

Article

Business Model Proposal for Energy Transition towards Operational and Economic Sustainability for Rural Electrification: Colombian Case

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Abstract: This study focuses on strategic development for incorporating distributed energy resources into the electrical off-grid power system operator, or isolated microgrids, to guarantee sustainability and energy transition by an adapted business model. A business model canvas was adapted to allow sustainability in an off-grid Colombian microgrid by integrating distributed energy resources with voltage and frequency control as ancillary services; support services that maintain the stability and security of energy supply in isolated rural electrification. The business model canvas was studied with government funds, who cover all the costs associated with making the model attractive and sustainable in a Colombian context, and some proposed technical incentives to analyze the profitability and guarantee the sustainability of rural electrification. The proposed modified business model canvas offers a useful tool for supporting microgrid market scheme development to include distributed energy resources in a Colombian case. The model showed the importance of motivating investors and increasing profitability by including a value proposition based on technical contributions that benefit the microgrid operation; by around 80%. These benefits can solve some stability problems, including ancillary services, like frequency and voltage support, using distributed energy resources. Finally, integrating rural electrification in off-grid zones into the national energy regulation system is vital for incentivizing sustainable projects in rural zones, such as microgrids.

Keywords: business model canvas; distributed energy resources; electricity access; off-grid rural electrification



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1. Introduction

Rural electrification and electricity access are predominant aspects of achieving sustainable development goals [1]. However, the electrification solutions for these areas have historically focused on increasing electricity coverage, without considering the projects' technical sustainability, which makes it possible to maintain a continuous electricity supply [2–5]. Moreover, there are no requirements and planning criteria that allow the integration of technical support services in the operation of these solutions to ensure security in the supply [4,6]

A solution to guarantee sustainability in rural electrification is microgrids [5–7]. Operation by off-grid rural electrification represents several technical and market challenges related to integrating variable generation sources, distributed control systems, storage, and active demand participation [3–6,8,9]. Currently, the installation of these sources is considered a key aspect of energy transition, since, in addition to allowing energy sustainability, it can reduce the effects of greenhouse gas emissions [10–14].

Nevertheless, the difficulties that arise due to the lack of regulation in technical and market specifications, which define the requirements for the provision of voltage and

frequency ancillary services in an off-grid rural microgrid, do not allow taking full advantage of the contributions of the connection of distributed energy resources (DERs) to the microgrids [6,9,10,15,16]. Therefore, the best way to combine the provision of ancillary services by integrating DERs, including a new market scheme that reduces the inconveniences and uncertainties associated with providing these services at the distribution level, is required [6].

It is critical for improving the robustness of energy policy to research some benefits. Sustainability tries to cover technical and economic issues to assess off-grid rural microgrids [17]. Around the world, energy transition arises from policies aimed at reducing greenhouse gas emissions [14], or by implementing systems that allow being sustainable and resilient [12,13,18], including incentives or mechanisms that are attractive to investors [11,16]. That is the Netherlands' case, where some wind energy laws were enforced to analyze sustainable microgrids in the long term [11]. In that country, some research pilot projects that are part of a road map to 2030 have been implemented since 2001. Other energy transition cases have been executed in China and India, where the policies guarantee all users' electricity supply [12].

In Latin America, some rural electrification policies have been put into effect to increase the population with access to electricity. Rural electrification focuses on using its resources in each region, like in Brazil, which has increased the use of small hydropower plants. In some Latin American countries, policy has tried to change operation into microgrids and mini-grids [17]. Thus, the Colombian electricity sector's energy transition towards integration of generation with renewable energy sources must include the non-interconnected zones (ZNI) to define mechanisms that allow the sustainable operation of the off-grid electricity solutions in rural electrification [19].

Off-grid rural electrification can be carried out through microgrids to integrate renewable energy sources to supply the energy [19,20]. These stand out as a solution for the electrification of off-grid rural areas that require a continuous supply of electricity. The proposed solutions are also focused on social or economic benefits, neglecting fundamental technical aspects for the electricity service's sustainable provision [8,20–22].

Within the global context, business models can be modified to achieve sustainability in the provision of a service, such as the business model canvas [6]. This model allows offering a product with a value proposition that gives users a benefit over other products [23]. We propose achieving technical and economic sustainability in microgrid operation by implementing ancillary services from DERs already connected to the off-grid rural microgrid.

Isolated microgrid operation has significant technical issues in the absence of inertia and controllability of technical variables, such as voltage and frequency. Thus, control strategies must be defined for DERs, since the connection of new resources can induce unexpected voltage and frequency variations in the microgrid [24–26].

With the implementation of DERs in isolated microgrids, it is necessary to consider topological variations and their effect on the control schemes. DERs have to include hierarchy-specific controllers to keep frequency and voltage in regulatory ranges [27–46]. Therefore, based on the controllers, energy management strategies that guarantee stability in the microgrid are implemented, and local controllers can maintain communication with the control center of the isolated microgrid and monitor it. The setpoints are set and sent to the DERs to ensure that the microgrid's voltage and frequency are maintained within the defined ranges [25].

Variables associated with voltage and frequency are intended to maintain a balance between generation and demand. According to the variations, DERs in the microgrid need to maintain and regulate the voltage and frequency values with an additional inversion in controllers, which increases the capital cost [25]. Some markets have special schemes associated with maintaining voltage and frequency in defined ranges; these are known as complementary services, precisely voltage and frequency control [47]. This article proposes a characterization of the provision of voltage and frequency ancillary services through energy transition and the integration of non-conventional renewable sources. A

business model for the provision of the service with continuity and security in an isolated microgrid, based on an innovative strategy that allows for analyzing the conjugation of providing added value, and that translates into income for investors and sustainability in the operation of the isolated microgrid is included in a modified business model canvas. The business model canvas was simulated in system dynamics to consider and compare the Colombian regulatory structure for the sustainability of the ZNI with another market scheme based on technical incentives, to guarantee the participation of the DERs already connected to the energy supply systems.

Therefore, in the following section, the proposed model for non-interconnected zones (ZNI) in Colombia is analyzed. In the third section, a model aimed at the energy transition is proposed. In the fourth section, the results obtained from the simulations and the conclusions are finally presented.

2. Business Model Methodology

Public electricity service providers located in isolated areas are composed in an integrated manner. Generation, distribution, and commercialization activities are executed by the same agent, owned by the community, and there is no diversified offer [21].

In the literature, some business models have used internal rate of return (IRR), and net present value (NPV), including taxes and tax benefits, as well as costs with conventional energy (diesel), or models that quantified the environmental benefits [20,21]. However, the benefits of providing technical support or ancillary services, which ensure sustainable operation and continuity, are not considered in traditional business models.

Business models define the objectives for providing a service based on reliability, profitability, social growth, impact, etc. These models can be applied to innovation and technology to define business strategies, environmental sustainability, social entrepreneurship, and relations between different agents [48]. Strategies for business model success are focused on serving as an interface between the technology developed and what the market is looking for [49].

For the market evaluation, it is proposed to structure a business model based on the business model canvas, and focused on specific and specialized markets, in which customers have similar needs and problems to the provided service, which is conducive to sustainability, and allows the massification of isolated microgrids [50]. This paper proposes to implement a business model for the provision of service with continuity and security in an isolated microgrid, based on an innovative strategy that allows analyzing the conjugation of providing added value, and which translates into income for investors and sustainability in the operation of the isolated microgrid [2,21].

In the literature, there are business models that accommodate different types of business. The business model canvas was chosen in this paper because it organizes the provided service with the resources and key activities for the value to be integrated into service provision [8]. In this case, the business model canvas allows analyzing a market scheme to provide ancillary services, such as voltage and frequency control, to incentive the integration of DER to an energy transition into the proposal's value.

Business model canvas makes isolated microgrids economically sustainable, guarantees technical and economic sustainability, and avoids energy transition in rural electrification [8]. In business model canvas, the market's basic structure is defined, considering its specific characteristics, such as energy resources, local potential, and demand. In addition, the remuneration of ancillary services in an isolated microgrid does not have a structure; therefore, it is essential to find alternatives for the characteristics that affect the environment in which ancillary services should be provided to the microgrid [50].

3. Proposed Model for the Sustainable Electrification of Non-Interconnected Zones (ZNI)

With the integration of renewable sources in ZNI systems, it is necessary to review the technical challenges faced with the coordination of these intermittent systems, such as continuity of supply and community interaction [6].

The Energy Mining Planning Unit (UPME) has developed a proposal to make an energy transition from operation with fossil energy sources, to the integration of renewable energies in the ZNI by restructuring the projects to give added value to the energization of remote areas [51]. This proposal aims to make operation by microgrids sustainable, taking into account regulatory factors that encourage investors to participate in these types of projects [51] through the smart automation of the grids for the optimal use of the DERs. However, these solutions leave aside the technical characteristics that allow the sustainable operation of microgrids in different temporal horizons, such as maintaining the voltage and frequency ranges within the established limits [6].

Some of the literature models have focused on the economic and regulatory aspects that should be considered in the operation of off-grid rural microgrids. That model proposes integrating the demand activities to take more advantage of energy [8,50]. However, there is a lack of technical foundations to guarantee technical and economic sustainability for implementing off-grid rural microgrids over an extended time period, such as the voltage and frequency control ancillary services definition [6]. Accordingly, the proposed business model is based on ancillary services to guarantee the microgrid's sustainable and safe operation.

Including business models in an existing market is an innovative way of providing a service with a new scheme [23]. The model allows structuring the service provision to meet the needs of the users [20] and the requirement of maintaining technical and economic sustainability in the operation of off-grid rural microgrids.

The areas in which off-grid rural microgrids operate have special considerations that hinder the proliferation and diffusion of energy supply systems, primarily because they are isolated from the bulk power system [52]. Therefore, it is essential to consider that even when communities are close to a substation of the interconnected system, expansion and modernization are costly, implying delays in implementing quality supply systems [50].

The sustainable operation of a microgrid is associated with the inclusion of developments and technological innovation in the control and automation of generation and demand, and the interoperability or integration of DERs with a social approach to enable energy integration focused on sustainable development goals [21].

Consequently, a business model for electricity provision with continuity and security in the energy supply in an off-grid rural microgrid or a segment of the system integrated into the rural electrification plan is proposed, to incorporate, through the provision of additional technical services, an added value in the supply service. This value can be translated into income for investors and an increase of sustainability in off-grid rural microgrids [2,21].

Therefore, an analysis of the investment of renewable energies in the ZNI, considering a business model canvas, is proposed [6]. This model considers that decisions are based on cash flow, and considers community participation as a critical element of these rural electrification programs' success; constituting a solution that can be attractive to expand the market [20,21,53]. In this context, one of the essential factors related to the sustainability of the business models for rural electrification with hybrid generation systems is tariff selection [6,21,54].

Additionally, the business model canvas will evaluate a scheme that allows the market to guarantee sustainability and enable the massification of off-grid rural electrification, considering the technical aspects of voltage and frequency control [23]. The business model is supposed to help recognize the concept of sustainability as a contribution, since it considers all the dimensions that may arise in the provision of a service, which transforms difficulties into business or market opportunities [6,48].

3.1. Proposal of the Business Model Based on Technical Sustainability

Off-grid rural electrification is one of the predominant problems in electrification worldwide [54]. Within the structuring of the market, it is necessary to have a value

proposition that will motivate clients and investors to carry out projects to integrate non-conventional renewable sources in ZNI, or in areas that can be electrified [6].

The projects that have been realized in some places satisfy the electricity supply coverage without paying attention to whether the solutions implemented are sustainable [2]. Thus, technical sustainability refers to the system's ability to maintain a reliable, safe, and efficient supply, despite problems such as voltage or frequency drops outside the established ranges [2,55]. It considers incentives for the provision of ancillary services involving a series of particularities and challenges that differentiate it from the conventional operation of traditional distribution networks [2,55,56]. The value proposition was to analyze some policies to regulate the provision of technical services (frequency and voltage control in an off-grid rural microgrid). This proposal's potential benefit is found in the incentive of technical sustainability to provide energy to end-users, regardless of events, and based on the provision of technical services.

Economic sustainability guarantees investment in infrastructure. If implemented in the Colombian ZNI or rural areas, it would increase the benefits and overcome some challenges faced in the electrification of these off-grid rural areas [6].

The dimension of technical sustainability is related to the reliability, security, and continuity of the electricity supply, and advantages such as reducing electrical losses and accidental disconnections, through voltage and frequency control [6,57,58], as well as the use of the potential renewable energy of each region. However, this energy transition involves all the infrastructure development of the distribution network, which includes advanced measurement and control technology that makes visible and communicates all the microgrid elements [50,57,59,60].

Agents are presumed to participate in ancillary services in a microgrid in the ZNI driven by incentives, subsidies, differential rates, and penalties, and depending on the energy sources installed in each microgrid. The continuous updating and modernization of the infrastructure are expected to provide the electric power service's quality and reliability [6].

3.2. Business Model Canvas for the Energy Transition to Operational Sustainability in the ZNI

For the business model's definition, it is necessary to consider the dimensions presented in Table 1.

Table 1. Dimensions of the business model source: adapted from [6].

	Dimensions
Who are the participating agents?	The agents that participate in the business model are the distributed energy resources (DERs)
What products does each agent offer?	✓ Based on the technical analysis, an operational policy is defined for each DER: providing ancillary services to maintain the security of supply and technical sustainability in non-interconnected zones (ZNI). The ancillary services are: Voltage control Frequency control
How is agent satisfaction achieved?	Satisfaction is based on sustainability, based on return on investment, taking advantage of regulatory policy that considers operational and economic concepts.
From who, how, and when is the money produced? Whom does it belong to?	The money is produced by some policies like incentives, tax benefits, and rates that include the Demand Side Management—DSM. The revenues come from different entities, and a structure of subsidies for the availability and provision of voltage and frequency control ancillary services is proposed.

Table 1 shows the dimensions that allow us to define the business model canvas [23] for energy transition and the sustainable operation of the off-grid rural microgrids with the provision of ancillary services, such as voltage and frequency control. The main changes in the business model canvas are defined and described below:

3.2.1. Value Proposition

The value proposition is why customers prefer one product or service over another; it solves a problem or satisfies a market need with innovative solutions [23].

In this case, off-grid rural electrification is one of the predominant problems in electrification worldwide [61]. Most countries have focused on increasing electricity supply access without considering whether the solutions implemented are sustainable [2].

Thus, it is crucial to develop off-grid rural microgrids capable of supplying reliable, sustainable, and safe electricity by providing support services to the operation with DERs, which involves a series of particularities and challenges that differentiate this type of operation from the conventional distribution network operation [55]. The balance between the energy generated in the distributed generation (DG) units and the power consumed by the demand [62,63] are among these challenges.

In isolated microgrid operation there are some challenges related to the continuity and sustainability of the service provision, intending to maintain a constant balance between demanded and generated power, avoiding load disconnections when there is a loss of generation or when fortuitous events occur in the microgrid, while at the same time, there are interoperability challenges related to the constant exchange of signals with the microgrid's central control [64–68].

Providing ancillary voltage and frequency control services makes it possible to ensure technical sustainability in microgrid operation [65]. Voltage control is associated with reactive power flow through the microgrid to avoid congestion and damage to equipment [68], and frequency control is related to the difference between generation and demand [66]. In the case of isolated microgrid operation, these changes are constant and noticeable compared with bulk power system operation (lower inertia), so maintaining stability is crucial for its operational sustainability.

This challenge is linked to the provision of ancillary services for voltage and frequency control, i.e., to overcome a small inertial difficulty, it is necessary to have DERs with the ability to increase or decrease the active and reactive power to recover the frequency and voltage profiles at the ranges defined in the regulation [47].

Table 2 shows a proposal that, if implemented in Colombia, would allow a possible increase in the impact of DERs utilization benefits, and which could help to overcome some challenges presented in the operation of the microgrids.

Table 2. Proposal for the operation by off-grid rural electrification in Colombia. Source: [6].

Proposal	Potential Benefit
Regulation for ancillary services with DERs (frequency control and voltage regulation in off-grid rural microgrids), based on a regulatory policy that encourages investment.	Technical sustainability that allows, after the occurrence of an event, to continue providing energy to users, based on the modernization of the distribution, communications, and control network infrastructure.
	Economic sustainability guarantees investment in active distribution network infrastructure, such as advanced measurement and control, that allows different DERs to communicate with the system operator.

The dimension of technical sustainability is related to the reliability and continuity of the electricity supply. The following events occur in the sustainable operation of microgrids with high DER penetration:

- Deferment of investments in the expansion of distribution networks [69–71].
- Reduction of electrical losses due to the installation of dispersed DERs in the system [57,58,72]
- Use of each region's energy potential through the connection of distributed generation from renewable sources close to consumption centers.
- Implementation of proposals related to sustainable project development would reduce disconnect hours by implementing frequency and voltage control services as ancillary services.

However, to achieve technical sustainability in this type of operation, the distribution network infrastructure must be active, i.e., the distribution system must include advanced measurement and control technology that allows DERs to be visible and to communicate with the system operator [2,57,60,73].

In defining a decision policy that encourages ancillary services in operation by off-grid rural microgrids, there are challenges related to the system's technical and economic operation, making it necessary to define each agent's responsibilities and commitments.

From a technical perspective, a technological infrastructure includes the control, communications, protections, and elements of an active distribution network associated with the installed DERs. It is also necessary that the mentioned infrastructure allows maintaining the balance between generation and demand in the off-grid rural microgrid to guarantee the provision of a sustainable service when variations and disturbances occur in the microgrid [60,74].

Economically, agents are expected to participate in the provision of voltage and frequency control ancillary services in an off-grid rural microgrid, driven by incentives, subsidies, differential rates, and penalties, depending on the nature of the DERs, and which guarantee constant updating and infrastructure modernization for the provision of ancillary services.

Table 3 presents a proposal for defining each DER's role connected to the off-grid rural microgrid, to differentiate each interconnected resources' responsibilities, commitments, and challenges.

Table 3. The proposed definition of roles for each DER connected to the off-grid rural microgrid. Source: [6].

Ancillary Service	DER	Technical Challenge	Economic Challenge
Voltage control	DG (Distributed Generation)	Reactive control. Reactive power reserve.	Incentives, Subsidies
Frequency control	DG Demand Response	Active power balance and frequency control. Reduction and increase in consumption.	

With the different actors involved in the off-grid rural microgrid's technical sustainability, safe and reliable operation is guaranteed with the provision of ancillary services. The experience obtained from implementing off-grid rural electrification in the Colombian ZNI can be replicated in the national interconnected system (SIN) to operate the system flexibly, and allow the distribution systems to provide ancillary services to the transmission system.

For this business model, the value proposition is classified as a perceived need in operation by off-grid rural microgrids. This value proposition is implementing off-grid rural microgrids that operate sustainably through the provision of ancillary services.

3.2.2. Customer Relationships

Customer relationships lead to redefining and keeping the business model up to date. These dynamics allow customers to acquire and retain or promote new business models based on providing a service [23].

In the off-grid rural microgrid, there are demand-response (DR) systems that allow the demand to participate in the microgrid operation when variations in the primary resource occur, or when there are oscillation events or generation losses. DR will enable us to know the behavior and preferences of the users. In this case, the demand must be able to be disconnected from the off-grid rural microgrid, according to the generation and demand power balance.

As a result, the possibility of making changes in the consumption patterns allows the system operator to program controlled load shifting and load curtailments, which would maintain the active power balance in the system, while allowing it to respond to emergencies that compromise the connection of users [70].

3.2.3. Revenue Stream

International experiences have presented this economic model with or without a social rate, since the populations of the ZNI should be considered to have limited financing [20]. The strategy proposed for the tariff is the inclusion of the DSM, due to the importance of having flexible demand to maintain the off-grid rural microgrid's technical sustainability.

Currently, in terms of electrical energy provision, there is a subsidy mechanism that guarantees that ZNI users have the same energy rates as any user that is supplied by the national interconnected system (SIN), justified by the high generation costs of electric power in these remote zones [75]. The rates applied to these projects must consider what is defined in El Consejo Nacional de Política Económica y Social—CONPES 3453 of 2006, regarding the characteristics of the ZNI, which allow the operation to be profitable with off-grid rural microgrids and to have a profitability consistent with the provision risks of these services [76].

The DSM contributes to security and continuity in the supply by the contribution of the DER. For the reliability indices to improve, and thus guarantee the security of the supply to the off-grid rural microgrids, DSM programs that allow the provision of voltage and frequency control ancillary services are proposed; to reduce the energy not supplied, traditional schemes have been “tropicalized” to implement a sustainable scheme called: renewable energy premium tariff (RPT) [77].

This scheme includes the demand as an agent in off-grid rural microgrids [77]. This DSM mechanism describes the inclusion of incentives in the user rate [77]. The bonus is discounted in the tariff formula because it provides ancillary services, as shown in Equation (1), measured in USD/kWh.

$$\text{New Tariff} = \text{ZNI Tariff} - \text{Ancillary services}, \quad (1)$$

where “New Rate” corresponds to the payment for electricity. This rate is taken from CREG resolution 091 of 2007 [75], and it is defined by Equation (2), measured in USD/kWh.

$$\text{ZNI Tariff} = G_m 1 - P + D_{mn} + C_m, \quad (2)$$

where

G_m : cost of generation available, USD/kWh

P : cost system losses, USD/kWh

D_{mn} : cost of distribution system usage tariff, USD/kWh

C_m : cost of commercialization, USD/kWh.

3.2.4. Sources of Income

The ancillary services incentive used to guarantee economic sustainability in operation by off-grid rural microgrids needs to define income sources, taking into account the value proposal [23].

This section is divided into two: first, the tax benefits described in the law, and the incentives that can be obtained for the provision of voltage and frequency control ancillary services will be described, then the commercialization revenues will be defined, according

to the document CREG 091 of 2007 [75]. Additionally, the source of income is related to the incentives to provide ancillary services, together with support for demand management, which may be associated with the microgrid's technical and economic sustainability [50].

- Income from benefits provided in laws and technical incentives

Due to the characteristics of the ZNIs, where off-grid rural microgrid implementation is proposed, state intervention is necessary to ensure the expansion of electrification and to make the investment is profitable for investors and agents. This intervention can be carried out through legislation or through investment incentives for providing ancillary services to guarantee the technical sustainability of the off-grid rural microgrid [20].

- Benefits provided by law

From the issuance of Law 1715 in 2014, the use of off-grid rural electrification initiatives has been encouraged, especially in ZNIs that are in the process of regulation, and mainly seeking to gradually replace generation with fuel, in an aim to reduce costs in the provision of the service and polluting emissions [78].

Law 1715 (2014) and decrees of the Ministry of Mines and Energy (MME), 1623 (2015) and 1513 (2016), define the policy guidelines for the universalization of the electric power service and the use of financial support funds. With this decree, a change in the policy was presented to favor the extension of the coverage through off-grid, centralized, individual solutions and microgrids [79]. The financial support funds that can be used are the Financial Support Fund for the Energization of Non-Interconnected Zones (FAZNI), the Non-Conventional Energy Fund, the Sistema General de Regalías (SGR), and the National Fund for Efficient Energy Management (FENOGE) [79].

The SGR coordinates and determines, between the territorial entities and the national government, the distribution, objectives, purposes, administration, execution, control, use, and allocation of income from the exploitation of non-renewable natural resources, specifying the conditions of participation of its beneficiaries [79].

The income information for coverage by type of technology allows considering the value assigned for technologies with renewable sources. For solar technology, a total of USD 26.4 Million were allocated in 2018 to hybrid projects in the ZNI [80].

- Benefits for technical incentives

The ZNI has subsidies so that the fossil fuel they are fed can be profitable for the operation. It is proposed to change the incentive delivered by fuel, to being used to compensate for the availability of DERs for the provision of voltage and frequency control ancillary services.

During the second half of 2019, the fuel subsidy assigned to one of the service providers was USD 2.5 Million [81]. However, the value to be analyzed will correspond to half of the lower subsidy (USD 200) because it is expected that these long-term subsidies can be dismantled in a longer time period [81].

3.2.5. Key Activities

These activities contain what must be done for the business model to succeed, such as the essential resources. They are related to the value proposition design and are necessary to maintain customer relationships and generate revenue [23]. The key activities for the provision of voltage and frequency control as ancillary services are presented in Table 4.

Table 4. Key activities defined for the business model canvas. Source: [6].

Key Activity	DG	Solar Photovoltaic (PV) + Energy STORAGE System (ESS)	Demand
Reactive control	X	X	
Active power reserve	X	X	
Active power and frequency control	X	X	X

3.2.6. Cost Structure

It is necessary to consider the annual recurring costs, equipment replacement costs, OPEX (Operational expenditures) and CAPEX (Capital Expenditures), and beneficiary rates to develop a market design. Likewise, the benefits defined by regulation and the economic advantages that arise when implementing this type of technology, such as international financing, must be analyzed [20].

Off-grid rural microgrid operation and the integration of the DERs to the distribution system require a high initial investment and adequate maintenance, so that the off-grid rural microgrid can provide ancillary services and ensure sustainability [54].

- Investment Costs: CAPEX

The learning curves show the evolution of technology's investment costs and how they are reduced by accumulating knowledge and experiences related to research and development (R&D), production, and implementation [77]. The costs associated with the off-grid rural microgrid tend to be reduced due to new technologies, asset management programs, and scheduled maintenance. The investment is related to the plant's profitability, and the ratio of income related to the operation support [77].

The costs analyzed in the business model canvas for the sustainable operation of the off-grid rural microgrids are the CAPEX, which are associated with the investment costs related to the necessary infrastructure for the operation of off-grid rural electrification, combined with the Comisión de Regulación de Energía y Gas—CREG methodology of the weighted average cost of Capital (WACC) [77]. The CAPEX behavior is based on learning curves, i.e., costs are reduced over time through learning, diffusion of technologies, and operation by off-grid rural microgrids that include voltage and frequency control ancillary services.

The CAPEX calculation formula contains the learning rate curve for the technologies installed in the off-grid rural microgrid.

$$\text{CAPEX} = \frac{\text{Capital costs}}{(1 + \text{Learning rate})} \quad (3)$$

The values considered the learning rate with which the business model is analyzed are taken from [82], and are associated with the generation technology installed in the off-grid rural microgrid, and are shown in Table 5.

Table 5. Learning rate by technology. Source: [82].

Technology	Learning Rate
Solar PV.	23%
Hydropower	1.4%

- Operation and maintenance costs: OPEX

The OPEX is the annual recurring costs associated with the operation and maintenance (O&M) expenses and the equipment's useful life costs. Traditionally, operation and maintenance costs in off-grid rural electrification solutions are higher than for microgrids connected to the electrical power system. These costs should reflect the value of the provision of the service [20].

4. Results and Discussion

The conditions described in the business model canvas were modeled using system dynamics (SD), which allows analyzing different agents' behavior in different scenarios holistically. Figure 1 shows a summary of the business model canvas.

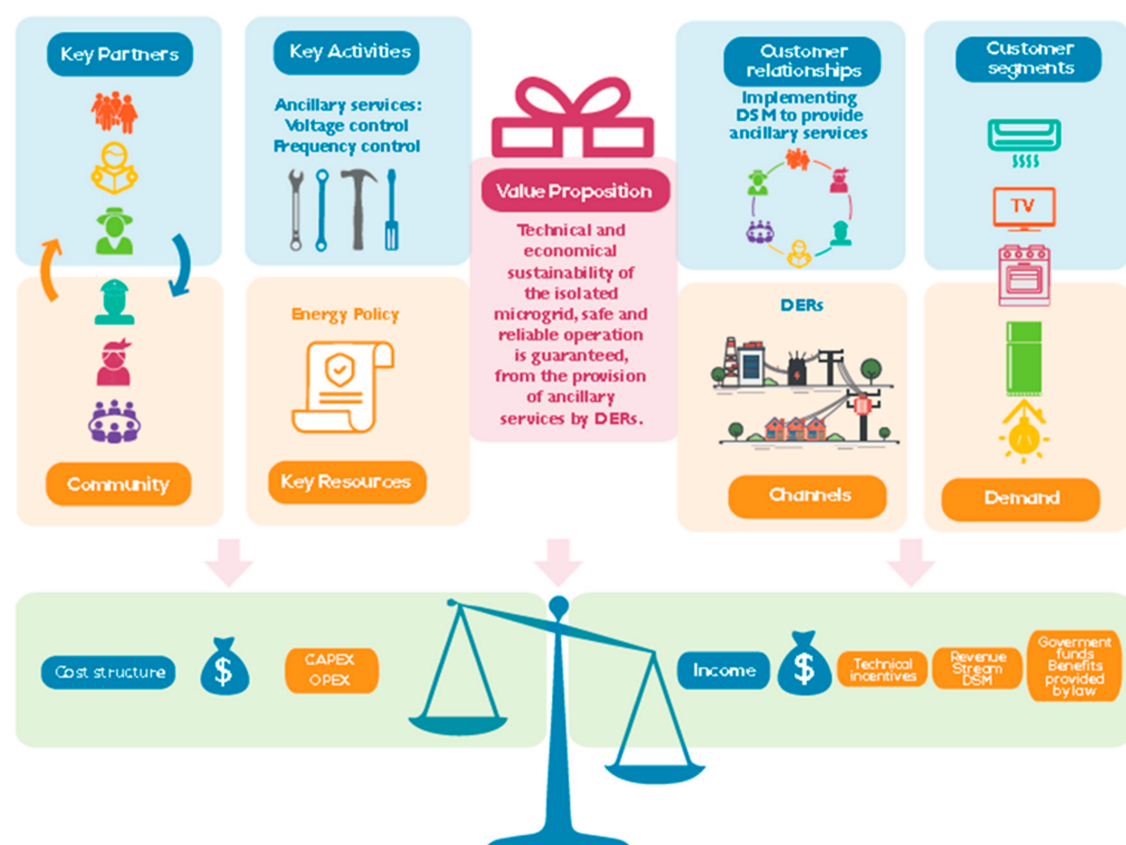


Figure 1. Business model canvas. Source: adapted from [6].

It is necessary to define adequate policies to analyze the investors' profitability in each proposed case. Table 6 shows a summary of the scenarios for an off-grid rural distribution system (microgrid) with three DG units.

Table 6. Simulation scenarios. Source: own design.

Case	Scenario
1	Commercialization (Base Case)
2	Law incentives + Technical incentives by a capacity for frequency control
3	Law incentives + Technical incentives by a capacity for voltage control
4	Law incentives + Technical incentives for availability

Figure 2 shows the results of economic sustainability, represented as profitability in the model. The figure shows the relationship between income and costs incurred in integrating solutions with DERs in an off-grid rural microgrid. It is expected that this ratio will be greater than or equal to one (1) to ensure that benefits are obtained.

Case 1 shows that the costs are higher than the income for the 20 years of the analysis. Therefore, it is not economically sustainable to maintain this type of operation in the ZNI. Thus, incentives that favor the investment in DERs must be incorporated.

For case 2, income is higher than costs, and investors will be attracted to this type of investment. Moreover, the benefit–costs relationship shows that the investment is recovered and has sustainability in the long term. The oscillation in profitability, stabilizing O&M costs when the potential DERs and the CAPEX correspondingly decrease with the learning rate. Therefore, in year 12, profitability is stabilized.

The profitability in case 3 also decreases when compared with case 2, and it is possible to balance costs and income. However, this incentive alone would not be so attractive to investors.

In case 4, profitability is below case 2 (in which DERs connection and the ability to maintain the balance of P is remunerated) and above case 3 (in which DERs connection and ability to maintain Q's balance is remunerated). However, the revenues are more significant than the costs, and, the DERs' availability to support the microgrid is remunerated. This incentive also maintains economic sustainability in the off-grid rural microgrid by having revenues higher than costs. This incentive can be used as a decision policy to attract investment in DERs connection to microgrids and the participation of the demand.

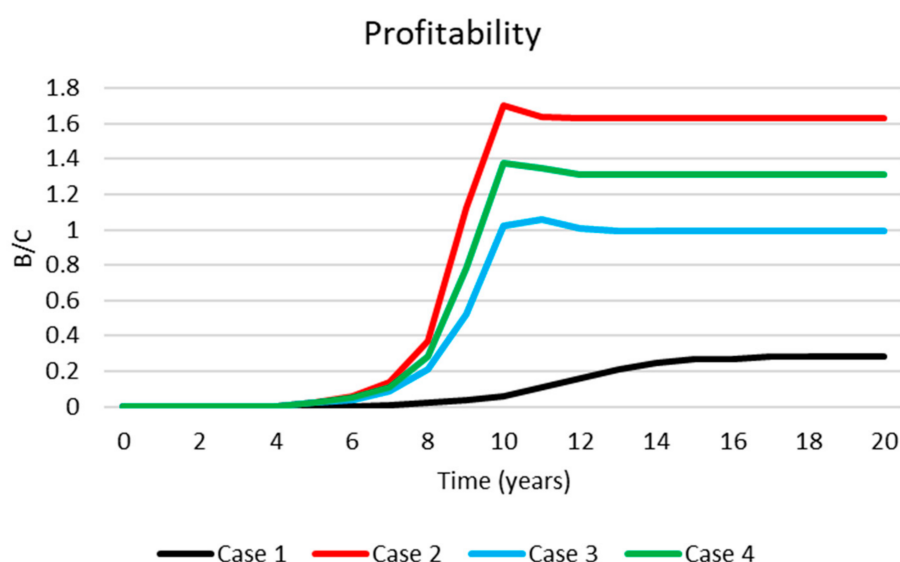


Figure 2. DER evolution. Source: compiled by author.

Sustainability in the provision of electricity supply to the non-interconnected zones is associated with the energy transition by implementing regulatory policies that facilitate the integration of renewable energy into the network, and the implementation of a business model attractive to investors. In this paper, the inclusion of technical incentives that become a source of income for investors through regulatory policies providing an electricity service that allows investors to have an investment return, and under considerations that will enable technical and economic sustainability, is proposed. Another proposal is that the added value guarantees the service's continuity and sustainability based on the provision of voltage and frequency control ancillary services by integrating DERs into an off-grid rural microgrid.

The requirements of the proposed business model canvas were developed around what is defined in the regulation. However, it is necessary to redirect the existing subsidies so that the integration of non-conventional renewable sources is massified, and an energy transition is possible in Colombian off-grid rural electrification.

The proposed model includes the direct interaction with the users, intending to involve the community in the maintenance of the electricity supply system, and raising awareness in the users that through the inclusion of technical support services and with the participation of the community, it is possible to have a continuous supply, and decreasing the billing price.

The energy transition must be associated with energy policies, including rural electrification off-grid zones that encourage DER integration, such as those proposed that include the compensation of the generation availability (dispatch) or a connection charge in case of possible unbalances, to incentivize the development of sustainable projects.

5. Conclusions and Future Research

In this paper, a business model canvas with a technical and economic view has been proposed. The value proposition is formulated to include support services to guarantee

microgrid operation and to improve the condition of inertia, reactivity, and stability problems with the ability to increase or decrease the active and reactive power to recover the frequency and voltage profiles at the ranges defined in the regulation, and using different DERs connected to it.

The business model canvas quantifies the costs associated with DER control and the infrastructure required to facilitate the provision of ancillary services, voltage and frequency control, and to guarantee microgrid operation sustainability. Additionally, in the incomes, the model includes some incentives evaluated under system dynamics methodology to analyze the impact of implementing the incentives on the investors' profitability and the participants of microgrid operations.

The results show that it is necessary to define the demand participation in the microgrid operation with a tariff that compensates for the energy interaction between the demand and the grid. Furthermore, to guarantee sustainability, investment is needed in DG with advanced control to provide active and reactive power when needed by the microgrid. Furthermore, DG investors' incentives have been according to the benefit and the services provided to microgrid sustainability.

Results focused on the profitability of different regulatory policies to incentivize the massification of DER in isolated microgrids must increase the connection and participation of DER, with technical and economic responsibilities adjusted in the business model canvas. The simulation shows that it is necessary to propose a market scheme that motivates the investors to include technological innovation, in control terms, to maintain voltage and frequency in regulatory ranges.

In future research, a big data analysis could be considered in the model to adjust the demand in ancillary services, taking into account the dynamics of demand. In these circumstances, the stochasticity of the demand can modify the participation and the flexibility of the microgrid. Moreover, the dismantling of incentives in the long term and determining user fees can be included in the model to help the government define a microgrid policy to develop Colombian non-interconnected zones.

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