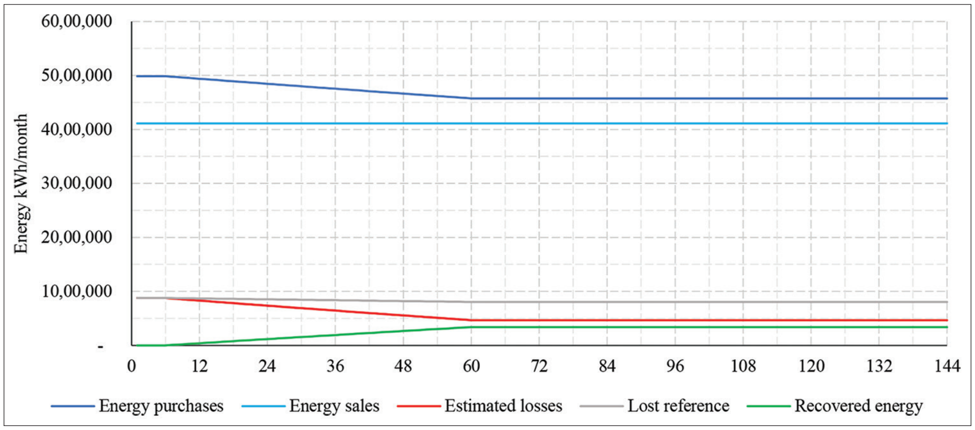
Type	Users	%	kWh	%
Biphase	1.688	7.8	371.630	12
Indirect	5	0.0	185.012	6
Single phase	19.393	89.5	2.286.585	71
Semidirect	22	0.1	1.412	0
Triphase	559	2.6	379.634	12
Total	21.667	100	3.224.273	100

Table 4: Business model performance over 12 years

Year	1 2 3 4 5	6 7 8 9 10 11 12
Activities	Technological Upgrading - user Regularization - Billing per user after 1 month	100% billing due to the regularization of all users.

2021). Additionally, Table 3 shows the number of users by meter type.

Figure 4: Forecast of Energy Balance Behavior in the Network



A total of 89.5% of users use a single-phase meter. The results suggest that the business model should focus on the urban area, particularly targeting residential users, with an emphasis on regularizing their usage. The proposal should consider the objectives of Advanced Metering Infrastructure and the Automation of the Distribution Network to facilitate the integration of Distributed Generation systems.

6. TECHNICAL-OPERATIONAL STRUCTURE FOR TECHNOLOGICAL UPGRADING AND USER REGULARIZATION

The business model proposes investing in the technological upgrading of the network and the regularization of users through a third-party company. This company will act as the financial muscle and serve as the direct contact with various creditors, meaning that the grid operator will not need to make any investment. The project is planned to last for 12 years, with Table 4 outlining the model's performance. The first 5 years will be dedicated to the upgrading and regularization process. One month after a user is regularized, the stipulated charges can be applied, allowing for the start of economic recovery and the repayment of various obligations. By the 6th year, all interventions are expected to be completed, with 100% revenue being achieved, obligations settled, and profits generated.

Table 5 outlines the initial considerations for the users to be addressed (21,780) and the timeframe for project execution (5 years). This indicates that at least 15 users need to be addressed per day. Assuming a productivity rate of 12 users per day and 24 working days per month (excluding Sundays), the expectation is to address 288 users per month. Given the total number of users, this would require approximately 1.3 crews.

The data from the crews enables an estimation of the expenses associated with salaries, machinery, locations, among other factors. According to the single-line diagram presented in Figure 4 and the 21,780 users, Table 6 presents the CAPEX expenditure estimation, while Table 7 presents the OPEX expenditure estimation.

Figure 5: Electricity price forecast

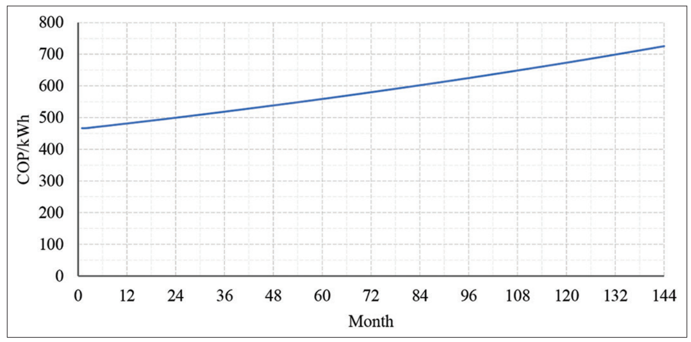


Table 5: Required labor calculation

Concept	Amount	Unit
Users	21.780	Users
Installation time (5 years)	60	Months
Manual installation required fee	363	Users/month
Required daily installation rate	15	Users/day
Performance	12	Users/day/crew
Business days	24	Days/month/crew
Installation according to business days	288	Users/month/crew
Crews necessary for compliance	1,3	Crews

Table 6: Project CAPEX summary

Description	Amount	Cost (COP)	Cost (USD)
100 A three-phase meters	11.103	$ 2.356.117.926	$ 589.029
Macrometers 1 (10) A. (Smart)	1.071	$ 224.205.520	$ 56.051
80 A single phase meters	9.607	$ 1.109.164.657	$ 277.291
Current transformers	3.212	$ 447.290.012	$ 111.823
RF display for Bicuerpo. V1 system	21.586	$ 1.604.907.828	$ 401.227
Collector+Xbee	3.501	$ 861.674.732	$ 215.419
Uriarte BRES Cabinet - 43	875	$ 634.449.272	$ 158.612
Uriarte BRES-64 Cabinet (4 three-phase - 6 single-phase)	3.501	$ 3.198.463.271	$ 799.616
Others		$ 576.180.161	$ 144.045
Total		$ 11.012.453.377	$ 2.753.113

According to the estimates in Table 6, the equipment required to replace network assets and normalize users amounts to a total of COP 11.012.453.377 (USD 2.753.113). These are itemized based on the needs of each user, as identified in Table 7.

Table 7 details the OPEX costs according to various categories. The estimated OPEX amounts to COP 29.187.765.562 (7.296.941 USD), with the largest portion attributed to costs associated with the human capital required for activities over the 5-year period. This cost decreases as only maintenance and administrative personnel are required. Figure 5 presents a forecast of electricity prices, used for the projection of cash flows.

According to technological replacements, a forecast is made for the behavior of electricity purchase, sale, and losses, and an estimate is developed for the recovery of these losses. Figure 4 illustrates the energy balance behavior.

Figure 6 presents the revenue estimation in alignment with the energy balance behavior and the electricity price forecast.

The revenue per unit is the amount collected from the energy billed to normalized users. Therefore, an upward curve is observed during months 0-60, followed by a linear behavior, as 100% of the users have been normalized. On the other hand, revenue from losses refers to the amount collected from the recovery of energy associated with both technical and non-technical losses, because of the implementation of management and control systems. Figure 7 presents the cumulative behavior, comparing Revenue against Costs, resulting in gross profit and then net profit.

It is observed that revenue equals costs in month 60; from this point onward, net economic recovery is achieved. Figure 8 presents the cumulative cash flows.

The cumulative cash flows indicate that revenue is generated starting from month 86. This is illustrated in Figure 9, which shows the project's cash balance.

During months 0-85, the cash balance remains at 0 due to investments and the amortization of acquired financial obligations.

Figure 6: Simulation of revenue

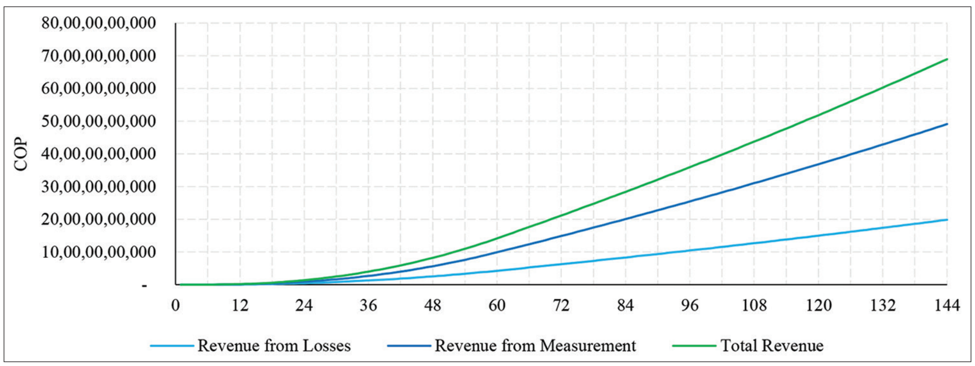


Figure 7: Cumulative behavior of revenue versus costs

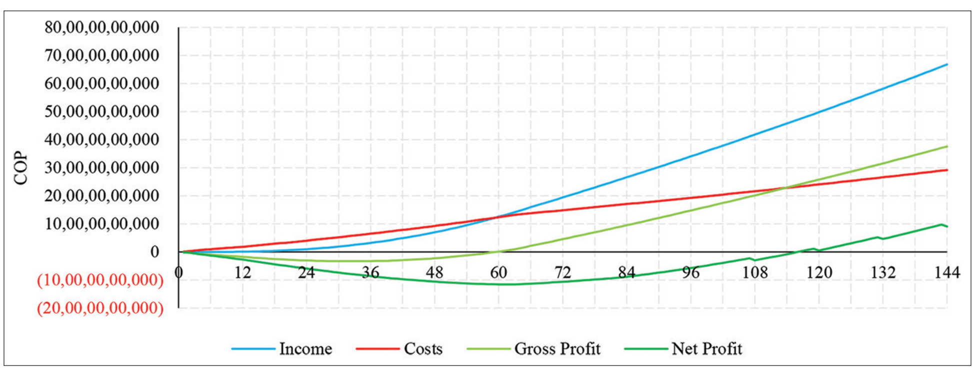


Figure 8: Cumulative cash flows (COP)

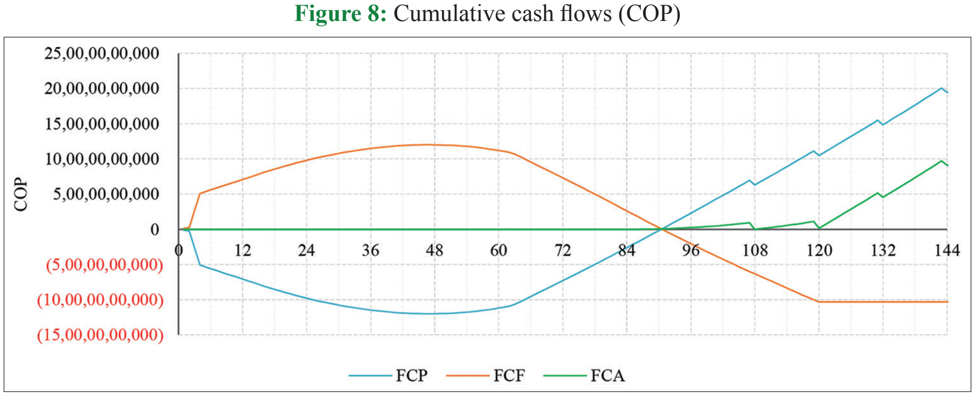


Figure 9: Project cash balance (COP)

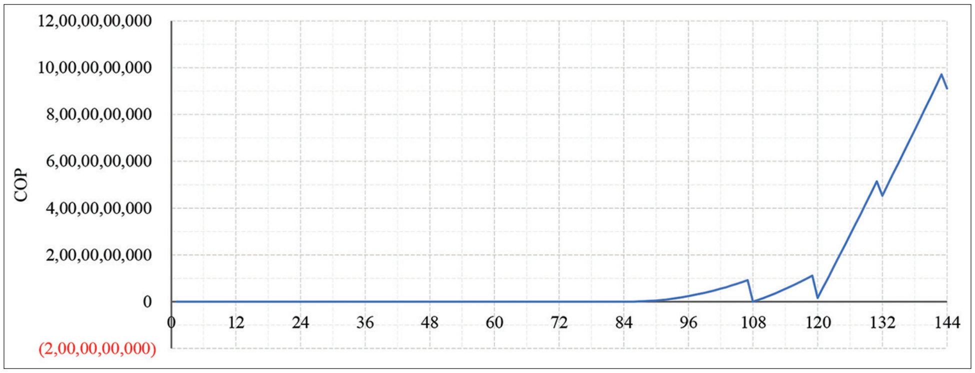


Table 7: Project OPEX summary

Concept	Cost (COP)	Subtotal (COP)	Subtotal (USD)
Tools			
Equipment and Tools	$ 64.795.790	$ 64.795.790	$ 16.199
Preoperative			
Administrative	$ 17.750.805	$ 53.088.730	$ 13.272
Operational	$ 35.337.925		
Facility			
Administrative	$ 1.742.002.412	$ 4.961.684.956	$ 1.240.421
Operational	$ 3.219.682.544		
Operation			
Administrative	$ 1.120.838.298	$ 7.799.359.304	$ 1.949.840
Operational	$ 6.678.521.006		
Subcontractors			
Material Transportation	$ 995.273.925	$ 2.929.475.175	$ 732.369
Data Transport	$ 1.907.660.611		
Mobile telephony	$ 26.540.638		
Transport			
Truck installation crews	$ 3.118.959.333	$ 3.118.959.333	$ 779.740
Others			
Technical advice+Staffing+Travel expenses+Insurance+Rental leases	$ 10.260.402.274	$ 10.260.402.274	$ 2.565.101
Total	$ 29.187.765.562	$ 29.187.765.562	$ 7.296.941

Table 8: Summary of the project's financial indicators

Concept	COP	USD
Income	$66.737.594.916	$ 16.684.399
Supply Cost	0	$ 0
Operating Costs (OPEX)	$29.187.765.562	$ 7.296.941
Capital Investment (CAPEX)	$11.012.453.377	$ 2.753.113
Financing cost	$10.321.356.111	$ 2.580.339
Total cost	$50.521.575.050	$ 12.630.394
Gross profit	$37.549.829.354	$ 9.387.457
Project utility	$25.202.624.079	$ 6.300.656
Net profit	$9.113.560.035	$ 2.278.390
VPN project	$2.600.446.524	$ 650.112
Investor VPN	$2.988.853.233	$ 747.213
Administration	$1.334.751.898	$ 333.688
Oper+Income taxes	$5.767.707.933	$ 1.441.927
Req. financing	$27.234.132.943	$ 6.808.533
Unforeseen	0	0
Advance	0	0
Gross margin	56,26%	
Operating margin	37,76%	
Net margin	13,66%	
TIRM project (EA)	10,89%	
Touch (EA)	11,00%	
Investor TIRM (EA)	13,52%	
Duration	144 months	

It is important to highlight that the project is sustainable and does not require additional capital injection, as proposed initially. In month 86, the first positive cash balance is achieved, marking the beginning of cash accumulation and revenue generation for the associated company. Table 8 presents a summary of the project's financial indicators.

The results indicate that the network operator will be able to achieve technological upgrades to the network, normalize users, and recover energy losses without the need to invest out of their own pocket. The users will benefit from an updated network that improves their service quality without impacting their finances. Meanwhile, the company will secure an excellent profit margin through its partnership with the network operator.

7. CONCLUSION

The research presented the design of a business model for developing distributed generation projects. The UPME indicates that it will strengthen the electricity sector through Advanced Measurement Infrastructure projects, network automation, Distributed Resources, and Electric Vehicles. However, there is a noted dependency on the automation and modernization of the distribution network to facilitate the integration of these other project lines.

Based on the requirements proposed by the national government, a business structure was proposed and designed. This structure offers network modernization and complementary services, including the recovery of both technical and non-technical energy losses. The proposed technical-operational structure enables the connection of solar parks as well as the integration of individual user initiatives, providing greater flexibility for generation systems.

Simulations show profitability for both the network operator and the company undertaking the project. Meanwhile, users benefit from improved service quality, reduced network operation costs, and flexibility in integrating personal generation systems. In a second scenario, the opportunity arises to lower electricity prices through distributed generation from the proposed solar parks, which can establish and sign Power Purchase Agreements (PPAs).

The research results establish a business model involving a third part a company that provides investment capital and leverage to facilitate compliance with the law, technical and scientific support, asset renewal for the power system, and economic stability for the network operator.

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