UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

REGULATORY AND PLANNING APPROACH TO RURAL ELECTRIFICATION IN ISOLATED AREAS OF THE AMAZON: BOLIVIA, BRAZIL, COLOMBIA, ECUADOR AND PERU

THE CASE STUDY OF VILLA SANTA ROSA, PERU

Author: **Iván Vladimir Cortés Valencia**

Supervisor: **Andrés González García**

Madrid, July 2016

Official Master's Degree in the Electric Power Industry (MEPI)
Erasmus Mundus Joint Master in Economics and Management of Network Industries (EMIN)

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ABSTRACT

The Latin America and the Caribbean regions are very close to achieving universal energy access. As a matter of fact, access to electricity is currently 95% according to the Inter-American Development Bank (IDB). However, although efforts have been made by governments to achieve universal access to electricity, there are still approximately 34 million people that are not provided with modern electricity services. Many of these people live in rural areas that are found in isolated remote locations, as it is the case of some of the inhabitants of the Amazonian region.

Providing electricity services to communities in the Amazon rainforest is a big challenge. Besides the remoteness and isolation situation of these people, there are additional factors that hamper the progress of electricity access for these populations such as; the high poverty levels they face, the lack of road infrastructure to access to these communities, the low density of these areas and, not to forget that some zones of the Amazon are protected which restricts possible electrification projects. Despite these difficulties, there are rural electrification solutions that can be implemented to tackle this problem.

Lack of electricity access in the Amazon is not due to a techno-economical problem, as now there are different technologies available for this purpose. The establishment of sustainable business models that have an impact on universal electricity access in this area require a sound regulatory framework, which plays an important role as national policies and legislations, as well as, rules of remuneration, financing programs and; subsidies can either incentivize or deter companies for investing in rural electrification projects.

Nevertheless, undertaking rural electrification projects in the Amazonian rainforest can be a complicated, time and money consuming task especially due to the lack of perfect information because basic data is not easy to obtain such as knowing the approximate number of people, their electricity needs or even worst, the exact location of some communities. Moreover, since rural electrification depends on limited economic resources, the need of taking advantage of software tools that help overcome the lack of information and that support the electrification planning becomes essential so that these resources can be optimally allocated in order to obtain cost-efficient solutions.

In sum, this thesis aims to contribute to the development of rural electrification in isolated areas of the Amazonian region that delimits Bolivia, Brazil, Colombia, Ecuador and Peru. First, by studying the current electrification situation of the Amazon rainforest and the existing rural electrification framework of each country. Second, by presenting a case study of the Villa Santa Rosa community in Peru where the implementation of software tools will be described to be considered as an option to support rural electrification planning in the Amazon.

ACKNOWLEDGMENTS

First of all, I would like to thank my supervisor, Andrés González, for giving me the opportunity to work in this fascinating project, it has been a great learning experience and words can't describe how grateful I am to you. Thank you very much Andrés for your patience, support and comments provided to improve this thesis.

A special thank you to Pedro Ciller, who provided me his support whenever I had doubts in the implementation of the Reference Electrification Model in this thesis.

Also, I want to thank the EMIN and MEPI Coordinator, Luis Olmos, who works really hard to ensure the quality of both master programs.

Thank you to all my EMIN friends who have been a key element during this amazing two years' life experience. My special thanks go to Carolina Contreras, who has always been there for me since the beginning of the program, I am very thankful for all your advices and for your true friendship. I would also like to thank Deniz Sun, Francisco Fournier, Eddie Chou and Maja Lojanica, with whom I have shared such great moments.

Finally, I want to thank my family for all the love and support provided in these last two years that I have been far from home.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Modern energy services are crucial to human well-being and to a country’s economic development. The fact that today millions of people in developing countries don’t have access to electricity represents a barrier to economic and social development that leaves them in a situation of disadvantage. The International Energy Agency (IEA) estimates that 1.2 billion people around the world do not have access to electricity; and that around 80% of this people live in rural areas (OECD/IEA, 2015). This problem is mostly found in developing countries where access to affordable and reliable electricity services could have positive impacts by: reducing poverty and improving health, increasing productivity, enhancing competitiveness and promoting economic growth among other benefits.

Based on estimations made by the IEA, in 2013 lack of electricity access affected around 7 million people living in Bolivia, Brazil, Colombia, Ecuador and Peru as it is shown in Figure 1. People Without Access to Electricity. For these Latin American countries, providing electricity services to rural areas represents the biggest challenge to overcome in order to achieve universal electricity access, especially for Bolivia and Peru who registered rural electrification rates below 75% as it can be seen in Figure 2. Rural Electrification Rates, 20131. More specifically, electrifying isolated areas, remain the main obstacle for governments and distribution operator companies who in the past have focused on prioritizing the increment of electricity coverage by expanding the network.

Nowadays, if universal electricity access is to be attained in Latin America, new rural electrification planning approaches have to be conducted in order to minimize the investments by efficiently allocating the economic resources to increase electricity coverage, bearing in mind the different electrification technologies and systems that could be installed with the less environmental impact whenever is possible (Fuso Nerini, Howells, Bazilian, & Gomez, 2014).

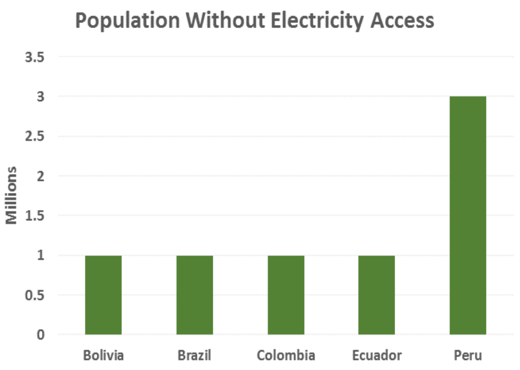

Figure 1. People Without Access to Electricity[1]

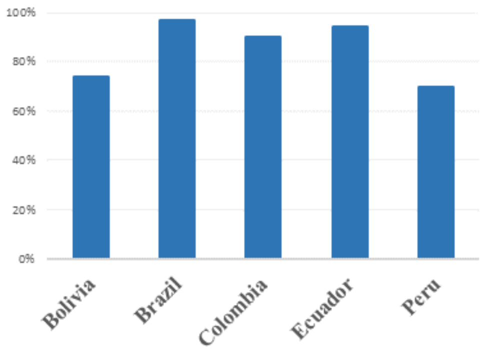

Figure 2. Rural Electrification Rates, 2013[1]

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[1] http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/

1.1 Motivation

This thesis project was carried out at the Institute for Research in Technology (IIT), which is part of the ICAI School of Engineering at Comillas Pontifical University, Madrid. The IIT's Universal Energy Access group has worked with different policy makers, companies and universities to reduce the lack of energy access in Africa, Asia and Latin America.

Rural electrification in the Amazonian region is an interesting research project due to the peculiar characteristics of this area; remoteness, low density, high poverty levels and, lack of road infrastructure, among others. These particularities require especial attention and create the need to propose a new methodology to support the electrification planning for these areas.

Bolivia, Brazil, Colombia, Ecuador and Peru have been chosen for this thesis as these countries are aware that the provision of electricity services to isolated areas in the Amazon rainforest remains a big challenge for them. Furthermore, these five countries have committed to the initiative Sustainable Energy for All (SE4ALL) launched by the United Nations Development Program. This initiative has as one of its main objectives to achieve universal access to modern energy services by 2030.

Not only governments have been making efforts to reduce the lack of electricity access but also, diverse international agencies and organizations support the ultimate goal of universal electricity access by providing resources such as; loans, credits and grants to rural electrification projects in developing countries.

The involvement of all of the different agents poses a great challenge but also provides opportunities to collaborate in order to increase electricity coverage by means of rural electrification. The special difficulties in the Amazonian region motivates this thesis for the development of a specific methodology that takes advantage of software tools already developed to support and improve the rural electrification planning in India, Ruanda or the Andean Peru, and extending their features for the specific requirements of this region, with the grounds of allocating optimally the economic resources in order to obtain cost-efficient solutions.

1.2 Objectives

The purpose of this thesis is to contribute to the study and development of electricity access, more specific, rural electrification in isolated communities of the Amazonian region that delimits Bolivia, Brazil, Colombia, Ecuador and Peru.

The specific objectives of this master thesis are:

- To understand the current situation of rural electrification in the Amazonian region and to identify its main challenges.
- To analyze the influence of existing energy policies, national objectives, regulatory approaches and funding programs of each country regarding the provision of electricity to rural communities and comprehend the key features of an enabling framework that would establish the foundations of sustainable electrification business models in the Amazon.
- To study the use of the Reference Electrification Model for rural electrification planning, and extend its capabilities so it can be applied in Amazonian area.
- To analyze, using the developed tool, an area of the Peruvian Amazon that is not provided with electricity services, assessing the suitability of the developed methodology to electrification planning in the Amazonian region.

1.3 Research Questions

To attain the objectives described before, this thesis will aim to address the following questions:

Question 1:

How do national policies influence the progress of electricity access to rural communities in the Amazonian region?

Question 2:

What software tools can be implemented to support the planning of rural electrification in the Amazonian region?

The first research question is crucial in order to understand the current rural electrification situation in each one of the five countries. To do this, the study of the existing regulatory framework complemented with academic literature review is going to be conducted in order to do an analysis and provide recommendations that could be implemented to accelerate the rural electrification development.

The second research question focuses on the study and application of software technologies that can be utilized to improve the rural electrification planning in rural areas of the Amazonian region. This question is addressed by applying different software tools in order to; obtain, estimate and gather basic data needed, more specifically; number of people, number of houses and location of houses, to run the Reference Electrification Model (REM) that will be used in this thesis to obtain the electrification planning of the area of study.

1.4 Methodology

In order to answer to the previous questions, two methods were selected. For the first question, literature review of rural electrification is conducted and also, the existing national policies and legislations of Bolivia, Brazil, Colombia, Ecuador and, Peru are studied and then, analyzed and compared under three aspects; electricity access regulation, funds and programs for rural electrification (either general or specific for the Amazon, if any) and, social tariffs in order to better understand the current situation of these countries. For the second question, in addition to literature review, the case study is carried out making use mainly of the following software technologies; LandScan, ArcGIS and the Reference Electrification Model (REM), these tools will be better explained in chapter 6 where the case study is presented.

The methodology applied in this thesis project can be better appreciated in the below figure:

Figure 3. Methodology applied

2. ELECTRICITY ACCESS

2.1 Universal Energy Access

Universal energy access is defined by the Advisory Group on Energy and Climate Change (AGECC) of United Nations (UN) as “access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses” (AGECC, 2010).

Worldwide, about 1.2 billion people do not have access to electricity and nearly 3 billion people rely on solid fuels (traditional biomass and coal) to meet some of their basic needs such as cooking and heating. The use of solid fuels intended for these purposes has a negative effect in the health of people because the smoke produced, kills an estimated of four million people a year and, it also causes a range of chronic illnesses (Practical Action, 2015).

Lack of modern energy access is a problem that is mostly found in the least developed countries where the poorest people are particularly disadvantaged. For instance, in urban areas, most poor people usually have at least some limited access to electricity, with poor reliability or frequent cuts. Many streets will show a mesh of wires that illegally connect households to an existing pole (while companies will struggle with non-technical losses that, in some countries, might account to a very significant share of their energy distribution). Un-electrified suburbs pose a challenge due to their low-income levels and informal settlement structure. Problems of urban areas lay more in adequate regulation, provision of efficient subsidies and need of appropriate business models for impoverished population. While in very isolated rural areas, where electricity access is often inexistent, and in areas where electricity is provided, it is usually with low quality and unreliable service and electrification faces the additional challenge of a much higher cost of provision of adequate service.

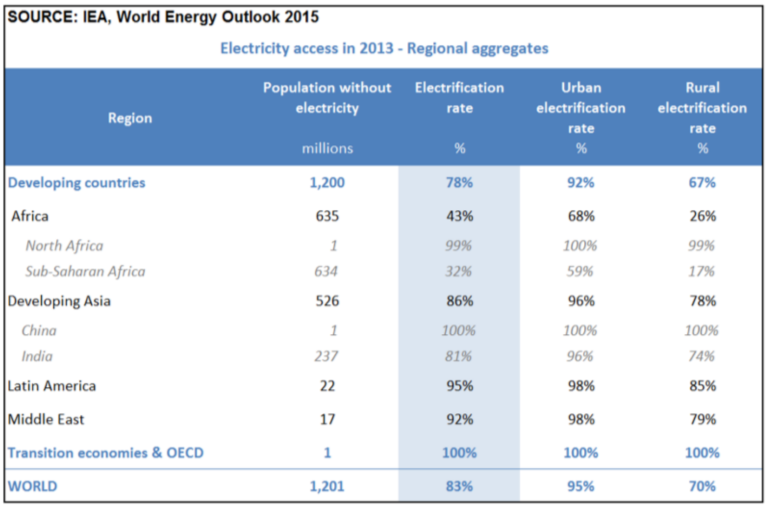
There are positive effects that modern energy access can provide to society as it develops the economic growth, enhances health and life conditions, provides better services in facilities such as schools and hospitals and improves the connectivity of telecommunications allowing rural communities to be less isolated.

2.2 Rural Electrification

Rural electrification is defined as the process of providing electricity services to communities located in isolated or remote areas of a country. These isolated communities are usually poor which leaves them in a disadvantaged situation in terms of electricity access compared to marginal urban areas.

In rural areas, physical access is often non-existent and in case they do have access to electricity, it tends to be of inadequate quality with an unreliable service, and prone to frequent failure. Figure

4. Worldwide Electricity Access 2013 shows the differences between urban and rural electrification rates around the world.



SOURCE: IEA, World Energy Outlook 2015

Electricity access in 2013 - Regional aggregates

Region	Population without electricity millions	Electrification rate %	Urban electrification rate %	Rural electrification rate %
Developing countries	1,200	78%	92%	67%
Africa	635	43%	68%	26%
North Africa	*1*	*99%*	*100%*	*99%*
Sub-Saharan Africa	*634*	*32%*	*59%*	*17%*
Developing Asia	526	86%	96%	78%
China	*1*	*100%*	*100%*	*100%*
India	*237*	*81%*	*96%*	*74%*
Latin America	22	95%	98%	85%
Middle East	17	92%	98%	79%
Transition economies & OECD	1	100%	100%	100%
WORLD	1,201	83%	95%	70%

Figure 4. Worldwide Electricity Access 2013

Sub-Saharan Africa is the most affected region worldwide by the lack of electricity services as in 2013 only 32% of its total population had access to electricity (OECD/IEA, 2015). In the case of Latin America, it reached a 95% electricity access rate and according to the IEA it will be the first region in the developing world to attain universal access to electricity.

2.3 Electricity Use in Rural Areas

The main use of electricity in rural areas is lighting for domestic, public services and productive activities but, depending on the size and the economic resources of the communities, electricity can also be used for different purposes. For households besides lighting, electricity is commonly used for television, radio, fans and mobile phones when these are available (IEA, 2010). For public services and productive uses, electricity is generally used to power hospitals, schools, farms and small businesses, among others.

The IEA defines three incremental levels of access to energy services according to different human needs. The first relates to basic human needs, the second one to productive uses and the third one to modern society needs. (AGECC, 2010). More specific, the IEA definition of access considers a minimum level of electricity consumption and makes a distinction between urban and rural areas. For rural households, the initial level of electricity consumption per year is assumed to be 250 KWh. This level of consumption could provide the use of a floor fan, a mobile telephone and two compact fluorescent bulbs for about five hours per day (IEA, 2011).

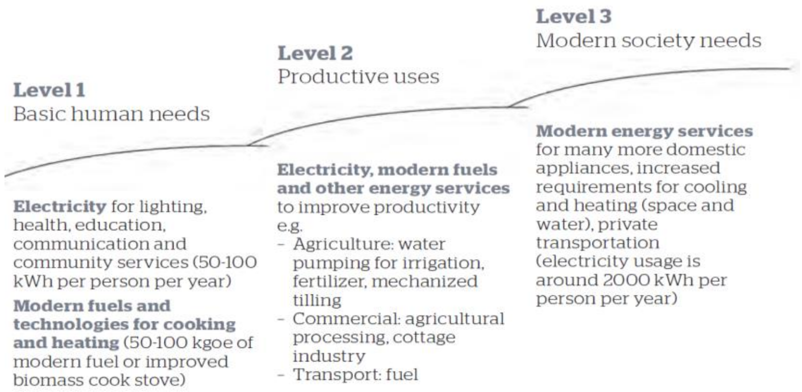


Figure 5. Incremental Levels of Access to Energy Services

Nevertheless, the use of electricity is sometimes limited to the installed capacity and the energy available of the system that provides electricity services in rural areas. It is well known that these systems are characterized by a low quality, intermittent and unreliable service with only few hours of service per day which reduces the economic growth and the further benefits that the electrification process would bring to the society.

2.4 Main challenges Faced by Rural Communities

Rural communities face different challenges, on the one hand is that these communities are usually located in remote areas and sometimes are not big in size. On the other hand, there is the poverty situation of these communities and the lack of economic resources which represents a barrier for them, making it harder to benefit from sustainable and profitable electrification projects.

The first has to do with the geographical location where the communities are found, meaning that sometimes as these are located in high mountains, jungles or rivers which are difficult to access and usually there are no distribution lines close to them so they can be connected to national or regional networks. Furthermore, the fact that communities are small in size and sometimes even dispersed among each other results in another challenge, as these communities tend to be the last to benefit from electrification plans or programs that might be available. The usually accompanying lack of economic resources poses another big challenge because by not having enough means to pay for the service, and if there are not the right subsidies in place, distribution companies will not have enough incentives to expand the network to rural areas as these companies might think that these projects are not economically viable enough for them.

2.5 Benefits Obtained

Access to electricity has positive impacts on society as it improves living conditions, and it can also increase economic growth. By having access to electricity, rural areas benefit from more light hours as they can make use of bulbs at night either for leisure or educative activities like studying or reading (World Bank Independent Evaluation Group, 2008). Moreover, living conditions of the rural areas are improved with education and health care, in schools by being able to have more light hours and the possibility of having computers and in health care as the hospitals improve their services by being able to make use of electric devices to maintain vaccines and other medicines in proper temperature conditions. At household level, living conditions are improved with leisure activities such as listening to radio or watching television, which can also be useful to be better informed about the weather and reduce the impact of imminent natural disasters, reducing also the educational, informational and digital divide, Moreover, the use of fans provides comfort, as these can be very appreciated in very hot areas.

Furthermore, access to electricity can allow and increase economic growth in rural areas as productive activities can be performed more efficiently by making use of electricity to power machines or electrical tools needed to run small businesses, farms or workshops that generate income for these communities.

2.6 Electrification Modes and Technologies Available

Lack of electricity access in rural areas is not restricted due to a technological problem as there are different types of technologies that can be implemented to provide electricity services. The choice of a technology to be installed depends on different criteria such as; economic aspects, environmental concerns, quality and reliability of supply, and size of the community among others. These criteria can be chosen by the preferences of the decision makers involved in the selection of the electrification method, where choosing the technology to be installed is one of the most important decisions in rural electrification. The provision of electricity services can be performed by; grid expansion, diesel generators, renewable energy sources and/or hybrid systems.

2.6.1 Grid Extension

It is the "*business as usual*" option, it consists on expanding the existing national or regional networks to connect communities to electricity. It is often the least-cost option in rural areas with high populations densities (if the communities are near the grid) but, in order to be feasible, the existing system needs to be functioning well enough to support the additional capacity and demand.

2.6.2 Diesel

It is the most used technology used for rural micro-grid electrification projects, one of the main advantages that this technology offers is the reliability and the quality of supply that it can provide (if there is enough fuel available). Nevertheless, it has a negative environmental impact and besides, operational costs tend to be high due to the cost of fuel and transportation costs.

2.6.3 Renewable Energy Sources

- **Solar Photovoltaic:** is commonly the most preferred one at domestic level for isolated communities where there is enough sunlight during the year. Solar photovoltaic technology can be used as a Solar Home System (SHS) for supplying electricity to a single house, which can power light bulbs and small appliances such as radios, televisions, cellphones or fans (IEA, 2010). And in a larger scale, solar can be installed as a micro-grid to power electrical devices such as refrigerators, water pumps, computers, etc. in a community. One of the main problems of this technology is its limited capacity and the storage of the batteries. Therefore, when excessive use of the consumers occurs (especially at night when there is no sun), batteries can discharge beyond their minimum level reducing their life cycle.

- **Wind energy:** it is a renewable energy that has a lot of potential in areas where high wind resources are available. This technology is one of the most cost-effective ones to install and operate. Wind energy can be installed with one or several turbines, and in a small or large scale to power remote communities. One of its main drawbacks is that it requires periodic maintenance, which if installed in isolated areas, can result in high maintenance costs.

- **Micro hydropower:** this technology is used to power communities located near a river. The capacity of this plants varies going from 500 KW up to 10MW. One of its main advantages is that it can generate electricity continuously during the day and night. However, it is often criticized because when installed as run-of-the-river plant, the installed capacity is not always enough to meet the demand of the communities at peak hours and vice versa, in off peak hours the plant can generate electricity in excess (IEA, 2010).

- **Biomass:** this technology is already being used by rural communities for cooking and heating. However, it could also be applied to provide electricity in areas where there are abundant biomass resources such as; forest residues, rice, cashew nuts, coconuts shells, etc. This technology is sometimes more competitive than diesel as the cost of unit generated with biomass can be lower than diesel generation.

2.6.4 Hybrid systems

These systems are a combination of installed technologies that are intended to ensure the continuity of electricity supply by supporting generation of it with different but complementary plants. This improves the reliability of the system as is the case of intermittent technologies especially wind and solar that are sometimes unable to generate electricity when there is no sun or wind therefore a complementary technology is used to support these technologies. The most common hybrids systems found in rural communities are; wind + diesel, solar + diesel, wind + solar, micro hydro + wind or solar.

2.7 Programs and Sources of Finance

In 2011, the IEA estimated that an approximate investment of $1 trillion dollars would be required to achieve the goal of universal electricity access and clean cooking facilities worldwide by 2030. This represented an additional $30 billion dollars per year to provide universal electricity access by 2030 and, an additional $3.8 billion dollars per year to provide clean cooking facilities by 2030, compared to the estimations made in 2009 (IEA, 2011). These investments are considered small compared to the global energy-related infrastructure investment, being equivalent to around 3% of the total.

Less developed countries are usually the most affected by the lack of electricity access where sometimes there are aggravated by the lack of enough economic resources to tackle this problem, extending the grid, which has always been the most common approach. Moreover, the lack of commitment by governments and without proper policies in place, the development of electricity access is quite limited. Nowadays, there are agencies and organizations around the world that promote universal energy access. For instance, the United Nations (UN) through the Secretary General, in 2011 launched the initiative Sustainable Energy for All (SE4ALL), which created a multi-stakeholder partnership between governments, the private sector, and civil society oriented to achieve 3 objectives by 2030:

I. Ensure universal access to modern energy services.
II. Double the global rate of improvement in energy efficiency.
III. Double the share of renewable energy in the global energy mix.

Moreover, different agencies and institutions provide financial resources such as; loans, credits and grants to developing countries in order to reduce poverty and promote development therefore, rural electrification projects can obtain one of these financial resources. Furthermore, there are also private energy companies engaged up to a certain point to provide access to electricity in some communities in developing countries. Also, there are Non-Governmental Organizations that work to promote energy access and, consulting firms, research centers and institutions, and different agents that are becoming part of the development of rural electrification and energy access.

3. THE AMAZONIAN RAINFOREST

The Amazon is a vast region located in South America, it spans across nine countries: Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, Guyana, Suriname and French Guiana (Figure 6. Amazon Rainforest). The Amazon rainforest covers 5,500,000 km^2 which is around 40% of the total surface in South America. More than 30 million people, including 350 indigenous and ethnic groups, live in the Amazon and depend on nature for agriculture, clothing and traditional medicines. The majority live in large urban centers but since the Amazonian rainforest has a vast extension, there are communities that are found in remote locations isolated from urban areas. For instance, in the Brazilian Amazon the last census determined that there are 20,998,731 people: 14,346,450 living in villages, towns and cities, and 6,652,281 living in rural areas[2].

Figure 6. Amazon Rainforest

The Amazon comprises the largest and most biodiverse tract of tropical rainforest in the world; as a matter of fact, one in ten known species in the world lives in the Amazon. This constitutes the largest collection of living plants and animal species in the world, being one of the most important reasons why the Amazonian rainforest is a protected area.

Deforestation is considered the biggest problem in the Amazon. Vast areas of rainforest are destroyed by clearing for agriculture, illegal logging for timber, and for industrial or urban development. Another big problem in the Amazon is agriculture as global demand for food increases, forests are often cleared to make way for grazing land or soya plantations[3].

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[2] http://www.greenpeace.org/international/en/campaigns/forests/amazon/people-of-the-amazon/

[3] http://www.wwf.org.uk/where_we_work/south_america/amazon/

3.1 Rural Electrification in the Amazon Rainforest

Provide electricity access to isolated areas in the Amazon is a big challenge. Besides, some of these remote communities are small in size which also constitutes a barrier for governments and/or distribution operators to give them priority to benefit from electrification programs. Even if there were enough people that would allow economic viability for these projects, these couldn’t be carried out because most of the countries protect the Amazon rainforest which restricts the expansion of the networks or settlements of new lines that could provide electricity services. Furthermore, most of the communities located in the Amazon register poverty levels which leaves them in a situation of disadvantage and social exclusion (Di Lascio & Fagundes, 2009). For these and more reasons the Amazon is a very interesting area of study, these peculiarities propose more challenges for the electricity access situation nevertheless, there are solutions that can be implemented in order to provide this service.

3.1.1 Bolivia

The Amazon rainforest in Bolivia is found in the north of the country and it covers completely the departments of Pando and Beni, and partially the department of La Paz (Figure 7. Regions of Bolivia). It has an extension of 824,000 km^2, which represent 75% of the total territory of Bolivia, it has the lowest density in the country by having less than 2 inhabitants per km^2. In the Amazon region, live around 30 indigenous groups which makes it the region with higher cultural diversity.

Regarding electricity access, in 2010, the departments that registered the lowest national rates of rural electrification were Pando and Beni, both belonging to the Amazonian region of Bolivia, with only 17% and 16% respectively (Figure 8. Rural Electricity Access by Department in Bolivia 2010).

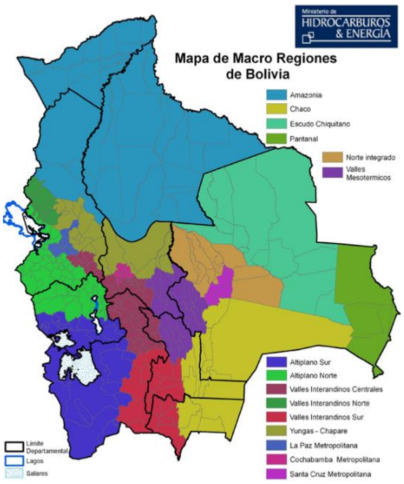

Figure 7. Regions of Bolivia

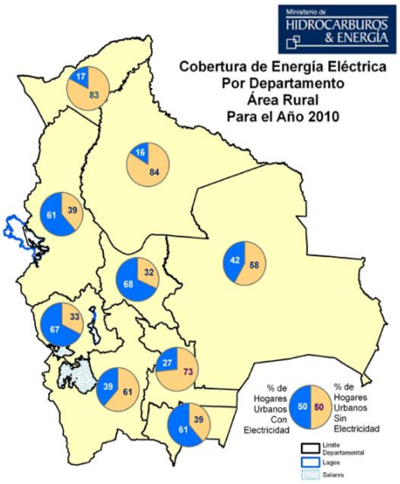

Figure 8. Rural Electricity Access by Department in Bolivia 2010[4]

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[4] Source: Bolivia with Energy Universalization Plan

Bolivia is one of the poorest countries in Latin America, even though poverty levels have been reduced in the past years, there is still a lot of progress to be made. In 2012, the poverty percentage that Bolivia achieved was 44.9% being the Departments of Beni and Pando two of the poorest ones in the country with poverty levels above 50% (Figure 9. Percentage of Poor People, Bolivia 2012).

Even though there is not much literature available about the Amazonian region of Bolivia, it is well known that it is characterized by the lack of electricity access and by having high poverty levels. In fact, this correlation that exists between electricity access and poverty levels affects all the country where the poorest communities are also the communities with the lowest electrification rates (Gomez, 2012).

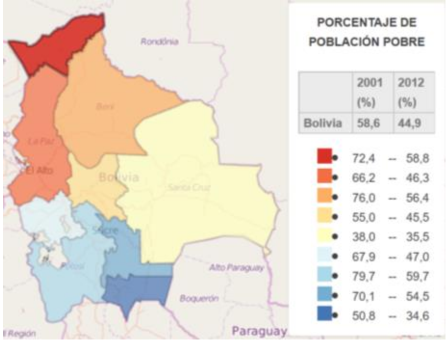

Figure 9. Percentage of Poor People, Bolivia 2012[5]

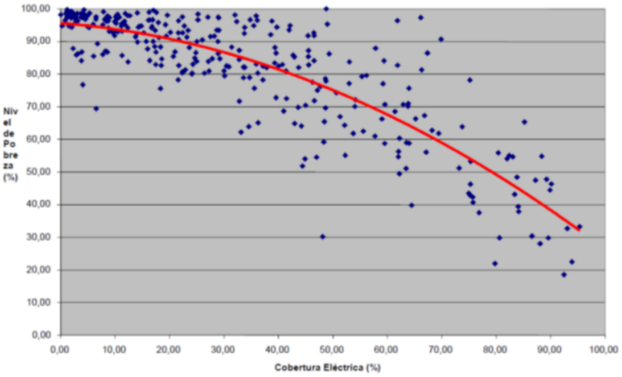

Figure 10. Bolivian Municipalities: Electricity Access vs Poverty Levels

3.1.2 Brazil

The Amazon rainforest of Brazil is found in the north part of the country and it covers completely 7 states and most part of two more states, it has an extension of about 3.8 million km^2 and it is characterized by; a very low population density of about 4 inhabitants/km^2, low income levels and, a complicated topography (Gómez & Silveira, 2015).

Generally, in remote zones of the Amazon region, households are located in areas that are difficult to access, typically found in dense forests or close to large rivers. In addition, the low population density and dispersion in these rural areas makes it difficult and expensive to provide electricity services. As a result, most of the Amazon villages and remote houses where only one family lives, do not have access to electricity yet. Moreover, the high price of fuel is a big obstacle that hinders the transport of people and goods leaving these communities isolated and with economic

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[5] Source: Statistics National Institut, Bolivia, obtained from: http://geo.ine.gob.bo/cartografia/inicial_controller/porcPobr3z4

difficulties therefore, they are found in a disadvantaged situation of poverty and social exclusion (Di Lascio & Fagundes, 2009).

In 2010, about 930,000 people living in rural areas of the Brazilian Amazon did not have access to electricity (Gómez & Silveira, 2015). In other words, only about 50% of these rural municipalities had achieved electricity access rates above 80% and, in 10% of the municipalities, electricity coverage was below 50% (Figure 11. Electricity coverage in rural areas at municipal level in the Amazon region, 2010).

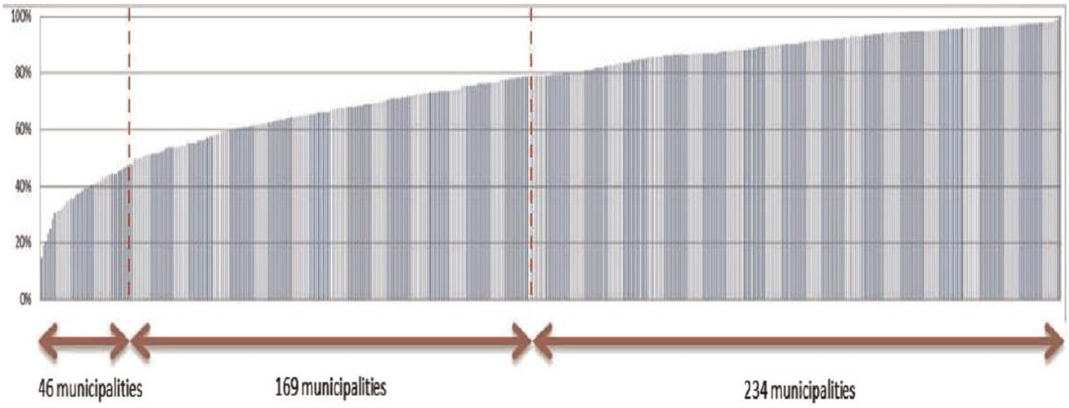

Figure 11. Electricity coverage in rural areas at municipal level in the Amazon region, 2010

3.1.3 Colombia

The Amazonian region in Colombia is located in the south of the country and it has an extension of 315,000 km^2, which comprises 42.2% of the national territory. It is characterized by an extensive area of old-growth forests with a hot and humid weather. Furthermore, it has the lowest density population in the country with an approximate population of 968,000 inhabitants which results into a density of 3.07 inhabitants/km^2. For these reasons, it is the less electrified and the most difficult to connect to the national network (UPME, 2006).

In 2012, the departments of Vaupes, Amazonas and Putumayo had the lowest national electricity access rates with only 65%, 57% and 61% respectively. These three departments are located in the Amazonian region (Figure 13. Electricity Access by Department, Colombia 2012). Moreover, network expansion is not possible because some areas of the Amazon are protected. Therefore, the municipalities that are found in the Amazonian region have low possibilities to be interconnected to the national system (Figure 14. Municipalities Interconnection Situation to National Network, Colombia 2012).

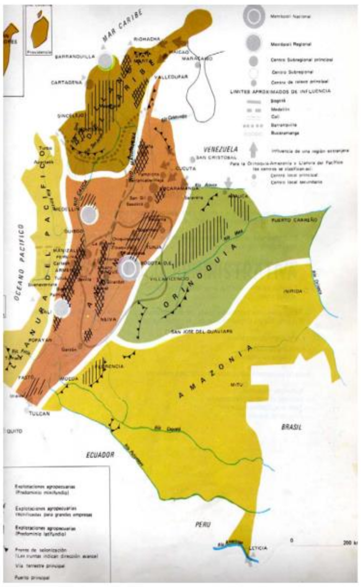

Figure 12. Natural Regions of Colombia[6]

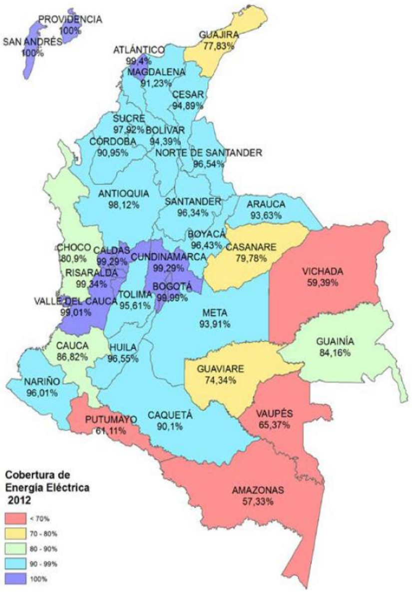

Figure 13. Electricity Access by Department, Colombia 2012[7]

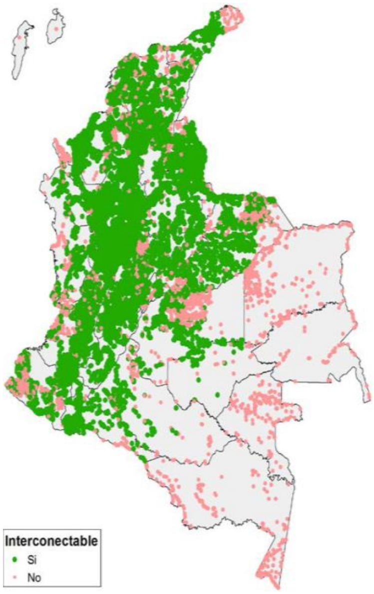

Figure 14. Municipalities Interconnection Situation to National Network, Colombia 2012

3.1.4 Ecuador

The Amazonian Region of Ecuador (RAE) is located in the east part of the country and covers the provinces of Orellana, Pastaza, Napo, Sucumbios, Morona Santiago and Zamora Chinchipe (Figure 15. Amazonian Region of Ecuador). It has an approximate area of 120,000 km^2, which represents 48% of the total surface of Ecuador.

The RAE is the home of several groups of indigenous people and, most of them are found in a disadvantage situation by not having access to basic services such as; potable water, electricity, housing, hospitals and schools (Petro Amazonas EP, 2013). Most of the communities located in the RAE are characterized by having high poverty levels. In 2014, the Amazonian region of Ecuador registered 47.7% of poverty level which is higher than the national average of 25.8% (INEC, 2014). The Amazonian provinces that are the most affected are Morona and Napo where more than 50% of their populations are poor (Figure 16. Poverty Rates by Province in Ecuador, 2014).

Likewise, in 2015, Napo, Pastaza and Morona Santiago which are three provinces of the Amazonian region, registered electrification rates lower than 91%, being also the lowest ones at national level (Figure 17. Electricity Access by Province in Ecuador, 2015). Rural electrification solutions based on network expansion have been prioritized in the past which left isolated areas without electricity services, as it is no longer economically viable to expand the network to remote locations[8].

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[6] Source: Indicative Plan of Electricity Coverage Expansion 2006-2010

[7] Source: Indicative Plan of Electricity Coverage Expansion 2013-2017

[8] http://www.energia.gob.ec/electrificacion-rural-con-energias-renovables/

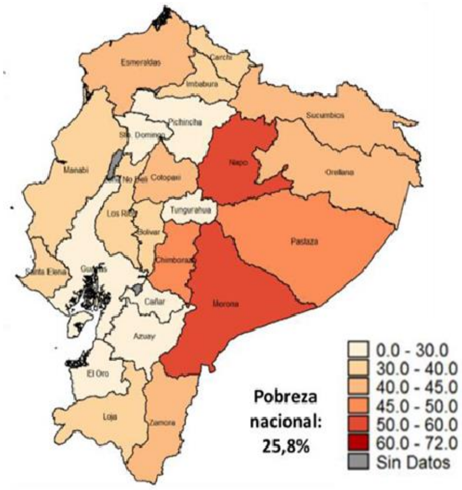

Figure 15. Amazonian Region of Ecuador

Figure 16. Poverty Rates by Province in Ecuador, 2014

Nowadays, efforts are being made to electrify isolated areas of the RAE by means of renewable energy technologies however, not all of these have been successful. As an example, in 2010 was launched the Program of Rural Energization for Households in the Amazon (PERVA) which intended to provide modern energy service to 15,000 households in 18 months. Unfortunately, this program was later suspended due to previous bad experiences of rural electrification projects in isolated areas where distribution operators ignored these systems by not performing the adequate operation and maintenance of the systems and also, they were not charging users for the cost of the service. As a result, these projects were considered as not sustainable for the government therefore, new rural electrification projects were suspended until a well-defined sustainability model was established (Ten, 2013).

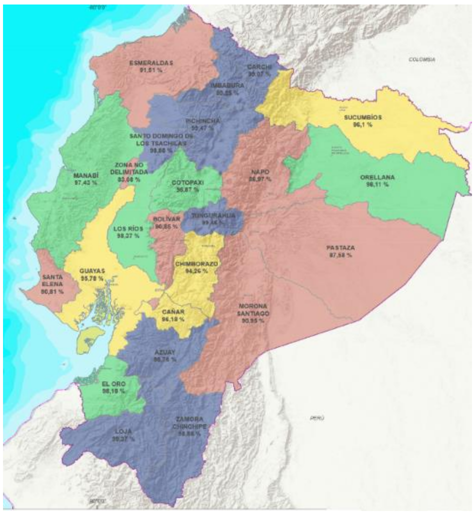

Figure 17. Electricity Access by Province in Ecuador, 2015 [9]

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[9] Source: ARCONEL http://www.regulacionelectrica.gob.ec/wp-content/uploads/downloads/2015/10/Cobertura-de-Servicio-El%C3%A9ctrico.pdf

3.1.5 Peru

The Amazonian Region of Peru covers an area of more than 728,000 km^2 formed by dense rainforests, it is the second country with the biggest Amazonian extension territory after Brazil. The Amazonian region of Peru is one of the areas with high biodiversity and also, the area in Peru with the lowest number of inhabitants. Nevertheless, it is also the most diverse in the country anthropologically speaking as it is the home of several indigenous groups of people.

The Amazonian region of Peru is located in the east part of the country (Figure 18. Natural Regions of Peru) and it covers completely 5 departments and partially a few more delimiting the latter. In terms of electricity, in 2014, the departments of Amazonas and Loreto registered the lowest electrification rates (served through public network) with 74.7% and 77.6% respectively (Figure 19. Access to Electricity by Public Network in Peru, 2014) which is below the national average of 92.9% (INE, 2015)

Figure 18. Natural Regions of Peru

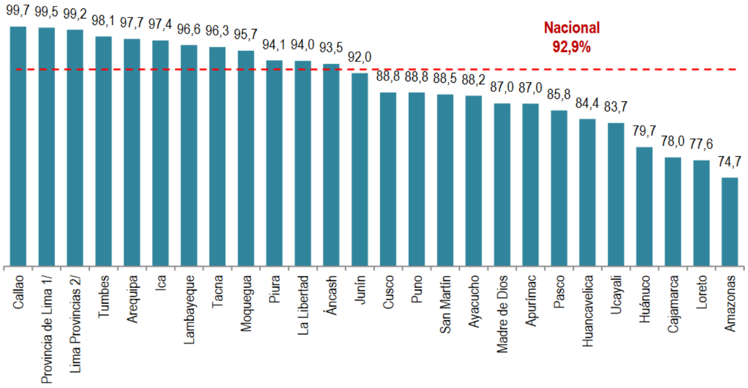

Figure 19. Access to Electricity by Public Network in Peru, 2014

This current situation shows the need of providing electricity services to the Amazonian region by means of off-grid solutions. The government of Peru tries to solve this problem and now in its rural electrification national plans, projects of rural electrification projects in the Amazonian region with renewable technologies, especially solar systems, are being promoted.

4. RURAL ELECTRIFICATION REGULATORY FRAMEWORK

4.1 Bolivia

The Plurinational State of Bolivia is a developing country located in the center zone of South America with an estimated population of 10 million people in 2012. It has a total area of 1,098,581 km^2 and it is bordered by Brazil to the north and east, by Paraguay to the southeast, by Argentina to the south, by Chile to the southwest and by Peru to the northwest.

Bolivia is a democratic republic whose capital is Sucre. It is divided into 9 departments, 112 provinces and 339 municipalities. The main economic activities of Bolivia include agriculture, fishing, mining, and manufacturing. In 2015 the total GDP was $33.537 billion with a GDP per capita of $2,914.

Bolivia registers one of the highest poverty levels in South America. In the Human Development Index (HDI)[10], Bolivia's value for 2014 is 0.662 which even if it is in the medium human development category, it is below the average of 0.748 for countries in Latin America and the Caribbean (UNDP, 2015a).

4.1.1 Rural Electrification Situation

Bolivia has an estimated population bigger than 10 million people and in 2010, approximately 3.5 million of Bolivians lived in rural areas representing more than 850,000 households of which only 50.8% had access to electricity services. Electricity access rates have been increasing in the last decade in both urban and rural areas. The progress in rural areas has been very significant increasing from 30.9% in 2004 to 64.4% in 2014 (Gomez, 2012).

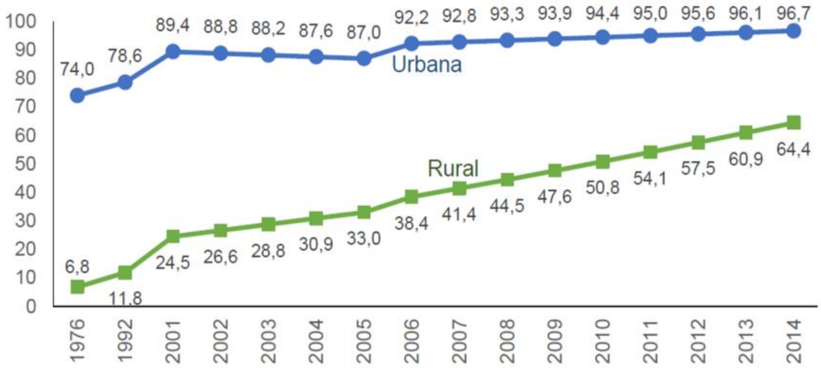

Figure 20. Urban and Rural Electricity Access in Bolivia

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[10] The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living.

This progress was achieved because the Bolivian government has been implementing plans and programs that promote universal electricity access assuming the responsibility of providing electricity services, as it is defined in the article 20 of the New Politic Constitution of the State:

"Every person has the right to universal access and equitable to basic services through public, mixed, cooperative or community entities, and in the case of electricity, the service can also be provided by private companies through contracts. Furthermore, it is responsibility of the government in all its levels, to provide basic services that must be aligned with the principles of; universality, responsibility, accessibility, fair tariffs and necessary coverage, with social participation and control through the National Enterprise of Electricity (ENDE)".(Asamblea Constituyente de Bolivia, 2008).

However, despite the progress obtained in electricity access, in 2015 there were still 35.6% of Bolivians living in rural areas that didn't have access to electricity. Nowadays, the government is working on achieving universal electricity access through different programs and national targets, as these will be described in the following sections.

4.1.2 National Energy Plan

The Ministry of Hydrocarbons and Energy (MHE) is the public authority responsible of creating and evaluating policies, norms and plans for the energy sector in Bolivia. Within the MHE, the Vice minister of Electricity and Alternative Energies (VEEA) manages the electricity division and has defined responsibilities as stated in the article 62 of the Supreme Decree 29894 (Morales, 2009):

- To define, design and evaluate policies for the electricity sector in concordance with the universality criteria.
- To propose policies oriented to achieve universal access and equitable to the basic service of electricity.
- To formulate policies, programs and projects of electrification for the whole country.
- To incentivize the integration of new electrification technologies with a sustainable use of renewable resources.
- To establish short, medium and long term targets to increase the coverage of electricity access in the whole country, among others.

Under this scheme, the MHE published in January 2014, the Electric Plan of the Plurinational State of Bolivia 2025.

4.1.2.1 Electricity Plan of the Plurinational State of Bolivia 2025

This plan was elaborated by the vice minister of electricity and alternative energies and approved by the Minister of Hydrocarbons and Energy. Its main objective is to establish general guidelines for the development of the electric infrastructure in order to satisfy national demand, impulse productivity in the sector, achieve a national electricity integration and universal electricity access with a vision of exports of the electricity surpluses (MHE, 2014).

This electricity plan is aligned with the objectives of the Patriotic Agenda 2025 that is intended to obtain benefits for the development of the nation in order to commemorate the bicentenary independence of Bolivia in 2025. In terms of universal electricity access, the Electric plan of Bolivia 2025 establishes as a main target to achieve universal electricity access by 2025. This will be accomplished by following the next lines of action:

a) To identify potentialities, energy needs and applicable technologies in function of regional characteristics.
b) To develop electrification plans by working close with governments of municipalities and departments in order to accelerate the universalization of electricity and, to define targets, budgets and chronograms.
c) To support regional governments in the performance of their responsibilities in terms of rural electrification.
d) To delimit responsibilities and the coordination among the different types of entities involved in the development of infrastructure of electric coverage and strength the institutional capabilities in departments and municipalities, facilitating the development of electrification projects.
e) To establish the minimum technical parameters needed to be applied at a national level for electrification projects and to upgrade the unitary prices of the rural electrification infrastructure.
f) To establish financing strategies for the implementation of plans and programs needed to achieve universal electricity access by 2025.

This will be obtained through a national and regional planning where the electricity demand can be reflected for urban and rural areas also, the electricity needs of the population can be identified considering its growth and the new number of households, taking into account the most disperse, vulnerable and less populated areas of Bolivia in order to benefit from energetic and economic resources and, available adequate technologies that will allow to achieve the established targets.

4.1.3 Rural Electrification Targets

Today, there are two national plans that have set electricity access targets for urban, rural and national levels to be attained in the next years. In general, all of these targets are oriented to accelerate significantly the progress of the main objective that is to reach universal electricity access by 2025 (Table 1. Electricity Coverage Targets Bolivia).

Plan	Targets for 2020	Targets for 2025
Bolivia with Energy Universalization Plan	Urban: 100% Rural: 87% National 96%	Universal Electricity Access
Electricity Plan of the Plurinational State of Bolivia		

Table 1. Electricity Coverage Targets Bolivia

The plan under which there are guidelines established to attain this targets is The Electricity Plan of the Plurinational State of Bolivia 2025. This document provides information about the percentages of electricity access to be attained, the number of estimated households that will be provided with electricity services and, the amount of investments needed to do so. Overall, the electricity access targets are shown in Figure 21 Urban and Rural Electricity Coverage Expected in Bolivia 2010 – 2025.

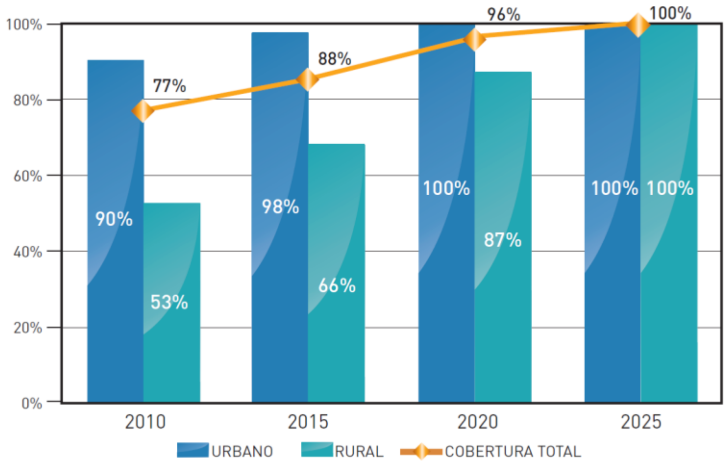
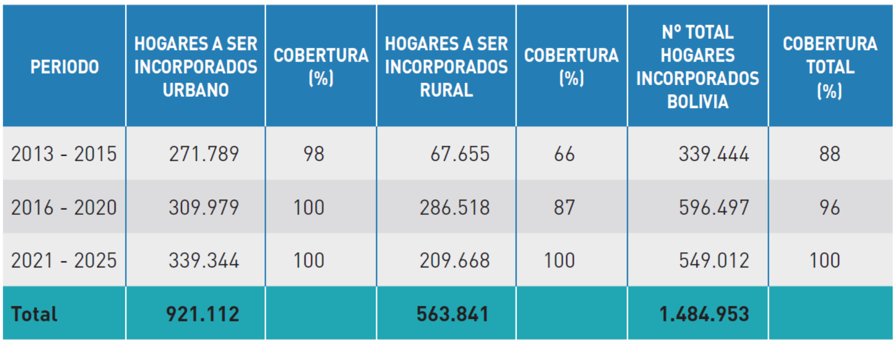


Figure 21 Urban and Rural Electricity Coverage Expected in Bolivia 2010 – 2025

This projection of electricity access is based on estimations that were made taking into account future number of people and households that will be electrified for both urban and rural areas as shown in Figure 22 Expected number of households to be electrified in Bolivia 2013-2025.



PERIODO	HOGARES A SER INCORPORADOS URBANO	COBERTURA (%)	HOGARES A SER INCORPORADOS RURAL	COBERTURA (%)	Nº TOTAL HOGARES INCORPORADOS BOLIVIA	COBERTURA TOTAL (%)
2013 - 2015	271.789	98	67.655	66	339.444	88
2016 - 2020	309.979	100	286.518	87	596.497	96
2021 - 2025	339.344	100	209.668	100	549.012	100
Total	**921.112**		**563.841**		**1.484.953**	

Figure 22 Expected number of households to be electrified in Bolivia 2013-2025.

Universal electricity access will be achieved by strengthening and expanding the network, and by implementing isolated systems in remote rural areas. In order to do so, a total investment of $1,986 million dollars from 2013 to 2025 would be needed. This investment will be provided by private and public distribution companies, national government, departments and municipalities involved in the electrification projects.

4.1.4 Funds and Programs for Rural Electrification

4.1.4.1 Living with Dignity Electricity Program (PEVD)

The objective of the program is to achieve universal electricity access in urban and rural areas by 2025. This will be accomplished by attracting public and private investments for electricity access in order to improve living conditions, to reduce poverty, to generate jobs and to strengthen the productive, economic and social structure for the Bolivians (Morales, 2008).

The universal electricity access will be achieved by strengthening and expanding the network and, by installing renewable technologies such as; photovoltaic systems, wind generators and, micro and pico-hydroelectric systems.

The economic resources of the Living with dignity electricity program will be obtained through:

a) Economic resources generated by concession rights, licenses, penalties and sanctions as established in the articles 8, 32 and 58 of the Electricity Law No. 1604 of December 21st 1994 that are intended to rural electrification.
b) Credits and donations made by international agencies intended to increase electricity access.
c) Resources provided by the government to increase electricity access.

These resources will be devoted to finance and co-finance universal electricity access projects to be performed by prefectures, municipalities, distribution of electricity entities and, beneficiaries that participate in the program.

The PEVD within the MHE relies on the VMEEA, which has the following responsibilities:

a) To facilitate the management of economic and technical assistance resources for the development of rural electrification projects.
b) To define prioritization criteria and eligibility requirements for rural electrification projects and, to ensure their compliance.
c) To promote private sector participation in the co-financing of rural electrification projects.
d) To incentivize the efficient use of technologies for rural electrification according to the economic efficiency of the systems.
e) To promote periodic training of the agents involved in rural electrification.
f) To guide the prefectures in the elaboration of their rural electrification plans.
g) To approve projects included in the rural electrification investment program.
h) To approve technical norms for the analysis and evaluation of rural electrification projects.
i) To develop an information system for rural electrification projects and investments.

4.1.4.2 National Fund of Regional Development (FNDR)

The National Fund of Regional Development is a decentralized public financing institution, that it is within the Ministry of Development Planning. Its objective is to contribute to “Living Well” by financing through credits and transfers; municipalities, governments, autonomous regions, public service cooperatives and, public service companies for the execution of plans, programs and projects of social and productive development that are defined under the National Plan of Development (FNDR, 2014).

Within the FNDR there is a specific program called Living Well Financing Program, this is intended to support projects related to; basic sanitation, health, education, tourism (as a productive activity), agricultural development, housing, electricity and public infrastructure. In electricity projects are included:

- Expansion of electrical infrastructure.
- Interconnections of isolated systems.
- Grid expansion.
- Generation of electricity using natural gas.

The economic resources of the FNDR-Living Well program come from debt collection resulting from loans of projects that were approved in previous years and from new resources allocated to this program.

4.1.5 Social Tariffs and Subsidies

4.1.5.1 Dignity Tariff

The dignity tariff is a social tariff that was implemented in 2006 to support electricity access and use for low-income households in Bolivia. This tariff provides a fixed reduction of 25% of the total monthly electricity bill to residential users with a consumption up to 70 KWh/month (Morales, 2014).

This 25% reduction is covered by the Agents that operate in the wholesale electricity market as accorded in march 2010 with the Strategic Alliance Agreement signed by the Bolivian government and the companies of the electricity sector (Morales, 2010).

The billing process of the Electricity tariff is as follows:

1) Distribution companies will issue an invoice charging only the 75% of the total monthly amount of electricity consumption to residential users that benefit from the dignity tariff.

2) The Authority of audit and electricity social control will determine and approve the monthly amounts needed that each agent has to provide for the dignity tariff in proportion to their respective participation in the wholesale market.

3) Once the amounts have been approved for each agent, distribution companies will bill an invoice for the remaining 25% of the dignity tariff to all the agents operating in the wholesale market.

4.2 Brazil

The Federative Republic of Brazil is the largest country in Latin America and the fifth largest in the world with a total area of 8,515,767 km^2 and an approximate population of 205,338,000. The country borders all other South American countries except Ecuador and Chile and covers 47.3% of the continent's land area. Brazil is also an extremely country thanks to its large tropical Amazon and Atlantic coast rainforests.

The country is a democratic republic where the president is both head of the state and head of the government. Brazil is composed by 26 states and one federal district, where the capital Brasilia is located. And it has a central government that is divided into three independent branches: executive, legislative and judicial.

Brazil is the largest national economy in Latin America, in 2014, the GDP per capita was $15,153. Its diversified economy includes agriculture, industry, and a wide range of services. In the Human Development Index (HDI), Brazil's value for 2014 is 0.755 which puts the country in the high human development group and, it is above the average of 0.744 for countries in the same category and above the average of 0.748 for countries in Latin America and the Caribbean (UNDP, 2015b).

4.2.1 Rural Electrification Situation

In 2013, 99.6% of the households in Brazil were provided with electricity services, the north region of the country registered the lowest electrification rate with 97.7% while in the rest of the regions electricity access was above 99%[11].

In Brazil, it was established in the article 175 of the Constitution of 1988 that the Government is responsible for the distribution of electricity as an essential public service, directly or by means of concessions or licenses through auctions. Therefore, these high electrification rates are the result of the *Light for all program*, promoted by the government with the objective to achieve universal electricity access.

However, it is estimated that there are still approximately 1 million people in Brazil that are found in rural isolated areas and that do not have access to electricity. Nowadays, actions are being taken by the regulator and the distribution operators to solve this problem, as it will be detailed in the following sections.

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[11] http://www.pac.gov.br/noticia/0d5ad997

4.2.2 National Energy Plan

In Brazil, the Ministry of Mines and Energy (MME) is the public authority responsible of formulating policies and of overseeing the enforcement of these for the mines and energy sector. Some of the main responsibilities of the MME are[12]:

a) Rural energization, agro-energy, including rural electrification when it is financed with purposes linked to the national electricity system.
b) To ensure the balance between supply and demand of the energy resources of the country.

Within the MME, the Secretary of Energy Planning and Development is responsible of the planning of the energy sector therefore, some of its mains responsibilities are:

a) Developing actions for the long term to apply sectoral policies.
b) Promoting the management of energy flows and energy resources.
c) Coordinating the studies about energy planning.
d) Promoting energy studies and technologies.

Moreover, the Energy Research Enterprise (EPE) is directly connected to the MME and, it provides services in the area of studies and research to support the planning of the energy sector such as; electricity, fuel and natural gas, coal, renewable energy sources and energy efficiency among others.

4.2.2.1 National Energy Plan 2030

The National Energy Plan 2030 was elaborated by the Secretary of Energy Planning and Development in collaboration with the Energy Research Enterprise and approved in 2007 by the MME. This plan provides a long term vision of the energy sector in Brazil by proposing strategies of expansion of energy supply considering energy efficiency and technological innovation in both generation and consumption of energy taking into account the sustainable development of the country focusing in the treatment of environmental problems (MME, 2008).

As for access to electricity, it is not included in this plan. This can be explained because Brazil has a specific program that has been successful in increasing electricity coverage over the past years, where distribution operators are supervised by the regulator in achieving access to electricity targets in determined periods of time.

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[12] http://www.mme.gov.br/web/guest/acesso-a-informacao/institucional/competencias

4.2.3 Rural Electrification Targets

Due to the high electrification rate in the country, currently there are no specific national targets for rural electrification. However, the National Agency of Electrical Energy (ANEEL) as the regulator of the electricity sector in Brazil is the authority that establishes rural electrification targets that have to be periodically achieved towards universal electricity access for each concessionary that provides the public service of distribution of electricity. Hence, there is not a national target but instead each distribution operator has its own target.

In 2013, ANEEL by means of the Normative Resolution 563, established universal electricity access targets to all the distribution operators taking into consideration the electricity coverage they had within the rural areas these operate, where 2018 was ultimate deadline to attain universal electricity access (ANEEL, 2013). However, this does not apply for remote regions to be electrified with isolated systems, as specific deadlines and procedures will be defined for these areas.

4.2.4 Funds and Programs for Rural Electrification

4.2.4.1 Light for All Program

The *Light for All* program was created in 2003 through the Decree 4873 to end electricity exclusion in the country. The main objective is to provide access to electricity for free to people living in rural areas. The program is managed by the Ministry of Mines and Energy, operated by Eletrobras and, executed by electricity companies and rural electrification cooperatives in coordination with regional governments[13].

The map of electricity exclusion in Brazil reveals that households without electricity access are located in areas that have the lowest Human Development Index and are also classified as low-income families. About 90% of these households have incomes lower than 3 minimum wages. In order to end with this situation, the government has defined that energy is a vector of social and economic development for these communities by helping them to reduce poverty and to increase their incomes. Electricity access facilitates the integration of social programs of the government and the access to the services of; health, education, water and, sanitation.

The program will provide electricity services through:

- Network expansion
- Decentralized generation systems with isolated networks
- Individual generation systems

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[13] https://www.mme.gov.br/luzparatodos/Asp/o_programa.asp

The economic resources that finance this program come from sectorial funds of energy; Account of Energy Development (CDE) and, the Global Reserve of Reversion (RGR). The funding gap of the inversions is shared among regional governments and distribution companies. The funds of the CDE are collected from yearly payments made by agents that participate in the wholesale market through fixed charges in the distribution and transmission tariffs, plus penalties imposed to electricity companies, transfer funds of the government, among others[14].

4.2.5 Social Tariffs and Subsidies

4.2.5.1 Social Tariff of Electrical Energy (TSEE)

This social tariff was created in 2002 with the law 10.438 and now it is regulated through the law 12.212 of 2010 and it consists of a discount provided to low-class residential users that are served by distribution companies. The economic resources that finance this social tariff subsidy come from the Account of Energy Development (CDE). The discounts are cumulative and are provided depending on the monthly electricity consumption as shown in the below table:

Monthly Consumption	Discount
<= 30 KWh	65%
> 30 KWh & <= 100 KWh	40%
> 100 KWh & <= 220 KWh	10%

Table 2. Social Tariff of Electrical Energy, Brazil

In order to benefit from this social tariff, households must comply with one of the following conditions:

a) Household must be registered in the database of national social programs of the government with a monthly income per capita lower or equal than half of the minimum national wage.
b) Households that receive the Continuous Benefit of Social Assistance.
c) Households registered in the database of social programs that have monthly income up to 3 minimum wages and that has a family member with a disease or incapacity that needs for his treatment the continuous use of electric devices.

In addition, indigenous people that are registered in the database of social programs can benefit of a 100% discount if their monthly electricity consumption is equal or lower than 50 KWh.

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[14] http://www.aneel.gov.br/informacoes-tecnicas/-/asset_publisher/CegkWaVJWF5E/content/conta-de-desenvolvimento-energetico-cde/654800?inheritRedirect=false

4.3 Colombia

Colombia is located in the northwest of South America, it has a total surface of 2,129,748 km^2 and has an approximate population of 47 million inhabitants. The country borders to the east Venezuela and Brazil, to the south Peru and Ecuador and, to the northwest with Panama.

Colombia is an upper middle–income country that is divided into 32 departments plus the capital district of Bogota. The Republic of Colombia is a representative democracy with a central government and separation of powers. The country has three branches of government; the Executive, the Legislative and the Judiciary.

In Colombia despite recent progress made in overall poverty reduction, inequality and informality, remain among the highest in Latin America. In terms of HDI Colombia's value for 2014 is 0.72 which places it in the high human development category however, it is below the average of 0.744 for countries in the high human development group and below the average of 0.748 for countries in Latin America and the Caribbean (UNDP, 2015c).

4.3.1 Rural Electrification Situation

In 2012, Colombia registered 96.1% electricity access at a national level and, 99.5% of electrification in urban areas while only 84.4% in rural areas. This means that there were 470,244 households without access to electricity of which 37,734 belong to urban areas and 432,511 are found in rural areas (UPME, 2013).

Overall the departments with the lowest electricity access rates are; Amazonas, Putumayo, Vaupes and Vichada where more than 30% of their population do not have access to electricity services. Concerning rural areas, Vichada and Amazonas are the most affected departments as these barely had 27% and 25% access to electricity respectively.

In Colombia, the article 365 of the Constitution of 1991 states that it is responsibility of the State to ensure the efficient provision of public services to all the inhabitants of national territory therefore, it is the government who has the obligation of reducing the lack of electricity access.

4.3.2 National Energy Plan

The Ministry of Mines and Energy (MME) is a public entity whose primary objective is the formulation and implementation of politics, general plans, programs and projects of the Mines and Energy Administrative Sector. Within the MME, the Planning Unit of Mines and Energy (UPME) is responsible of planning in coordination with public and private entities, the development and use of the energy and mining resources and, to produce and publish the required information in the mining and energy sector (MME Ministerio de Minas y Energía Colombia, 2013). Some of the main functions of the UPME are:

a) To establish the mining and energy needs of the population and economic agents of the country based in demand forecasts.
b) To establish the way to satisfy these demand requirement taking into account the existing mining and energy resources; conventional and non-conventional, according to economic, social, technological and environmental criteria.
c) To elaborate and update the Mining National Plan, the National Energy Plan, the Electricity Sector Expansion Plan and, the other sub sectorial plans, in concordance with the National Plan of Development.
d) To evaluate the economic and social impact of the development of non-conventional energy sources and use.
e) To elaborate the Expansion Plans of the Interconnected System.

Under this structure, in January 2015 the UPME published the National Energy Plan Colombia: Energy Ideas 2050.

4.3.2.1 Colombia National Energy Plan: Energy Ideas 2050

This National Energy Plan was elaborated by the UPME and approved by the Ministry of Mines and Energy. In this Plan, some ideas are presented regarding the future development of the energy sector in Colombia that can be used as a reference to elaborate and implement energy policies. This document is intended to be considered as a National Energy Plan 2014-2050 but without establishing guidelines to accomplish the defined objectives (UPME, 2013).

Regarding electricity access, this National Energy Plan proposes ideas for a long term energy policy where one of its objectives is the implementation of schemes that promote universality and affordability of electricity services, this is broken down in four categories:

1) Increase energy coverage
2) Sustainable Rural Energization Plans
3) Standardization and quality of service for electricity and combustion gas
4) Subsidies Policy

Increasing energy coverage is directly related to universal energy access hence, the UPME proposes four possible lines of actions to achieve this goal during the period 2014-2018:

- To assign and execute in an efficient way the economic resources coming from the Financing Support Fund for the Energization of non-interconnected zones (FAZNI) intended basically for isolated systems with a total amount of $486,000 million needed for this period of four years.

- To make use of the economic resources of the Financing Support Fund for the Energization of Interconnected Rural Areas (FAZNI) to finance pre-paid meters and to finance surplus tariffs.
- To increase the distribution charge during the period 2014-2018 to those operators that report investments made to increase coverage as a way to facilitate the financing of these projects.
- To cover the remaining resources needed for interconnection projects with resources coming from the General System of Royalties.

4.3.2.2 Indicative Plan of Electrical Energy Coverage Expansion (PIEC) 2013-2017

This indicative plan was developed by the UPME where by considering the estimated number of households that do not have access to electricity services, it identifies the investments needed to achieve the universalization of the service. The investments are classified in network expansion for both the interconnected system (SIN) and isolated systems.

Computations were made to analyze the increase of electricity coverage with respect to the variations of the distribution charge in the electricity tariff for each distribution operator. The results obtained propose two financing schemes to increase the electricity access; the first one is by direct participation of the distribution operators when the investments are recovered with an increase in tariff and, the second one concerns the national economic resources of the funds intended to increase electricity coverage. This plan is only a study to analyze how can electricity access be increased and can be seen as a reference but, it does not establish goals or targets to be achieved within the next years.

4.3.3 Rural Electrification Targets

The Ministry of Mines and Energy in the Indicative Plan of Electrical Energy Coverage Expansion (PIEC) 2013-2017 which is the main plan directly focused on electricity access, establishes as a main general objective to attain the universalization of access to electricity however, there are no specific targets to be accomplished within the next years. In this plan, a report is presented where estimations of the public and private investments needed in each region for attaining universalization of electricity access by 2017 are detailed. Nevertheless, this does not represent a formal commitment but rather an indicative study of the economic resources that are required to accomplish this goal.

The few electricity coverage expansion targets that are formally established in the country, are found in the Colombia Vision Centenary II: 2019 Program which was published by the Planning National Department where the targets set are shown in Table 3. Electricity Coverage Targets Colombia.

Plan	**Targets for 2019** *Interconnected zones*	 *Non-interconnected zones*
Colombia Vision Centenary II	99.37%	75.49%

Table 3. Electricity Coverage Targets Colombia

These targets will be achieved by restructuring the current regulatory framework in order to create incentives to expand the distribution and retail activities to the zones that do not have electricity services (DNP Departamento Nacional de Planeación, 2005).

4.3.4 Funds and Programs for Rural Electrification

4.3.4.1 Financial Support Fund for the Energization of Interconnected Rural Zones (FAER)

The FAER is managed by the Ministry of Mines and Energy and it was created in 2002 through the article 105 established in the law 788, its purpose is to finance rural electrification projects related to medium voltage interconnection lines and distribution substations in order to increase the reliability, quality and, coverage expansion of the interconnected zones in rural areas of low development.

This fund allows territorial entities with the support of distribution operators, to manage investment; plans, programs and, projects for the construction and installation of new electrical infrastructure. The objective is to increase electricity coverage and to satisfy the energy demand in the interconnected rural zones according to the coverage expansion plans developed by each distribution operator, that were previously approved by the UPME[15].

In the article 190 of the law 1753 of 2015, it is stated that since January 1st 2016, the economic resources for the FAER will be obtained in the wholesale market through the System Administrator of Commercial Exchanges (ASIC) who will collect $2.10 Colombian pesos per KWh transported. This amount will be paid by the owners of the actives of the National Transmission System (STN) and it will be added to the charge of the STN use.

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[15] https://www.minminas.gov.co/faer1

4.3.4.2 Financial Support Fund for the Energization of non-Interconnected Zones (FAZNI)

The FAZNI is managed by the Ministry of Mines and Energy and it was created in 2001 through the articles 81-83 established in the law 633, its objective is to finance investment plans, programs and/or projects for the construction and installation of new electrical infrastructure and, for the replacement or the repair of the existing one with the aim of increasing the coverage and to satisfy the energy demand in the non-interconnected zones[16].

In the article 190 of the law 1753 of 2015, it is stated that since January 1st 2016, the economic resources for the FAZNI will be obtained in the wholesale market through the System Administrator of Commercial Exchanges (ASIC) who will collect $1.90 Colombian pesos per KWh dispatched in the wholesale market and from this, $0.40 pesos will be devoted to finance the Non-Conventional Energies and Efficient Management of Energy Fund (FENOGE). This amount will be paid by the energy generator agents and it will be added in the electricity tariffs.

4.3.5 Social Tariffs and Subsidies

4.3.5.1 Solidarity Fund for Subsidies and Income Redistribution (FSSRI)

The FSSRI was created in 1994 through the article 99 of the law 142 as a fund for managing and distributing the resources assigned in the general budget of the nation in order to cover the subsidies for the low income residential users of the electricity public service[17].

Colombia’s population is classified in six socio-economic strata according to their income level. This classification is used to determine the level of tariffs for electricity, gas, water and other services. According to that system, consumers living in areas considered as poor (strata 1,2 and 3) receive electricity and natural gas at subsidized tariffs. While users with higher incomes (those classified in strata 5 and 6) together with users belonging to commercial and industrial sector, pay the 20% of contribution of the costs of electricity services that it is intended to cover the subsidies given to users of low income. These subsidies are classified as follows:

Residential User	**Monthly Electricity Consumption**		**Discount**
	Altitude < 1000 meters above sea level	*Altitude >= 1000 meters above sea level*	
Strata 1	<= 173 KWh	<= 130 KWh	50%
Strata 2			40%
Strata 3			15%

Table 4. Social Tariff Colombia

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[16] https://www.minminas.gov.co/fazni1

[17] https://www.minminas.gov.co/fssri1

For the subsidies, the maximum quantities of monthly electricity consumption are defined by the subsistence consumption, which is the minimum amount of electricity consumed per month by a typical user in order to satisfy basic needs that can only be satisfied through this form of final energy (UPME, 2004).

Additionally, in the article 2 of the law 1117 of 2006, it was established that subsidies for the non-interconnected zones will be set in the conditions and percentages established by the Ministry of Mines and Energy taking into consideration the payment capacity of the users in these zones.

4.4 Ecuador

The republic of Ecuador is located in the northwest of South America, it limits Colombia to the north and Peru to the east. It has a total area of 283 561 km^2 with an approximate population of 16 million people. The country is known for its rich ecology, hosting many endemic plants and animals and it is also considered one of the megadiverse countries in the world

Ecuador is a democratic presidential republic where the president is head of state and head of government on a multi-party system, leading a cabinet with further executive power. Ecuador is divided into 24 provinces where the capital city is Quito, while the largest city is Guayaquil.

Ecuador has a developing economy that is highly dependent on commodities, namely petroleum and agricultural products. The country is classified as a medium-income country and registered a GDP per capita of $11,244. In the same year, the Human Development Index of Ecuador was 0.732 which put the country in the high human development category however, it is below the average of 0.744 for countries in the same category and below the average of 0.748 for countries in Latin America and the Caribbean (UNDP, 2015d).

4.4.1 Rural Electrification Situation

In 2013, electricity access in Ecuador was 93.4% at a national level which resulted in 96% in urban areas and 88% in rural areas (Gomelsky, 2013). This means that around 196,000 households had no access to electricity of which, 54,000 are found in urban areas and approximately 142,000 in rural areas (Figure 23. Number of houses without electricity access by province, Ecuador).

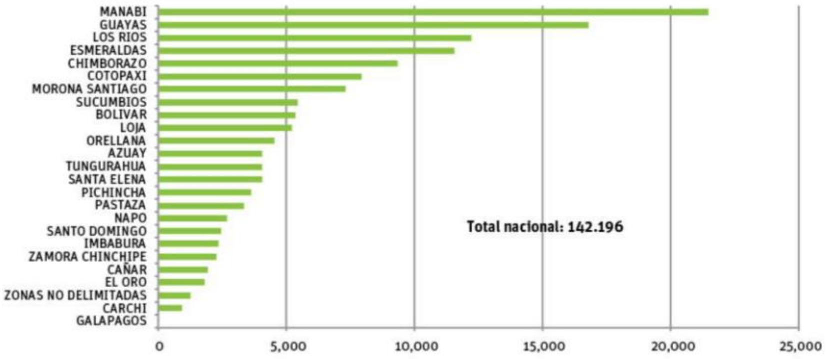

Figure 23. Number of houses without electricity access by province, Ecuador

In Ecuador it is stated in the article 314 of the Constitution of 2008 that the State will be responsible of the provision of public services of water, sanitation, electricity, telecommunications, etc. Moreover, the State will guarantee that the public services and the provision of these will be in concordance with the principles of obligatory, generality, uniformity, efficiency, responsibility, universality, accessibility, regularity, continuity and quality (Asamblea Nacional República del Ecuador, 2008). Even though that nowadays efforts are being made to increase electricity coverage, the limited amount of economic resources impacts negatively the progress of electricity access.

4.4.2 National Energy Plan

The Ministry of Electricity and Renewable Energy (MEER) is the public entity in charge of the electric, renewable energy and nuclear sectors. Its main objective is to satisfy the energy needs of the country by implementing the appropriate legislation, development plans and policies, considering the efficient use of the resources. On January 16 2015, the organic law of the public service of electrical energy was published (Asamblea Nacional República del Ecuador, 2015), with this law, the structure of the electricity sector in Ecuador was modified and it is stated in the article 12 that some of the main responsibilities of the Ministry of Electricity and Renewable Energy are:

a) To elaborate the Master Plan of Electricity (PME) and the National Plan of Energy Efficiency (PLANEE).
b) To supervise and evaluate the execution of; policies, plans, programs and projects, for the development and management within its area of responsibility.
c) To propose to the president of the republic law and regulation projects.
d) To promote the Regional Electricity Integration.
e) To impulse the scientific and technological research in terms of electricity, renewable energy and energy efficiency.

4.4.2.1 Master Plan of Electrification 2013-2022

This master plan of electrification 2013-2022 was elaborated by the National Council of Electricity (CONELEC) which before the electricity law of 2015 had the responsibility of elaborating this plan. After this law was implemented, CONELEC was dissolved and as a result, the Regulatory Agency and Electricity Control (ARCONEL) was created. Currently, the elaboration of the electricity plan is now responsibility of the Ministry of Electricity and Renewable Energy.

The Master Plan of Electrification 2013-2022 is aligned with; the Constitution of the Republic of Ecuador, the objectives of the National Plan for Living Well, the agenda of the Ministry of Electricity and Renewable Energy and, the law of the electricity sector (CONELEC, 2013).

Regarding electricity access, this plan through the Program of Rural Energization and Electrification of Marginal Urban Areas (FERUM) promotes the extension of electricity coverage to those zones that do not have electricity services yet.

4.4.3 Rural Electrification Targets

Nowadays, there are two national plans where electricity access targets are established. The first one is the Institutional Strategic Plan 2014-2017 of the Ministry of Electricity and Renewable Energy where the objective 5 is to increase the electricity coverage through the execution of electrification plans performed by distribution companies (Ministerio de Electricidad y Energía Renovable, 2014). The second is the Master Plan of Electrification 2013-2022 where for each year, from 2013 to 2022 an electricity access target is set. These targets can be better appreciated in the below table:

Plan	Targets for 2017	Targets for 2022
Institutional Strategic Plan 2014 - 2017	96.88% electricity access at national level.	/
Master Plan of Electrification 2013 - 2022	98.4% urban areas 94.03% rural areas	98.92% urban areas 96.29% rural areas

Table 5. Electricity Coverage Targets Ecuador

4.4.4 Funds and Programs for Rural Electrification

4.4.4.1 Rural Energization Program

As established in the article 63 of the organic law of the public service of electrical energy, the state will promote and finance development projects of rural electrification by giving priority to zones isolated from the distribution systems (Asamblea Nacional República del Ecuador, 2015). The economic resources needed to execute these projects will be managed by the MEER, in light of the Ministry of Finance.

The Rural Energization Program will be financed with resources coming from the General Budget of the State. Nevertheless, it can also be financed with contributions or donations made by public or private, national or international entities, and others that are determined in the organic law of the public service of electrical energy or other laws and, controlled by the Ministry or Electricity and Renewable Energy.

In order to be included in the PME, the MEER will elaborate in the first trimester of each year, the Rural Energization Program in which priority will be given to zones of low development in order to foster the progress in all the regions of the country for the upcoming year.

Moreover, the Regulatory Agency and Electricity Control will be responsible of defining regulations for the identification or the rural energization projects and, for the supervision and control of the execution of the program. While distribution companies will be in charge of the identification, execution, operation and maintenance of the projects.

4.4.5 Social Tariff and Subsidies

4.4.5.1 Dignity Tariff

The Dignity Tariff was established in the Executive Decree 451-A of July 12th, 2007. This tariff is intended to reduce the payment of the electricity services for the scarce economic resources population based on a maximum electricity consumption per month depending on the geographical location of residential users as shown below:

Residential User	Monthly Electricity Consumption	Fixed Price
Sierra Region	<= 130 KWh	$0.04 USD per KWh
Coast, East and, Insular Regions	<= 110 KWh	

Table 6. Dignity Tariff Ecuador

This subsidy is given to residential users that are classified in the income quintiles 1 and 2 by the National Institution of Statistics and Census (INEC). This subsidy is covered by the general budget of the state and it consists on a monthly amount that covers the difference between the value of energy consumption and the fixed monthly value of 0.04 USD per KWh registered by each residential user, in addition to the value of 0.71 USD for the concept of commercialization of electrical energy (Correa, 2007).

4.4.5.2 Tariff for Isolated Systems

The article 64 of the organic law of the public service of electrical energy states that the systems that can't be connected to the interconnected national system will be considered as non-incorporated therefore, the regulated users of these systems can have different tariffs of the interconnected zones that will be approved by the ARCONEL (Asamblea Nacional República del Ecuador, 2015). The subsidies that might be originated from these systems will be covered by the consumers or final users of the interconnected system or covered by the State, according to the policies established by the Ministry of Electricity and Renewable Energy.

4.5 Peru

The Republic of Peru is located in the west of South America, it borders Colombia and Ecuador to the north, Brazil to the east and, Bolivia and Chile to the southeast. It has a total area of 1,285,216 km^2 and an estimated population of 31,151,643 people. Peru is an extremely biodiverse country with habitats ranging from the arid plains of the Pacific coastal region in the west to the peaks of the Andes mountains vertically extending from the north to the southeast of the country to the tropical Amazon Basin rainforest in the east with the Amazon river.

Peru has a presidential representative democratic republic, whereby the President of Peru is both head of state and head of government. The politic system is divided into three branches; executive, legislative and judiciary. Moreover, Peru is divided into 25 regions and the Lima province, which is also the capital.

Peru is classified as upper middle income and it is an emerging, social market economy characterized by a high level of foreign trade. The inequality of opportunities has declined in the last couple of years. As for 2014, the country registered a GDP per capita of $13,735 and in that same year, Peru's value of the Human Development Index was 0.734 which put the country in the high human development category nevertheless, it is below the average of 0.744 for countries in the same category and also below the average of 0.748 for countries in Latin America and the Caribbean (UNDP, 2015e).

4.5.1 Rural Electrification Situation

At the end of 2015, it was estimated that electricity access in Peru was 93.3% at the national level and only 78% in rural areas (MEM, 2015). Rural electrification in Peru has some characteristics such as; the remoteness and inaccessibility of its communities, low electricity consumption, dispersion between communities and households, and the low economic resources of the communities to pay for the service. Moreover, in some areas there is not enough road infrastructure therefore, these communities tend to be isolated. In addition, they do not have social infrastructure in health, education, sanitation, etc.

Even though it is stated in the article 58 of the Constitution of 1993 that the development of the country in the areas of; employment, health, education, security, public services and infrastructure is open to private initiative (Congreso Constituyente Democrático, 1993), for rural electrification, the situation previously described determines a low economic profitability for these type of projects which results unattractive to private investment hence, rural electrification projects require the active participation of the State.

4.5.2 National Energy Plan

The Ministry of Energy and Mines (MEM) is the public entity whose function is to formulate and evaluate national policies of the energy and mines sectors in regards of a sustainable development. Its main objective is to promote the full development of the activities in the energy-mines sector by legislating, auditing and/or supervising its complaince taking into account the rational use of natural resources in harmony with the environment[18].

Within the MEM, the General Direction of Rural Electrification (DGER) is the entity responsible of rural electrification procedures as stated in the Law 28749 "General Law of Rural Electrification" (Congreso de la República, 2006). Its main objective is to expand national electricity coverage in coordination with local and regional governments and also with public and private companies dedicated to this purpose by allowing the electricity supply to towns in the inside part of the country as a way to; contribute to their social and economic development, mitigate poverty, improve quality of life and discentivize migration from rural areas to big cities. This doing it cojointly with the State for the full rural development trhough the implementation of rural electrification projects with technologies and action programs that allow the increase of acquisitive power of the rural populations by promoting electricity in productive activities. Moreover, for these projects they will identify, avoid, prevent, mitigate or compensate the cultural, social and environmental projects that these might provoque[19].

Under this structure, the DGER published in December 2015 the National Plan of Rural Electrification 2016-2025.

4.5.2.1 National Plan of Rural Electrification (PNER) 2016 – 2025

This rural electrification plan is a tool for planning management that it is intended to achieve the objectives of the policy of rural electrification in the nation. The PNER consolidates; the approved regional and local development plans, the expansion programs of distribution companies, the private initiatives and the programs or projects to be developed by the national government therefore, it is not only a list of projects but it also considers prioritization and evaluation criteria that responds to the technical conditions of social projects evaluation and, the national, regional and local policies (MEM, 2015).

One of the main features of the PNER is its big flexibility, which allows it to adequate the priority order and to introduce new projects and programs according to the possibilities of auto financing or co-financing that the interested people obtained. The PNER contains projects and programs identified by the national, regional and local governments.

The main objectives of the National Plan of Rural Electrification 2016-2025 are:

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[18] http://www.minem.gob.pe/

[19] http://dger.minem.gob.pe/Institucional_Presentacion.aspx

a) To expand electricity coverage by implementing projects in the rural electricity systems, which use the adequate technologies that optimize its costs in order to achieve a greater electricity access for the populations in rural zones and isolated communities.
b) To propose the execution of rural electricity systems of sustainable operation.
c) To impulse through rural electrification, the socio-economic sustainable development in rural zones and isolated areas in order to improve quality of life or rural populations by fomenting the promotion of productive uses of the energy.
d) To foment the use of renewable energy sources in distributed systems integrated in the distribution networks.
e) To coordinate financing with public and private entities in order to obtain economic resources and eventually advantageous credits for financing the execution of projects.
f) To improve the formulation of projects developed by regional and local governments.
g) To optimize the administrative management and to consolidate the institutional strength through an adequate resource dotation.

4.5.3 Rural Electrification Targets

Rural electrification targets are established in the PNER 2016-2025. In general, the targets are oriented to impulse the rural development of the most isolated areas that are diffciult to access by giving priority to projects related to renewable energy, to positionate Peru as one of the countries with higher electricity access index in the latinamerican region and, to intervene in social programs in favor of reducing the lack of basic infrastructure. Regarding electricity access, the main target is to supply electricity services to 3.3 million rural people by 2025.

4.5.4 Funds and Programs for Rural Electrification

At this time there is not a specific fund or program established for rural electrification. However, there are different economic resources that are collected for this purpose such as (MEM, 2015);

a) Transfers from the public sector.
b) External financing sources.
c) 100% of the penalties imposed by the Supervisor Organism of the Inversion in Energy and Mining (OSINERG) to the concessionary companies.
d) 25% of the total resources obtained from the privatization of electricity companies.
e) 4% of the total earnings of the companies of generation, transmission and distribution in the electric power sector.
f) Contributions, allowances and donations.
g) Resources obtained through agreements.
h) Surpluses coming from the General Direction of Electricity of the MEM.
i) Others that may be assigned.

4.5.5 Social Tariffs and Subsidies

4.5.5.1 Fund of Electricity Social Compensation (FOSE)

The FOSE was created in 2001 through the law 27510, this fund is intended to benefit residential users whose monthly electricity consumptions are lower than 100 KWh by obtaining a discount on the electricity bill depending on their monthly consumptions. The discounts vary depending on; the type of system where the user is connected, the sector where users live and, their monthly consumptions (Congreso de la República, 2001). These tariff reductions are established as shown in the below table:

Residential Users	Sector	Monthly discount on consumptions equal or lower than 30 KWh	Monthly discount on consumptions higher than 30 KWh and up to 100 KWh
Interconnected System	Urban	25% of the energy charge	7.5 KWh
	Urban-Rural & Rural	50% of the energy charge	15 KWh
Isolated Systems	Urban	50% of the energy charge	15 KWh
	Urban-Rural & Rural	62.5% of the energy charge	18.75 KWh

Table 7. Social Tariff Peru

The fund of Electric Social Compensation will be financed by a fixed charge included in the electricity bill to users of the interconnected system whose monthly electricity consumptions are higher than 100 KWh. This fixed charge will be represented as a percentage that will be determined by the OSINERG according to a forecast of sells for the next period. Furthermore, the OSINERG will be in charge of managing the FOSE by; determining the amount of the transfers between the contributing and receiving companies of this fund, approving the transfer procedures of the FOSE, specifying its scopes and establishing compensations and penalties of non-compliance of this procedure. Electricity companies will submit to the OSINERG a detailed monthly report of the tariff compensations and of the billing charges.

5. COMPARATIVE ANALYSIS

For this thesis, a regulatory analysis will be performed by comparing Bolivia, Brazil, Colombia, Ecuador and Peru under three main criteria:

- Electricity access commitment
- Funds for rural electrification
- Social Tariffs

These criteria are studied by taking as a reference a set of three Yes/No questionnaires, which were answered according to the literature review made for each country in the previous chapter. Afterwards, final comments and recommendations will be provided in general or individually depending on the criteria and the country.

5.1 Electricity Access Commitment

Under this criterion, the commitment that Bolivia, Brazil, Colombia, Ecuador and Peru show to reduce the lack of electricity access is studied. This is the most basic concept that allows us to understand the current situation of each country and more important, it defines the direction they are heading in the future to increase electricity coverage. The commitments were analyzed by answering to the questionnaire shown in Table 8. Electricity Access Commitment Questionnaire.

Even though these five countries present similar characteristics, the approaches taken to reduce the lack of electricity access are rather different in some aspects and quite similar in others, this is better illustrated in Table 9. Comparison of Electricity Access Commitment in Bolivia, Brazil, Colombia, Ecuador and Peru.

Question	Bolivia	Brazil	Colombia	Ecuador	Peru
1. Is the provision of electricity services established as a right in the constitution?	Y	N	Y	Y	N
2. Does the energy or electricity national plan include in its priorities to increase electricity coverage?	Y	N	Y	Y	Y
3. Are there national electricity access objectives in place to be attained within the next years? (If no, go to question 4)	Y	N	Y	Y	N
3.1. Are the objectives set in quantitative terms or percentage rates?	Y	-	Y	Y	-
3.2. Are the objectives well defined, planned with guidelines and delegated to a responsible agent?	Y	-	N	Y	-
4. Is there any established commitment to achieve universal electricity access in a specific year with specific guidelines to be followed?	Y	Y	N	N	N
5. Does it exist a rural electrification plan with well-defined objectives that is updated every determined period of time?	N	N	N	N	Y
6. Are distribution operators, cooperatives or electricity companies that provide electricity services committed to increase electricity access within the area they operate?	Y	Y	Y	Y	Y
7. Do local and regional governments participate or get involved in rural electrification projects?	Y	Y	N	N	Y

Table 8. Electricity Access Commitment Questionnaire

Country	National Electricity Plan	Electricity Access Targets	Universal Electricity Access expected by	Agents Involved in Electrification Projects
Bolivia	Electricity Plan of the Plurinational State of Bolivia 2025	2020 Urban: 100% Rural: 87% National 96%	2025	Distribution operators, local and regional governments
Brazil	National Energy Plan 2030	Specific targets for each distribution operator	2018[20]	Distribution operators, local and regional governments
Colombia	Indicative Plan of Electrical Energy Coverage Expansion 2013 - 2017	2019[21]: 99.37% Interconnected Zones 75.49% Non-Interconnected Zones	Not defined	Distribution operators
Ecuador	Master Plan of Electrification 2013-2022	2022: 98.92% urban areas 96.29% rural areas	Not defined	Distribution operators, national government
Peru	National Plan of Rural Electrification 2016-2025	2025: Provide electricity services to 3.3 million people living in rural areas	Not defined	Distribution operators, national, regional and local governments

Table 9. Comparison of Electricity Access Commitment in Bolivia, Brazil, Colombia, Ecuador and Peru

After comparing the countries under the electricity access criterion, it has been found that:

- National electricity access targets to be attained in different periods of time have been established in most of the countries. Whereas Bolivia, Colombia and Ecuador have defined their targets in terms of electricity coverage percentages, Peru has defined these by quantity of people to be electrified. To increase the electricity coverage and, in a way to accomplish the electrification targets, Bolivia, Ecuador and Peru have opted for a plan determining lines of actions, the agents involved and the estimated investments needed. Similarly, Colombia provides lines of actions, agents involved and estimated investment

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[20] Does not apply for isolated systems.

[21] Target established in the Plan Colombia Vision Centenary II

needed but, only as an indicative report to attain universal electricity access, not a formal commitment to increase coverage. Finally, Brazil by taking a different approach, delegates to the electricity regulator the imposition and supervision of individual targets to each company that has a distribution of electricity concession.

- The commitment to achieve universal electricity access is only enforced in Bolivia and Brazil. While Bolivia backs it up with different national plans, Brazil does it directly through the regulator who monitors and supervises the compliance of the targets that have been imposed to every distribution operator. Even though these countries are committed to attain the universalization of electricity services, it does not really guarantee that they will achieve this goal but, it clearly shows them the pathway that has to be followed and it is also a learning process where experience is gained when difficulties are faced during the practice.

- Enabling local and regional governments to participate in rural electrification projects is very important because it can create awareness of the problematic so that they can get involved and work close with distribution operators. In addition, it can also lead to efficient results by tackling the problem at local levels. This practice is implemented in Bolivia, Brazil and Peru where local and regional governments work with distribution operators in electrification projects because they can benefit from funds while doing it. In the case of Ecuador and Colombia, they rely completely in distribution operators to increase electricity coverage by working mainly with economic resources provided by the national government.

- Electrification Plans are an efficient mean to determine the scope of the electricity access targets. This is of course if the proper guidelines are established. These five countries have implemented different approaches to design their national electrification plans. On the one hand Peru, by having low electrification rates, has the need to develop an exclusive plan for rural electrification that is updated every year. On the other hand Brazil, by having high electrification rates, only developed customized electricity universalization plans for each distribution operator. In between these countries, Bolivia, Colombia and Ecuador develop electricity plans that include electricity coverage expansion for both urban and rural areas. The main difference in the latter, is that Bolivia and Ecuador show the commitment to reduce the lack of electricity access and have established targets in their electricity plans whereas Colombia does not commit at all, it only provides the estimation of investments needed to achieve universal electricity access.

5.2 Funds and Programs for Rural Electrification

Distribution operators usually do not have the incentives to undertake rural electrification projects because these tend to be not economically viable for them due to several reasons including; high investment costs versus low profits and also, high operation and maintenance costs incurred. Therefore, governments have to intervene to ensure that distribution operators can work on increasing the electricity coverage within the areas they operate. This government's intervention often involves the provision of economic resources by means of transfers, credits and loans among others.

In this section, the funds and programs that are available in Bolivia, Brazil, Colombia, Ecuador and Peru are studied as shown in Table 10. Funds and Programs for Rural Electrification Questionnaire and the results can be better appreciated in Table 11. Comparison of Rural Electrification Funds and Programs in Bolivia, Brazil, Colombia, Ecuador and Peru.

Question	Bolivia	Brazil	Colombia	Ecuador	Peru
1. Are there economic resources coming from the national budget intended to increase electricity access?	Y	Y	N	Y	Y
2. Are there specific funds or programs established exclusively for electrification projects?	Y	Y	Y	Y	N
2.1. Are the economic resources collected for these funds or programs properly defined with a structured procedure to be followed?	Y	Y	Y	N	-
2.2. Is the allocation of these resources well defined with an established methodology implemented to select which electrification projects can benefit from these funds?	N	N	Y	N	-
2.3. Are isolated systems given priority to benefit from these funds or programs?	N	Y	Y	Y	-
3. Is there any fund or program designed especially for isolated systems?	N	N	Y	N	N
4. For electrification projects, are the technologies to be installed chosen according to a well-defined procedure taking into consideration environmental impact and availability of resources?	N	Y	Y	N	Y

Table 10. Funds and Programs for Rural Electrification Questionnaire

Country	Fund or Program	Electrification Mode	Technologies	Financed by
Bolivia	Living with Dignity Electricity Program (PEVD)	Network Expansion	Renewable	Public and Private Investment
	National Fund of Regional Development (FNDR)	Network Expansion Interconnection of Isolated Systems	-	Public Investment
Brazil	Light for All Program	Network Expansion Micro grids Individual Generation Systems	Renewable	CDE, RGR, Public investment
Colombia	Financial Support Fund for the Energization of Interconnected Rural Zones (FAER)	Network Expansion	-	Agents operating in the wholesale market
	Financial Support Fund for the Energization of non-Interconnected Zones (FAZNI)	Microgrids Rural Interconnections	Renewable	Agents operating in the wholesale market
Ecuador	Rural Energization Program	Not specified	Not specified	General Budget of the State
Peru	Not specific program	Network Expansion	Solar PV Pico hydro Wind	Diverse resources

Table 11. Comparison of Rural Electrification Funds and Programs in Bolivia, Brazil, Colombia, Ecuador and Peru

After comparing the countries under the funds and programs for rural electrification criterion, it has been found that:

- There are different ways to finance funds and programs intended to increase electricity coverage, as an example, in these five countries the way that economic resources are collected varies. While Bolivia and Ecuador rely mostly in resources provided by the government, Brazil and Peru do it through concessions and penalties from electricity companies and, finally Colombia does it through the agents participating in the wholesale market who provide a fixed amount per KWh transmitted or dispatched and in the end is added to the consumers' tariff.

- In order to benefit from the funds and programs for rural electrification, all of the countries consider as a first option network expansion as the electrification mode to be executed whenever it is feasible. As a second option, the installation of microgrids and stand-alone systems by means of renewable sources is considered.

- On the one hand, in Ecuador, a new electricity law was established in 2015. This reform is transforming the electricity sector in the country and as a result, the operation rules of the Rural Energization Program have not been clearly stated. This situation jeopardizes the progress towards universal electricity access. On the other hand, Brazil's *light for all program* is considered on f the most successful ones in the world that has help to reduce the lack of electricity access by benefiting a lot of families in the last years. It has been recognized internationally and nowadays Brazil has one of the highest electrification rates in Latin America and it is expected to achieve universal electricity access by 2018.

- Colombia acknowledges the problematic of the poor quality of service in current electrified rural areas. Therefore, the implementation of two different funds was necessary, one for rural areas that are or can be interconnected to the national system (FAER) and, another one considering only isolated systems (FAZNI) in order to increase electricity coverage. Moreover, since January 2016 the country has increased the charges to the agents participating in the wholesale market that are intended to subsidize both electrification funds.

- Peru does not have a specific program but, the country develops a rural electrification plan each year where it keeps track of the current electrification projects and study the viability of future ones. This has led the country to significantly increase electricity coverage in the last years.

5.3 Social Tariffs

Social tariff is a reduced tariff intended to enable low-income users to have access to electricity services. This tariff is a subsidy that depending on the country, it can be usually subject to socio-economic conditions and/or electricity consumption limits. For electricity access, social tariffs are very important for two main reasons, the first reason is directly linked to social aspects and, the second reason has to do with electricity companies.

From the social point of view, social tariffs are relevant because these are an efficient mean to provide the opportunity to high-poverty communities to benefit from electricity services by allowing them to pay according to their possibilities. In addition, social tariffs can also help to reduce social exclusion by contributing to the development of marginal areas.

From the standpoint of electricity companies, social tariffs can reduce the risk of economic losses in case of lack of payment of the consumers because at least one part of the cost of the tariff will be recovered with the subsidy that these users receive.

The electricity social tariffs of Bolivia, Brazil, Colombia, Ecuador and Peru are studied by taking as a reference the questionnaire shown in Table 12. Social Tariff Questionnaire.

Question	Bolivia	Brazil	Colombia	Ecuador	Peru
1. Is there any social tariff implemented?	Y	Y	Y	Y	Y
1.1. Is this tariff clearly stated in quantitative terms following an established procedure? (i.e. a fixed energy price, percentage discount, reduction on kwh per month, etc.)	Y	Y	Y	Y	Y
1.2. Is this tariff covered totally or partially by cross-subsidies?	N	N	Y	N	Y
1.3. Is this tariff covered totally or partially by the government?	N	N	N	Y	N
1.4. Is this tariff covered totally or partially by electricity companies?	Y	Y	N	N	N
2. Is there any special tariff or subsidy designed for isolated areas and/or high-poverty communities?	N	Y	Y	Y	Y

Table 12. Social Tariff Questionnaire

Overall, social tariffs in these countries share some similarities in the way these are implemented but these do differ in the limits of monthly electricity consumption and the subsidy provided. The results found can be better appreciated in Table 13. Comparison of Social Tariffs in Bolivia, Brazil, Colombia, Ecuador and Peru.

Country	Monthly Electricity Consumption		Discount	Applies to	Financed by
Bolivia	<= 70 KWh		25%	All residential consumers	Agents operating in the wholesale market
Brazil	<= 30 KWh		65%	Households whose monthly income per capita is lower or equal than half of the minimum national wage[22].	Account of Energy Development (CDE): Electricity Companies[23]
	> 30 & <= 100 KWh		40%		
	> 100 KWh & <= 220 KWh		10%		
Colombia	<= 173 KWh *Altitude < 1000 m* <= 130 KWh *Altitude >= 1000m*		50%	Strata 1	Cross-subsidies paid by users of Strata 5 & 6
			40%	Strata 2	
			15%	Strata 3	
Ecuador	<= 130 KWh Sierra Region <= 110 KWh Coast, East & Insular Regions		Fixed price of \$0.04 USD per KWh	Consumers classified in the income quintiles 1 and 2	National Budget
Peru	Interconnected System	<= 30 KWh	25% Urban 50% Rural	All residential consumers	Cross-subsidies paid by users consuming more than 100 KWh per month
		> 30 KWh & <= 100 KWh	7.5 KWh Urban 15 KWh Rural		
	Isolated System	<= 30 KWh	50% Urban 62.5% Rural		
		> 30 KWh & <= 100 KWh	15 KWh Urban 18.75 KWh Rural		

Table 13. Comparison of Social Tariffs in Bolivia, Brazil, Colombia, Ecuador and Peru

After comparing the countries under the social tariff criterion, it has been found that:

- Social tariffs present some similarities in Bolivia, Brazil, Colombia, Ecuador and Peru. First, all of them are restricted to a certain amount of electricity consumption per month. Second, except Ecuador who provides the subsidy in a fixed price for electricity, the rest of the countries provide the subsidy in terms of a percentage discount. Finally, excluding Bolivia, the rest of the countries take into consideration socio-economic aspects in an attempt to target the subsidies to the poor and low-income households.

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[22] Household must be registered in the database of national social programs of the government.

[23] The funds of the CDE are collected from yearly payments made by agents that participate in the wholesale market through fixed charges in the distribution and transmission tariffs, plus penalties imposed to electricity companies, among others.

- Brazil and Peru send a strong signal to consumers: “*the more electricity it is consumed, the lower will be the subsidy*”. However, even if both countries developed a social tariff based on consumption patterns, the main difference relies in the fact that in Brazil the subsidies are classified in blocks of monthly electricity consumption and these blocks are cumulative. Whereas in Peru, efficient use of the electricity is taken into account hence, blocks are not cumulative, once the limit consumption of a block is exceeded, consumers can no longer benefit from the subsidy belonging to this block.

- Colombia and Peru have implemented cross-subsidies but these are quite different. In the one hand, Colombia applies the principle of income redistribution where high-income users (those classified in Strata 5 & 6) cover the subsidies provided to users of strata 1,2 and 3 through an additional fixed charge in their electricity bills. On the other hand Peru, by taking a different approach, applies the principle of efficient use of electricity where regardless the socio-economic condition of the consumers, if their monthly electricity consumptions are higher than 100 KWh, they will cover through an additional fixed charge in their electricity bills, the subsidies provided to users consuming equal or less than 100 KWh. The message is very clear in terms of efficient use of the electricity in the sense of preventing possible excessive consumptions of subsidized users: “*consume less than 100 KWh and you’ll be subsidized but, if you consume more than 100 KWh, you’ll be penalized*”.

- Who should cover subsidies is always a delicate issue, each country tries to approach it in the most convenient way but the truth is that there is not a magic rule to apply. As a proof, in these five countries subsidies are financed by different sources. As explained previously, Colombia and Peru do it through cross-subsidies, while in Ecuador, the subsidies are covered by the general budget of the state. Conversely, Bolivia came to an agreement with agents operating in the wholesale market making them cover the subsidies. Finally, Brazil uses the account of energy development to cover the subsidies, which is mainly funded by electricity companies.

5.4 Comments & Recommendations

- Social tariffs in all countries are subject to established monthly electricity consumptions per household. This is a good approach however; its main disadvantage is that number of people per household is neglected in these tariffs, meaning that the electricity consumption of one household composed of 4 people is not the same as another composed by 8 people. If social tariffs are intended to benefit the people who need it the most, a new method considering number of people per household should be implemented to not limit the electricity consumption to bigger families.

- Most of the countries want to attain universal electricity access however, reliability and quality of service is often not considered a priority when performing electrification projects, so a trade-off has is usually done when deciding if electrify a high number of people but with an intermittent service or, to electrify a low number of people but with continuous electricity supply. Disregarding continuity of supply can lead to incur in higher costs in the future as reinforcement of the systems will have to be done when these will not be able to operate efficiently.

- Electricity access should not only be about increasing coverage hence; governments should develop social programs that promote productive uses of electricity so that poverty levels can be reduced and living conditions of rural communities can be improved. In addition, when electrifying an isolated area, special training should be given to consumers in order to guarantee the appropriate operation of the systems and also, create conscience about the efficient consumption of electricity to not overload the systems in order to avoid damage of it.

- Governments should pay special attention to electrification projects in isolated areas performed by distribution operators, a clear methodology should be established and its compliance has to be monitored frequently because distribution operators usually only have experience in increasing electricity coverage by means of network expansion and when they have to deal with renewable technologies the outcome might not be as good as expected.

- Colombia needs to enforce its universal electricity access commitment in all the senses, the electrification programs in the country are only indicative studies that can be useful because these can be taken as a reference. However, the lack of commitment affects the accomplishment of universal electricity access. Progress is being made to increase electricity coverage but, it is not enforced to attain electrification targets periodically.

6. CASE STUDY PERU: VILLA SANTA ROSA

Villa Santa Rosa is located in the Province of Jaen which is a wide Amazonian territory found in the department of Cajamarca in Peru. Cajamarca is characterized by its high poverty level and its low electrification rate. In 2014, Cajamarca registered one of the lowest electrification rates in the country with only 78% of its population having access to electricity compared to the national average of 92% (INE, 2015). Villa Santa Rosa was chosen for this case study as it is defined in as one of the Rural Electric Systems (SER) in the National Plan of Rural Electrification 2011-2020[24] (Figure 24. SER Villa Santa Rosa).

Figure 24. SER Villa Santa Rosa

This case study is presented with the objective to develop a methodology to support rural electrification planning in regions of the Amazon. To do so, three software tools will be implemented: LandScan, ArcGIS and the Reference Electrification Model (REM).

LandScan is used to obtain the population spatial distribution of the Villa Santa Rosa area, ArcGIS is used to process data in order to estimate the geographic location of houses and, the REM is applied to obtain the electrification planning.

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[24] PNER 2011-2020 GIS: http://dger.minem.gob.pe/pnergis/

6.1 Population Spatial Distribution

Population spatial distribution of an area is relevant in order to be able to develop a detailed system design, more specific, the geographic locations of all the houses in the study area are needed to run the Reference Electrification Model. This is the most basic input to the model and this level of specificity is critical for the realistic calculation of technical feasibility, as well as for cost estimation (Borofsky, 2015).

Obtaining this data is not easy, generally such records do not exist or are not available for public consultation. There are different methodologies that can be applied to estimate this data. Accurate results can be obtained by means of performing field visits to the households to be electrified however, this approach can be time consuming if the area is big and it also represents an extra cost for the electrification project hence, this is not the most time-efficient solution to implement despite the accuracy that it offers.

Satellite imagery is a good option that can be used to detect houses and buildings, as a matter of fact, previous works performed with the Reference Electrification Model (REM) have used free images from Google Earth complemented with a satellite image processing algorithm to identify household locations (Ellman, 2015). The main advantage of satellite imagery is that relevant information can be obtained for free while the main disadvantage is that if the images do not have a good resolution it will be complicated or sometimes impossible to detect the houses, either by visual inspection or an algorithm, as it is the case for the Amazon (

Figure 25. Left: Typical satellite image of a rural area in Peru. Right: Typical satellite image of a rural area in the Amazonian region of Peru).

Figure 25. Left: Typical satellite image of a rural area in Peru. Right: Typical satellite image of a rural area in the Amazonian region of Peru

Another possibility to estimate population distribution of an area is to use gridded population datasets. Basically, this method consists on making population spatial distribution data available as a high-resolution raster database which facilitates rapid GIS analysis at the local level and for any zoning (Hall, Stroh, & Paya, 2012), the gridded population dataset product chosen for this case study was LandScan.

6.1.1 LandScan

LandScan[25] determines global population distribution by using spatial data and imagery analysis technologies. The population distribution is represented spatially in cells of approximately 1 km x 1 km resolution where the population count is an estimate of the average over 24 hours population count and it is tailored for each individual country and region. LandScan Global was developed by Oak Ridge National Laboratory (ORNL) and it is funded by the U.S. Department of Defense who uses it for rapid consequence and risk assessment as well as emergency planning and management.

In literature, LandScan has been used primarily to estimate the impact of natural disasters in human life, for instance; earthquakes (Li, 2011) and floods (Fleiss, Kienberger, Aubrecht, Kidd, & Zeil, 2010). The main advantage of LandScan compared to other population spatial distribution products; Gridded Population of the World (GPW), Global Rural-Urban Mapping Project (GRUMP) and, the dataset covering the European community (EU+27), is that in terms of global statistics, LandScan seems to perform best (Hall et al., 2012).

6.1.1.1 Villa Santa Rosa Population Distribution

The spatial population distribution obtained with LandScan was a classification of the Villa Santa Rosa area in cells of approximately 1 km x 1 km that were grouped in different colors according to the number of people, where 0 was the lowest and 631 the highest value of number of people detected by LandScan as can be appreciated in Figure 26. Villa Santa Rosa Population Distribution.

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[25] http://web.ornl.gov/sci/landscan/index.shtml

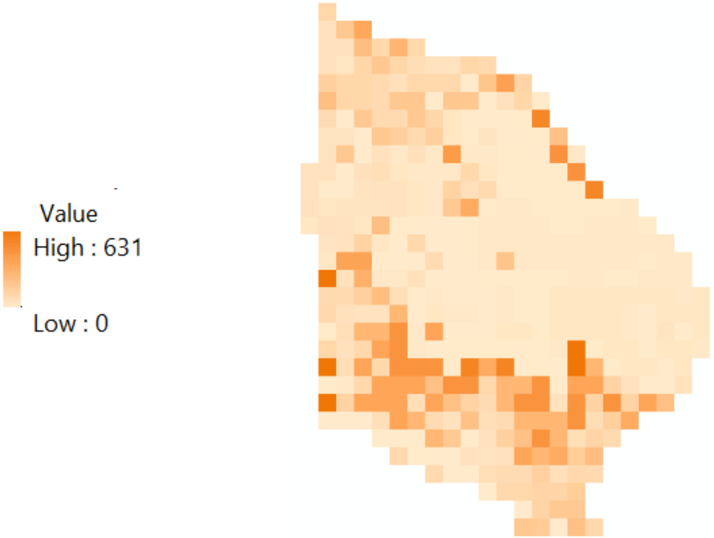

Figure 26. Villa Santa Rosa Population Distribution

Even though LandScan is a good tool that provides the spatial distribution of people per 1 km^2, for the Villa Santa Rosa case study, more precise results are required so that the geographic location of the houses is obtained. This pre-processing was carried out simulating different location profiles, aided by using a Geographic Information System (GIS) ArcGIS as will be explained below.

6.2 Geographic Information Systems (GIS)

Geographic Information Systems are efficient tools that help visualize, manage, store, modify, analyze, and interpret geographical data to understand relationships, patterns, and trends of a study area. GIS are used in diverse fields, as for the electricity sector, there is literature available regarding the implementation of these systems to select site locations for wind farms in: the United Kingdom (Baban & Parry, 2001), New York (Van Haaren & Fthenakis, 2011) and, Tuscany (Mari et al., 2011).

For this case study, ArcGIS was chosen to modify the population distribution data that was obtained in LandScan. It was a key pre-processing element between different software tools that allowed the process and manipulation of the data required to run the REM model, in order to estimate the number of houses and their geographical locations, as it will be explained afterwards.

6.2.1 Number of Houses in Villa Santa Rosa

The population distribution data obtained with LandScan was modified in ArcGIS so that cells could represent number of households instead of number of people. In 2014, the national average household size in Peru was 4.1 people per household[26]. For simplicity purposes, number of people obtained in LandScan was divided by 4 to obtain the approximate number of houses per cell and also, cells with no households were eliminated (Figure 27. Number of Households in Villa Santa Rosa) to simplify the analysis.

The result obtained was 324 cells that ranged from 1 to 158 houses, being the one house value the most frequent by registering 90 cells as it can be appreciated in Figure 28. Relationship between number of houses and number of cells. Moreover, 67% of the cells are composed by less than 10 houses while only two cells registered more than 150 houses, this demonstrates the low population density of Villa Santa Rosa.

Figure 27. Number of Households in Villa Santa Rosa

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[26] Peru Average Household Size Map 2014 available in ArcGIS online, the source of this data is Michael Bauer Research.

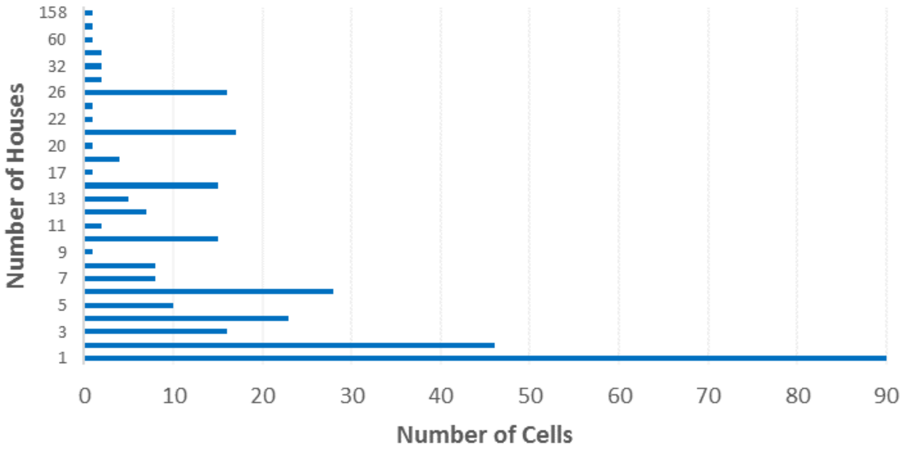

Figure 28. Relationship between number of houses and number of cells

Once the approximation of number of houses per cell was obtained, the next step was to estimate the location of these houses.

6.3 Algorithm to Estimate Location of Houses

To estimate the location of the houses, first the coordinate points that delimit every cell had to be obtained to make sure that each house would be located within its respective cell. Then, an algorithm was executed to generate two coordinate points; one to represent the latitude and another to represent the longitude for each house, these values are expressed in decimal degrees.

The assumption made is that in rural areas houses tend to be located closely together forming small communities, however, there might also be houses isolated from these high density areas.

The algorithm implemented assigns random numbers to each house location, where the first pair of coordinate points obtained per cell will be assigned to house 1 which is taken as a reference to generate the following houses' location points. This is done with the objective to obtain a normal distribution based on probabilities.

Basically, the main idea is to randomly locate the houses however, the algorithm will more frequently generate coordinate points that are closer to house 1. In other words, the probability of locating the following houses closer to house 1 will be higher than the probability of these houses being placed farther from it. To do so, each cell of 1 km^2 is subdivided into smaller squares of 100 m^2 (Figure 29. Subdivision of cells).

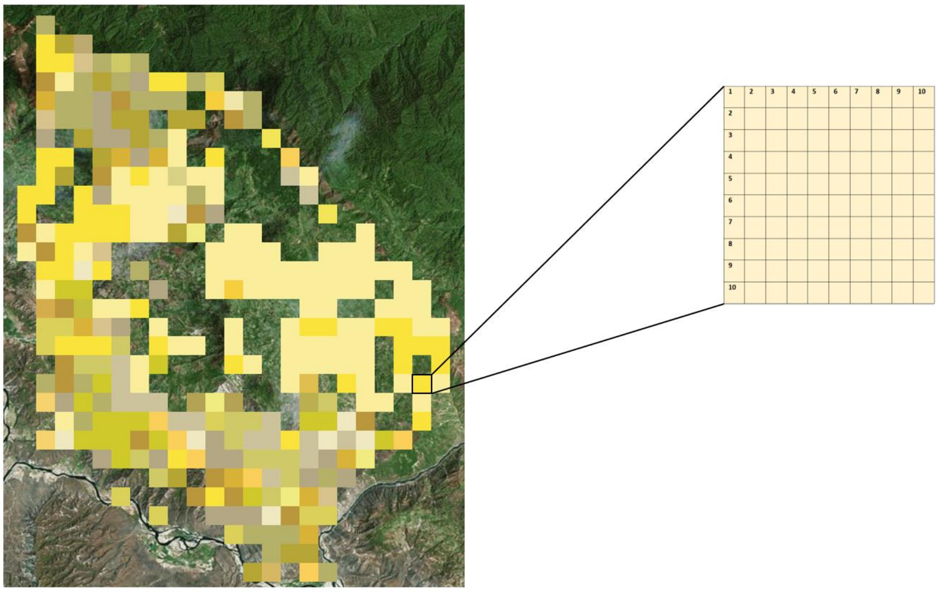

Figure 29. Subdivision of cells

Once the coordinate points of house 1 have been obtained, the 100 m^2 squares will be reclassified into levels. Level 1 will be defined as the square where house 1 is located, while level 2 is the area composed by the neighboring squares surrounding Level 1 and Level 3 is the area composed by the neighboring squares surrounding Level 2 and so on, until the squares that border the cell are reached.

The number of levels will depend on the square's position where house 1 is located, meaning that if house 1 falls under one of the squares located in the center of the cell the maximum number of levels will be 6, whereas if house 1 falls under one of the squares that borders the cell, the maximum number of levels will be 10 (Figure 30. Maximum number of levels per cell).

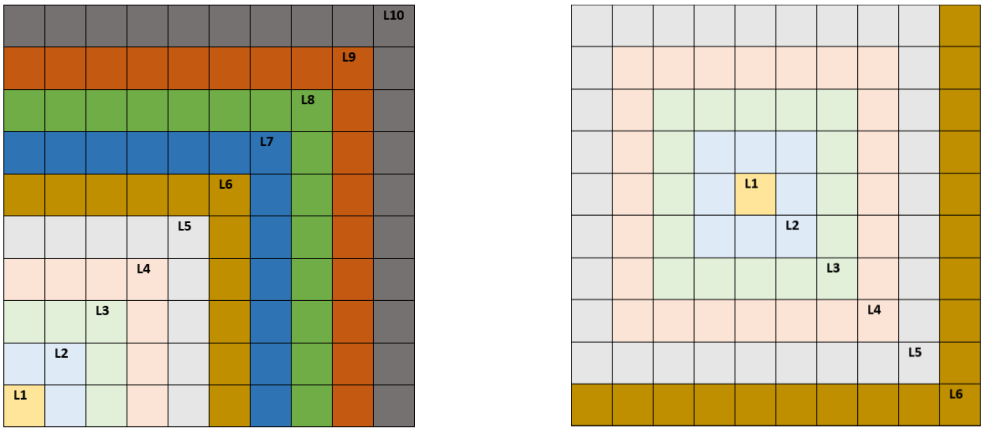

Figure 30. Maximum number of levels per cell

For each level, a probability will be assigned so that a normal distribution of house locations can be obtained and, as mentioned before, the probability is intended to locate houses closer to house 1. For the Villa Santa Rosa case study, three simulating location profiles were considered; one consisting on a fully random pattern where houses could be located anywhere within a cell as a way to represent a high dispersion profile between houses and two more taking into consideration probabilities for each level to represent medium and low dispersion profiles between houses.

The probabilities per level used to locate the houses are shown in Table 14. Probability per level to locate houses, where the column that assigned the probability of 0.5 to level 1 represents the low dispersion profile and the column that assigned the probability of 0.25 to level 1 represents the medium dispersion profile.

L	**Probability**	∑	**Probability**	∑
L1	**.5**	50.00%	**0.25**	25.00%
L2	**.25**	75.00%	**0.25**	50.00%
L3	**.125**	87.50%	**0.25**	75.00%
L4	**.0625**	93.75%	**0.125**	87.50%
L5	**.03125**	96.88%	**0.0625**	93.75%
L6	**.01562**	98.44%	**0.03125**	96.88%
L7	**.00781**	99.22%	**0.015625**	98.44%
L8	**.003906**	99.61%	**0.0078125**	99.22%
L9	**0.001953**	99.80%	**0.00390625**	99.61%
L10	**0.001953**	100.00%	**0.00390625**	100.00%

Table 14. Probability per level to locate houses

It is important to mention that in the case of one house is located to a level that is higher than the maximum number of levels in a cell, then the algorithm will locate the house in the area belonging to the maximum level available of that cell. Moreover, this algorithm was used for cells containing more than one household.

The algorithm proposed to estimate the geographic location of houses for this case study is mathematically expressed as follows:

$$LX_c = R[XI, XS]_c$$

$$LY_c = R[YI, YS]_c$$

$$lx_{clh} = Rp[xi, xs]_{clh}$$

$$ly_{clh} = Rp[yi, ys]_{clh}$$

$xi_l \geq XI_c$

$xs_l \leq XS_c$

$yi_l \geq YI_c$

$ys_l \leq YS_c$

Where:

$LX = Latitude\ of\ house\ 1$
$LY = Longitude\ of\ house\ 1$
$R[XI, XS]_c = Random\ number\ representing\ the\ latitude\ of\ house\ 1$
$R[YI, YS]_c = Random\ number\ representing\ the\ longitude\ of\ house\ 1$
$XS = Superior\ latitude\ limit\ of\ a\ cell$
$XI = Inferior\ latitude\ limit\ of\ a\ cell$
$YS = Superior\ longitude\ limit\ of\ a\ cell$
$YI = Inferior\ longitude\ limit\ of\ a\ cell$
$h = house$
$c = Cell$
$l = level$
$lx = Latitude\ of\ a\ house$
$ly = Longitude\ of a\ house$
$Rp[xi, xs]_c = Probabilistic\ random\ number\ within\ level\ l$
$Rp[yi, ys]_c = Probabilistic\ random\ number\ with\ respect\ to\ Rp[xi, xs]$
$xs = Superior\ latitude\ limit\ of\ level\ l$
$xi = Inferior\ latitude\ limit\ of\ level\ l$
$ys = Superior\ longitude\ limit\ of\ Rp[xi, xs]$
$yi = Inferior\ longitude\ limit\ of\ Rp[xi, xs]$

After the algorithm was executed, three house location scenarios were obtained: High Dispersion Scenario (HDS), Medium Dispersion Scenario (MDS) and Low Dispersion Scenario (LDS). The results can be better appreciated in Figure 31. Scenarios of house dispersion.

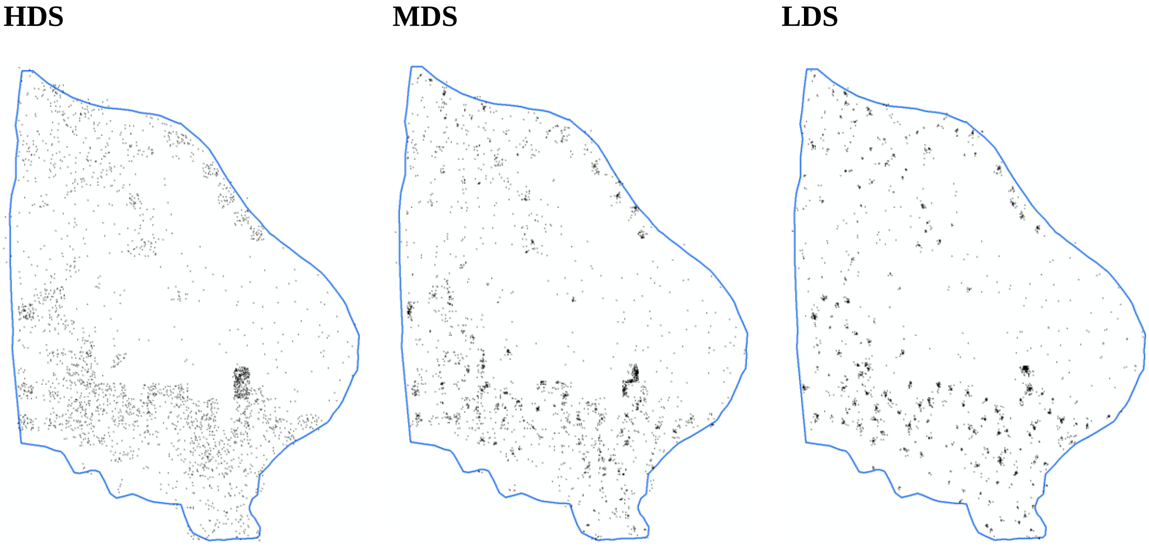

Figure 31. Scenarios of house dispersion

6.4 Reference Electrification Model (REM)

The Reference Electrification Model, or REM, is a computer model that can assist rural electrification planning by providing techno-economic results. Given information about a region, the model identifies areas for extension of the electric grid and development of off-grid systems, based on cost-minimization (Ellman, 2015).

Besides the REM, there are other software tools found in literature that support rural electrification in Latin America, for example, GISA SOL aims at planning renewable energies in rural areas of the northeast of Brazil (Tiba et al., 2010). One of its main features is that it takes into consideration social aspects such as; HDI and the identification of possible productive uses of electricity in some areas however, its implementation is limited to only 8 states in Brazil. Another tool is IntiGIS (Domínguez & Pinedo-Pascua, 2009) which performs the electrification planning by selecting the electrification technologies to be installed in rural areas based on the levelized costs of electricity (LCOE).

One of the main advantages of the REM compared to the previous one mentioned, is that this model provides flexibility as different electrification planning scenarios can be studied so that better informed decisions can be taken. Furthermore, the REM does take into account the customers' loss of utility, or in other words, the Cost of Non-Served Energy (CNSE). This occurs when customers want to make use of electricity and this service is not provided by the system. The CNSE in included in the REM to drive balance between quality of service and cost of supply, as the model aims to minimize the total cost of service plus non-served energy cost.

6.4.1 Implementing REM in Villa Santa Rosa

The execution of the REM for this case study will be carried out in two stages. In both stages, the model will be run with the three house dispersion scenarios; HDS, MDS, and LDS. In the first stage, it will be considered that if network expansion is not possible then, only renewable energies technologies could be installed to generate electricity. This is done to comply with the Peruvian legislation which states that electrification of rural areas has to be done by means of renewable energies (MEM, 2015). The second stage will consist on running the model under three scenarios; one where the electrification will be performed only by means of grid expansion, another one where diesel is allowed to be installed and, finally another where only off-grid can be installed with renewable energies. Overall, this process is better illustrated in Figure 32. Implementation of the Reference Electrification Model.

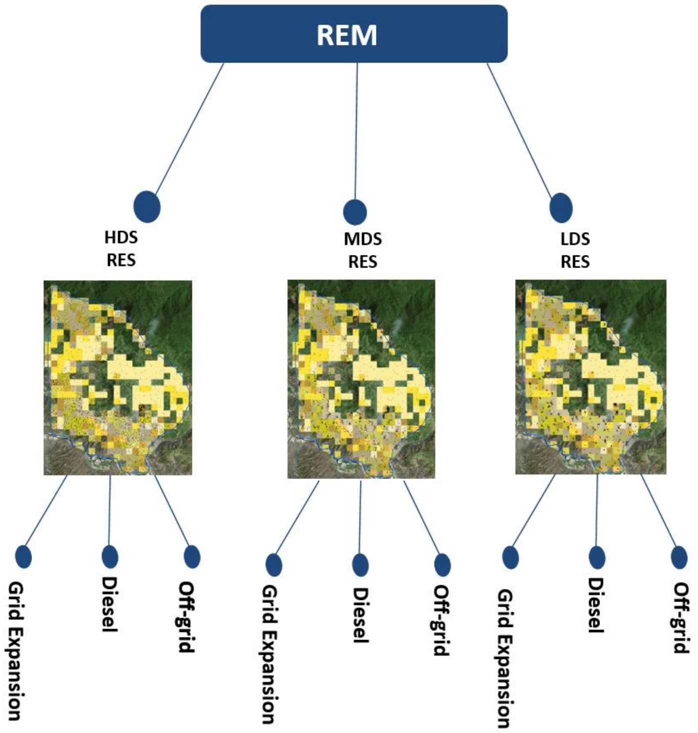

Figure 32. Implementation of the Reference Electrification Model in Villa Santa Rosa Case Study

6.4.2 Assumptions

For the Villa Santa Rosa Case Study, the following assumptions were considered:

Network lines: it will be assumed that all the national network lines are already in place (Figure 33. Network lines installed and planned by the government).

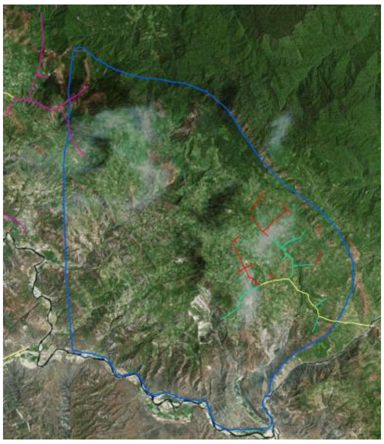

Figure 33. Network lines installed and planned by the government

Reliability of the network: it will also be assumed that the reliability of the network is able to meet the demand 85% of the times.

Demand

The demand target estimated will be a basic demand and will consist on:

- 1 light (critical demand)
- 2 additional lights (non-critical demand)
- 1 television for 26% of the households (non-critical demand)

The average demand can be better appreciated in Figure 34. Demand per household in the different seasons of the year, where the peak demand reaches 120 W and the average is around 36 W therefore, the approximate annual consumption per household would be 323.25 KWh which places these consumers under the respective tariffs under 30 KWh. The customers of this case study fall under the following electricity tariffs:

B7 Tariff[27]: \$0.11 usd per KWh + monthly fixed charge of \$1.09 usd (applies for grid extension).

BT8-320 Tariff[28]: fixed charge of \$11.236 usd (applies for microgrids and solar).

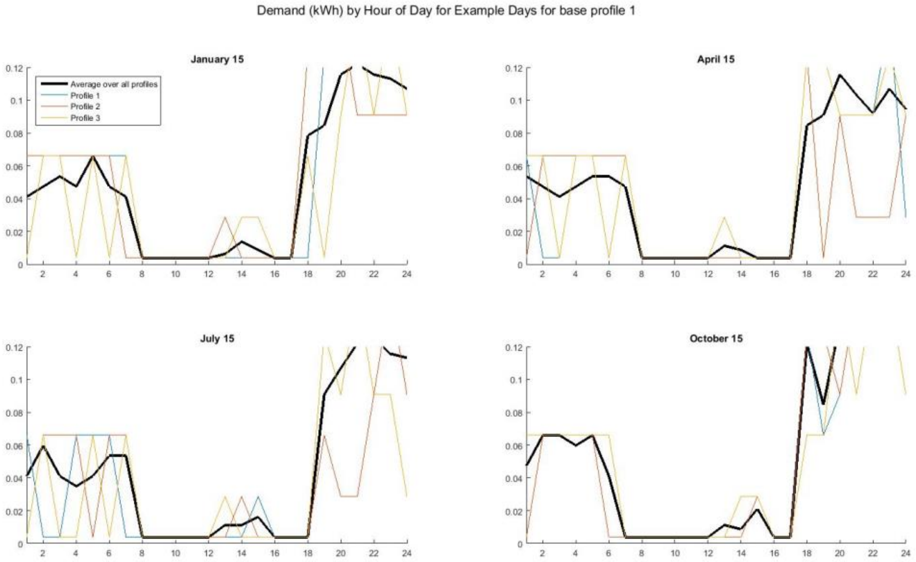

Figure 34. Demand per household in the different seasons of the year

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[27] http://www2.osinergmin.gob.pe/tarifas/electricidad/TarifasMapa.html

[28] (OSINERGMIN, 2014) Tariff taken considering the electricity consumption of customers in this case study.

6.4.3 Inputs

- Cost of diesel: 10$/L[29]
- Cost of energy supplied from the grid: 0.05
- Critical CNSE: 2.5 $/KWh
- Normal CNSE: 1 $/KWh
- Network lifetime: 40 years for grid extension and 20 years for microgrids
- Distribution system losses: 5%
- Demand growth rate: 2%
- Year for which generation is designed: 5 years from present time, considering demand growth.

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[29] The cost of diesel was heavily penalized in order to obtain results with 100% renewable technologies for the Normal Case Scenario, in other circumstances the cost of diesel would be estimated at 2 $/L in isolated areas of the Amazon.

6.5 Results

6.5.1 Normal Case Scenario: Renewable Energies + Network Expansion

After running the model under this case scenario, the electrification mix results obtained for the three dispersion profiles were quite similar; network expansion for most of the users and a small portion of isolated systems and micro-grids. As shown in Figure 35. Mix of electrification mode in the normal case scenario, the higher the dispersion of the houses, the more isolated systems there will be while, on the other hand, the lower the dispersion, the higher the number of micro-grids.

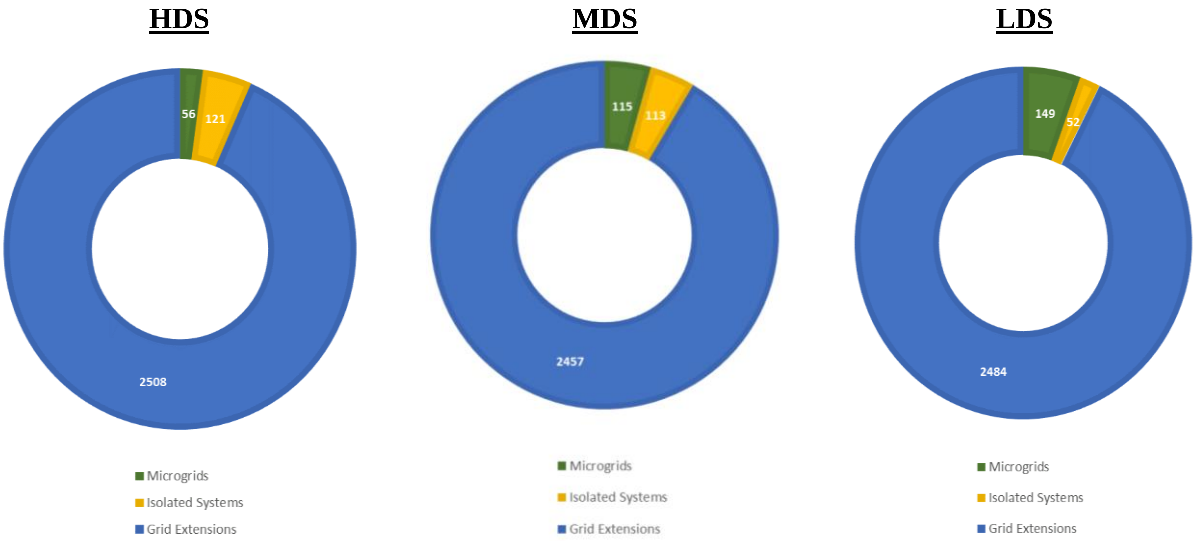


Figure 35. Mix of electrification mode in the normal case scenario

Grid extension remains as the main electrification mode under the three dispersion scenarios, the electrification results obtained with the REM can be illustrated in Figure 36. Electrification Outcome Under Normal Case Scenario.

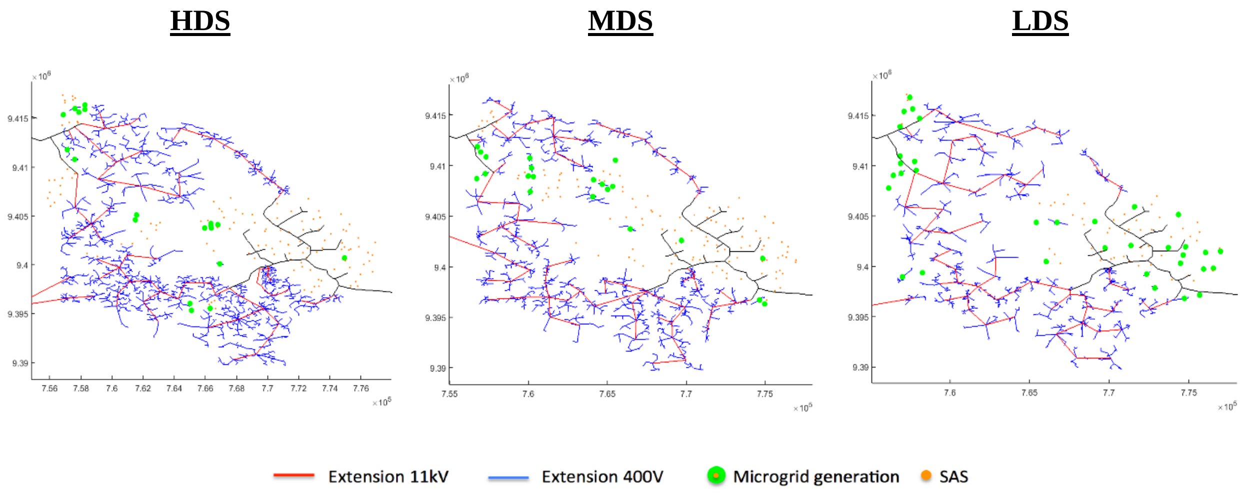


Figure 36. Electrification Outcome Under Normal Case Scenario

Since reliability of the network was an assumption made, the model will always meet the demand 85% of the times. For isolated systems, the reliability in the three dispersion scenarios was the same by meeting the demand 96% of the times. While the reliability of microgrids did register some variations by having 84% in HDS, 89% in MDS and, 87.5% in LDS (Figure 37. Reliability of the Systems under the three House dispersion scenarios). Here it can be noticed that contrary at what would be expected, the reliability of isolated systems is higher than the reliability of microgrids, this can be explained because the capacity of the batteries can be enough to store electricity for one household while for microgrids can be sometimes limited.

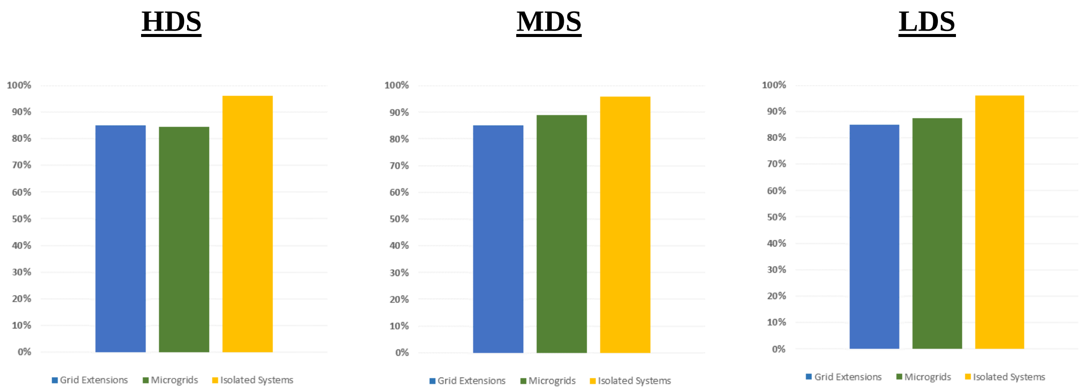


Figure 37. Reliability of the Systems under the three House dispersion scenarios

The reliability of the microgid systems is better appreciated in Figure 38. Microgrid Hourly Generation Dispatch in a day of January and July where the generation dispatch of a summer and a winter day are compared. In all the dispersion scenarios, there is non-served demand, in January it only lasts a couple of hours early in the morning while in July it lasts from midnight to early in the morning.

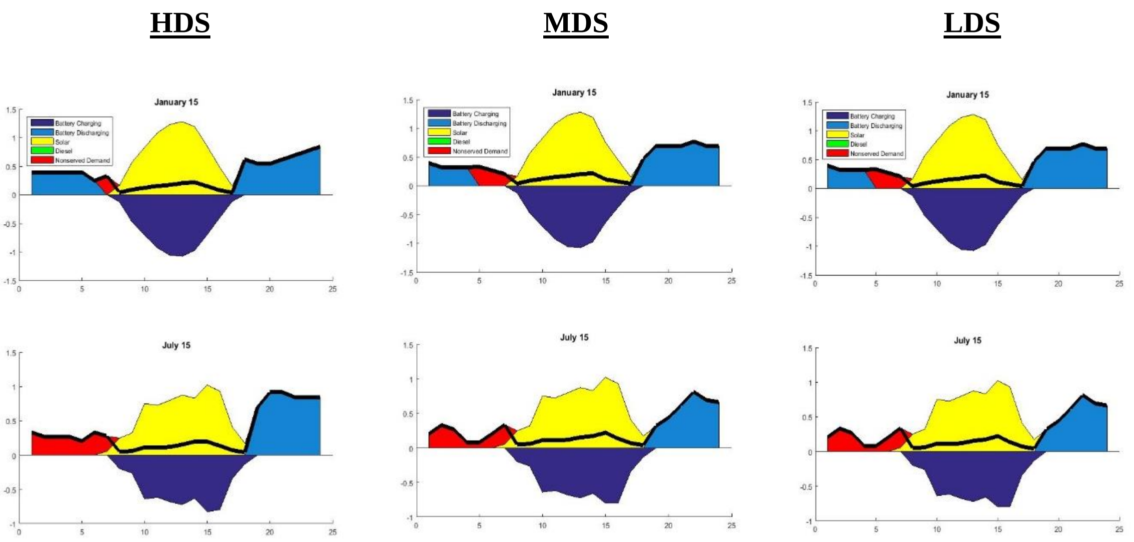


Figure 38. Microgrid Hourly Generation Dispatch in a day of January and July

The Cost of Non-Served Energy is taken into consideration by the REM in its objective function to minimize total cost therefore, it is directly linked to the reliability of each electrification mode where the higher the reliability of the system, the lower the total annual CNSE. Figure 39. Average Yearly CNSE per Customer under the three dispersion scenarios shows that isolated systems have the lowest average CNSE per household as these systems have the highest reliability (96%).

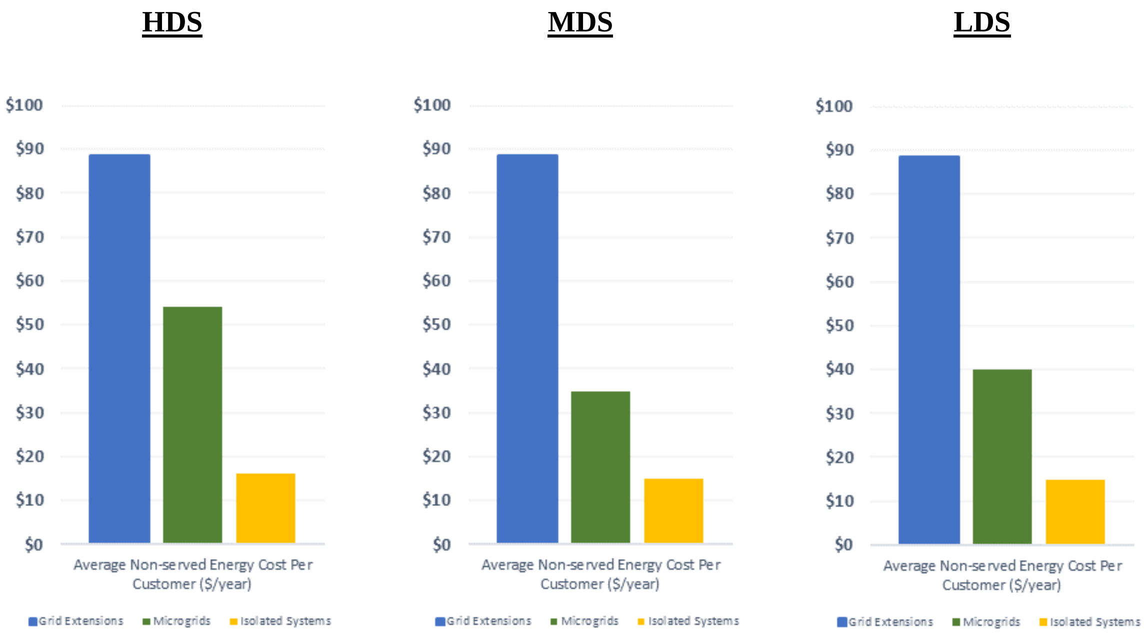


Figure 39. Average Yearly CNSE per Customer under the three dispersion scenarios

For the average cost of energy served, the cost for micro-grids and solar remains similar under the three dispersion scenarios, around 0.77 and 0.83 $/KWh respectively. While the cost of energy in grid extension decreases as the houses show less dispersion patterns. This can be explained because when houses are more disperse, the installation of more lines is required therefore, the investment costs are higher which has an effect on the cost of energy as can be seen in Figure 40. Average Cost of Energy $/KWh under the different dispersion scenarios.

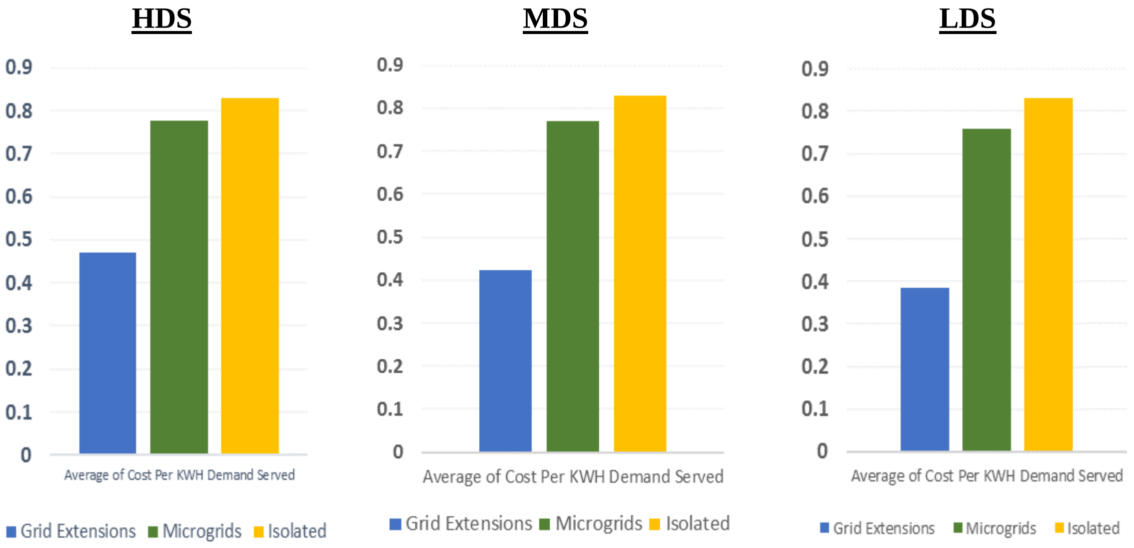


Figure 40. Average Cost of Energy $/KWh under the different dispersion scenarios

The average annual cost per customer follows the same pattern as the one of average cost of energy, solar and micro-grids do no show relevant variation with respect to the dispersion of houses while the annual cost per customer in grid extension is higher in the high dispersion scenario and lower in the low dispersion scenario.

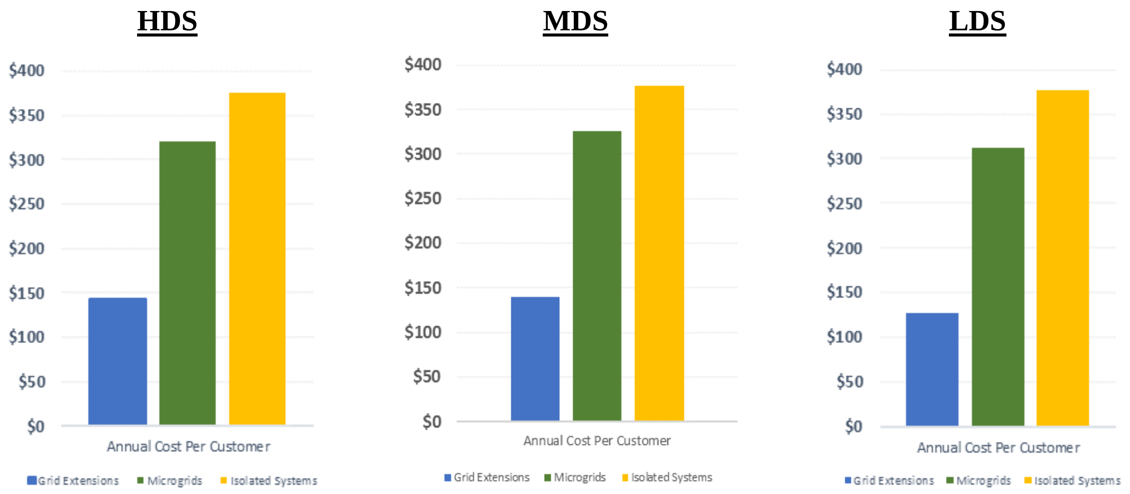


Figure 41. Average Annual Cost per Customer and System under the Normal Case Scenario

Electricity tariffs in Peru are regulated so there is a fixed charge that is applied to residential consumers, either monthly or by KWh depending on the type of electrification mode and the monthly consumption per customer. These tariffs were previously described, and now, comparing these with the average annual cost per customer, in Figure 42. Annual Funding gap per customer, it can be appreciated the funding gap per customer that it is needed so that the annual costs can be recovered.

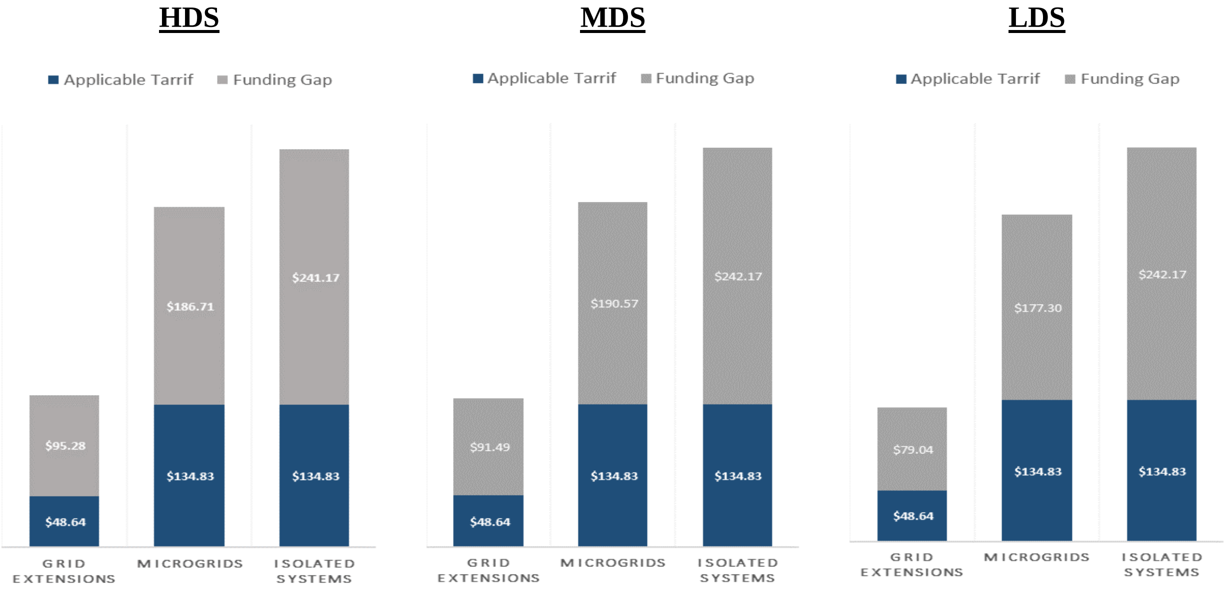


Figure 42. Annual Funding gap per customer

Annual Cost per electrification mode show variations between the dispersion scenarios as it can be seen in Figure 43. Annual Cost per Electrification Mode. The costs of solar and microgrids are proportional to the total number of users while, in grid extension, dispersion of houses has an impact on the annual cost as the less disperse the houses are, the lower the annual cost.

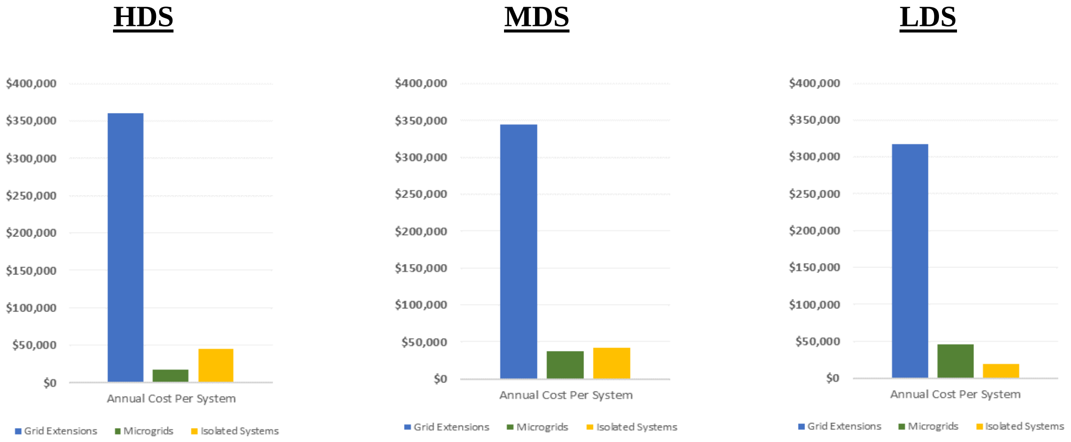
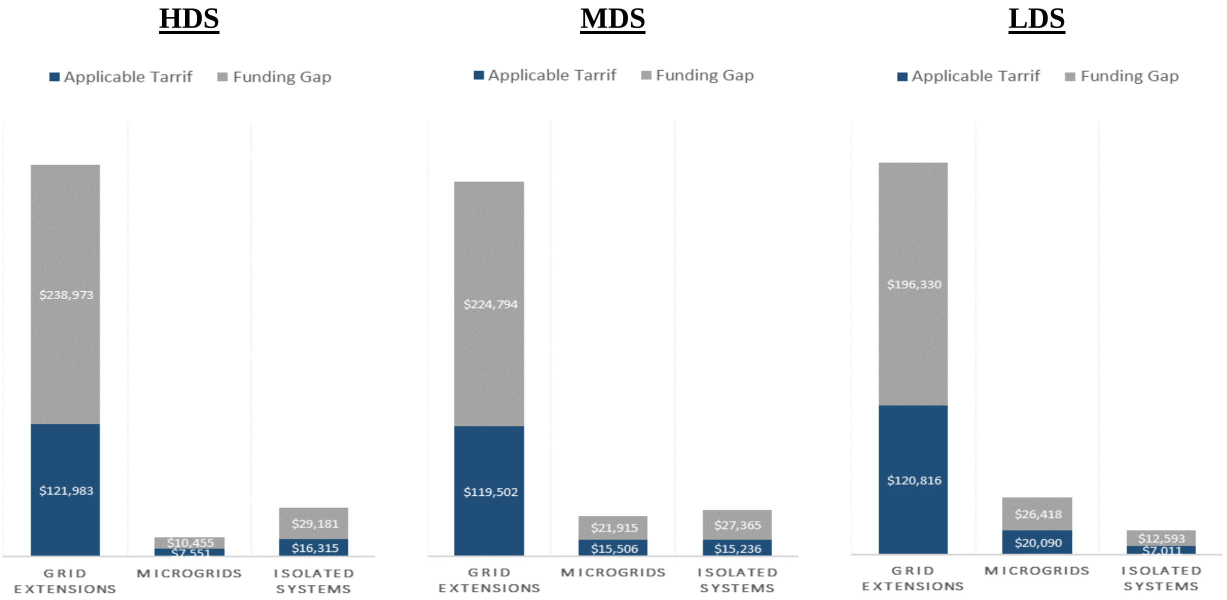


Figure 43. Annual Cost per Electrification Mode

Providing electricity services to rural areas implies high investment and, operation and maintenance costs that usually can't be recovered through the regulated electricity tariffs hence, support from governments is needed by means of subsidies to cover this funding gap. Taking into consideration the electricity tariffs in Peru, the annual funding gap needed per electrification mode under the normal case scenario is shown in Figure 44. Annual Funding Gap per Electrification Mode.



HDS **MDS** **LDS**

Figure 44. Annual Funding Gap per Electrification Mode

Total annual cost of the system under the normal case scenario is shown in Figure 45. Total Annual Cost under the normal case scenario. In this case study, it is demonstrated that under the normal case scenario, depending on the dispersion of houses, the impact on cost can be significant or not. On the one hand, there is a difference of $41,200 USD between the LDS and the HDS while on the other hand, there is only a difference of $140 USD between the MDS and the HDS.

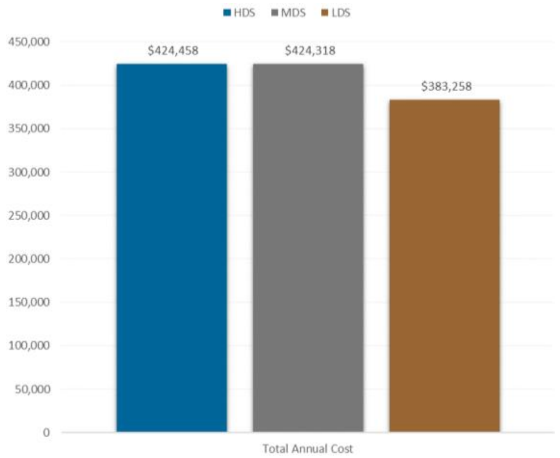


Figure 45. Total Annual Cost under the normal case scenario

Finally, the total annual funding gap that would be required depending on the dispersion of houses is shown in Figure 46. Total Annual Funding Gap in Normal Case Scenario.

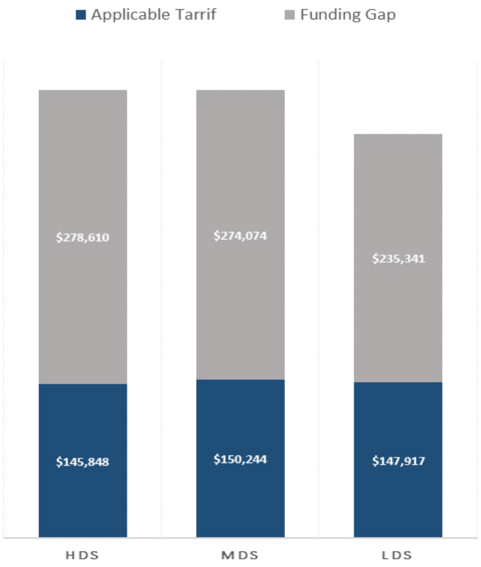


Figure 46. Total Annual Funding Gap in Normal Case Scenario

6.5.2 Case Scenario 1: Off-grid

Under this case scenario it is analyzed the possibility of electrifying Villa Santa Rosa with off-grid solutions by means of renewable energies. Figure 47. Electrification Mix in Scenario 1 shows that microgrids are the electrification technology chosen for most of the households and in Figure 48. Electrification Outcome in Scenario 1 the representation of the electrification planning is illustrated.

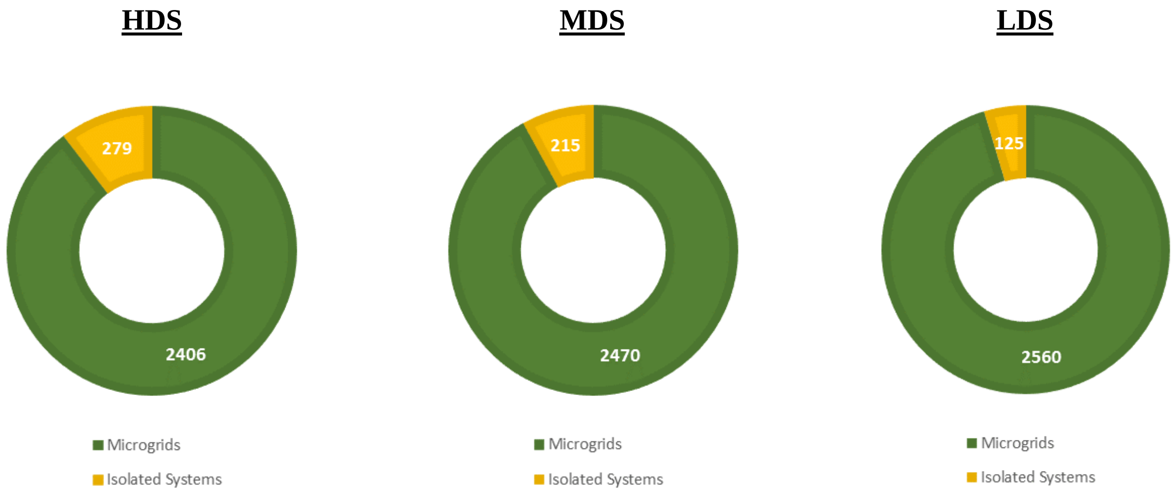


Figure 47. Electrification Mix in Scenario 1

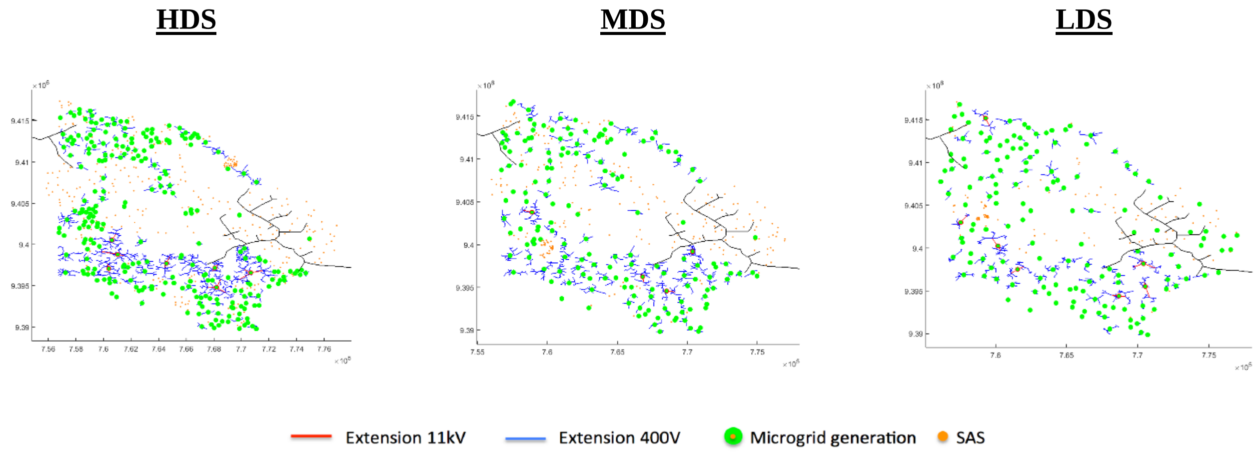


Figure 48. Electrification Outcome in Scenario 1

For the HDS, the REM proposes 2,406 households to be electrified by microgrids, this resulted in 258 microgrids to be installed with an average of 9.3 households per microgrid. For the MDS, 2,470 households would be electrified by microgrids, resulting in a total of 162 microgrids to be installed and average of 15.2 households per microgrid. For LDS, 2,560 households would be electrified by microgrids, resulting in 153 microgrids to be installed and an average of 16.7 households per microgrid.

Figure 49. Annual Cost per Customer in Scenario 1 shows that economies of scale are present in microgrids because as compared to isolated systems, the annual costs per user are lower for microgrids than for isolated systems. Also, economies of scale appear in microgrids where in the low dispersion scenario by having a higher number of households being electrified with a lower number of microgrids installed, the annual cost of the system per customer is lower compared to the other scenarios.

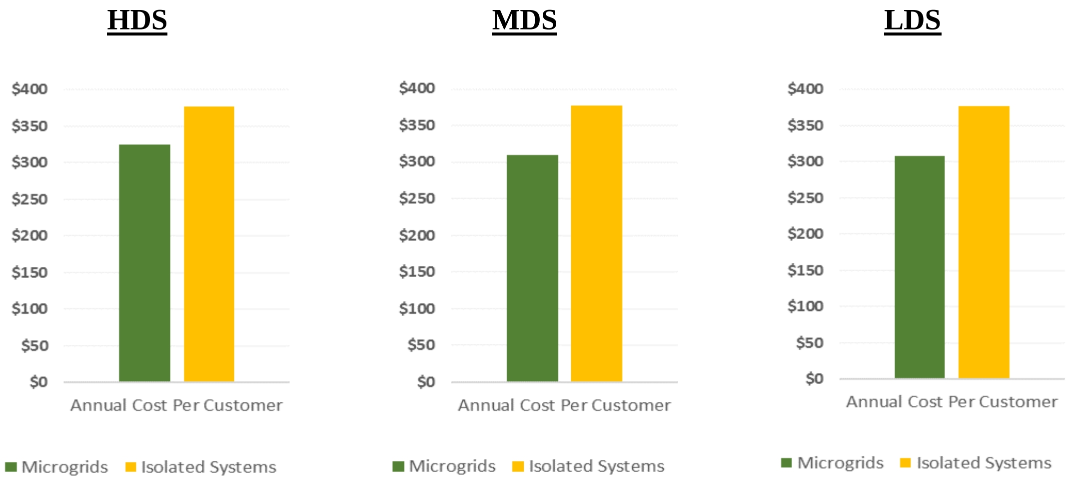


Figure 49. Annual Cost per Customer in Scenario 1

In terms of total annual costs, the HDS registers the highest cost while the LDS the lowest cost. Figure 50. Total Annual Cost of the System in Scenario 1 shows that under this scenario, the impact of dispersion is significant between the LDS and the HDS as there is a difference of $49,471 USD, while the impact is lower between the MDS and the LDS with a $9,741 USD difference.

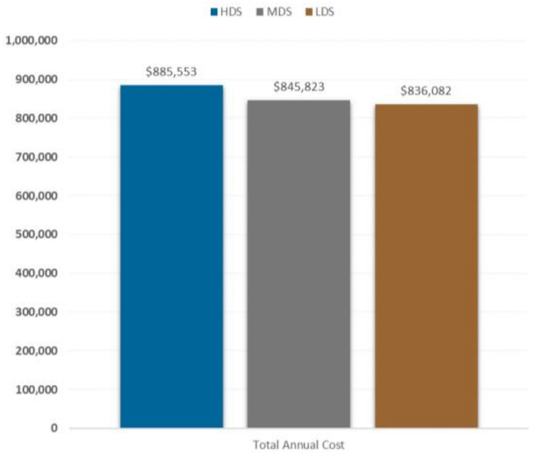


Figure 50. Total Annual Cost of the System in Scenario 1

6.5.3 Case Scenario 2: Diesel

Under this scenario, all electrification modes and energy sources can be used. As previously mentioned, under the normal case scenario, diesel was not allowed due to Peruvian legislation of electrifying isolated areas with renewable energies exclusively. Nevertheless, under this case scenario, diesel will be included in order to analyze its impact on the costs of the system.

The electrification mix provided by the REM is shown in Figure 51. Electrification Mix in Case Scenario 2. The impact of diesel is evident as now there are more microgrids compared to the normal case scenario where diesel was not allowed. The electrification planning can be appreciated in Figure 52. Electrification Outcome in Case Scenario 2.

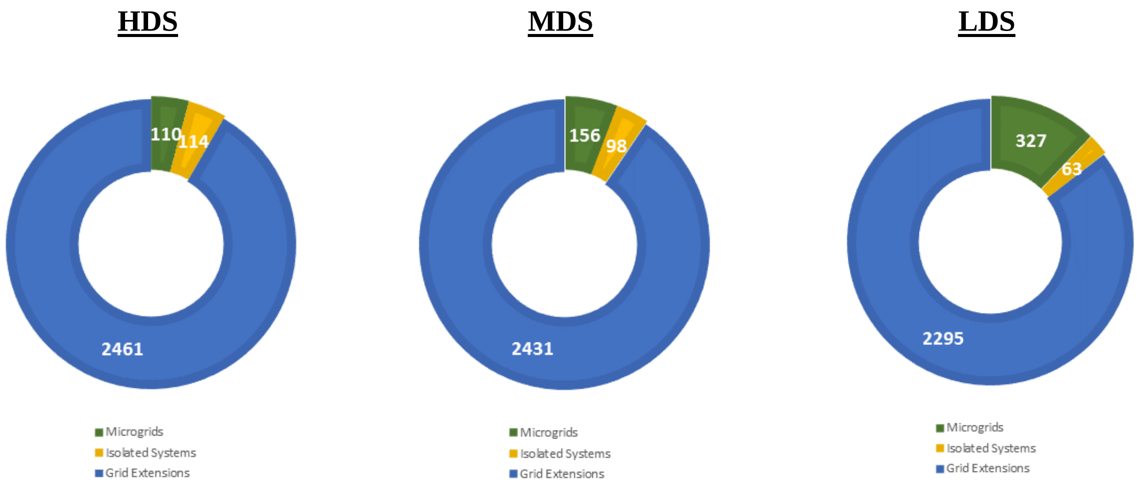


Figure 51. Electrification Mix in Case Scenario 2

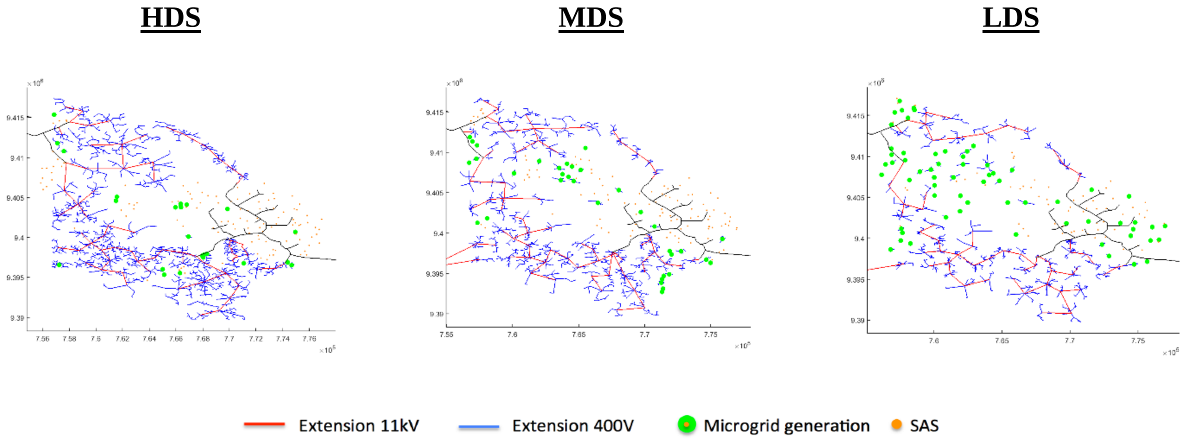


Figure 52. Electrification Outcome in Case Scenario 2

In terms of costs, diesel does have an impact on the total cost of the system specially in the high dispersion scenario where microgrids of bigger size can be installed due to the proximity of houses. The total annual cost of the system is shown in Figure 53. Annual Cost per Electrification Mode in Scenario 2. Under this scenario, the difference of costs is reduced between the three dispersion scenarios. These are higher to those compared to the normal case scenario and this is explained because diesel, besides improving reliability, it also increases the total cost of the system as the price of diesel to isolated areas of the Amazon is high (considered 2$/L under this case scenario).

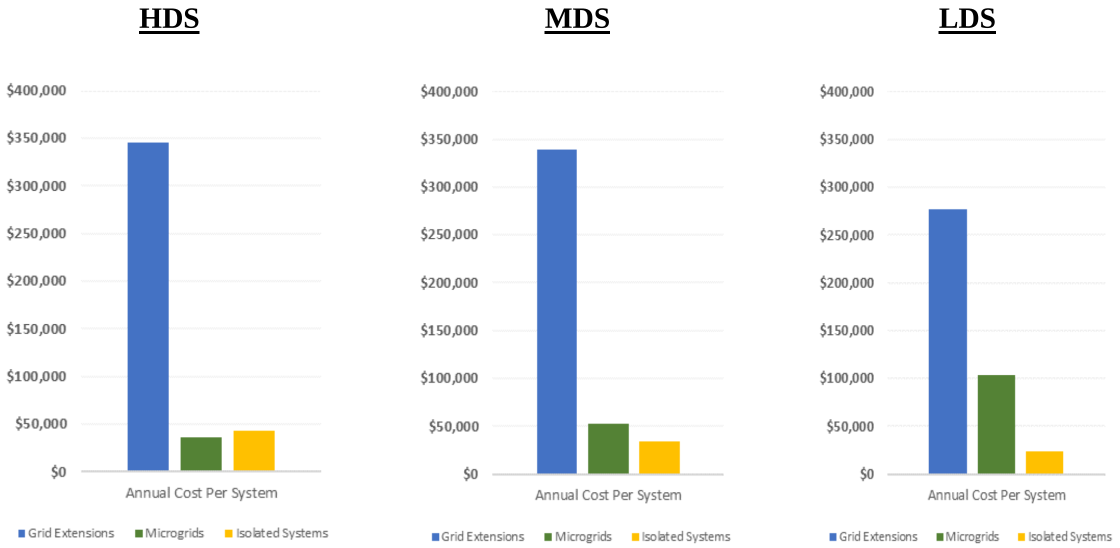

HDS **MDS** **LDS**

Figure 53. Annual Cost per Electrification Mode in Scenario 2

The impact of dispersion on the total annual cost of the system is less significant under this case scenario as there is a difference of $21,426 USD between the MDS and the HDS while, the difference between LDS and MDS is $1,334 USD. It is also important to notice that the MDS reports the highest cost of the system.

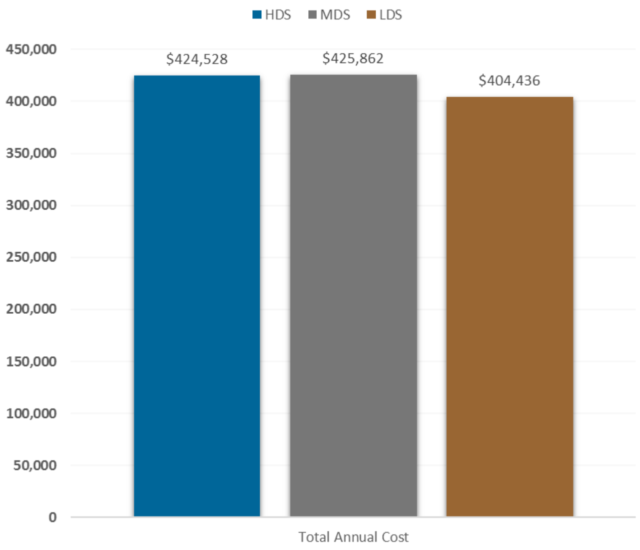


Figure 54. Total Annual Cost of the System in Scenario 2

6.5.4 Case Scenario 3: Grid Extension

Under this scenario, it is analyzed the possibility of electrifying Villa Santa Rosa entirely with grid extension. To do this, the operation and maintenance costs of microgrids and isolated systems were modified with very high values so that the model will only select grid extension. The electrification planning is shown in Figure 55. Electrification Outcome in Case Scenario 3.

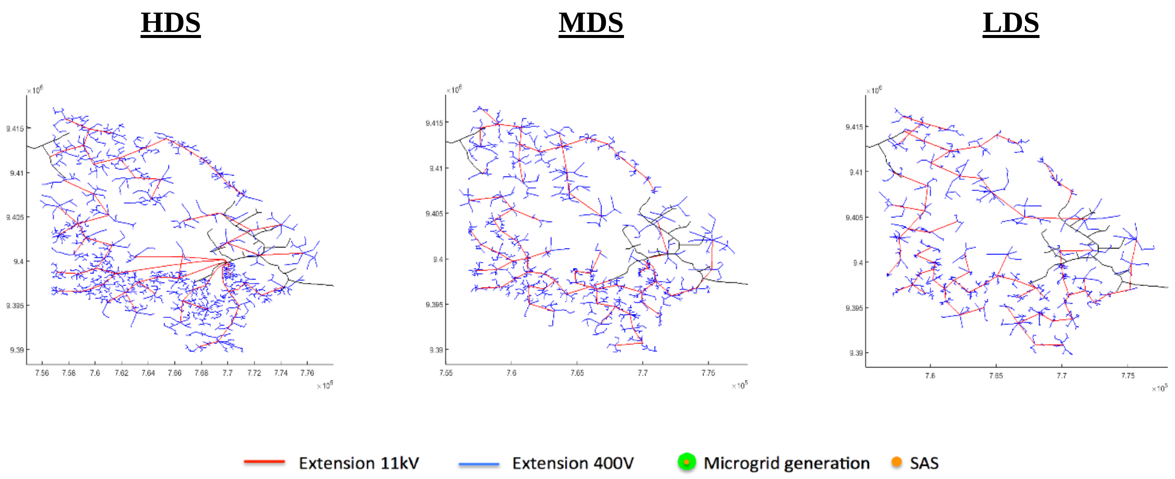

HDS **MDS** **LDS**

Figure 55. Electrification Outcome in Case Scenario 3

The results show that dispersion of houses does have an impact on the average cost per household (Figure 56. Average Annual Cost Per Customer in Case Scenario 3). High Dispersion Scenario reports the highest cost while the Low Dispersion Scenario has the lowest cost because as previously mentioned the lower the dispersion, the lower the cost for grid extension.

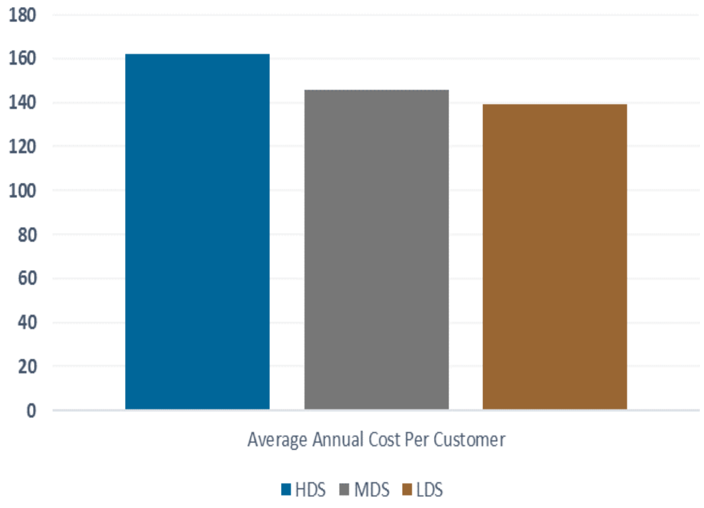


Figure 56. Average Annual Cost Per Customer in Case Scenario 3

The impact of dispersion on cost of the system is very significant, in fact, this scenario reports the highest impact as the difference between the HDS and LDS is $61,088, the difference between HDS and MDS is $44,383 and finally the difference between MDS and LDS is $16,705. These variations can be better appreciated in Figure 57. Total Annual Cost of the System in Case Scenario 3. It is important to mention that the total cost of the system under this scenario is lower than the total cost of the normal case scenario. This is due to the fact that reliability of Case Scenario 3 is lower than the Normal Case Scenario.

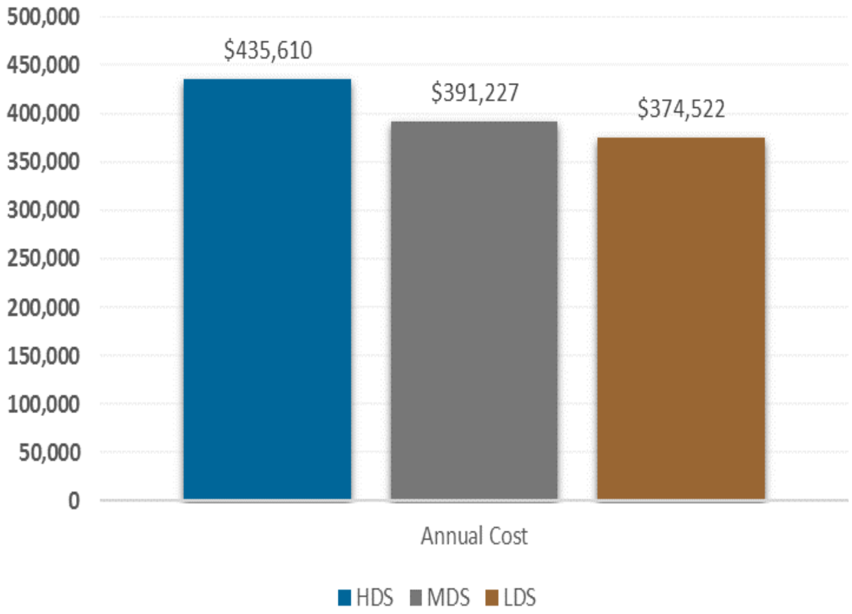


Figure 57. Total Annual Cost of the System in Case Scenario 3

6.5.5 Impact of Dispersion on Total Costs

With the results obtained from the REM, the impact that dispersion of houses has under the different electrification scenarios can be analyzed. Table 15. Total cost of the systems under dispersion and electrification scenarios shows the total annual costs for the different scenarios studied in the Villa Santa Rosa case study.

REM CASE	HDS	MDS	LDS
Normal Case Scenario: Renewables + Extension	$424,458	$424,318	$383,258
Scenario 1: Off-grid	$885,553	$845,823	$836,082
Scenario 2: Diesel	$424,528	$425,862	$404,436
Scenario 3: Grid Extension	$435,610	$391,227	$374,522

Table 15. Total cost of the systems under dispersion and electrification scenarios

Table 16. Comparison of total cost of the system between dispersion scenarios per electrification scenario shows the variation in terms of percentage and money ($) that resulted between the dispersion scenarios under each electrification scenario.

REM CASE	Δ HDS-MDS		Δ HDS-LDS		Δ MDS-LDS	
	%	$	%	$	%	$
Normal Case Scenario: Renewables + Extension	0.033%	**$140**	10.750%	**$41,200**	10.713%	**$41,060**
Scenario 1: Off-grid	4.697%	**$39,730**	5.917%	**$49,471**	1.165%	**$9,741**
Scenario 2: Diesel	-0.313%	**($1,334)**	4.968%	**$20,092**	5.298%	**$21,426**
Scenario 3: Grid Extension	11.345%	**$44,383**	16.311%	**$61,088**	4.460%	**$16,705**

Table 16. Comparison of total cost of the system between dispersion scenarios per electrification scenario

In the above table, the impact of dispersion of houses on the total costs of the system is better illustrated. This impact varies significantly depending on the dispersion and the electrification scenarios, here it can be highlighted:

- ***Lowest impact between dispersion:***
  $140 of difference between HDS and MDS under normal case scenario.

- ***Highest impact between dispersion:***
  $61,088 of difference between HDS and LDS under Scenario 3: Grid Extension.

- ***Lowest average impact under electrification scenario:***
  $13,839 the average difference between dispersion under Scenario 2: Diesel.

- ***Highest average impact under electrification scenario:***
  $40, 725 the average difference between dispersion under Scenario 3: Grid Extension.

Overall, even though dispersion does have an impact on the total costs of the systems, the results obtained are good estimations that can be taken into consideration so that decision makers involved in rural electrification projects can obtain approximations of the costs that would be incurred under different scenarios when performing the rural electrification planning of an area.

7. CONCLUSIONS

This thesis has studied the regulatory framework towards achieving the goal of universal electricity access in Bolivia, Brazil, Colombia, Ecuador and Peru. Also, a methodology was proposed to support electrification planning in isolated areas of the Amazon and this methodology was applied in a case study performed on the community Villa Santa Rosa in Peru.

Achieving universal electricity access is not an easy task for governments, under the three criteria studied for these five countries, it was exposed that the approaches that are being implemented to attain this goal are sometimes different. The various factors that intervene in increasing electricity access by means of rural electrification can be very complex requiring special attention as it is the case of the collection of the economic resources to finance subsidies and funds intended for rural electrification. Furthermore, specific considerations are also taken into account such as; the formulation of national electricity plans, the appropriate enforcement of electrification targets, the agents involved in rural electrification projects and the technologies to be installed, among others.

Since the regulatory framework plays a key role for attaining universal electricity access, these countries should take advantage of the practices that were successful in other countries and adapt these and then, implement these according to the actual situation of each country. These five countries are found in a different stage in terms of the current electricity coverage situation therefore, policies and legislations have to be established according to the stage in where they are found.

Regarding the application of the methodology to support electrification planning in isolated areas of the Amazon, the use of existing software technologies; LandScan, ArcGIS and the REM together with the implementation of an algorithm to estimate the location of houses provided a possible solution that could be employed not only in the Amazonian region but also in other areas when electrification planning is to be performed and the location of houses is unknown.

Moreover, this methodology demonstrated that the algorithm implemented to locate houses was useful in order to analyze the results provided by the REM. Overall, costs approximations were obtained and these can be taken as a starting point so that governments, distribution operators, private companies or any agent involved in rural electrification projects can get an estimation of electrification costs under different dispersion and electrification scenarios, in this way better informed decisions can be taken to provide electricity services to communities in the Amazon.

7.1 Future work

Rural electrification is a topic that is under continuous research and development therefore, this master thesis project can be complemented and improved in some aspects, some of the most relevant are:

- **Improve the algorithm:**
  The algorithm to locate houses could be improved for future projects by adding a restriction in the distance between houses. A minimum distance should be considered in a way to ensure that houses will be located at least 8 meters away from other houses, for instance. This would provide more realistic results, especially in those cells where LandScan detects high population distributions.

- **Increase reliability of the network:**
  In the Villa Santa Rosa case study under all the electrification scenarios, the reliability of the grid was set at 85% of the times the system would be able to meet the demand. For future projects if the real value of the reliability of the network can't be obtained, it would be interesting to increase the reliability at 95% for example, as this was more or less the reliability that the REM obtained for isolated systems and microgrids under the different scenarios. In this way, comparisons between the electrification modes can be performed under similar values of reliability.

- **Apply the methodology to different areas of the Amazon in the rest of the countries:**
  This methodology can be applied to study Amazonian regions of the rest of the countries included in the regulatory section of this thesis. It would be exciting to take into account electricity tariffs and electrification modes that can be considered for rural electrification projects according to national legislations and compare the results of the five countries.

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