EVALUATION OF ISOLATED PHOTOVOLTAIC SYSTEMS AND THEIR SUSTAINABILITY MODELS IN NON-INTERCONECTED ZONES OF COLOMBIA

Executive Summary

UPM team

Technical Team:
Andrea A. Eras Almeida
Tatiana Vásquez Hernández
Merlyn Johanna Hurtado Moncada
Coordinator
Miguel A. Egido

November 2020

FUNDACIÓN BARILOCHE DESDE 1963 | POLITÉCNICA | INSTITUTO DE ENERGÍA SOLAR | itd UPM Centro de Innovación en Tecnología para el Desarrollo Humano

Funding
Inter-American Development Bank (IADB)
Global Environment Fund (GEF)

Implementers
Center for Innovation in Technology for Human Development (itdUPM)
Instituto de Energía Solar (IES)
Universidad Politécnica de Madrid
Fundación Bariloche

For
Institute for Planning and Promotion of Energy Solutions for Non-Interconnected Zones (IPSE)
The Mining and Energy Planning Unit (UPME)

The project «Mechanisms and Networks for Technology Transfer Related to Climate Change in Latin America and the Caribbean», developed by the Inter-American Development Bank (IADB), was approved by the Board of the Global Environment Fund (GEF) on September 11, 2014 and by the BID executive board on December 17 of that year.

The goal of the project is to promote the development and the transfer of environmentally sound technologies (EST) in several countries of Latin America and Caribbean (LAC) in order to contribute to the reduction of greenhouse gas (GHG) emissions and of the vulnerability of some of the region specific sectors to climate change (CC).

Bogotá D.C.-Colombia. November 2020

Authors

Coordinator
Miguel Ángel Egido Aguilera
miguel.egido@upm.es

Technical Team:
Andrea A. Eras Almeida
Tatiana Vásquez Hernández
Merlyn Johanna Hurtado Moncada

Technical Coordination and Support

Renato Oña Pólit
Renewable Energies Coordinator
Fundación Bariloche

Hilda Dubrovsky
Executive vice-chairwoman
Fundación Bariloche

Those interested in the final report can request the document to:
Fundación Bariloche: info@fundacionbariloche.org.ar
Miguel A. Egido: miguel.egido@upm.es

This document presents the findings of the work entitled *Evaluation of Isolated Photovoltaic Systems and Their Sustainability Models,* as part of the project "Mechanisms and Networks for Technology Transfer Related to Climate Change in Latin America and the Caribbean", developed by the Inter-American Development Bank (IADB), funded by the Global Environment Fund (GEF) and carried out in Latin America and the Caribbean by the Fundación Bariloche.

It also includes the analysis of primary and secondary information of the photovoltaic energy projects for rural areas electrification in Colombia. The information was obtained through interviews to the different stakeholders who work in the solar electrification in NIZ (Non-interconnected Zones) of Colombia. A comparative study of the international projects selected- all of them in Latin America- was made. The results are showed as lessons learned, with a SWOT study representing the current situation of rural electrification with PV technology as perceived, and describing the opportunities for improvement based on the successful experiences in the region. Lastly, a series of guidelines are proposed to support those public policies that foster access to energy in the rural non-interconnected areas of Colombia.

Situation of electrification in isolated rural areas in Latin America

The investments made in the Latin American public sector in recent decades has been remarkable. Thus, the quality of service has improved; the electricity loss has been reduced and the generation capacity, with a large percentage of renewable sources, has increased. Broadly, most countries have chosen to liberalize the market. They are electrifying rural areas with sustainable technologies, and their biggest challenge has been bringing electrical power supply to isolated communities, mainly due to population dispersion and to the difficulty to reach these areas. Although electricity coverage has reached more than 97%, the electrification rates of rural areas remain low, especially in Central America, the Andean region and the Amazon. The low access rates of these areas are explained by the population's poverty and by the complex geographic characteristics of some regions, but also by the delays in the implementation of electrification policies or by the use of inappropriate designs both for the implementation model and the technological solution.

In rural and remote areas, the service is not profitable enough to attract investors. Therefore, from the nineties, national authorities have implemented specific electrification programs to ensure energy access to these areas. Also, in most countries, social tariffs are set to increase the affordability of the service. According to several studies, the adoption of renewable energies has become a cost-effective solution for rural areas, where off-grid and small-scale electricity generation systems are often used. However, technology is not the only success booster. For these programs to succeed, the design of equipment and the choice of specific technological options must go beyond the technocratic logic which cares only about cost efficiency.

Rural electrification programs rely greatly on fiscal resources to meet their overall goals and to foster the social and economic progress of most disadvantaged populations as well as to drive every country's ability to attract private investors and international cooperation funds. One of the main financial supports of Latin American governments is the IADB, which allocates about 15% of its resources to the funding of off-grids and mini-grids which are connected to the grid and use renewable

technology. However, in 2014, the IADB's budget was reduced by nearly 45% and, to date, its portfolio of projects aimed to finance off-grid systems is far below what the region requires to achieve universal access to energy.

Rural Electrification in NIZ of Colombia

The challenges arising from supporting the universal access to energy in Colombia are reflected in the National Plan for Rural Electrification (PNER), which seeks to make the necessities of rural communities compatible with the technological solutions to be implemented, to develop capacity building, and to arise social awareness about the efficient use of energy. The plans that deal with rural electrification in Colombia are: The Energy Coverage Expansion Plan (PIEC), the National Energy Plan (PEN) 2014-50, the PNER 2018-31, the Sustainable Rural Energization Plan (PERS) and the Plan *Todos Somos PAZcífico* (PTSP). Their main goal is to provide the basic guidelines for the broadening of the electric coverage, the efficient allocation of public resources for electrification projects, the promotion of electric generation solutions -according to the characteristics of the different communities, especially with Non-Conventional Energy Sources (NCES)-, and teaching the communities how to use energy adequately.

The Energy and Gas Regulation Commission (CREG, by its Spanish acronym) determines general criteria and methodologies to remunerate the generation, distribution and commercialization of electricity, and the general tariff formulas to calculate the unit cost of the public electricity service in non-interconnected areas. In the case of solar systems, these costs are expressed in $/Wp. These regulations must be applied to every photovoltaic system that is installed in the NIZ, regardless of the institution that has financed the project.

The current tariff framework has shown significant weaknesses. In fact, neither the projects financed by FAZNI (Colombian program) nor those funded by the IPSE itself –which are the subject of this study- have implemented it for stand-alone systems, i.e., users are not paying for the power generated with isolated photovoltaic systems designed for domestic use. Recently, the CREG has published a resolution that sets a tariff for the electric service of stand-alone photovoltaic systems whose power is over 500 Wp.

Case Studies in Colombia

Rural electrification in NIZ is implemented mainly through three energy solutions: stand-alone photovoltaic systems, mini grids with diesel generator sets and hybrid mini-grids. Stand-alone photovoltaic systems are the preferred solution for the widely dispersed population. Nowadays, more than 13,000 users have one of these systems, with an installed power capacity higher than 500 Wp. Additionally, it is estimated that, in the rest of the year, about 4,821 new units will be operational. As for hybrid mini-grids, this has been the preferred solution for the islands. These grids are comprised of generating units, distribution networks, a photovoltaic generator, inverters and a battery bank to store energy. The consulting team has evaluated six case studies. For this purpose, local leaders, users and installation companies, among other stakeholders were contacted. The case studies about stand-alone photovoltaic systems in NIZ are located in Acandí, in the Chocó region, in Aguachica, in the César region and in Cartagena del Chiará, in the Caquetá region. The cases about hybrids mini-grids are those

of Isla Fuerte, El Islote and Isla Múcura, which belong to the municipality of Cartagena, in the Bolivar region.

Based on the interviews with local stakeholders and government officials for rural electrification in NIZ and on the review of secondary information, a separate SWOT analysis reflecting the particularities of both contexts has been made. The analysis examines the following aspects: management, technical, environmental, socio-economic and gender-based aspects, and impact of the project. The following matrix is a summary of the SWOT analysis.

Item	Strengths	Opportunities	Weaknesses	Threats
Management	(I) Public sector leadership to broaden the electric coverage in NIZ with renewable energies.	(i) Improving the management and the interaction between public bodies and service providers, and between these institutions and users.	(i) Lack of formal assignment of responsibilities to the body that carries out the OAM.	(I) Decisions based on political interests.
	(i) Promotion of investment in rural electrification projects through funds.	(i) Possibility of public-private partnerships with local stakeholders to strengthen the business model.	(I) Lack of funds to pay for the house installations of the new users.	
	(i) Tool to calculate tariffs and subsidies, so that projects are financially viable.	(i) Setting the tariff and charging the users according to the context.	(I) Lack of subsidies to PV Systems users to help in the projects' OAM.	
Technical	(i) Availability of solar resources.	(I) Implementation of PV Systems whose capacity is adapted to the energy needs of users.	(I) Lack of verification of compliance with technical standards in bid proposals.	(I) Unawareness of the replacement costs of equipment by the population.
	(i) A more suitable option for scattered populations.			
	(I) Capacity to cover every basic need: lighting, charge of mobiles, small appliances, entertainment and, sometimes, refrigeration and ventilation.	(I) Promoting the buy of efficient household appliances in rural areas with sound policies.	(I) Average availability of just 4 hours for basic needs.	(I) Increase of the electricity demand due to the use of high-powered equipment.
	Titiza: (i) Building of the necessary systems inside every dwelling.	(i) Implementation of pre-paid metering systems in the most scattered communities.	(I) Low quality of the installed equipment, mainly of batteries and inverters.	(I) Lack of development of a local network of companies to replace equipment.
Environ-mental	(i) Reduction of CO_2 emissions and noise pollution of generators.	(i) Creation of collection points for electronic waste and hazardous material such as batteries.	(i) Frequent replacement of batteries. Old ones are thrown away instead of being recycled.	(i) (i) Household energy solutions based on fossil fuels.
Socio-economic	(i) Household savings when families switch from traditional energy sources of generation (candles, oil lamps, thermoelectric generators) to PV sources.	(I) Teaching the "culture of payment" to families.	(I) Lack of general awareness about the importance of efficiently using energy.	(I) Users that cannot pay a service fee because they live isolated or are in poverty. (ii) armed conflict.
Gender-based	*Titiza*: (i) Community councils are led by women.	(i) Women can open businesses to sell frozen products, for example.	(i) Low interest in women's participation in decision-making regarding energy.	
Impact	(i) Improvement of the quality of life thanks to the replacement of the use of fossil fuels for lighting, and the possibility of refrigerating food.	(I) Generation of local business based on the availability of electricity such as the sale of frozen foods.	(I) Decline of trust in governments to manage the projects.	(I) Widespread rejection of the population of NIZ to photovoltaic energy solutions, if they are not carried out with the proper technical quality.

The fact that the public sector leads the process is one of the biggest strengths in the implementation of PV technologies to improve the energy access rates in NIZ. In this case, public funding to install the systems is preferred. However, one of the main barriers is the difficulty to build horizontal

partnerships (local agencies) and to reinforce local management (local responsibility over the systems). Add to that the fact that the local communities do not usually take part in the decision-making, which implies distrust in the community leaders. The bright side of the case studies is the strong social and community cohesiveness. The population (especially young people and leaders) is willing to change, to become active agents in the development of energy solutions, and to be part of monitoring and control committees. In order to do so, they need to be trained in every aspect - technological, information analysis, management, tariffs and subsidies, among others- and, of course, to be listened to. At the same time, this would offer the possibility of implementing innovative business models, as per Goals 7 and 17 of the 2030 Agenda, where the political agenda cannot influence neither decision-making nor the continuity of the projects.

The politicization of PV projects is a factor of high concern, especially for rural communities. On the other side, islands communities complain about the lack of interest and support from local agencies, mainly due to the limited resources these entities have. Likewise, the changes of government and of government officials in national institutions hinder the normal development of projects.

As for the technical aspect, the high availability of the energy source (solar) stands out, which facilitates the implementation of PV systems along the country. It is also important to mention that the newest part -the PV module or the solar panel - is functioning in every case study. That is, the failures reported are mainly due to different problems with the storage system or the electronical equipment of power conditioners, and not with the solar panels. This factor is closely linked to the low quality of the equipment and to the little compliance with quality standards in technical parameters and guarantees. Also, the evaluation of the islands cases shows that basic O&M (operation and maintenance) works (e.g. fuel and oil change of generator sets, panels cleaning) can be done by local workers, but for complex works, it is necessary to look for trained staff outside the island, which directly affects the cash flow of the service providers.

The socio-economic aspect is one of the most sensitive factors. Household economies are highly vulnerable to the seasonality of income, being agriculture the main source in the rural context, and tourism in islands. In both cases, households' economic well-being is very susceptible to external factors that affect severely to their incomes, as is currently the case, because of the pandemic. An added factor is that, in most cases, there are no set tariffs. The exception is the case of mini-grids, where customers are being charged according to different tariff models, but this is not enough to pay for the operations, administration and maintenance of the systems despite that the community devotes a great amount of resources to it. This shows that the electricity service is not affordable for NIZ populations. Likewise, the economic sustainability is also threatened by the lack of a "culture of payment" among users, due mainly to the fact that the first public service that reaches these areas is electric power, and the communities are not aware that they need to pay to guarantee a service. Lastly, the greatest weakness in the environmental chapter is the lack of defined policies for electronic waste recycling and batteries disposal. Therefore, the creation of collection centers for this type of waste in the urban areas of the municipalities would be an opportunity for improvement.

Leaving aside weaknesses and threats, we must also highlight that the implementation of this type of projects (PV and hybrid systems) has had a positive impact on the community, since the quality of life has improved thanks to the development of its economy and its businesses, most of them led by women. People may engage in different activities after dark, replace other energy sources such as batteries, oil lamps or candles, save some money, and access to other services apart from just lighting: communication, information, food conservation (although with limitations), and a better educational

level among children and youth. Despite these positive aspects, electrification strategies in the country still require innovative proposals and proposals to adapt projects to current conditions, in which multi-stakeholder partnerships are a potential alternative so that no one is left behind.

Comparative International Analysis

To better understand some of the problems that are yet to be solved and to determine the successful elements of electrification initiatives, seven Latin American rural PV electrification projects have been analyzed. All of them illustrate the importance of governmental commitment and of the local population involvement, and the relevance of innovation. The analysis reveals also that the access to financing is one of the major barriers for the region. Hence the relevance of the 2030 Agenda's urge to include every stakeholder, that provides a clear guideline for the formulation of public policies both national and regionally.

In Peru, for instance, the project "Luz en Casa" ("Light at Home") implemented by acciona.org Peru, has developed a solid management model, that ensures self-sufficiency to finance their projects and their sustainability once they are implemented. Also, the model guarantees that the access to electricity is affordable for users, and the compliance with quality criteria thanks to a rigorous verification process. The creation of a multi-stakeholders' alliance has been key to implement it, with a ESCO (Energy Service Company) management model. However, the current model, a concession, has become a barrier, because it halts the prospective application of the project in new areas.

In the cases of Iluméxico and "Light at Home", both in Mexico, the community involvement as one of the central axis of project development is very relevant, because these projects are not limited to the

promotion of the project, but they take care of the installation, the users' capacity building and the sustainability of the projects. In particular, the case of the program "Light at Home" shows the success of the PPA model (Public-Private Alliance for Rural Development), which has not only provided access to energy to low densely populated areas in the region of Oaxaca, but also, thanks to the recent interest shown by the government, it can be applied to water-supply systems and other services such as health and cooking. Also, in both cases, it has become clear that adapting the business model to the economic situation of the beneficiaries allows to contribute tailor-made technological solutions, according to their payment capacity, thus having low default rates.

The electrification in remote rural areas in Brazil is part of the Plan for the Universalization of Access and Use of Electricity, the program "Light for All". The performance of the program has improved through the implementation of pilot projects, which allows the Department of Mines and Energy to make the necessary adjustments and to introduce innovative mechanisms in their policy. One of the pilot projects that has allowed to introduce these innovations was led by Eletrobras Amazonas Energía-Guascor. In this project, several hybrid micro-grids were installed in some Amazonian communities. After the implementation of this pilot project, the government defined the technical quality standards for electrification projects, the energy consumption control, the provisions of credits, the alliances with local stakeholders to strengthen the capacities and the design of inclusive materials for the indigenous communities. However, all this does not fully fit the complexity of the Amazon. Also, the government measures regarding the privatization of energy service operators has destabilized the program, because the most remote areas of the Amazon are not attractive for the companies.

In Bolivia, Energética, a private company, has acted as an intermediary in the transition towards sustainability through the project "Microfranchises for Access to Clean Energy", catalyzing the knowledge transfer, the integration of stakeholders, and the development of a model that was gradually born as a response to the social, socio-economic and institutional characteristics of the area where they work in. Key to institutional sustainability has been: i) the transfer of powers to local authorities (decentralization) so that they can execute the PV Systems; ii) a microfranchise model based on the inclusion of local workforce in the business model; and iii) the use of international aid to develop the potential of the community, rather than just importing foreign knowledge and technology. Fundamental to achieving the economic sustainability has been: i) the payments system adapted to harvest time, the season where the users have income, and ii) the close relationship of the microfranchise with the population. The offer of basic standard products to the users, the availability of local technical workers and the after-sale service to communicate providers and users have ensured the operation and maintenance in the long term.

In Chile, the PPA (Private-Public Alliance) has been a success in the long term, not only because of the rate of electricity coverage achieved in the region, bus also thanks to the way the OAM (operations, administration and maintenance) of the systems is carried out: by handing over the management of the equipment to the local energy distribution company, the operation of the systems and, above all, the continuity of the service are guaranteed. Also, the bottom-up approach of the projects allows the community to take part in the design of the projects, thus contributing to the empowerment of the beneficiaries and to the good use of the equipment. However, the project lag between project formulation and execution remains a barrier to achieving 100% of electricity coverage in the medium term. The same happens with the direct allocation of resources to electrification projects by regional

governments, which generates uncertainty about the ownership and the replacement of the PV systems equipment.

The case of Floreana, Ecuador, an example of mini-grid on islands, is marked by the high amount of funds provided by international cooperation entities to finance the renewable energy projects as a contribution to the national initiative "Zero Fossil Fuels" for the Galapagos. In fact, this public policy that aims at the decarbonization to preserve the ecological value of the environment, has been key to boost the use of renewable energy on the islands, with the help of donor countries. Although there are still some challenges, such as the availability of biodiesel for electricity generation in order to maximize the introduction of renewable energy in the island, it should be noted that the combination of different technologies (diesel + biodiesel + PV + batteries) guarantees electricity service on a permanent basis, thus improving the quality of life of the islanders thanks to the boosting of their economy.

As illustrated, in Latin American countries, there is a great variety of strategies for rural and insular electrification, in which business models, stakeholders' involvement, technological solutions and user financing options vary widely among regions. The challenge of rural and insular electrification cannot be taken up by the private sector alone. The strategies promoted by the 2030 Agenda seek to join forces in order to work to common purpose: "universal access to energy". This fosters also the exchange of experiences in the different regions to strengthen present and future initiatives. Many of these findings will be taken into account to define the recommendations for the improvement of the Colombian management model.

Lessons and Opportunities

Identification of lessons learned

The lessons learned through the different stages of the PV electrification projects included in the case studies are identified. The difference in the interviewees' narratives is reflected, and the cause-effect relationships inside a given context are defined. These lessons learned are a useful source of information to anticipate problems and key factors in the development of future projects. Recommendations of good practices for the application or mirroring of the acquired knowledge in similar projects are also made.

Lesson 1. Active participation of leaders and those in charge of the community organization in every stage of the project: The communities that have taken an active part in all the stages of the project, such as the selection of families, the coordination of activities or the project monitoring, have a greater commitment in regards to the care of the equipment and the facilities. This commitment has also made it easier to overcome challenges related to the approval and the implementation of the project.

Lesson 2. Horizontal communication and transparency among all stakeholders, including the leaders of the communities, during the stages of structuring and implementation: transparent communication builds the necessary trust among institutions, companies, and communities during the project execution. It allows to mediate with the community in the conflicts that may arise, for instance, the long waiting time to get the projects approved or the necessary commitment to carry out the execution works.

Lesson 3. The design and management of electrification projects must be born from co-creation, and the users' community must be the pillar of this stage: The analysis of the Colombian cases shows that the projects that suffer from sustainability problems have something in common: the teams responsible for planning and project structuring did not design together with the communities neither the PV solutions nor the operations, administration and maintenance plan. The way in which projects are designed leads to static solutions, which overlook the complexity of the territories, the families' reality and the promotion of the development of the affected communities. This social, geographic and cultural diversity specific to the complexity of NIZ makes it necessary to co-create the solutions, so that they are focused on the needs and realities of the families and flexible to future demands, and that involve the agency that will operate the service.

Lesson 4. The operations, administration, and maintenance (OAM) strategy must be defined from the beginning of the projects: Although, in the analyzed projects, stakeholders had reached an agreement to ensure the OAM, it had not been enforced. Most agreements remained unheeded. In some cases, the community does not know about them or about the OAM strategy, especially in stand-alone systems. The region authorities, along with the beneficiary community and the entity responsible for OAM, must define the business plan, so that the projects are sustainable. This includes informing the community about the tariffs the households will have to pay and determining the ideal strategies to collect payments and to avoid the risk of default in every community.

Lesson 5. Without local capacities, an effective operations, administration and maintenance plan cannot be achieved: Although the capacity-building projects have been few, in those projects where local leaders have advised the community about energy solutions, the results have been better. It is important to engage leaders, children, youth, and women as knowledge transmitters inside the community. In addition, there is a need to improve capacity building with technical training so that locals can take care of maintenance, especially in the case of the storage systems and generating sets. Training in some aspects related to management, such as conflict resolution techniques (non-payment of public service bills), to the development of skills that allow the locals to be part of the projects, and manage alliances and business, and to equipment disposal are also necessary.

Lesson 6. It is necessary to discuss with the community how energy can change their daily life to avoid conflicts: We presume that energy systems only bring benefits. However, in some communities, there have been changes in some of the dynamics specific to their ethnicity and to the rural culture as a consequence of the access to energy, especially in the case of young people. This has to be dealt with by families and communities. Thus, reflecting both about advantages and disadvantages of energy projects is imperative within the community. First, to avoid disadvantages and second, to appreciate the importance of positive changes as a strategy to finance the project in the long term.

Lesson 7. PV solutions must promote the inclusion of women in every step of the project, from the design to the implementation: In those projects, where a high integration of women has been achieved, community organizations had encouraged the inclusion of women in every aspect of the decision making, as in the cases of Isla Fuerte and Acandí. On the other hand, those projects where women were not involved had not promoted any kind of strategy along these lines, not even in the training courses for equipment use. There is a widespread perception among project and government staffs that women do not engage in the technical aspects of energy "because they don't want to" or "because they are not interested in that sort of things". This is not true, because the sustainability of energy generates more interest among women. They do not want to feel again the pollution derived of the use of burners and candles, instead they want to have quality light longer and to take advantage

of having power in their households to open small business. Also, their domestic workload is reduced thanks to appliances. However, women have been given the role of caregivers in rural areas, which prevents them from participating in the decision making. Thus, when technical staff does not promote the integration of women in every stage of the project, gender inequality increases. When they do not listen to women opinions, they are designing projects for men, because they are the only ones in charge of decision making.

Lesson 8. Coordination between programs and alliances: Sustainability has many dimensions, which requires the coordination of different programs and stakeholders, both locally and nationally. Thanks to the coordination between local government programs and the development of the community, in some cases, energy is related with income generation. Also, in some regions, the alliances among different organizations have achieved peace agreements with armed groups, which allowed the service operation. On the other hand, the lack of cooperation among entities affects the service. This is the case of IPSE and the Superintendency of Domiciliary Public Utilities, which means that communities and local businesses are unable to communicate the problems of the service. Interinstitutional coordination is necessary, but the sharing of agendas is not easy.

Lastly, because of the potential of these lessons learned to improve the sustainability of rural electrification projects, we suggest their inclusion in a global knowledge management strategy coordinated by the Department of Mines and Energy, so that the lessons may be shared with stakeholders of the rural electrification ecosystem in NIZ.

Opportunities for improvement based on international experiences

Ensuring the access to affordable, sustainable, and modern energy to all is a major challenge for developing countries, in particular for Latin American countries, due to the geographical dispersion and remoteness of their rural communities compared to other regions. Limited access to financing, conservative policies, lack of government support, and lack of capacity building to ensure the operations and maintenance works are some of the many and diverse barriers to the universalization of energy in the region. Thus, this section describes opportunities for improvement for rural PV electrification in Colombia. They arise from the lessons learned in Colombia, from the international experiences of rural electrification, and from the results of the analysis of strengths and weaknesses. This analysis takes into account several dimensions: institutional, financial, technological, socio-economic and environmental sustainability; putting the focus on rural and island electrification.

Institutional sustainability: This dimension reflects the integration of the efforts made to develop the Colombian legal framework on electricity access under the following considerations: (i) the government leadership to guarantee the financing of energy access programs; (ii) the allocation of subsidies to the most impoverished, isolated and low-income communities, and (iii) the inclusion of the communities in the implementation and operation phases of energy solutions to achieve co-creation. In this sense, the drafting of a new law that deals exclusively with energy access would be advisable. It should be based on these principles: subsidiarity and sustainable development, as well as technological adaptation and diversification. These principles have greatly improved institutional efficiency, especially the management and the speed of implementation and revision of projects, and the easy access to long-term financing. The simplification and integration of regulations builds on the

work already made by the Colombian government in terms of energy access laws, e.g. Decree 1623 (2015) and Decree 884 (2017), and must contemplate the principles of the well-established laws: Law 143 of 1994, Law 1715 of 2014 and Law 1955 of 2019.

This *complementarity* would foster the development of electrification projects of public interest, thanks to a coordinated action of the separate levels of government (national, regional and local) for rural and insular areas, action that should differentiate the characteristics of both contexts. The *subsidiarity*, that enables the State to intervene in electrification projects with a subsidiary role to ensure the efficient management of resources, would allow the participation of communities and other private entities as electricity service providers or rural operators -possibly under Law 1715 (2014). Sustainable development would promote the socio-economic development, which would complement the projects with different productive and employment generation initiatives, which in turn would contribute the overall sustainability of the projects. These aspects would be perfectly supplemented by the Law 1995 (2019) and may be integrated in the National Development Plan 2018-22, as part of the goal of social and productive inclusion through productivity and legality. *Technological adaptation and diversification* imply an efficient management or energy and economic resources, the security of energy supply in NIZ, the prioritization of renewable energy sources and the application of energy efficiency measures in parallel.

Therefore, integrating the regulatory framework and drafting an Energy Access Law would also promote the ideas proposed by the Mission for Energy Transformation[1], in its Focus 4, about the focalization of financing facilities and the standardization of the criteria to implement projects, which would reduce administrative obstacles.

Financial sustainability: "The combination of several business models based on adequate financing mechanisms, subsidies and technological innovation is a key element to encourage the implementation of renewable energies in vulnerable regions: islands and rural areas"[2]. In this regard, and taking into account the successful implementation of several business models in other Latin American countries, the following alternative models are proposed:

- **Energy Service Company (ESCO)**

The Energy Service Company provides energy services -using mostly renewable energy sources- to the electric installation of a particular user, who, in turn, must pay for this service. The ESCO is the owner of the electricity generation facilities. The goal of this kind of companies is to guarantee the user a quality and reliable electricity supply. In a regulated and participative market, this financing model guarantees investment, implementation, and operations and maintenance works of the off-grid technology in exchange for a tariff. Also, and more importantly, it ensures the affordability of the service in the last mile. Tariffs would be differentiated according to the geographical area, to the type of modules implemented, and to the kind of investor (state, private companies, or other entities). This model builds on a fee-for-service model (cross-subsidization). The subsidies come from a social compensation fund that is fed by users of the whole network. This social fund would unify those

[1] Web of the Mission for Energy Transformation of the Colombian Department of Mines and Energy: https://energiaevoluciona.org/transformacion

[2] Eras-Almeida, Andrea A., & Egido-Aguilera, M. A. (2020). What Is Still Necessary for Supporting the SDG7 in the Most Vulnerable Contexts? Sustainability, 12(17), 7184. https://doi.org/10.3390/su12177184

already existing in the Colombian model and goes hand in hand with the proposal of the Mission for Energy Transformation.

— **Solar auctions**

In order to achieve that both rural areas and islands have a different tariff because of their particular contexts, the implementation of solar energy auctions is recommended. The great potential of this model, especially in developing countries, where it is already possible to ensure low electricity generation costs, has been proven. This instrument is implemented by the national government through public service companies that acquire PV capacity through power purchase agreements. Keeping low prices and ensuring that quality regulations are met in projects depends on several factors: low equipment prices, low capital cost, risk-free investment climate, and other factors such as particular project development strategies. Generally speaking, developing countries where the solar PV resource is large, as the Caribbean region in Colombia, are well-positioned to boost the general introduction of PV energy. Well-designed auctions are an especially unique opportunity to expand solar photovoltaic energy into many new markets profitably. For instance, this kind of model was implemented in the Spanish island El Hierro, whereas in Galapagos, the contracting power process began in 2020.

— **Microfranchises**

This model is an alternative for NIZ, defined by their economic vulnerability, and allows, on the one hand, to keep the cashflow inside energization projects, and, on the other hand, to increase income of the communities, as it benefits employment generation. The microfranchise is a model where a small business and the owner of a company or patent reach an agreement. For the sector of energy access and in some Latin American countries, microfranchises are positioned as a strategy with great potential to involve the population (with or without business) in the commercialization of equipment compatible with solar systems (e.g., household appliances or appliances with productive purposes), in the provision of maintenance and repair services, in the collection of payments, and as a communication channel between the promoters and the communities. In Colombia, the role of microfranchisees may be assumed mainly by the locals. Here, the focus must be put in the participation of both women -as entrepreneurs- and regional governments. One of the most relevant characteristics of this model is its flexibility to adapt the context easily.

— **Pay As You Go (PAYG)**

The use of cell phones has driven this technological model, which allows the user to pay for the provided service (electricity) or to purchase some equipment. This model simplifies the management of work orders for equipment maintenance and of payment collections and invoices. To implement it, the installed equipment (solar system) must have an electronic system to facilitate their monitoring, as is mostly the case of Third Generation Solar Home Systems (3G-SHSs). In the Latin American context, the PAYG model is clearly a key factor in improving the efficiency of both human and economic resources to support sustainability and cash flow in electrification projects.

Technological sustainability: To achieve technological sustainability, not only the technical design and the quality of equipment and implemented technologies must be considered, but also the adaptation

of the energy solution to the local context. Therefore, the flexibility of power systems, the reliability of the service, the social acceptance of technology, the access to basic services in the household and small businesses, and the community infrastructure must be analyzed. Technological sustainability comprises several key points: (i) adapting the technological solutions to the user's energy need, that is, to the characteristics of the demand. This, in turn, will help the diversity of regions and contexts as much as flexibility. For instance, in the cases of acciona.org in Mexico and Peru, and the case of Energética in Bolivia, 3G-SHSs cover the basic needs of lighting and communication devices, which, in Colombia, would be applicable to the indigenous communities. (ii) Promoting energy efficiency to create a market for efficient appliances in NIZ. That way, those impacts on demand that condition the operation of implemented solutions would be avoided. The Caribbean Energy Efficiency Program Sustainable Energy (PEECES, by its Spanish acronym) is an example. It was implemented in the Atlántico, Córdoba and Bolívar departments to replace domestic refrigeration systems and could be reproduced in the rural and insular NIZ. (iii) Guaranteeing the technical quality of equipment for stand-alone and mini-grid solutions according to international standards (IEC), many of which have been already adapted to the Colombian context. Technical quality ensures the useful life of equipment and the social acceptance of technology, thanks to a low failure rate and the reliability of its operation. (iv) Including the household installations in the design to ensure the smooth operation of generation systems. (v) Guaranteeing the operations and maintenance works in the region. Microfranchises are a good solution, because thanks to the proximity between promoter and user, the maintenance and repair works inside the communities is easier.

Socio-economic sustainability: This aspect highlights the value of bottom-up strategies when designing projects. The implementation of participatory methods fosters regional development and inclusion, by recognizing the communities as changemakers of their own development, especially women, because of their high leadership skills for initiatives with social impact. This would help to strengthen the community spirit, to minimize the inequality gap and to promote a real implication in projects in the medium and long term. Additional actions would be required: First, the generation of employment opportunities (e.g. microfranchises, with a positive impact on the household economy), the promotion of capacity building in technology and management (data collection and analysis, entrepreneurship, business, tariffs and subsidies, among others) so that communities can contribute the general projects' management. Second, the creation of payment culture in these areas through awareness-raising campaigns; and third, ensuring the affordability of the electricity service once the economic vulnerability of rural communities and islands has been determined.

Environmental sustainability: The environmental dimension integrates two key factors in the improvement of rural electrification strategies in Colombia. First, synergies between the energy and environment sectors have to be established. There is a great potential for initiatives because the introduction of quality renewable technologies, the adequate installation of equipment and the promotion of energy efficiency to reduce CO_2 emissions to the atmosphere would help achieving a circular economy. The second factor has to do with the use of sustainable finance as a new opportunity for funding, in which energy access must be considered a goal. In other words, we propose the integration of the Country Objectives for this area and the local NDCs to make investments more attractive and to reduce the risk with national and international support -based on financial and technical cooperation-, as other countries are already doing.

In summary, Colombia has a great challenge ahead: the design of an energy policy that favors adequate holistic planning aiming at long-term sustainability. There are multiple factors that

contribute the improvement of energy access, but the will of decision-makers and the establishment of synergies among stakeholders are vital. Also, the actions to be implemented must answer above all the needs of the population and the context. This translates into the development of a process of incremental innovation in terms of organization, financing, technology, socio-economy and environment. Organizational innovation, since institutional quality is essential to the management of natural resources. Financing innovation to allow the participation of new stakeholders, the emergence of new business models and the access to new financing sources, putting people and environment at the center of decisions. Socio-economic innovation to reduce inequalities regionally and to generate opportunities for employment, taking into account the role of women as part of this change process. And environmental innovation, as an answer to the negative effects of climate change (that has an impact on every development process) and as a way to access new sources of financing and cooperation.

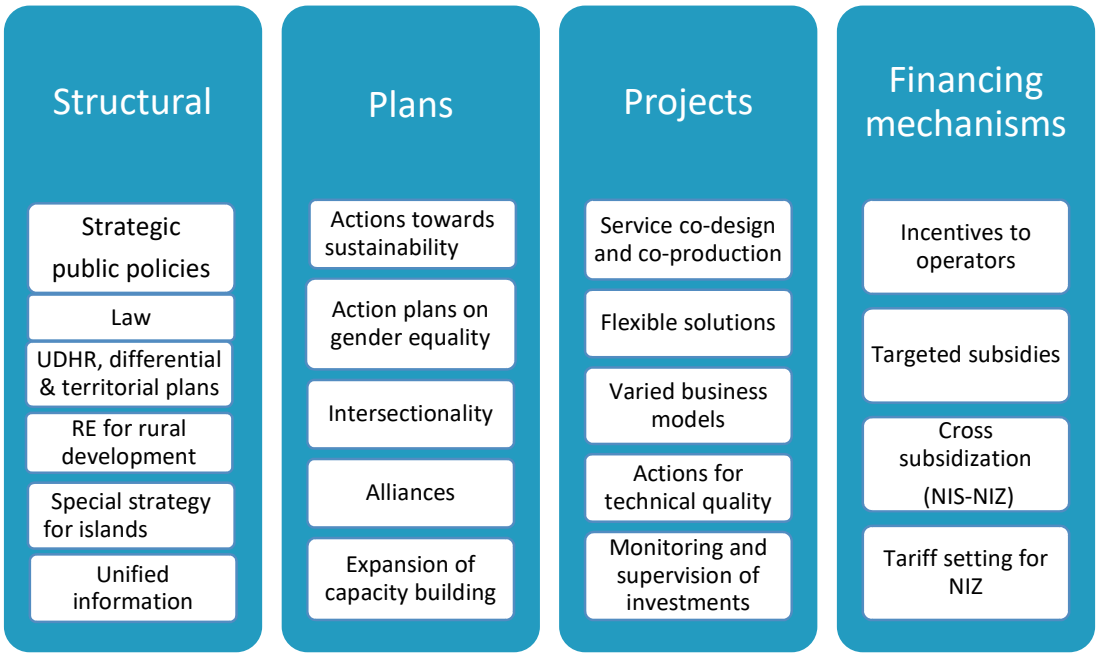
Recommendations for Public Policy Guidelines for the Sustainability of Rural Electrification Projects in NIZ

The expansion of energy coverage in Colombian NIZ is part of different plans, regulations and planning and financing mechanisms that were designed and improved to achieve broader coverage and the sustainability of electrification in NIZ. The cost of the electricity coverage expansion means that the current government will have to invest a total of 2.2 billion USD, which, added to the electrification barriers specific to the NIZ, the technical and economic limitations, and the social conditions, shows the need to improve the sustainability mechanisms that promote the development in the different NIZ.

The following recommendations are made in order to open the discussion and to get feedback from the different stakeholders interested in achieving sustainable electrification in NIZ. The guidelines have been structured according to five conditioning factors that determine the formulation of the recommendations:

- The results obtained in the study carried out by this consultancy.
- The complexity of the situation of NIZ in Colombia, characterized by the damage that the longest armed conflict in the world caused to these communities and for the post-conflict they live in after the peace agreement, under the control of multiple criminals and illegal forces.
- The understanding of the multidimensionality of rural and community life.
- The contributions of non-governmental organizations to rural development policies and to the peace agreement.
- The progress made by the Department of Mines and Energy through consultancies and diagnosis.

The following table summarizes the proposed guidelines:



Structural Guidelines

In the short term, it is advisable to formulate a public policy on energy access in NIZ, through the National Council for Social and Economic Policy (CONPES, by its Spanish acronym), and in the long term, to pursue a national energy access law.

This recommendation arises from the fact that, in Colombia, the public policy on energy access is carried out through projects, and the main obstacle for the projects is sustainability. One of the shortcomings found is the implementation of projects that had not been previously approved by the communities or in which there are no business models for the operation of the service. Hence, the need of formulating a public policy, in the form of a CONPES document of strategic importance, which compiles the existing regulations and includes the necessary guidelines to mobilize stakeholders, actions, and resources to ensure the sustainability of the service, thus achieving the transformation that communities require.

We start from the fact that energy access is a fundamental right recognized by the Colombian Constitution, and that, in NIZ, illegal forces and criminals are violating human rights. We also take into account the recommendation included in the national strategy for the protection of human rights. It recommends that policies incorporate the human rights-based approach, the provisions of the peace agreement and the government's pursuit of innovation in public policies. The goal of proposing a differential and territorial approach based on UNHR is to guarantee energy access according to the necessities and characteristics of every community. Also, innovation should be introduced in public policies, which would go hand in hand with the agreement signed between the government and the OECD (Organization for Economic Co-operation and Development). In addition, the use of renewable energies is encouraged as a rural development accelerator, which would depend on to the articulation of the different policies that promote renewable energies and those for rural development in Colombia.

An accessible, transparent and unified information about projects and rural electrification policies should be provided; one that connects the different sources of information (entities), thus allowing the registration and the access to project traceability, regardless of its source of financing or of the company that execute it. This information should be disaggregated and of interest for public policy decision making.

Strategical Guidelines for Plans

We recommend the inclusion of actions aimed at achieving sustainability in the National Rural Electrification Plan (PNER), integrating institutional, technological, environmental and financial aspects.

Also, energy policies, documents, and the PNER and its strategies should include cross-cutting gender matters in actions, that is, actions for women's empowerment. The PNER recommends training courses specific to women. However, this action should transcend the processes' promotion, in such a way that women, as a collective, may make their needs visible within the community, and use their skills to be empowered. Electrification projects should contain programs of interest for women, and the plan for capacity building should spread the gender guidelines defined by the Department of Mines and Energy to technical staff, public entities and private companies responsible for the operation of projects locally. All this to erase any sentence of technical speeches and documents of the project that revictimizes and discriminates women and girls.

A guideline is proposed to stress the importance of the coordination and the alliances to develop projects with a geographically-differentiated approach. This implies the coordination of different areas of the Department of Mines and Energy, the unification of finance facilities and the standardization of criteria for the implementation of projects, the coordination at local level with the territorial planning kit and with the programs of interest for the communities, especially those related to connectivity, health, education and rural development.

Another important guideline would be the strengthening local capacity building, with new training courses in conflict resolution and alliance making. Internal awareness-raising campaigns should be launched and training courses should take into account the traditions, symbols, languages, and appropriate communication channels of the communities. With respect to technology and government, it is necessary to develop the co-design and the co-creation methodology skills, the use of inclusive language and the application of protocols to work with victims of violence in communities. As for education, it is important to support the incorporation of the new energy and project management technologies, with a regional approach, at the professional and technical levels.

Strategical Guidelines for Projects

We deem that it is a priority to implement the co-creation and co-production methodology to ensure the sustainability of projects. These methodologies offer solutions to complex problems in an innovative and agile manner, which would stimulate the local ideas generation and would empower the community through active participation, listening and validation.

Flexible technical solutions must be designed to meet the demands and the socio-economic reality of users. The flexibility of the systems must allow a household to increase its energy demand and, at the

same time, to let the community access to solutions for small demand, because, due to their geographical and cultural characteristics, the demand of NIZ is lower than the standard.

It is important to promote adaptable business models, designed with the broad consensus of all stakeholders in NIZ, in particular of local ones. The models will depend on local conditions and on the capacities, but they might include microfranchises, auctions, ESCOs, Public-Private Alliances for development, social entrepreneurship, or community companies.

In addition, the technical quality of solar photovoltaic equipment must be guaranteed through the promotion of alliances with technology centers, universities and innovation centers that can evaluate technical parameters of the main components, and that carry out R+D+i and pilot projects about technologies and service operation plans. Also, the quality parameters to evaluate the projects must be based on the quality of equipment and on the support and experience of the manufacturer.

Another proposed line of action is the monitoring and supervision of investments through the incorporation of control systems, collecting information either with remote or on-site technologies or with community control systems. Also, information must be analyzed, and the users should be provided with two-way communication channels.

Recommendations for financing mechanisms

Lastly, these three recommendations aim to improve financing mechanisms:

We suggest the promotion of cross-subsidization from the National Interconnected System (NIS) to the Non-Interconnected Areas where poverty levels are high. This means that the analysis and the definition of energy needs is of the essence.

In the light of the problems observed in the operations, administration and maintenance of isolated photovoltaic systems (mainly in the case of mini-grids), we deem necessary the design of incentives to attract new operators, guaranteeing the return on the investment by setting a tariff that covers the costs of coverage in NIZ. Companies and social impact funds should be connected to allow the integration of components of the systems that cannot be easily financed, such as metering equipment. Also, project approval timelines should be shorter to help the relationship between companies and communities.

To conclude, as it was previously noted, it is important to calculate the tariff for NIZ according to the local characteristics, the demand, the operative and administrative costs, the solar radiation availability, and the technology used. This means that, in the case of photovoltaic systems, the tariff must be set according to the generated energy -as opposed to power.

These recommendations are part of a work in progress that does not end with this report. On the contrary, their goal is to open the debate, to help ideas generation and to favor mutual understanding to achieve the making of public policies on energy access. These guidelines have been formulated for different elements of public policy and are therefore specific actions that respond to the multiple dimensions of sustainability. We present the specific actions for every guideline categorized according to these dimensions. The guidelines are divided in three tables: guidelines for plans, guidelines for projects and guidelines for financing mechanisms. It should be clarified that the classification of actions is based on the immediate relationship within sustainability, not on the impact they may generate.

Guidelines for plans (PNER and Capacity-building Plan)

Guideline	Institutional	Technical	Financial	Socio-economic	Environmental
Promoting the integration of sustainability in the National Rural Electrification Plan (PNER).	• Entities' commitment	• Introduction of technological innovations	• Inclusion of innovative business models	• More capacity building • Design validation • Generation of entrepreneurship initiatives	•Prioritization of RE projects
Integration of the gender perspective in the National Rural Electrification Plan and in energy projects.	• Cross-cutting gender actions • Articulation of actions and programs • Awareness-raising of technical staff • Dissemination of the gender guidelines of the Department of Mines and Energy	• Co-creation and co-production spaces with women • Necessities and interests of the women affected by the armed conflict	• Business models in the energy sector for women	• Productive projects and service projects • Indicators for gender equality	
Promotion of cross-sectoral articulation, complementarity and coordination.	• Coordination of government agencies. • Promotion of articulation and communication from the Department of Mines and Energy • Consolidation of information • Building of local capacities	• Consolidation of projects' approval • KPT -with instruments update		• Coordination for actions prioritization	• Alliances for energy efficiency
Fostering local multi-stakeholder partnerships.	• Alliance training • Agreements and systematization	• Co-creation and co-production		• Awareness-raising of the importance of alliances	• Efficient stoves • Efficient appliances

Guidelines for electrification projects, PV System

Guideline	Institutional	Technical	Financial	Socio-economic	Environmental
Introduction of co-creation and co-production in projects	• Collective innovation spaces	• Co-creation and co-production • Publication of innovation methods			
Flexible technical solutions for user communities		• Community participation in the validation • Company Design = Grid Operator • Different technological solutions according to the local demand (energy steps) • Open innovation pilots			
Identification and implementation of adaptable business models	• Alliances for projects	• Open innovation skills	• Different business models • Attracting impact investors	• Involvement of communities in OAM from the start • Incentives for social entrepreneurship	• Promotion of investments in RE
Technical quality of systems	• Promotion of the R+D+i ecosystem	• Local quality assessments		• Parameters for quality assessments at community level	
Plan for capacity building on isolated electrification with renewable energies	• Including the study of RE in Engineering educative programs • Increasing of the programs offered by the National Learning Service (SENA) • Involvement of women's organizations	• Voluntary national certification system • Innovation skills • Awareness-raising on Human Rights		• Strengthening of community capacities • Gender-differentiated approach learning	• Energy efficiency capacities • Awareness campaigns about efficient energy use • Waste disposal
Monitoring and supervision of investments	• Alliances for ICT coverage and innovation • Dissemination of generated knowledge	• Development of monitoring systems with R+D+i • Definition of useful indicators		• Communication channels for complaints • Design of local monitoring systems	

Guidelines for financial mechanisms

Guideline	Institutional	Technical	Financial	Socio-economic	Environmental
Incentives for new grid operators		• Metering systems • Flexible solutions	• Tariff setting that covers the cost of coverage in NIZ • Including the transport costs according to the area • Private investors from the start • Attracting social impact investors	• Reducing the duration of projects' approval	
Targeted subsidies				• Subsidies to cover the cost of equipment replacement and OAM • Cross-subsidization, with certain focus	
Tariff calculation	• Setting of a tariff according to the subsidies that the state can provide	• Adjustment of the tariff to the local situation, the demand, the technology and the availability of solar radiation	• Setting of the tariff according to the energy - as opposed to power- to ensure an equal access to energy • Adjustment of the tariff to the operative and administrative costs of the NIZ		