Rural Electrification in off-grid areas in Colombia

Case study of Cumaribo Municipality

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Synopsis:

This work takes interest on analyzing the business and socio-economical effects that hybridization can have on NIZ localities. To this end, the above mentioned problem will be investigated using the municipality of Cumaribo as case study. Cumaribo has a population in its municipal seat of 4.486 inhabitants that enjoy a 24 hours energy service based on diesel generation. Interviews with energy consultants, extensive literature review, and numerical modeling have been carried out to present insight on this problem. Business economical, policy and stakeholder analyses make part of this insight.
Energy system calculations in this work are done based on an optimization model called HOMER. From the model results, the financial effects of hybridization were calculated for different stakeholders in Cumaribo municipality. Finally, a discussion of these results is conducted and presented.

Preface

This project is carried out by a 4th semester student from the Sustainable Energy Planning and Management master program at Aalborg University. The project is written in the summer term, spanning from June 2 to August 31, 2017.

Reading Instruction

Sections, tables and figures are numbered chronologically in accordance to chapter number (e.g. the first figure in Chapter 2 is numbered 2.1, the next is numbered 2.2, and so forth). Explanatory text to figures and tables can be found in the related captions.

The Harvard Referencing System has been chosen for references. The references used in the text have labels of the type [Author, Year]. All the references are listed in the Reference Chapter at the end of the report. Figures and tables are placed with mention of their respective sources.

Monetary values and Numerical representations

All monetary values in this report are given in Euro (EUR) as it stood on 02 June, 2016 with regards to inflation and exchange rate, unless otherwise stated. Cited sources presenting values in Colombian Pesos (COP) or American dollars (USD), were converted accordingly using the following exchange rates: 1 EUR = 3256.59 COP and 1 EUR = 1.17 USD.

Acknowledgements

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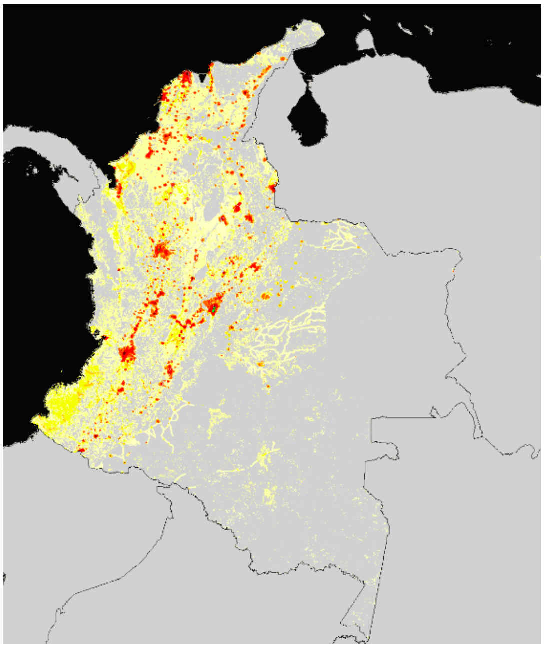
Contents

1 Introduction

Colombia occupies the northwestern corner of South America. It has coastlines on both the Pacific Ocean on the west and the Caribbean Sea on the east. Its population is approximately 48.6 million according to the official population clock by [DANE, 2017]. Colombia is a unitary state divided into 32 departments and a Capital District in Bogotá city where the central government is installed.

The climate of Colombia is characterized for being tropical and isothermal as a result of its proximity to the Equator. It presents variations within five natural regions: Andean Region, Caribbean Region, Pacific Region and the Orinoquia Region. Each region maintains an average temperature throughout the year with only mild variations determined by precipitation seasons. Geographically, the country is dominated to the west by the Andes mountains where the majority of the population resides as can be seen in Figures 1.1a and 1.1b. To the east there are extensive plains. To the south a thick jungle extends towards the Amazon river. These lowland regions, comprising about 54% of Colombia's area, host less than 3% of the population.

(a) Relief Map of Colombia, Andes mountains to the West and extensive plains to the East.



(b) Colombian Population Density, the brighter zones demonstrate that the population resides mainly on the mountain range compared to the lowland zones.

Figure 1.1: Taken from Agustin Codazzi Geographic Institute [IGAC, 2016]

1.1 Not Interconnected Zones

The demographic distribution shown above causes a noticeable division in the access to electricity of different regions in Colombia. Energy-wise there exist two zones, the National Interconnected System (NIS) zone, and the off-grid zones, also known a Not Interconnected Zones (NIZ). As shown in Figure 1.2.

The NIS is the system that consists of the following interconnected elements; The centralized generation plants, the interconnection network, the transmission lines, the distribution lines and the end-user loads. In Colombia, NIS supplies around 97% of Colombia's population. Next to 45.6 million people [DANE, 2017]. This system relies on hydro-power for the bulk of its electricity needs. By 2015 Hydroelectrics covered approximately 64% of power generation. The remaining 36% was produced almost entirely by thermal plants, with a small share of renewables (around 0.4%). In turn, Thermal power generation was fueled approximately 72% by natural gas, and mostly coal for the rest. [procolombia, 2015] [Medrano, 2015].

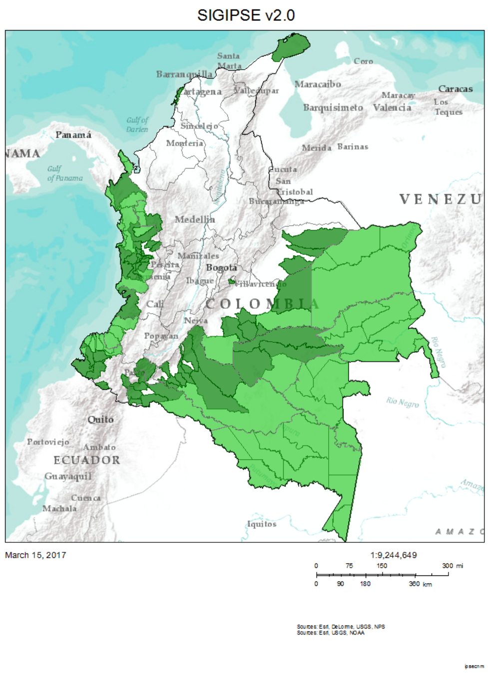


Figure 1.2: NIZ (In green) vs NIS zones in light gray. It can be noticed that it resembles the demographic heat map in Figure ??. Taken from [c.n.m., 2017].

By definition, the NIZ consists of all the townships, localities and settlements not interconnected to the NIS. The institution in charge of implementing energy solutions for NIZ is the "Institute for Planning and Promotion of Energy Solutions in off-grid areas" (IPSE, by its Spanish acronym). IPSE has identified that NIZ corresponds to 32% of the national territory and is composed by 1.448 settlements, of which 37 are municipal seats and 5 are departmental capitals. Roughly 84% of these settlements have less than 600 inhabitants, 9% have between 600 and 1000, and only the remaining 7% have more than the thousand, among them, all municipal seats. [IPSE].

These settlements are normally difficult to access, its dwellers usually have low income levels, sometimes below the extreme poverty line (about 100 EUR per family per month) and low education level. Many of these settlements are indigenous (around 842,000 people by 2014 mostly in the regions of Vaupés and Amazonas) or racial minorities, such as African-Colombians (950,295) and Raizales (40,201). [IPSE, 2014]. In total by September last year there were nearly 1.26 million Colombians outside the NIS of which approximately 840,000 (202 thousand households) had access to electricity, roughly 66% of NIZ population. [IPSE]. [c.n.m., 2017].

NIZ energy system consists of a distributed system with a total installed capacity of 167 MW of which only 151 MW are in operation and available. This system is constituted 88% by diesel plants, while most of the remaining 8% consists of small hydroelectric plants and a small presence of solar energy [IPSE]. Around 85.8% of these diesel plants have a capacity which falls bellow the 100 kW. The remaining 13% have power specifications between 100 kW and 1000 kW, with a small percentage of 1.2% going over 1000 kW [USAENE LLC, 2013]. The service in NIZ is 1-6 hours for 32% of the energy users, with 24 hours being the second most common case with 31.3% [c.n.m., 2017]. Figure 1.3 illustrates these and other statistics that help characterize the NIZ in Colombia.

Despite its prevalence, diesel generation has a relatively high production cost per kWh and negative environmental impacts. This fact, however, doesn't affect financially the residents of NIZ, including private,industrial and official consumers, because the tariff scheme protects them against high energy prices, as will be explain in more detail in Chapter 3. As a result, diesel generation is highly subsidized. For example, last year the state (through IPSE) spent around 10.7 Million EUR covering production costs of energy operators in NIZ, around 44% of the total budget for investments in off-grid areas [IPSE]. This situation has already reached a point in which the state is now invested in promoting alternative energy sources seeking to reduce generation costs and lower these subsidies.

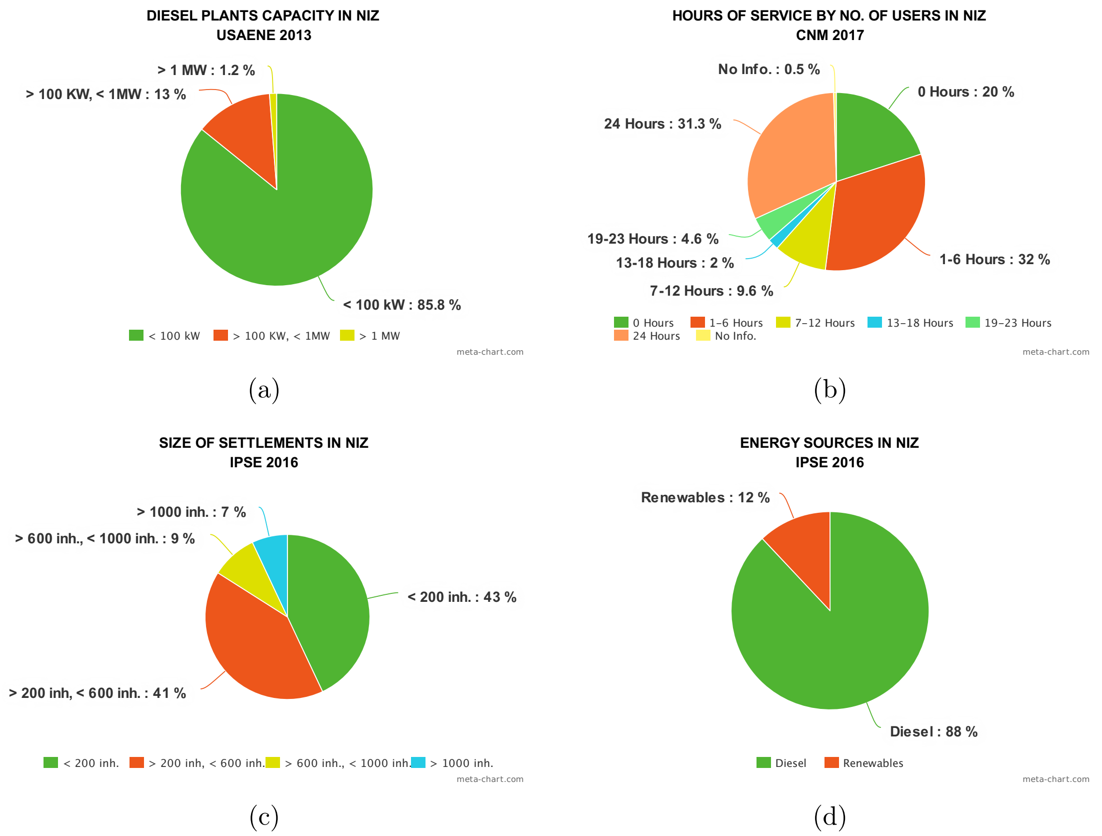


Figure 1.3: Characterization of NIZ in Colombia. Four pie charts are presented featuring the following statistical information: (a) Amount of diesel plants in different capacity ranges. (b) Amount of localities providing different ranges of service hours. (c) Amount of localities with different range of settlements size. (d) Amount of energy provided by different sources types.

1.2 Hybrid Systems as an Alternative

Hybrid systems constitute a reasonable approach to mitigate the tax gap generated by high diesel subsidies. By means of replacing part of the fossil generation with renewable alternatives hybrid implementations can lower the production costs of diesel systems.

From an economical standpoint hybridization with renewable technologies should be an attractive alternative in NIZ for energy operators, since investment costs, which are usually a great limitation, are either fully or partially subsidized by IPSE through the FAZNI fund [MME, 2014]. In 2016, IPSE investment in renewables was around 94% PV and only 6% biomass. However, out the investment in PV only a fraction of 14% went to a hybridization project solar-diesel of 40 KW in the municipal seat of Barrancominas, Guainia. This is rather odd, given that these systems have proofed to bring socio-economical benefits in the past, such as the case of solar-diesel hybridization in Isla Fuerte, Bolivar, a 1.3 Million EUR project that made it possible to have a school and a rudimentary health spot in this settlement. Or the Titumate, Chocó case, which upgraded the electricity service from 4 hours to 24 hours IPSE [2014].

This low investment in Hybrid, however, is perhaps the result of the working policy structure. In Colombia, the energy operators in NIZ that own diesel plants find it economically convenient to have a high diesel consumption, because the higher the consumption, the higher the production costs and the higher the subsidies given to them by the state. This point will be developed further in Chapter 4. On the one side, this situation has promoted a strong opposition to hybridization initiatives. On the other side, in places in which hybridization has taken place, energy operators have either renounced their posts, or deliberately wasted renewable energy with the purpose of maintaining certain level of diesel consumption, which favors their financial scheme. According to Eric Davila, member of the International Solar Energy Society (ISES) and founder of a consulting company in sustainable energy called ESEI S.A., this problem is the single biggest challenge for the future of renewable energies (RE) in Colombia [Dávila, 2017].

1.3 Problem and Research Question

Based on the previous sections, several points are noticeable regarding the Colombian NIZ energy system. On one side, there is great interest from the state to promote renewable energies in NIZ localities. Renewables are meant to strengthen the security of supply and bring advancement to these zones. On the other side, renewables bare the potential, through hybridization, to lower the subsidies given to diesel systems and hence the overall cost of providing energy services in these localities. To this regard there is a number of programs and new policies, such as the FAZNI fund and the recent law 1715 of 2014 [Congress, 2014]. Which suggest that renewables will gain plenty of relevance in the near future. This work takes interest on analyzing the business and socio-economical effects that hybridization can have on the principal stakeholders in NIZ, to seek for solutions that make hybrid system feasible for these actors. Hence, the following research question is addressed:

What are the barriers for hybrid systems in Colombia and how can these be overcome to make a feasible solution for the principal actors related to these systems?

In order to answer this question, the following sub-questions must be answered:

1. What are the most relevant stakeholders and what roles do they play towards the NIZ energy system?
2. What is the current policy framework in Colombia regarding NIZ tariffs, funds and subsidies?
3. What is the current business-economical feasibility of hybridizing an diesel energy system from the perspective of the different stakeholders?
4. What are the barriers for hybrid systems in Colombia, in relation to the actors and the current policy structure?
5. What policy suggestions could be implemented to hybridize the diesel systems in a feasible way for the stakeholders?

1.4 Limitations

The above mentioned problem will be investigated using the municipality of Cumaribo as case study. Cumaribo has a population in its municipal seat of 4.486 inhabitants that enjoy a 24 hours energy service, unsurprisingly based on diesel generation. This township is interesting, among other things because it's the municipality with the biggest land extension in Colombia and in the world, with a size of 65,193 km^2 (Denmark has around 42,924 km^2). However, the main reason for choosing it, is that by collaboration of ESSEI S.A., access to data and privileged information has been granted for this locality.

Another important limitations of this project is the renewable technology. To this regard it should be noted that in Colombia, hybridization solutions are almost certainly a mixture between diesel and solar based generation. This is not only a matter of resource availability i.e. the relative abundance of solar radiation compared to other resources such as wind, biomass, or hydro, but also because PV has a relative low operation and maintenance (O&M) costs and complexity, as well as relatively simpler and quicker installation and infrastructure requirements, which make it more attractive than other technologies [FS-UNEP, 2014]. Hence, this project only considers PV panels in its technical analysis. Further developments in this report, will reinforce this notion in the Chapters to come.

1.5 Report Structure

Figure 1.4 illustrates the relation between the methods, the sub-questions and the chapters of the report.

Outline of the report The report includes 6 chapters:

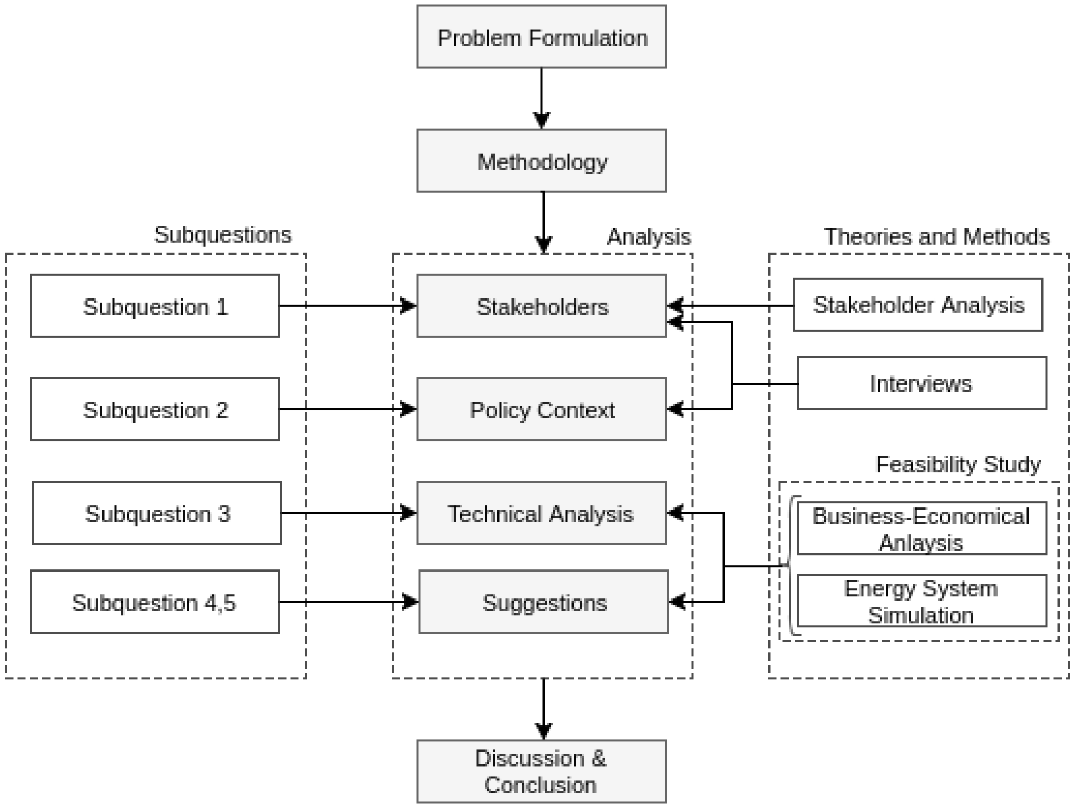


Figure 1.4: Diagram illustrating the report structure. Light gray boxes represent the body of the report.

- **Chapter 1 - Introduction** Serves as an introduction to the topic of the project and presents the background and contextual information towards the problem formulation and the research question and sub-questions.
- **Chapter 2 - Methodology** Presents an overview of the methodology used to investigate the problem and presents the theoretical basis of the analysis. Main topics here are, business-economical analysis, energy calculations, stakeholder analysis, literature review and interview methodologies.
- **Chapter 3 - Stakeholder Analysis** A detailed study of the different stakeholders involved is conducted at the national and cases-study levels to investigate the role and interests of different stakeholders. The chapter ends with an identification of the main actors to be further investigated in the following chapter.
- **Chapter 4 -Policy Context** A summary of the policy context is presented. Emphasis is done on the tariff structure in NIZ, the funds involved in hybrid implementation, and their relation to the subsidies for NIZ population.
- **Chapter 5 - Technical Analysis** Presents a simulation of the reference scenario in Cumaribo together with a number of hybridization scenarios. Economic feasibility of this scenarios is then assessed from the perspective of the stakeholders chosen in Chapter 3.
- **Chapter 6 - Barriers and Suggestions** In the first part of the Chapter, a summary of the barriers for hybrid implementations is presented. Next, a couple of policy suggestions are introduced as possible means to overcome these barriers. The suggestions are thus simulated and the results analyzed.

The report concludes with the discussions and analysis in Chapter 7, as well as the conclusions in Chapter 8.

Methodology 2

The different methods that were used in order to investigate the research question are accounted for in this Chapter.

2.1 Stakeholder Analysis

A stakeholder analysis is a process of systematically gathering and analyzing qualitative information to determine whose interests should be taken into account when implementing a policy or program [Schmeer, 2012]. In this work, a stakeholder analysis was conducted using the following steps:

1. Defining the purpose
2. Selecting and defining a policy
3. Identifying key stakeholders
4. Adapting the tools (Interviews and power-interest grid)
5. Analyzing and using the information

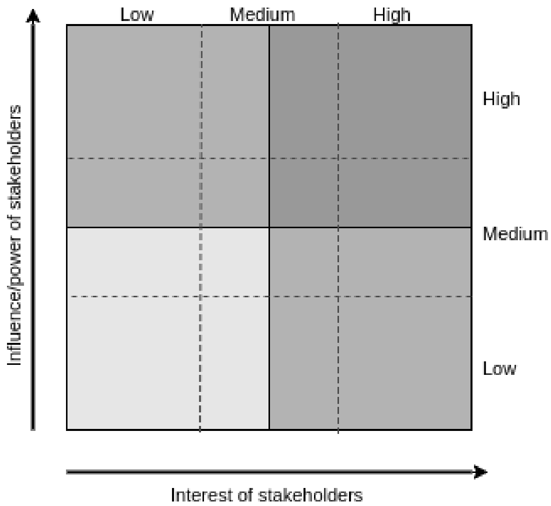
The first step consists of clarifying the purpose of the stakeholder analysis. After defining the purpose, the second part is to identify the specific issue at hand, this issue should be specific, and would benefit from having some degree of social or political controversy according to the source. Next, an identification of the stakeholders that merit further investigation is conducted. The tools that will be used for this process should be define and "adapted" to the problem at hand. Finally, the results derived from these tools are analyzed and used in accordance to the purpose in step 1.

The purpose of this stakeholder analysis is to identify the actors for which the feasibility of hybridization is a financial issue, rather than a political or cultural one (step 1). For this actors a deeper investigation will be held regarding the economic consequences of hybridization from their standpoint. Following this line of thought, the policy that was selected is the hybridization of diesel systems in NIZ. i.e. the initiative of IPSE to *perform capital investments in renewable implementations, with the aim of partially substitute diesel consumption in off-grid systems in Colombia* (step 2). To this regard, the investigation began by listing the actors in NIZ system at a national level. The aim was to provide a general picture of the governmental entities and actors involved and the roles they perform (step 3). At this point, an interview process was conducted (see Section 2.2) as a tool for gaining further insight on the actors as well as other matters (step 4). With the information obtained from the interview the identification of actors is narrowed down to the case-study level. In this case the regional key actors were chosen with specific regard to the nature of their relation with the hybridization policy. At this point, the study circled back to step 3.

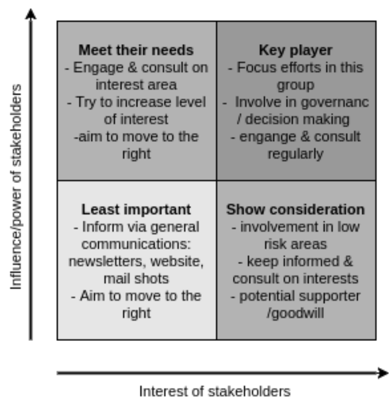
Next, the interview insights were used to draft a power-interest grid. The resulting diagram is analyzed. Specific attention is paid to the level of involvement of different actors and the nature of their interest (step 4). The actors with deeper financial involvement and whose stakes in the hybridization policy are higher are singled out for further analysis in the technical part of the report, while strategies on how to approach the other actors are suggested (step 5).

2.1.1 Power Interest Grid

In order to build a power-interest grid the stakeholders should be place in a diagram with four zones, as shown in Figure 2.1a. Power and interest are divided into three levels; low, medium and high. This levels should help the placement of stakeholders. Depending on the zone in which the actor is placed, the theory proposes different ways to approach the different stakeholders so as to maximize the probability of success of the issue or policy at hand [Eden C. and Ackermann, 1998]. The general guidelines for this are shown in Figure 2.1b. These guidelines should be adjusted to the specific case so that they tend to the main interests of the stakeholders, be them legal, political or financial.



(a) Template diagram for a power-interest grid.



(b) General guidelines on how to approach stakeholders in different zones

Figure 2.1: Power interest grid template. Adapted from [Eden C. and Ackermann, 1998]

2.2 Interviews

Relevant information about the actors, policies and technical aspects of hybridization in NIZ were collected by conducting interviews with field experts from Hybritec and ESSEI. S.A. in Colombia. *This method was chosen to address some unanswered questions regarding hybrid systems with the help of field experts.* In the case of Hybritec informant the focus was on the general strategies for approaching hybridization from a technical perspective. In the case of ESSEI. S.A. informant, the interest was centered on identifying the specific actors involved in hybrization at the case-study level. This informant also brought unexpected insight on the governments point of view on the implementation of hybrid systems in NIZ.

The first informant, Sebastian Vargas, is an electrical engineer currently working in Hybritec. The informant has participated in many projects involving the implementation of PV panels in NIZ. As the name of the company suggests, a number of these implementations are hybridization projects. The second informant, Eric Davila, is the head of a consultant firm that works with IPSE, this person has deep involvement in the planning stage of hybridizing the municipality of Cumaribo and other NIZ localities, and his insight on the overall policy structure was vital to the project. The insights harvested in this interview also shaped the business-economical calculations from the government perspective. Finally, this interviewee provided the hourly data of Cumaribo's energy consumption.

The topics to be covered in these interviews, separated by their qualitative or quantitative nature are summarized in Table 2.1. After this topics were identified, a document with questions was prepared. The first interview was conducted in Medellin, as Hybritec representative is rooted in this city. The second interview was done in Bogotá in the offices of the consultant company. Both are cities in Colombia.

Table 2.1: Key topics to be discussed during the interview

Qualitative	**Quantitative**
- National and regional actors - Interest and motivations of these actors - Policy Context in NIZ : Laws and policies of relevance - Social context in NIZ	- Feasible technologies for Hybridization - Technical guidelines - General figures: costs and subsidies - Data Available for NIZ localities

Even though the questions were prepared beforehand they were not handed directly, but progressively as the conversations unveiled. Therefore, the prepared questions were put in the background and the interviewees were put in charge of the interviews. This was done to make the interview resemble the characteristics of a fluent conversation, as more knowledge is gained if the informant is not bounded to answer only specific questions, and can develop on areas of interest that the interviewers did not anticipate or knew about. These factors made each conducted interview a semi-structured interview [Cohen and Crabtree, 2006]. Both interviews were recorded and later transcribed. Interviews with other field experts were also agreed upon, but ultimately the meetings where canceled.

2.3 Policy Context

Before conducting a technical analysis in Chapter 5, a summary of the policy context was done in Chapter 4. The purpose of this chapter is to ensure that the technical analyses are in accordance with the current incentives and regulations. The emphasis was made around three topics; The current tariff structure for NIZ, the funds that are involved in the NIZ context and the overall situation that encourages the government to invest in hybridization schemes in off-grid zones. Relevant insights regarding the last topic were acquired from the interview with ESSEI S.A. representative, as a result of the semi-structured methodology depicted in the last section. Finally, extensive literature review was conducted to back-up the interview remarks with specific laws and official documents.

2.4 Feasibility Study

The general frame of this investigation is a feasibility study. *The purpose of which is to determine the most feasible hybridization strategy for the key actors that were chosen in the stakeholder analysis.* According to [Hvelplund et al., 2007] a feasibility study should cover the following points: A screening of feasible technological alternatives, and evaluation of the social, environmental and economic costs as well as an analysis of the institutional conditions which influence the implementation of these alternatives.

In this study the technological alternatives are not explore in the sense of screening different technologies, but rather the study focuses on photovoltaic panels. However, different scenarios for hybridization with PV were explored, as will be explained in more detail in Section 2.4.2 to determine the most feasible options. Also, this study was held from a business-economical perspective, so social and environmental calculations were not conducted. However, some policy recommendations were proposed in Chapter 6. Finally, the institutional conditions that influence the implementation of hybrid alternatives were covered and are the focus of Chapter 4.

2.4.1 reference scenario

In this work the reference scenario consists of the tariff and subsidies conditions that were covered to some extend in Chapter 4, Policy Context, on one part. On the other part it consist of the the current energy system of Cumaribo municipality, which is described to some extend in the first part of Chapter 5, Technical Analysis. This scenario was done for calculating the economic feasibility of the different hybridization scenarios explored during the project.

2.4.2 System Modeling

The software application HOMER Energy was used with the purpose of simulating the energy system of Cumaribo (reference scenario) and the different hybridization scenarios. This software focuses on stand-alone applications of renewable energy for distributed systems of small to medium scale [D. Conolly and Leahy, 2009]. HOMER Energy works as an input/output model. The program first simulates the performance of different system variations and then determines one solution that minimizes the net present cost (NPC). If several technologies are involved in the system, it presents a solutions for each system configuration. Finally, the program can also be used to simulate deterministic system designs with relative simplicity and facilitates the process of performing sensitivities and investigating multiple scenarios. The latter is the principal reason for choosing this software.

The main data that was inputted to the program consisted on the hourly electricity demand of Cumaribo, weather data for solar irradiation, the energy system components; Diesel generator and PV panels, the components capacity, price data and financial parameters. The main outputs were; the energy produced by each technology and the fuel consumption.

Data Collection

The hourly electricity demand of Cumaribo was obtained from the second interviewee, ESSEI. S.A representative. His involvement as IPSE consultant gives him access to privileged information on several NIZ municipalities. The data was validated by contrasting the resultant daily profile outputted by HOMER model with the profile published by [c.n.m., 2017], the official organism for performing energy measurements in NIZ in Colombia. In turn, solar irradiation was obtained from the NASA Atmospheric Science Data Center [Atmospheric Science Data Center, 2017]. Price data was obtained as a result of a literature review on the costs of energy implementations in NIZ in Colombia, the main sources were [USAENE LLC, 2013] and [Dávila, 2017].

Hybridization Scenarios

The installed PV capacity was changed in the simulations in order to explore different hybridization scenarios. The intention was to achieve different levels of renewable penetration and record the changes in fuel consumption. Also the balance of the energy used from the diesel generator versus the energy used from PV was recorded. With these records, economic calculations were performed from the perspective of the government and from the perspective of the energy operator in Cumaribo. Economic calculations are described bellow.

2.4.3 Economical Calculations

A business-economical analysis was performed for the different scenarios from the government perspective, which is the actor performing the investment in PV panels. In turn, Electrovichada S.A. economic assessment constitute a simple balance of the gains versus the looses that result from the hybrid implementations. This is due to the fact that this actor doesn't perform an investment as such, but merely experiences an increment or decrease in its monthly income.

Societal effects, like employment and other external costs were not consider during this analysis. All economical calculations were made in Euro (EUR) with a Colombian Peso (COP) to EUR exchange rate of $(3256.59)^{-}1$ and an American Dollar (USD) to EUR exchange rate of $(1.17)^{-}1$ as it stood on 05 June 2017 according to [XE, 2017]. As part of the analysis the net present value (NPV) was calculated. This variable is important to identify whether or not an investment pays off. It shows the difference in cash outflow and inflow over the lifetime of an investment and is calculated according to Equation 2.1.

$$NPV(i,N) = \sum_{t=0}^{N} \frac{C_t}{(1+i)^t} = C_0 + \sum_{t=1}^{N} \frac{C_t}{(1+i)^t} \tag{2.1}$$

Where t is the period of each cashflow, C_t is the net cash flow at time t, N is the total number of periods, i is the discount rate used and C_0 is placed to the left and outside of the summation to emphasize its role as initial investment. In this study the initial investment is the cost of PV including the civil works, which is fully covered by the state and has a cost rate of 2 USD/W, as per the results of the interview with ESSEI. Now, for the part of the C_t components, in Chapter 4 it is explained how hybrid implementations lower the amount given in solidarity subsidies to NIZ localities. This subsidies plunge is in the best interest of the government, for reasons that will be explained in this very same chapter. This is why the drop in the solidarity funds is interpreted as a cash inflows in this analysis and corrrespond to the C_t values in equation 2.1. Finally, the discount rate used is 11%. With 9% opportunity cost and 3% inflation rate. This figure was also obtained by means of the interview with ESSEI representative.

The internal rate of return (IRR) is another criteria that was used for evaluating the investments. While NPV just calculates the profit of an investment at a given discount rate, IRR compares the profit in relation to the investment and its a measure of how fast will it pay back, the higher the IRR the faster this happens. If the IRR of an investment is higher than a given discount rate, the NPV will be positive for that discount rate. IRR can be used as an investment criteria, where the project with the highest IRR is preferred. The IRR is calculated using Equation 2.2: [Serup, 1998]

$$NPV(ir,N) = \sum_{t=0}^{N} \frac{C_t}{(1+ir)^t} = 0 \tag{2.2}$$

In short, The internal rate of return ir is the discount rate that equals the formula in Equation 2.1 to zero.

Now, for the part of the energy operators, Electrovichada S.A. in the case study, the economic assessment is done by subtracting the looses from the gains that result from hybridizing their diesel system. The gains are given by the savings in fuel consumption that result from hybrid implementations. The looses come from the energy service tariff, which is lowered when their system is hybridize with renewable energies, as per the results of Section 4.1. The resulting quantity is referred to as net gain. And the criteria for profitability is whether the net gain is positive or negative.

2.4.4 Barriers & Suggestions

The results derived from the investigation of hybridization scenarios were analyzed. As a result a couple of changes were suggested to the current tariff scheme in order to extent economical feasibility to all the actors that are involved financially with hybridization in Cumaribo. These suggestions are simulated again in different hybridization scenarios to identify their effectiveness. The results were then analyzed and correspondingly. Finally, the aggregated results throughout the report were used to draw conclusions.

3 Stakeholder Analysis

This chapter begins by presenting the NIZ stakeholders at a national level, together with their roles. This is done in order to present a general picture and introduce the reader to a first level of actor identification. In this first stage, the actors that are involved with the resource allocation are highlighted, as they are more relevant to the study at hand. Next, the information gathered during the interview process with ESSEI representative is used to draft a power-interest grid. Finally, an analysis of the power-grid is conducted to determine the better way to approach different actors. Those actors with deeper financial involvement are singled out for further analysis.

3.1 Stakeholders in the Colombian Energy System

Organizations, economic agents and final users of the NIZ energy system are summarized in the diagram in Figure 3.1. As can be seen from the figure, some actors were highlighted with color boxes. These colored links represent the actors that are more closely involved in the resource allocation and implementations processes for projects in NIZ. Among these actors one of the key players is IPSE, which is a national entity with technical character appointed by the ministry of mines and energy (MME). As mentioned before, IPSE is in charge of promoting and implementing energy solutions for the NIZ, be it maintenance initiatives for already existing projects, or investments plans for new ones. This institution makes great emphasis on renewable solutions [IPSE, 2014].

It should be clarified that IPSE doesn't deal with interconnection projects aimed at connecting new zones to the National Interconnected System (NIS). For this purpose, another institution called UPME determines a guide for connecting new localities to the centralized grid, this guide is called the Coverage Expansion Plan (PIEC, by its spanish acronym). This plan relies on the Financial Aid Fund for the Electrification of Rural Areas (FAER, by its Spanish acronym) and the National Royalties Fund (FNR, by its Spanish acronym). [PIEC, 2016].

PIEC determines the viability of different localities of becoming interconnected zones. From these results, IPSE focuses in the zones for which interconnection is not a viable option and then uses the Financial Aid Fund for Not interconnected zones (FAZNI) and the FNR to implement projects there. The projects to be implemented are chosen from a number of suggestions by NIZ territorial entities, energy companies and by IPSE itself.

Now, in order for a suggested project to be implemented it has to pass a two step viabilization study conducted by IPSE and UPME. UPME is of particular relevance here

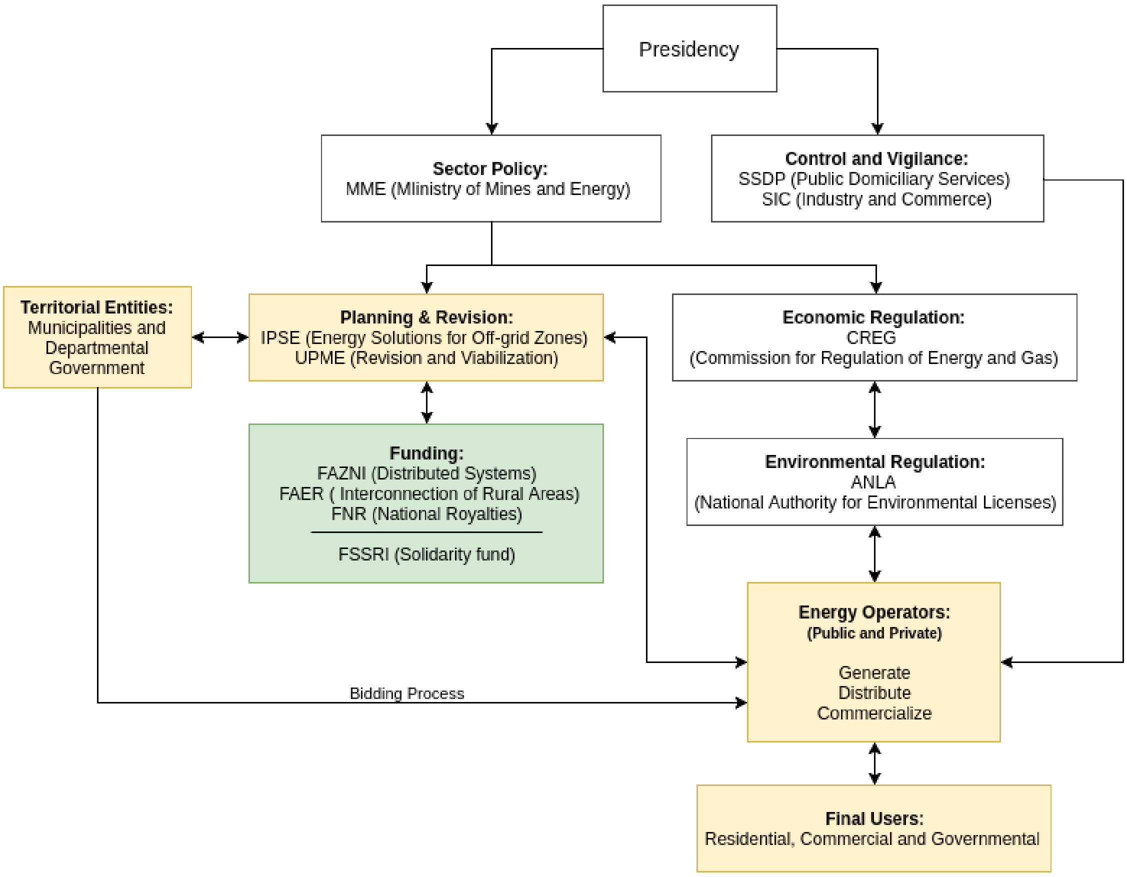


Figure 3.1: A diagram of the stakeholders involved in the implementation of new projects in the NIZ energy system. The actors in color boxes correspond to those that are more directly involved to the resource allocation process. Adapted from [CREG, 2014]

because it counteracts the decision power of IPSE, specially when the projects are filed by IPSE itself. On top of being viable the projects will be chosen giving priority to those that feature non-conventional energy sources. Finally, the resources are given to a public or private company for implementation, either directly or by means of a public bidding process. [MME, 2014].

The companies that ultimately receive this funds are referred to as energy operators. They are in charge of either generate, distribute or sell energy in the NIZ localites. In many occasions a single company will perform all of the above economic activities. Finally, the last actor of this streak would be the end-users, which in NIZ have a generalized profile of low income, many of them within the lower bracket of socio-economical strata, strata 1 and 2. [IPSE].

Now, for the part of the actors in white boxes, their role is more related to control and supervision. To begin with, on the right side of the diagram, next to the ministry of mines, we encounter two delegations of the presidency, under the label "Control and Vigilance". This entities are technical organisms in charge of protecting the rights of domiciliary services users, SSPD for public domiciliary services, and SIC for industry and commerce. Among other things, they ensure that the guidelines of CREG (Commission for the regulation of energy and gas) are followed. Finally, we have ANLA, the national authority for environmental licenses, which is in charge of regulating projects in the energy sector (and other sectors) so that they follow the environmental normative. [CREG, 2007].

3.2 Stakeholders at the Case Study Level

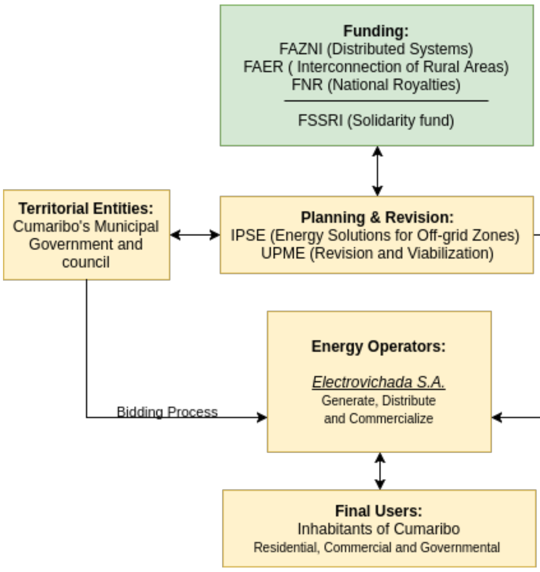


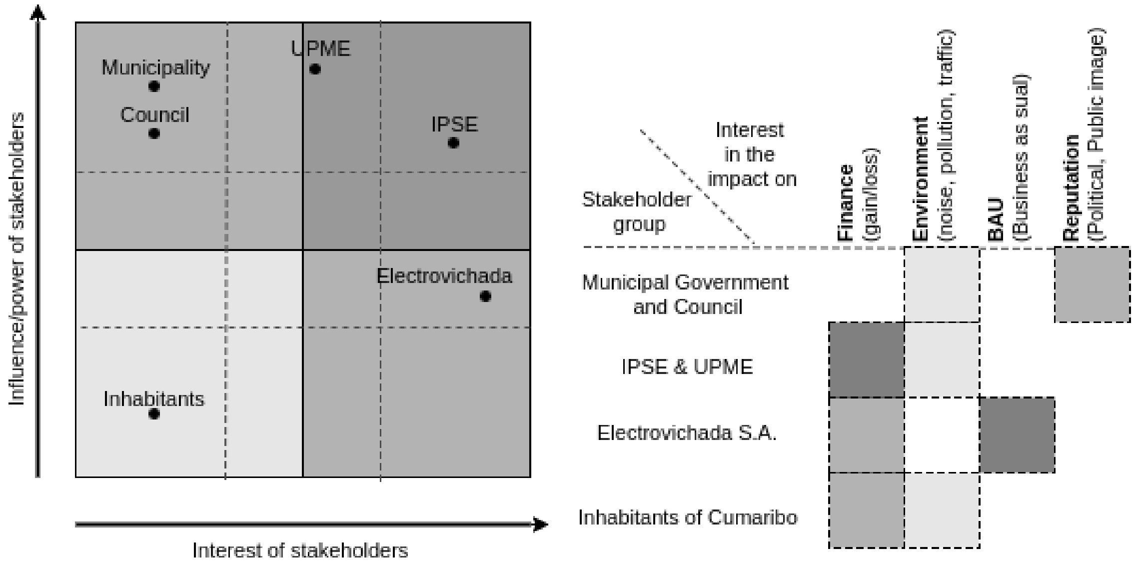
Figure 3.2: A diagram of the stakeholders involved in the implementation of new projects in the NIZ energy system at the case study level of Cumaribo.

As previously mentioned in Chapter 2, one of the purposes of the interview with ESSEI representative was to gather more information regarding the actors at the case study-level. Figure 3.2 illustrates the results of this endeavor. Notice that this figure is an adaptation from the previous figure with the national actors, Figure 3.1. Some of the actors presented previously were replace with their regional counterparts, and some others remained the same given that they are present in both scopes. Also, the actors that remained in this depurated picture, are mostly the ones involved with resource allocation.

In Figure 3.2 the municipal government and the council represent the territorial entities, the company Electrovichada S.A. being the responsible for generation, distribution and commercialization of electric energy in the township represents the energy operator for the case-study level by itself. Finally the inhabitants of Cumaribo constitute the end-users, including all the sectors; commercial, industrial and domiciliary. In the sections to follow, the impact that hybridization might have for each of these actors, their level of influence and power, and the strategies that might be used for engaging them to ensure feasibility are investigated.

3.2.1 Power-Interest Grid

In the last section the regional actors were identified and their roles briefly described. In this section the focus is more prevalent on the interest of the actors, the nature of these interest and the level of influence of different stakeholders. These aspects are summarized in Figure 3.3. On one side Figure 3.3b displays the power-interest grid. In order to analyze this graph, some additional information about the actors is discussed in the sections bellow. The relative position of these actors in the zones of the diagram will also help shape the strategies that should be utilized to approach them. Now, on the other side we have Figure 3.3a. This Figure is meant to complement the contents of the power-interest grid. It should help the reader visualize the nature of the interest axis in Figure 3.3b.



(a) Power-interest grid for Cumaribo stakeholders.

(b) Mapping of the actors interests. The grey scale indicates different levels of interest.

Figure 3.3: Power versus interest grid and interest map. Adapted from [Eden C. and Ackermann, 1998]

Territorial Entities: Municipal government and council

According to Dávila [2017], the interest of these entities exist only in relation to the good will of the project, specifically the good image that green energies have nowadays. If the project would be implemented they would try and seek a political profit out of the initiative. However, they are not actively pushing it forward nor opposing it. However, if by any chance they would find the project inconvenient, these actor do have the influence to forbid or block the project. These actor are a perfect example of high influence but low interest.

Their position in Figure 3.3b suggest that they need to be consulted on the aspects of the project that are more interesting to them. As mentioned before, this might be related to the good image that green energies have with the general public. In order to increase their interest some means of collaboration can be pursued to strengthen the presence of this actors as public supporters of the initiative.

End-users: Inhabitants of Cumaribo

As has been mentioned before, the inhabitants of Cumaribo enjoy a service of 24 hours of electricity. Also, they are about the only township in Colombia that has a prepaid system, in which they can top-up their address balance in one of the local markets and then utilize the corresponding amount of energy [Arango, 2015]. This means that in terms of access end-users in Cumaribo don't face any difficulty. Also, as will be explained in more detail in Chapter 4, end-users in NIZ don't perceive any change, tariff-wise, from hybridization. Hence, from a financial standpoint an investment in hybridization is indifferent to them, making the inhabitants of Cumaribo an actor with low interest and low power.

Theory suggest that these actors should be informed via general communications; newsletter, website, radio announcements. With the aim to increase their interest in the project and harvest goodwill from the population by highlighting the good aspects, such as the environmental benefits and the employment generated from the civil works and implementation process.

UPME & IPSE

As shown in Figure 3.3b and mentioned in Section 3.1 UPME has a higher degree of influence over IPSE. However, in this matter their interests are aligned, so UPME wont be opposing IPSE initiatives so far as IPSE can provide compelling evidence for technical and financial feasibility of its projects [MME, 2014]. So, from this point forward, IPSE will be treated as representing the interests of UPME. Also IPSE standpoint will be considered the standpoint of the government when it comes to business-economical calculations later in this project.

Now, from the interview with ESSEI representative, it was established that a hybrid investment in Cumaribo would be provided in full by IPSE by means of utilizing one of the capital investment funds in Figure 3.2. Also, it was discussed how the interests behind hybrid investments in localities like Cumaribo, with already 24 hours of energy service, are financial rather than social or environmental. From this, it can be said that IPSE is an actor with high interest and high influence, given that they are financially invested, but also because they have great influence on the process of resource allocation in NIZ [MME, 2014].

In this case, the recommended strategy is that IPSE, as a central actor, should be regularly engaged and consulted to guide the project specifications and boundaries. However, this is not enough to ensure economic feasibility for this actor. IPSE would most likely require solid evidence for financial profitability. Hence, a deeper analysis on the economic consequences of hybridization should be held, in order to propose approaches that ensure feasibility on quantitative grounds.

3.2.2 Electrovichada S.A.

Hybridization of Cumaribo's energy system affects the finances of the energy operator in two ways; On one side the system will present some fuel savings, which derived from the fact that generation is now partially covered by solar energy. On the other hand, there is a drop in the overall tariff of energy services that is charged by the energy operator, which goes in detriment of their finances. This will be shown in more detail in Chapter 4. The whole matter revolves around the fact that the balance could be negative, meaning that hybridization would affect Electrovichada S.A. negatively, despite the fact that the implementation costs are fully covered by IPSE.

According to [Dávila, 2017], IPSE would be able to bring these implementations forward, despite the fact that the energy operator is likely to oppose the initiative. This hints towards the idea that the influence of this actor is limited, while their interests in this kind of initiatives are very high. As illustrated in Figure 3.3a, this actor is very concerned with the impact in the BAU order of things.

Despite IPSE's level of influence, is not in their best interest to cross this important stakeholder, specially since a similar situation is replicated in a number of other localities, given that it arises from the tariff structure in NIZ, as will be discussed in Chapter 4. Hence, a solution should be found. In that sense, the economic consequences of hybridization from the perspective of Electrovichada S.A. should be further investigated in order to formulate how the situation could be sorted out in favor of the company's interest.

Policy Context 4

The purpose of this chapter is to ensure that the technical analyses in Chapter 5 are in accordance with the current policies and regulations. It should also help the reader identify the situation from a national perspective and the way in which it influence the case-study locality. The emphasis was made around three topics, presented in the following way;

- First, the current tariff structure for NIZ is introduced. In this section a number of assumptions are made to simplify the regulation. The purpose is to show in a simple way how the tariffs are affected when a hybrid implementation comes into place alongside a diesel system in NIZ.
- Next, the funds situation is explained with focus on localities that enjoy 24 hours of energy service, this section should clarify the government motivation for investing in hybrid solutions in localities like the case-study of Cumaribo.
- Finally, the way in which the policy shapes the business-economical model for IPSE and for the energy operators is explained using a qualitative approach. This should clarify many details regarding the economic calculations in Chapter 5.

4.1 Tariffs Structure in NIZ

In Colombia, the tariffs structure for electric energy is dictated by the Regulatory Commission for Gas and Energy (CREG, by its acronym). The regulations dictated by this organism are effective throughout the national territory and apply to both Interconnected Zones (IZ) and NIZ. In the IZ the tariffs are dependent primarily on the socio-economical strata, and they are the same regardless if the consumers are located in cities or in rural areas. NIZ on the other hand have it's own tariff structure, one that aims to compensate for the extra costs involved in providing the service in these areas.

Now, for the sake of clarity, it is important to clarify the convention that will be used throughout this chapter before going any further. First, the term Energy Service Tariff or **Service Tariff** for short, will correspond to the tariff charged by the energy operator for generating and distributing energy. On the other hand, the tariff that is actually payed by the end-users and inhabitants of NIZ localities will be called **User Tariff**. Finally, the difference between the service and the user tariffs will be referred to as **Solidarity Subsidy Rate (SSR)**.

Service tariffs take into account investment, administrative, O&M, fuel and transport costs. It also considers investment costs for the implementation of distribution systems, when they take place. Finally, data acquisition costs, be it the monitoring of equipment or the measuring of end-user consumption are also recognized [Castillo, 2014]. In the case of diesel generation in NIZ the tariff per kWh for any given month has the following components:

$$G_D = (CI + CM + M) + (CC + CL) \cdot 1.1 + CP \tag{4.1}$$

Where,G_D is the service tariff for diesel generation in COP/kWh, CI is the tariff component that originates from investment costs, CM is the tariff component due to maintenance costs, M is the component that arises from monitoring costs, CC is the average cost of fuel per kWh in that month, CL is the average cost for lubricant and CP takes into account the energy operators own consumption and the distribution losses.

Now, in the case of photovoltaic implementations the administrative and O&M components are less complex, and the fuel and transport costs are null. Hence, the resulting service tariff is one with fewer components:

$$G_F = CI_F + AOM \tag{4.2}$$

Where, G_F is the tariff rate for photovoltaic generation in COP/kWh, CI_F is the tariff component that originates from investment cost for this particular technology and AOM is the tariff component due to administrative, maintenance and operational costs.

4.1.1 Hybrid Implementations

In the case of a hybrid implementation diesel-solar in NIZ, a mix tariff scheme would apply depending on the percentage of renewable energy in the distributed system, or renewable rate for short. For any given user the amount in the energy bill would be given by:

$$C_{user} = G_D \cdot (1 - r) \cdot X_{user} + G_F \cdot r \cdot X_{user} \tag{4.3}$$

Where $user$ is any given energy user in NIZ, C_{user} is the bill amount for $user$, r is the ratio of renewable penetration of the system from 0 to 1, and X_{user} is the energy consumption of $user$. It's important to understand that the bill amount C_{user} will seldom be paid in full by $user$ because a portion of it is covered by the SSR. Now, from equation 4.3, it can be inferred that the service tariff for a hybrid system would be:

$$G_H = G_D \cdot (1 - r) + G_F \cdot r \tag{4.4}$$

Where G_H is the hybrid service tariff. In reality, however, several funds such as the FAZNI fund and policies like the latest law for renewable energies, law 1715 of 2014, are responsible for the CI_F component in equation 4.2 to tend to zero. These policies will be described in more detail in the sections to come. On the other hand, the AOM component in PV implementations is often negligible when compared to the administrative, operational and maintenance components in equation 4.1, which involves maintenance, as well as fuel and lubricant [Castillo, 2014]. In this sense, it could be argued that that equation 4.4 is perceived by energy operators as:

$$G_H = G_D \cdot (1 - r) \tag{4.5}$$

4.1.2 Subsidies

In order to calculate the subsidies for different socio-economical strata in NIZ, tariffs from the closest NIS population are taken as reference and used as the user tariff. The difference between the service and the user tariffs is subsidized by the solidarity fund FSSRI [Castillo, 2014]. Subsidies are applied so far as they don't surpass the subsistence level, which is set at 130 kWh/month for users located over a 100 meters above the sea level (MAMSL), and 173 kWh/month for user below the 1000 MAMSL. In this sense, the solidarity subsidy rate (SSR) for a diesel can be expressed as:

$$SSR_D = (G_D - G_{user}) \tag{4.6}$$

Where SSR_D is the subsidized amount per kWh in a diesel system and G_{user} is the tariff rate for the reference population in the NIS. for a hybrid system the equation would go:

$$SSR_H = G_H - G_{user} = G_D \cdot (1 - r) - G_{user} = SSR_D - G_D \cdot r \tag{4.7}$$

Where SSR_H is the subsidized amount per kWh in a hybrid system. In this equation the subsidy tends to zero when renewable penetration r approaches SSR_D/G_D which is always a number between 0 and 1. The equations in this section will be used to calculate the changes in subsidies that result from hybridization and the changes in the service tariff. The user tariff is granted by law, so it won't be experiencing any changes.

4.2 The funds Situation

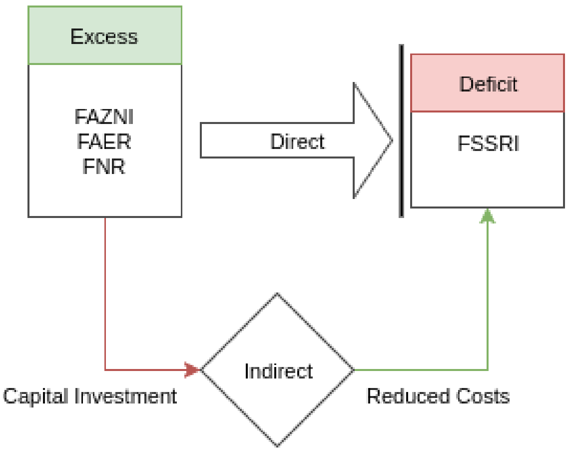


Figure 4.1: Capital investment funds need to be used indirectly in order to aid in the deficit situation of the solidarity fund. This could be done through the implementation of projects that help lower the costs of providing energy services. In this diagram the arrows represent the flux of capital.

When it comes to the process of introducing renewable energy into an NIZ locality, one of the following cases is always encountered; 1. There isn't an existing energy system, 2. There is an existing energy system but the service is less than 24 hours, 3. There is an existing energy system which provides 24 hours of energy service. The social benefit in the first two cases is clear, because it brings either access to electricity where there wasn't, or it extends the hours of service. In both cases the result is improved quality of life for the communities.

The third case, however, has a different drive, related to the way in which resources are allocated in NIZ; On the one side, it is important to understand that the funds FAZNI, FAER and FNR from Figure 3.1, which are allocated by IPSE and UPME, are reserved for capital investments. FAZNI and FAER, are funds raised by the national trade administrator (ASIC, by its spanish acronym) , and correspond to 1 COP or 0.00028 EUR per each kWh that is settled in the wholesale market [CREG, 2015]. This values are indexed every year. FNR on the other hand is raised as a percentage of the royalties perceived by the state [ANH, 2008]. FAZNI and FAER, are exclusively destined to projects in NIZ, while FNR has a broader field of action. The situation at hand, is that every year these funds display excess resources, because the amount of projects that are filed for capital investments in NIZ are not enough [Dávila, 2017].

On the other hand, there exists the FSSRI fund, which is a solidarity fund meant to protect energy users in NIS and NIZ from high electricity prices. This fund is raised from all the energy users of higher strata (strata 4,5 and 6) as a contribution fee. Strata 3 doesn't contributes neither receives any subsidies in SIN but does receives subsidies in NIZ. In the end, the bulk of the fund is used to subsidize energy tariffs in strata 1 and 2. In the case of NIZ the subsidies are calculated in a special way as depicted in Section 4.1.2. In this case, the closest NIS locality is used as reference point. The subsidy corresponds to the difference between the cost of energy services in the NIZ locality and the users tariffs in the reference locality [CREG, 2007]. In this case the situation is quite the contrary to the capital costs funds, this fund experiences deficit every year, and IPSE is forced to use loans from the national treasure to cover for it.

The solution to this problem may seem straightforward, given that one sort of funds is plentiful, while the other sort is lacking resources. However, the direct transference of resources from the capital investment funds to the solidarity funds are forbidden by law

[Ortega, 2014]. This means that the government requires an indirect mechanism to transfer capital, and hybridization is just the perfect tool, because it lowers the tariff service in NIZ, hence decreasing the need for subsidies. This situation is depicted in Figure 4.1.

4.2.1 Hybridization as Indirect Mechanism

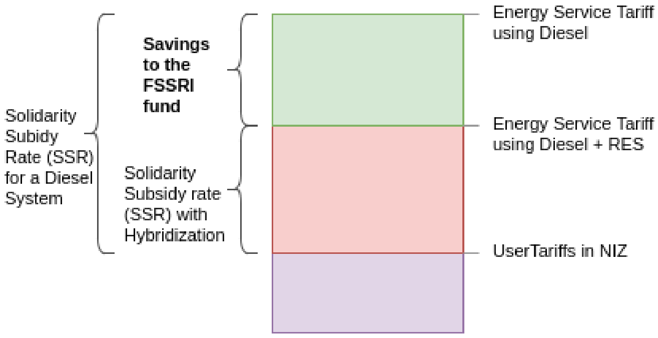
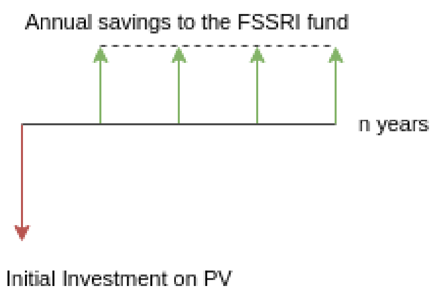
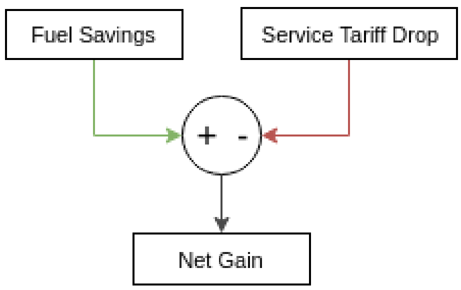


Figure 4.2: A representation of the relation between the energy services tariff in diesel and hybrid systems, the approved user tariffs in NIZ, the solidarity subsidy rates and the savings to the national treasure that result from the inclusion of RES in the diesel system.

The way in which hybridization is used as indirect menchanism for aiding the funds situation is as follows; The process begins with IPSE identifying a locality with 24 hours of service with a diesel energy system. The idea is to invest in hybridizing such a system with a renewable energy solution that features lower costs than diesel for providing energy services. In the case in which this solution is photovoltaic, the SSR for the system will drop by an amount that can be derived from Equation 4.7. Hence resulting in savings to the FSSRI fund, and indirectly to the national treasure, which is the main goal. The relation between the different quantities is illustrated in Figure 4.2. So far as the annual savings to the FSSRI fund compensate for the initial investment in renewable energies, the project will be considered profitable and hence feasible for IPSE. In this case, the motivation is neither environmental nor social, but purely economical. However, one may argue that aiding the sustenance of the solidarity fund could be considered a social oriented initiative. The feasibility criteria for IPSE is illustrated in Figure 4.3a.



(a) NPV and IRR for this investment will determine feasibility for IPSE.



(b) Energy operators dont perform any investment, but the balance between the economic effects of hybridization will determine feasiblity for these actors.

Figure 4.3: Illustration for feasibility criteria in the case of IPSE and energy operators.

Now, for the part of the energy operators, the economic assessment is done by subtracting the looses from the gains that result from hybridizing the existing diesel system. The gains are given by the savings in fuel consumption that result from hybrid implementations. The looses come from the energy service tariff, which is lowered when the system is hybridize. The resulting quantity is referred to as net gain. And the criteria for feasibility is whether the net gain is positive or negative. The reasoning behind this feasibility criteria is illustrated in Figure 4.3b.

Technical Analysis 5

The goal of this chapter is to determine the most feasible way of implementing a hybrid system solar-diesel in the municipality of Cumaribo. Feasibility is assessed from the perspective of IPSE and the local energy operator Electrovichada. To this end, the chapter begins by describing the reference scenario and presenting the quantitative assumptions and data used; such as Cumaribo's energy demand and the current energy system of the municipality. These assumptions are then fed into a HOMER model and some results are derived.

Next, the hybridization scenarios are introduced, as well as some additional data for the solar irradiation and the PV panel specifications. These scenarios are then modeled and a comparison analysis is held between the hybridization alternatives and the reference scenario. The numerical results are then used to calculate NPV and IRR from IPSE perspective. And the quantity "net gain" from Figure 4.3b is calculated for Electrovichada. Finally, the chapter ends with some concluding remarks on the results obtained.

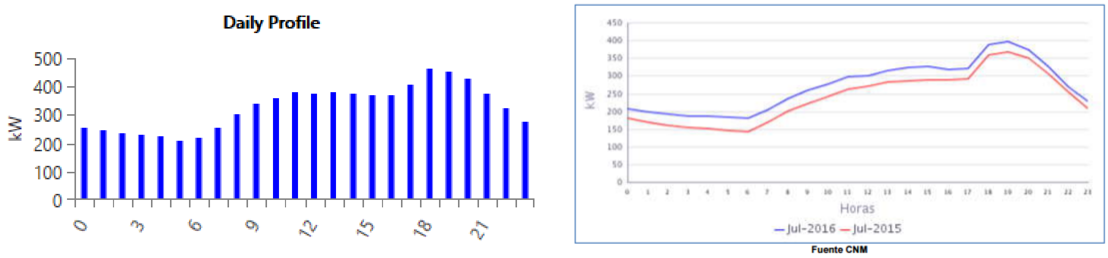
5.1 Reference Scenario

In this work a reference scenario is done to make an estimation of the current energy production and the fuel consumption of Cumaribo, hence providing a point of departure to calculate the quantitative effects of hybridization. Of particular interest are the diesel savings, and the percentage of energy that is produced with an alternative energy source.

This reference scenario consists of two parts. On one part it includes the current policy context, which was briefly covered in Chapter 4. On the other part it consist of the current energy system of Cumaribo municipality. Two main components are needed to describe this system; the municipality's energy demand and the current installed capacity. These components will be described next.

5.1.1 Energy Demand

Hourly data for the year 2016 was obtained from ESSEI [Dávila, 2017]. This data was then included in HOMER, which resulted in the daily curve that can be seen in Figure 5.1a. The figure shows that the municipality has a small peak around midday of 300 kW, with a higher peak around 7:00 pm of 450 kW. Figure 5.1b is placed there for validation purposes and is taken from CNM repositories [c.n.m., 2017]. CNM is the official measuring organism for NIZ. From both figures it can be seen that the demand curves are fairly similar, and hence one can assume that the information obtained privately from ESSEI is valid.



(a) Daily profile (Data) (b) Daily profile []

Figure 5.1: Daily demand profile for Cumaribo municipality

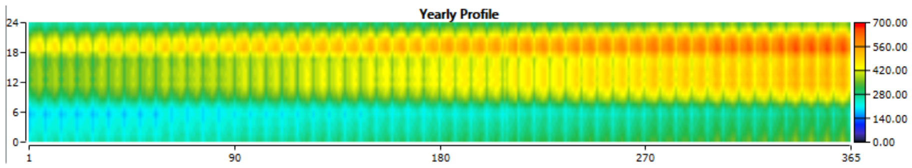


Figure 5.2: Yearly demand profile for Cumaribo municipality from two different sources; (a) Imported to HOMER from privately obtained data [Dávila, 2017]. (b) Taken from [c.n.m., 2017]

Now, another product of the software used is the seasonal profile shown in Figure 5.2. The figure shows that there is a clear tendency for the demand to increase towards the last months, with a peak load in the month of December with an overall maximum of 650 kW. This behavior could be attributed to the holidays at the end of the year, which would explain the November and December rises and the increasing demand during night hours in these months, yet it doesn't explain the overall increasing tendency. Further investigation could be put into this matter, yet for the moment it will be assumed that this behavior constitutes a typical year.

5.1.2 Current Installed Plant

Nowadays, Cumaribo's energy plant consists of three CUMMINS/STANFORD generators and a 1000 kW transformer. These generators have a capacity of 1040 kW, 884 kW and 900 kW correspondingly. A single-line diagram of this system is shown in Figure 5.3. It can be shown by means of a HOMER simulation that a 760 kW diesel plant would be enough to cover for Cumaribo's energy demand, however, it should be taken into account that the municipality is at least 600 km away from the nearest city, meaning that additional power needs to be installed in order to take into account both demand growth and security of supply. Another reason is the equipment transport costs, which constitute a considerable share of the investment. There might be some savings if several generators are taken to the town in the same trip.

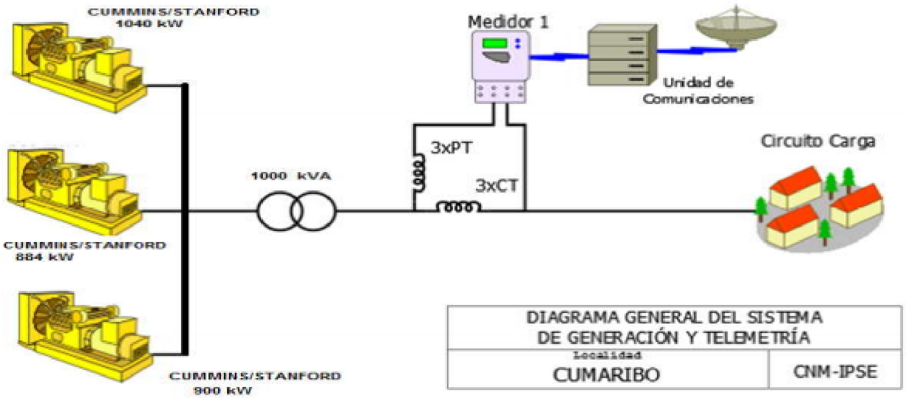


Figure 5.3: Single-line Diagram of Cumaribo's Energy System

5.1.3 Diesel results

The generators shown in Figure 5.3 never operate simultaneously, as can be noticed from the transformer capacity. Hence, the HOMER simulation will run a single diesel plant of 940 kW, which is the average capacity. Financially, there ought to be a sensible difference between the real system and the simulation, but since the variables of interest for the reference scenario are energy production and fuel consumption, a 940 kW plant constitutes a good approximation. Table 5.1 summarizes the main results for this scenario. Information regarding emissions is included as well to make some remarks on environmental impact later in this report.

Table 5.1: Diesel Generator Results

Energy	
Consumption [MWh/yr]	3,409.4
Fuel	
Total Fuel Consumed per year [L]	970,185
Average Fuel per day [L/d]	2,658
Emissions	
CO_2 [ton/yr]	2,539
CO [ton/yr]	16.01
Nitrogen Oxides [ton/yr]	15.04

5.2 Hybridization Scenarios

In order to calculate the possible effects that hybridization has in Cumaribo's energy system, a model was built adding solar energy to the diesel system that was presented in the last section. In this model, solar energy is added in increments of 50kW up until 800kW, hence generating different scenarios for hybridization, corresponding to different amounts of installed PV. These simulations for the hybrid scenarios build up on the assumptions made for the diesel system in the last section. Only solar irradiation data is new to these simulations and is presented next.

5.2.1 Solar Irradiation

The solar irradiation data used for Cumaribo is presented in Figure 5.4. Here it can be seen that the municipality has relatively high irradiation levels throughout the entire year, with the higher levels during the months of December,January and February and the lower levels from April to November, a behavior that is consistent with the reported dry and rainy seasons of the region [IDEAM, 2017]. Overall the seasonal profile is very homogeneous when compared to other latitudes. The resulting annual average is 4.73 kWh/m^2/day.

Figure 5.4: Average daily radiation per month of the year in Cumaribo Atmospheric Science Data Center [2017]

5.2.2 Hybrid Results

Using the results from Table 5.1 as reference point, the percentage of fuel savings and the percentage of renewable penetration are calculated for the different scenarios. These percentages will be used in the next sections to calculate the **drop in energy service tariff**, the **savings to the FSSRI fund** and the **fuel savings**, hence allowing the calculation of the feasibility criteria for Electrovichada and IPSE that were shown in Figure 4.3 in the policy Chapter.

The results of the hybrid model are presented in Figure 5.5. Here it can be seen that the renewable penetration curve is very close to the fuel savings curve for small PV implementations, meaning that the energy from the installed PV is efficiently replacing diesel generation. However, as more PV is installed, solar energy becomes more difficult to incorporate into the system and the impact on fuel savings decreases, because PV is utilized with less and less efficiency. Another indication of this is the decreasing slope of both curves.

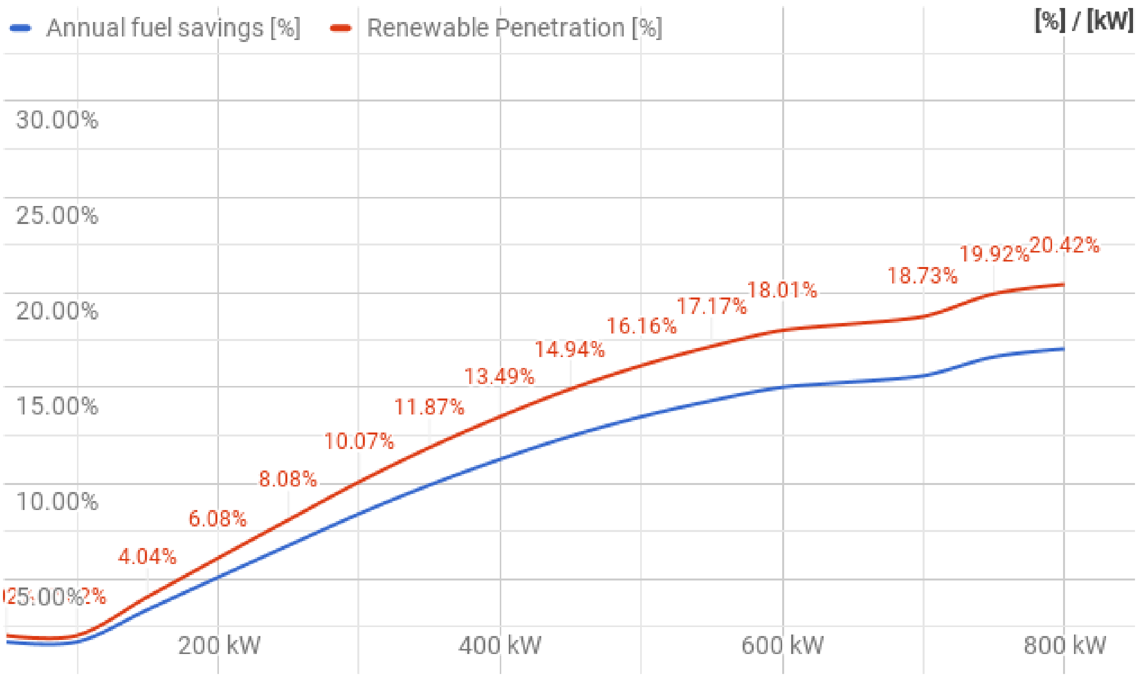


Figure 5.5: Fuel savings and renewable penetration versus the installed PV capacity.

5.3 Economical Calculations

In this section the numerical results derived from the model will be used to calculate the economic feasibility of hybridization for IPSE and Electrovichada. For each actor some additional assumptions are presented beforehand. These assumptions correspond to quantities that are needed for the economic calculations. Net gain would be the central quantity for Electrovichada, while NPV and IRR will be the criteria for IPSE.

5.3.1 Electrovichada

As can be seen in Figure 4.3b the net gain is calculated as the difference between the **fuel savings** and the **drop in the energy service tariff**. The fuel savings can be calculated using the following expression ($F \cdot fs \cdot D_P$). Where F is the total annual fuel consumption of the reference scenario, fs is the percentage of fuel savings, and D_P is the diesel price. In this calculation different values are used for the diesel price; 0.733 EUR/L as the Colombian average, 0.840 EUR/L as the NIZ average, and 1.163 EUR/L as the global average. These prices are taken from [GPP, 2017].

Now, the drop in the energy service tariff, can be calculated by subtracting equations 4.1 and 4.5, and is given by the expression ($r * G_D$). Where r is the renewable penetration and G_D is the service tariff for the original diesel plant. The assumed G_D value is taken from an official Cumaribo bill [Ruiz, 2015]. In order to transform this quantity from [EUR/kW] into [EUR], the tariff drop is multiplied by the annual energy consumption from Table 5.1.

The resulting net gain for the different hybridization scenarios is presented in Figure 5.6. The reason for using different diesel values, is because the exact value that was used to calculate the service tariff G_D is not known. Hence, using lower and upper bounds is a means to gravitate around the true behavior. In the figure it can be seen that there is no feasibility range for any PV implementation. The only difference between the diesel prices is how acute are the looses that hybridization causes for Electrovichada.

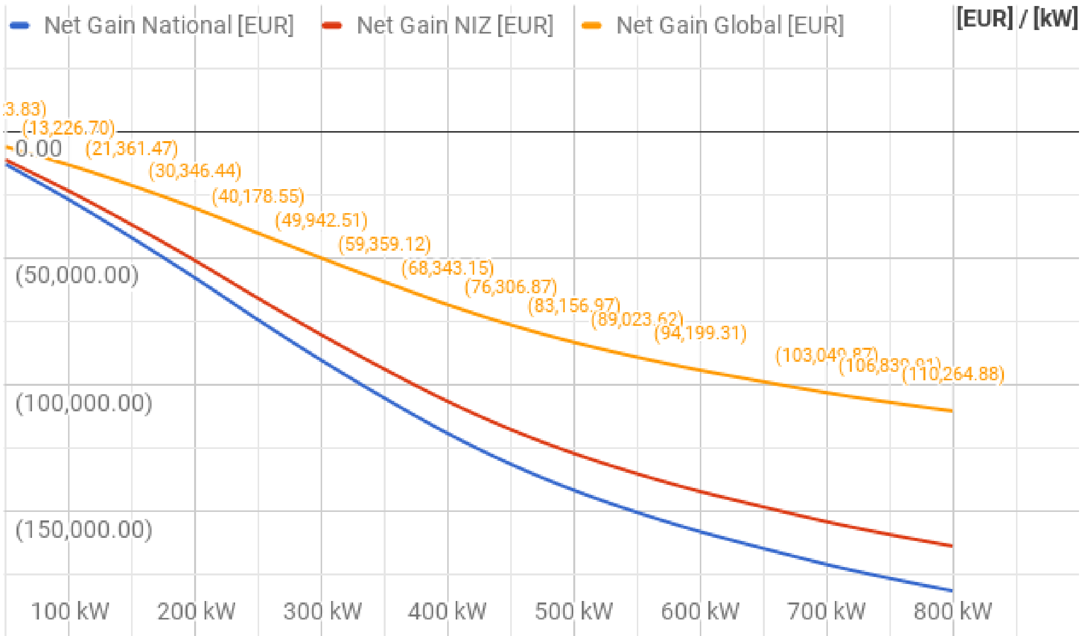
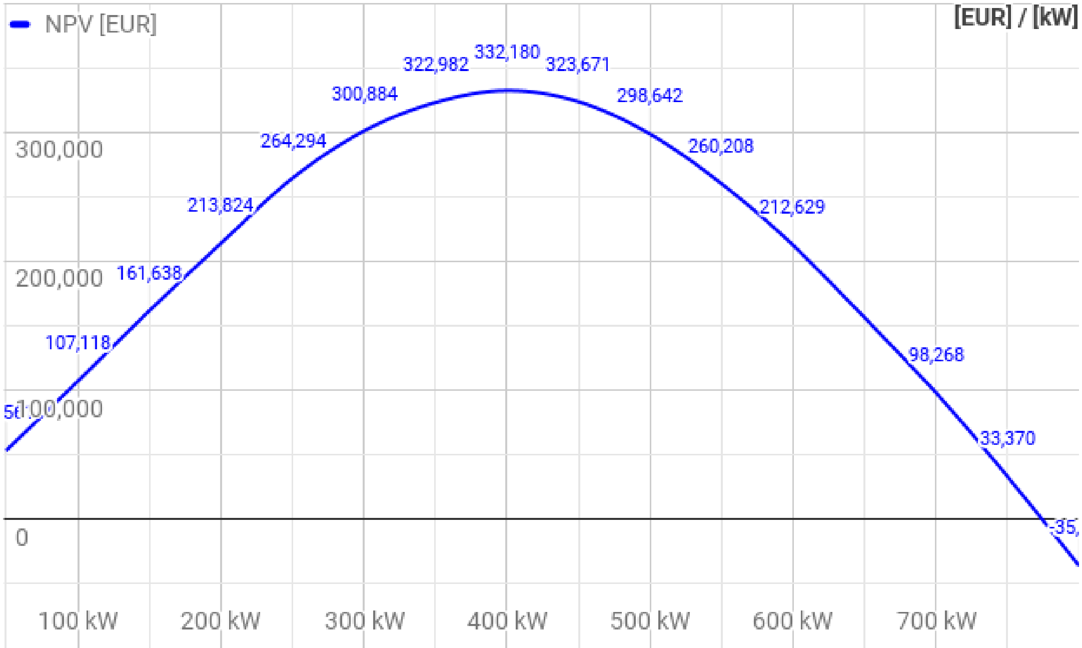


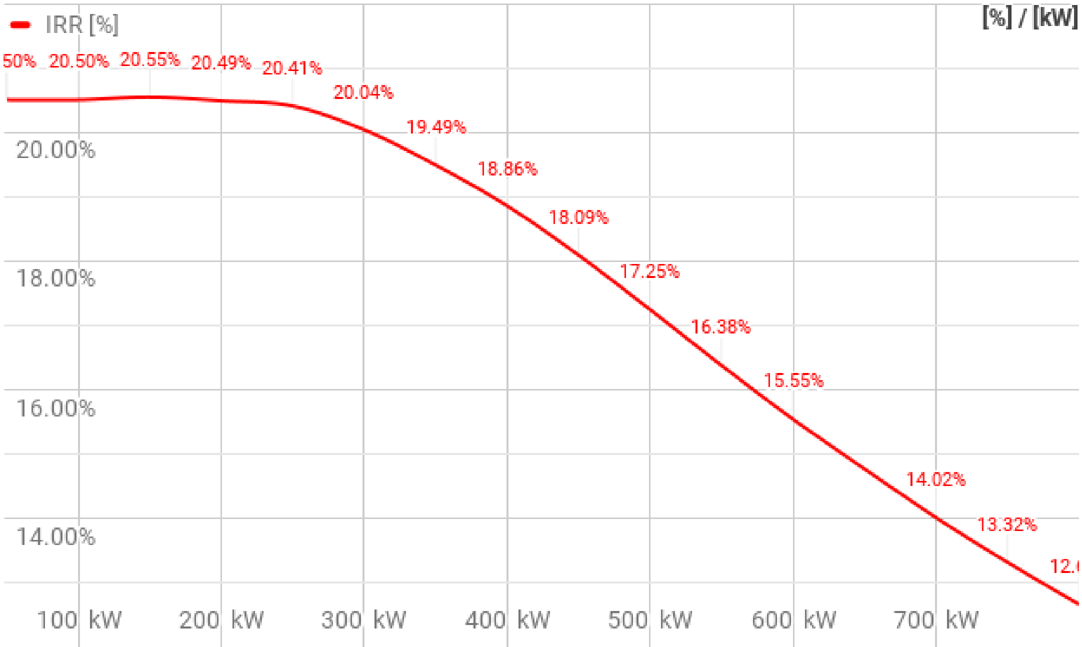
Figure 5.6: Net gain for electrovichada vs the installed PV capacity. Different diesel prices are used, the national average, the NIZ average and the global average.

5.3.2 IPSE

Now, in order to calculate the feasibility from IPSE perspective an investment is modeled according to the guidelines of Figure 4.3a. First, the investment costs are calculated, which correspond to the PV panels costs including civil works. The reported value for Cumaribo is 2 EUR per W [Dávila, 2017]. In this case replacement cost is not taken into account given that the lifetime used for economic calculations is of 25 years, and the same lifetime is used for the panels. Now, for the part of the **savings to the solidarity fund**, it can be noticed from Figure 4.2 that they are proportional to the drop in the energy service tariff, o this quantity will be calculated using the same assumptions as the last section. Finally, the opportunity cost used for IPSE is the one reported by ESSEI representative during the interview, which corresponds to 13%. With this assumptions NPV and IRR are calculated for the different hybridization scenarios. The results are summarized in Figure 5.7. Here it can be seen that the investment has maximun NPV around 400 kW and that it cease to be profitable when the installed PV capacity goes over 775 kW. Also it shows that the IRR is stable around 20.5% until 250 kW approximately, after which the return rate starts to drop with a steeped slope. In this case the feasibility range is rather broad, and the specific recommendation depends of the economic criteria that IPSE prefers. Be it to maximize NPV, to maximize IRR, or to make a compromise in which good profits can be achieved with a decent return rate.



(a) NPV versus the installed PV capacity



(b) IRR versus the installed PV capacity

Figure 5.7: Economic metrics for IPSE versus the installed PV capacity

5.4 Final Remarks

One of the most revealing results of this chapter, are those related to the feasibility of hybridization for Electrovichada. As can be seen in Figure 5.6, hybridization is not feasible for this actor for any of the simulated scenarios. This means that among the explored scenarios the problem of **finding a feasible hybridization solution for all actors** has no solution.

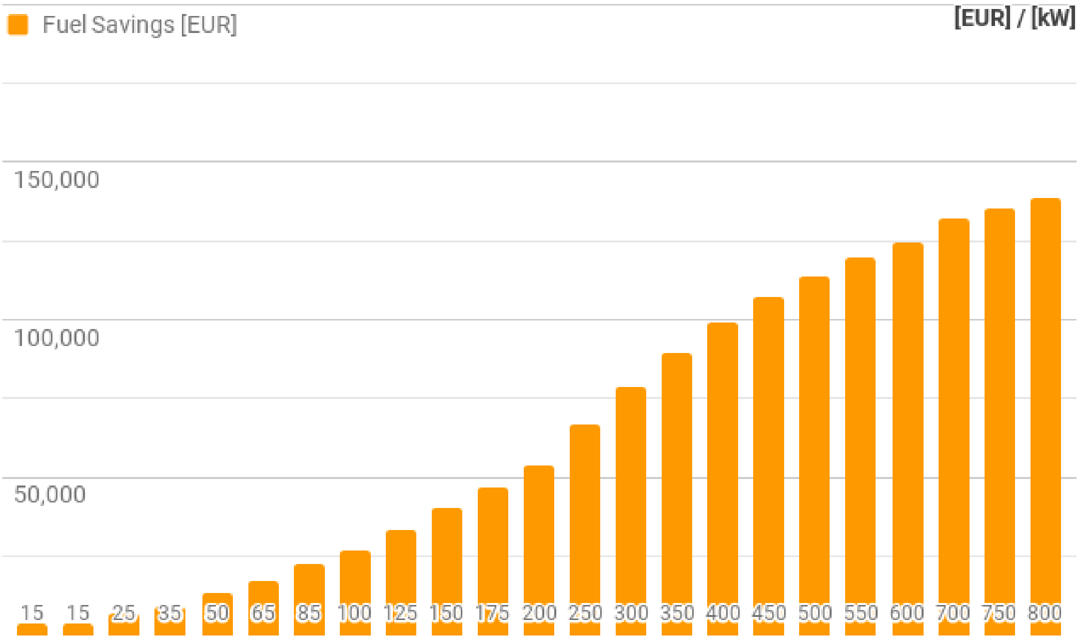
Now, since this situation originates from the current tariff structure. There is no way, under the current policy context, in which IPSE can invest in solar-diesel implementations without affecting Electrovichada. Hence, there is a need to explore scenarios that differentiate from the reference scenario in the policy aspect. To this end, some policy suggestions will be explored in the next Chapter, in order to find a solution to the problem at hand.

Another interesting fact to mention, is that during the interview, ESSEI representative reported that their recommendation for IPSE was an investment that corresponds to a renewable penetration of approximately 12%. By checking the graphs this corresponds to a number around 375 kW, which is very close to the maximum NPV. This tell us that is probable that ESSEI criteria for feasibility was maximum NPV, specially taking into account that the IRR is still a healthy 19.5% around that range. A quick estimation using the statistics from 1.3 tells us that the maximun NPV strategy will produce savings of around 88.9 Million Euros for the FSSRI fund.

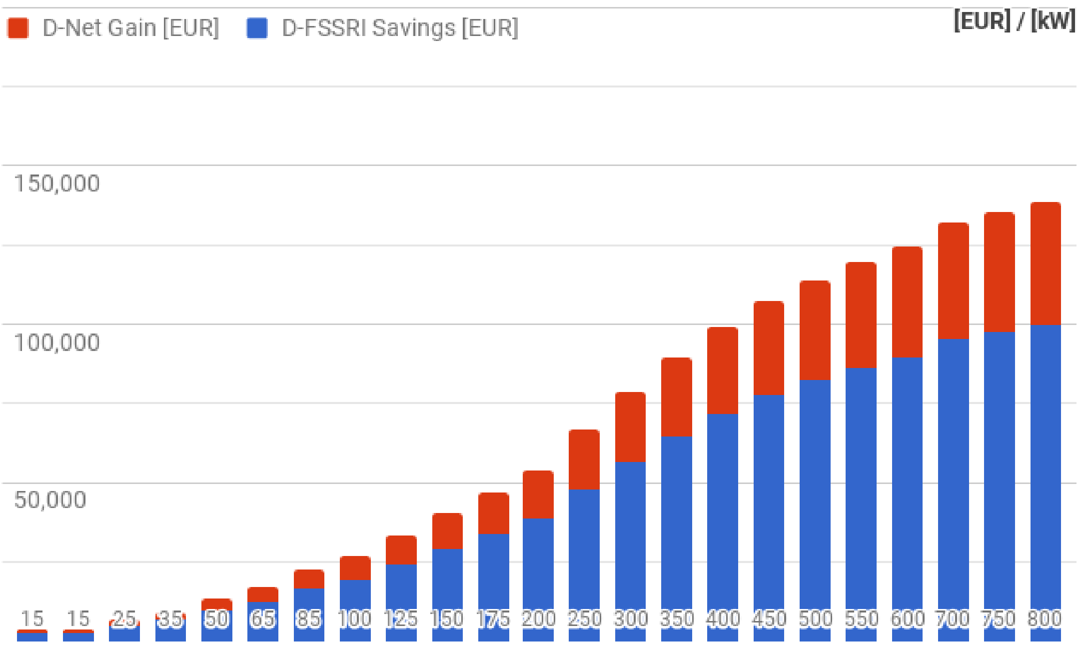
Barriers & Suggestions 6

In this Chapter, the barriers for hybridization are first identified, and then a number of suggestions are made as to how to overcome these barriers. To this end, it is imperative to understand that the value generated from hybridization solar-diesel in NIZ, in the manner depicted in this project, is generated exclusively by means of the fuel savings to the diesel system. The value generated by selling solar energy is for all practical purposes null. Here is why. If solar energy is sold too expensive, the extra profit generated to the energy operator is ultimately cover by IPSE, because energy is subsidized. On the other hand, if solar energy is sold very cheap, the savings generated to the FSSRI fund, end up being cover by the energy operator looses. In this sense, the tariff structure only determines the way in which this "value" is distributed among the actors.

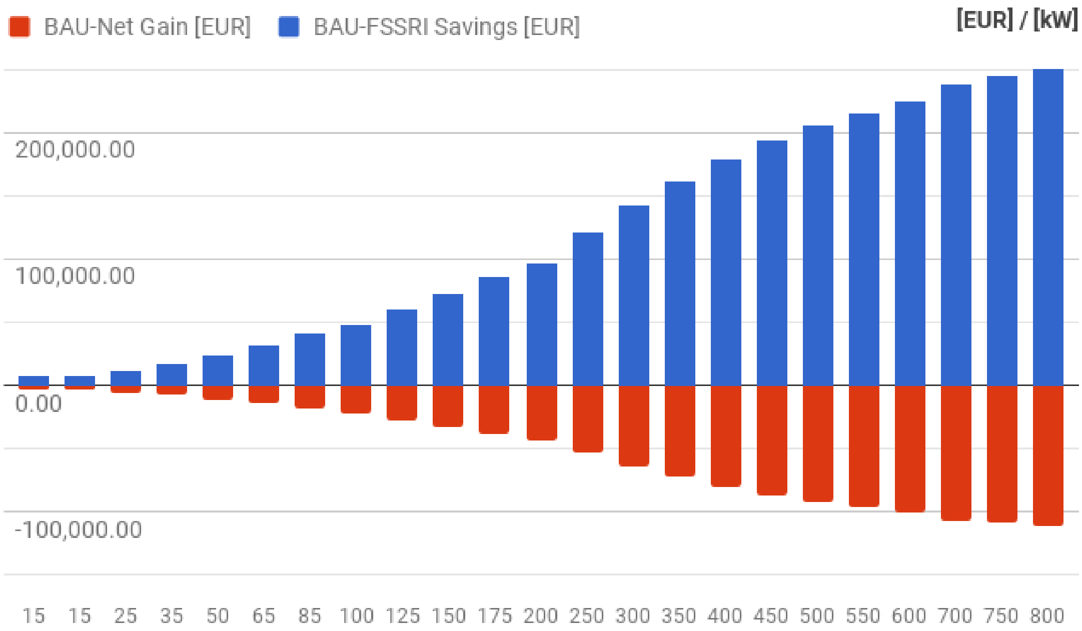
Proof of this statement, is the fact that the sum of the quantities **Net Gain** and **FSSRI Savings** always add up to the **Fuel Savings**. An illustration of this fact is presented in Figure 6.1. If the tariff structure is balanced, like the one that will be presented in the next section in tariff scenario (D), both actors take a portion of the value generated and feasibility is made possible for everyone, see Figure 6.1b. However, if the tariff structure is unbalanced, like the current tariff structure, one of the actors end up taking more than is due, and the other end up paying for the difference. As can be seen in Figure 6.1c. *This unbalanced tariff constitutes the greatest barrier for hybridization being feasible for all actors in NIZ in Colombia.*



(a) fuel savings vs the installed PV capacity



(b) Net gain and FSSRI savings for a balance tariff vs the installed PV capacity



(c) Net gain and FSSRI savings for the current tariff vs the installed PV capacity

Figure 6.1: Illustration on how fuel savings are always a constant for the system, while different tariffs generate different relations between the Net Gain and the savings to the FSSRI fund.

6.1 Suggestions

In this section, different tariff scenarios will be analyzed alongside hybridization scenarios. This means that the hybridization of Cumaribo's energy system will be studied in the light of hypothetical changes to the current tariff structure. The objective is to explore possible solutions to the problem at hand, in which hybridization can be made feasible for both IPSE and Electrovichada. After a brief technical analysis and recommendations, the chapter ends by presenting the challenges for hybridization in Colombia.

6.1.1 Tariff Scenarios

The results in Chapter 5 are the result of assuming that the photovoltaic component in the hybrid system tariff is neglectable. As can be seen from equations 4.3 and 4.4. Here, 4 scenarios are proposed in which this tariff is modified in different ways, so that they mitigate or nullify the acute drop in the energy service tariff observed in the last chapter. For simplicity these scenarios are labeled with letters, which will be used as reference in figures and text:

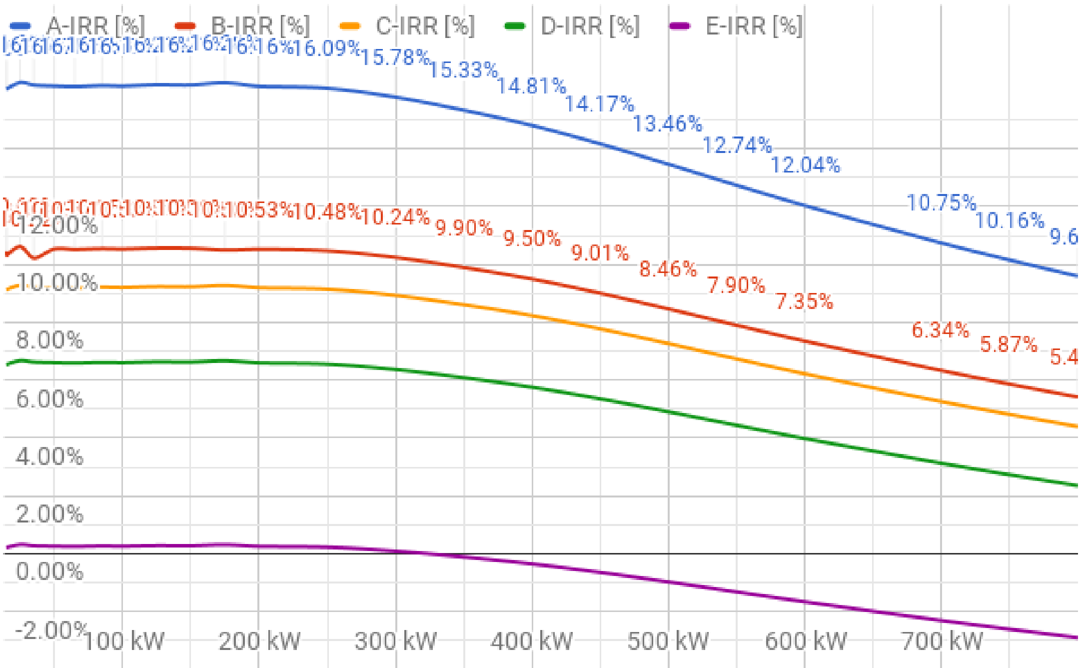
(A) The photo-voltaic tariff is modified to be 20% of the Diesel tariff.
(B) The photo-voltaic tariff is modified in a way that the Net Gain for energy operators is zero at all times.
(C) The photo-voltaic tariff is modified to be 50% of the Diesel tariff.

(D) The photo-voltaic tariff is modified to be 60% of the Diesel tariff.
(E) The photo-voltaic tariff is modified to be 80% of the Diesel tariff.

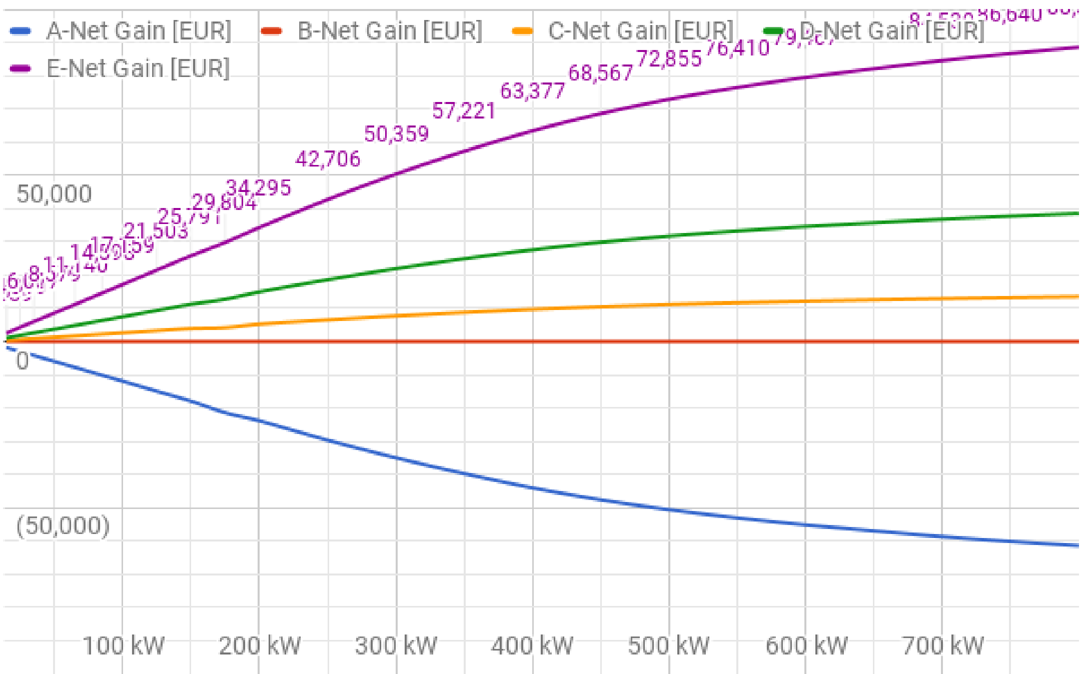
The results for these scenarios are summarized in Figure 6.2. The analysis of these results will be held assuming that IPSE uses different discount rates to judge the feasibility of the investments. Without this assumption the range of scenarios that could be a solution is heavily restricted. Another important assumption is that the diesel price used is the NIZ reference of 0.840 EUR/L. The case of 13% opportunity cost is discussed first, and the cases in which this bound should be lowered to reach a solution are discussed afterwards.

In the case of 13% discount rate the scenario (A) is the only scenario that displays feasibility for IPSE. Figure 6.2a shows that the 20% tariff strategy would be feasible for PV implementations of up to 525 kW corresponding to savings of around 160 thousand Euros to the FSSRI fund, which in principle is the main goal of the investment. Hybridization is still not feasible for Electrovichada, but looses are around 60% smaller. However, they are still looses, and the potential of this tariff scenario is still limited.

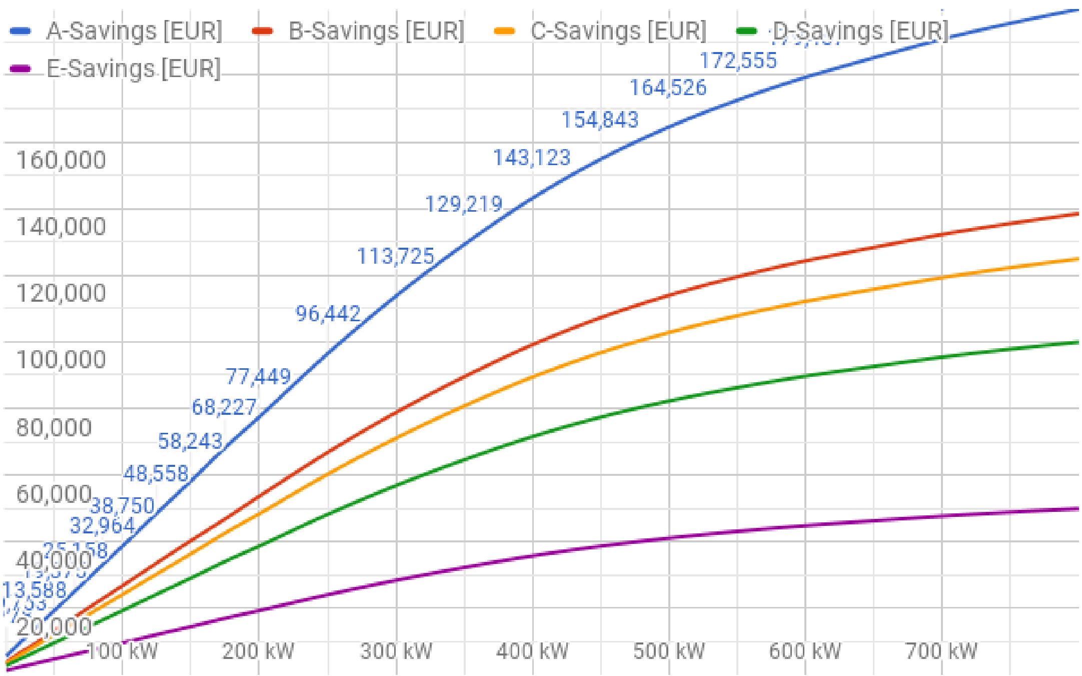
If IPSE would be willing to lower the opportunity cost to 9% the scenario (B) becomes a feasible scenario up until 450 kW with corresponding savings at this point of 100.000 EUR to the solidarity fund. In this case however, the investment becomes indifferent to Electrovichada, since it neither benefit nor affect them financially. This is a significant improvement with respect to the previous scenarios in the sense that energy operators would probably stop opposing hybridization initiatives in NIZ. However, it probably wouldn't serve the purpose of gaining their favor.



(a) IRR versus the installed PV capacity



(b) Net gain versus the installed PV capacity



(c) Savings to the FSSRI fund versus the installed PV capacity

Figure 6.2: Economic metrics for IPSE and Electrovichada versus the installed PV capacity for different tariff scenarios

Now, the feasibility standard for IPSE could be further lowered, to an 8% discount rate, in which case the scenario (C) becomes feasible for PV implementations up to 425 kW with savings to the FSSRI fund of 90 thousand Euros. In this tariff scenario IPSE profits a little less, but the energy operator receives a small incentive of around 10.000 Euros a year. Here the course of action should be determine by the government, regarding how willing they are to participate Electrovichada in the profits as means to gaining their favor. Also, the question remains as to how effective would such a small amount would be.

Tariff scenario (D) is very similar to (C), but dialed down to a of 6% opportunity cost. Here the feasibility goes until 350 kW with 65.000 EUR of savings to the solidarity fund and close to 25.000 EUR for the energy operator. In this case the positive effects on Electrovichada would be more palpable, and the opportunity cost would still have the standard of many government investments. Same as before, is a matter of how important this actor is considered.

Finally, tariff scenario (E) is the opposite of scenario (A). This is nicely illustrated in Figure 6.2b, with the net gain curves. Here IPSE would have to settle for a simple payback, in which case (E) becomes a viable option up to 300 kW with a mere 30 thousand Euros in savings to the FSSRI fund. The benefits for Electrovichada then would be in the order of the 50 thousand Euros. However, this solution is unbalanced, and defeats the purpose of trying to motivate the energy operators and find a feasibility range for all the actors, while at the same time solving the **fund situation** depicted in Chapter 4, Policy Context.

Strategies (A) and (E) are ultimately considered unbalanced and they are not recommended. Strategies (B), (C) and (D) are considered the best range of solutions to make hybridization feasible for all actors and constitute the recommendation of this project. However, the explicit policies that would make these tariff changes possible are not investigated in this report and are rather consider as part of the further work. In fact, tariff structure (C) was already considered by IPSE at some point [Dávila, 2017], but the implications were deemed unconstitutional, because they would imply giving money to the energy operators for selling energy that comes to them virtually free.

Discussion 7

The main objective of this report was to find solutions that made hybridization solar-diesel in NIZ feasible for the principal actors. The first results of this work were obtained in Chapter 3, Stakeholder Analysis. In which it was determined that the principal actors in the case-study of Cumaribo were IPSE and Electrovichada. IPSE as representative of the government interests and Electrovichada in representation of the energy operators of the not interconnected zones (NIZ). This result, and in general all the results in this report, holds for any other locality in which IPSE is planning of making a hybrid investment, so far as the following limitations are met; That the locality have an existing energy system which is 100% diesel, that this system provides 24 hours of service and that the hybridization is made with solar energy. In those cases IPSE and the energy operator will always be central to the investigation.

Next, the policy context was investigated in Chapter 4. Central to this chapter were the tariff structure and the so called "funds situation", which motivates the government investments in hybrid systems. The principal result of this chapter was the definition of the feasibility criteria for IPSE and Electrovichada. In the case of IPSE, it was found that its main interest is to generate savings to the FSSRI fund. It was also identified that hybridization is a mechanism to generate such savings, and to this end, IPSE is willing to pay for hybridization investments in full. The balance between the savings and the investment costs, can be modeled using a business-economical analysis. Now, in the case of Electrovichada, hybridization produces two effects. On the one side, the introduction of solar energy generates fuel savings, which translates as profit. On the other side, the energy service tariff drops in the presence of solar energy, which translates as looses. The difference between this quantities is refereed as "Net Gain". If the net gain is positive, hybridization is feasible for the energy operator.

Other studies that asses feasibility of hybrid implementations in Colombia were reviewed during this project. It was found that the feasibility criteria used in these references is fundamentally different to the one used in this work. Among the literature reviewed a particularly thorough financial analysis was found in in [FS-UNEP, 2014] for a hybrid implementation in Puerto Leguizamo. However, in this case the focus was entirely on the diesel savings and it's impact on the levelized cost of energy (LCOE), but no mention to the impact on the energy tariff. On other references, the distributed diesel system was often for own used, so the tariff structure wasn't taken into account. These studies constituted a departing point for this assessment.

Cumaribo's energy plant was then modeled in Chapter 5, and the feasibility criteria for the main actors was calculated for different hybridization scenarios, corresponding to different amounts of installed PV. These calculations were made under the current policy context. In this conditions hybridization turned out to be very beneficial for IPSE. Virtually all the scenarios were feasible for this actor, with high NPV and IRR values for most of the feasibility range. In turn, feasibility was not possible for Electrovichada. In fact, the net gain reached very low negative values. By analyzing the calculations, it was concluded that the tariff structure was at the root of this problem and constitutes one of the main barriers for hybridization in Colombia. This argument was illustrated later in Figure 6.1.

Some modifications to the tariff structure are finally suggested in Chapter 6. This suggestions are presented in Chapter 6 as tariff scenarios. A couple of these scenarios are recommended because they can generate feasibility for IPSE and Electrovichada. However, for them to be useful, the discount rate used by IPSE needs to be lowered to at least 10%, but 6% would allow more solutions. Basically, these solutions consist of different modifications to the renewable component of the energy tariff. One of the principal limitations of this approach is that the actual policies that could make this modifications possible were not investigated in this work, so legal boundaries or other regulations could render this solutions unfeasible.

7.1 Further Work

Many approaches can be adopted to complement and refine the results obtained in this project. For the stakeholder analysis it would be interesting to include the actors that sell and transport diesel into the NIZ localities. For the part of the policy context and technical analysis, it would be beneficial to include more technologies other that solar energy into the analysis, in order to gain a broader view of the hybridization problem in Colombia. Finally, for the suggestion chapter, a deeper discussion of the specific challenges involved in implementing different tariff scenarios would give valuable insight on the problem.

Conclusions 8

Based on the analyses that were performed on the last section and other sections of this report, the following conclusions were reached:

- IPSE and the energy operator are the actors with the higher stakes when the government is hybridizing a distributed diesel system in an NIZ Locality.
- One of the drivers of hybridization in NIZ in Colombia is the government interest in generating savings to the FSSRI fund.
- Hybridization is a mechanism in which capital investment funds such as the FAZNI fund and the FNR fund can aid O&M funds such as the FSSRI fund.
- Under the current policy context, hybridization in NIZ is only feasible from the government perspective, with an NPV that can reach around 300.000 EUR with an IRR of 19% for the case study of Cumaribo.
- Under the current policy context, hybridization in NIZ could yield annual savings of roughly 88.9 Million Euros to the FSSRI fund, if hybrid systems were to be installed in all the localities that have 24 hours of energy service.
- Under the current policy context, hybridization in NIZ affects negatively the finances of the energy operators. up to 100.000 EUR in annual looses for the case study of Cumaribo.
- One of the main barriers for hybridization arises from the current tariff structure for NIZ, which generates and unbalanced distribution of the savings generated by hybridization, hence preventing feasibility for all the actors.
- In order for hybridization to be feasible for all the principal actors, the tariffs must be modified.
- In order for hybridization to be feasible for all the principal actors, renewable tariffs must be drastically increased. For example, when the photovoltaic tariff is 50% of the diesel tariff the energy operator of Cumaribo perceives annual net gains of up to 8000 EUR. Which is somewhat modest.
- Feasible solutions are only possible if IPSE is willing to lower its opportunity cost to at least 10 %. But more solutions are available if the opportunity costs is lowered to 6%.

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Appendix A

In order to make it easier for the reader to identify the relevant content of the conducted interviews, a summary of the important ideas gathered during this process is presented in Tables A.1 and A.2. Table A.1 summarises the important highlights of Hybrytec interview with Sebastian Vargas while Table A.2 does the same for ESEI interview with Eric Dávila.

A.1 Interview 1: Hybrytec

Date: June 05, 2017

Location: Medellín, Colombia

Participants

Interviewee: Sebastian Vargas (SV), business developer engineer - Hybrytec

Interviewer: Sergio Rodriguez (SR), graduate student

Table A.1: Highlights of the interview with Hybrytec

Highlight	Critical View

In my experience, there are three cases for designing hybrid systems you may encounter in practice. The first case, in which the end-user begins with nothing, no energy access whatsoever. The second case, in which there is a diesel generator already installed, but the service is not 24 hours. And the third case, in which there is a diesel system and the service is 24 hours. For the 3 cases I will speak only about their solar potential, because solar energy is my area of expertise. The first case is the easier one. In this case the load is measured/calculated thoroughly and the diesel generator is roughly sized to equal the load with a 1.5 security factor. Thereafter, the solar capacity is set to be around 30% of the diesel capacity, as a right-hand rule. The second case is the most interesting one, because there are many localities in this situation in the country. In this case the goal is to take a system of say 6 hours a day, and extend the hours of service by introducing solar energy. The design is make so as to maximize the saving potential of the photovoltaic system in the most cost-effective way, with a restriction on the amount of fuel available. The case of 24 hours is fairly similar to the first case.	The case scenario in this work is the 24 hour service case. However, for the design of the system the 30% right-hand rule might not apply, given that there might be other restrictions and priorities different than maximize the solar energy saving potential. Also, the 1.5 security guideline is not observed, but merely because the energy system in Cumaribo is already implemented. However, the actual system is oversized to some extend.
In order to take full advantage of solar energy the system needs to be designed so that the peak of the generation curve fails approximately below the demand curve. In the case of equatorial regions, this peak is almost always located between 10 a.m. and midday. In principle, this fact would mean that a social strategy, one that modifies consumption habits in order to shift them towards midday, would increase the solar potential however slightly. Nonetheless, this would only make sense if the end-users perceive the benefits, like for example, more hours of electricity in a day.	As mentioned, the case scenario in this work is a 24 hour service case, so the appeal to social strategies to increase the saving potential of solar energy wouldn't really apply here. Given that the benefits for the population are difficult to account for. For once, extra hours of energy service wont be possible. Also, despite the possibility of a drop in the generation costs, energy prices might still be above the maximum rate chargeable to the end-users, so from the end-user perspective the implementation of these alternatives might not even make any perceivable difference.

Renewable alternatives other than solar might be viable. However, they are usually either very expensive or limited to certain specific climate conditions less generalized than solar radiation. For example, there are a couple of success cases of biomass implementations in Colombia that I can recall, but I know for a fact the investment costs where very high in comparison to solar energy. In the case of wind, I would say that is a very good alternative, so far as certain conditions are met. The conditions that are needed for this energy to be viable are only met in the northern region of Colombia known as la Guajira.	This reinforces the idea that choosing solar energy as the alternative was well funded. It also brings the matter that NIZ localities that are located in the Guajira region need to take wind energy into account, because the meteorological conditions apparently are favorable and wind could be a viable option in these zones.
Interconnection to the grid as an alternative to implement a distributed system is ruled out for many NIZ townships because transmission lines are costly. In Colombia one kilometer of transmission line costs around 1 million dollars, and many localities are placed up to 600 kilometers away from the central transmission grid. Not taking into account that many of these have small populations that can be attended with systems that cost less than a million dollars.	This facts help understand why many localities feature distributed diesel systems. However there are many localities that are in the interconnection plan in the near future. For the other part, the Plan for Colombian Electrical Interconnection (PIEC, by its spanish acronym), makes a great emphasis in identifying all the localities for which interconnection is not viable, hence leaving their coverage entirely in the hands of IPSE.

A.2 Interview 2: ESEI

Date: June 18, 2017

Location: Bogotá, Colombia

Participants

Interviewee: Eric Dávila (ED), manager - ESEI

Interviewer: Sergio Rodriguez (SR), graduate student

Table A.2: Highlights of the interview with ESEI

Highlight	Critical View

In Cumaribo analyses where run on various renewable sources in order to asses the different alternatives for hybridizing the town's energy system. In particular biomass, wind, hydro and solar. Biomass was discarded because there wasn't enough resource availability. On the other side, wind was ruled out because appropriate wind measurements were not available. The process of acquiring this data usually takes several months and the schedule and budget of the project wouldn't hold for such enterprise. It wouldn't be fair to say that wind conditions are bad, only they are unknown. For the part of hydroelectric potential there is a river close to the township, but the conditions weren't good for harvesting energy. In the end, solar energy was used as the best alternative for hybridization of the Cumaribo's diesel plant.	Again, this can be used as an argument to backup the general direction of this work towards solar energy. However, it also should be clarified that this argument applies well to the case study, but other regions can cope well with either wind, as was mentioned before, or with hydroelectric. In fact there are a number of NIZ localities which feature hybrid systems with small hydropower as one of the components. But that is because the geographical conditions for this type of energy are met.
To the question of economic viability it should be clarify that the designs built for Cumaribo and many other NIZ localities are made to be profitable from the perspective of the national government. Not the investors or the energy operators. In the case of Cumaribo hybridization is profitable up until replacing next to 12% of diesel energy with solar generation, with some specific assumptions about diesel price, equipment efficiency, demand curve and solar irradiation. However, in our experience the most important factor limiting these systems is the amount of renewable energy that can be utilized, and in isolated systems without batteries this depends very much on the demand curve features around midday.	While 12% is not a restriction for designing a hybrid system, it actually is for the case study of Cumaribo, in the sense that IPSE is paying for the implementation. So whatever capacity is installed, it would be within their approval. ESEI works as energy consultants for IPSE so is very likely that a hybrid implementation in Cumaribo would at least roughly follow their guidelines.

The question remains if these projects are profitable for energy operators, and I would guess they aren't. This is a great obstacle because operators are very important actors and as such they should be benefited somehow. Now, if you ask about the end-users and inhabitants of Cumaribo the investment is indifferent to them, provided the prices they perceive remain the same after adding solar to the town's system.	This is a critical point here. Because it means IPSE is making the implementation of renewables on diesel systems, giving away the capital investment costs, and putting OR in charge of the resulting hybridized systems, while affecting negatively their finances. Is very inconvenient that this actor get the worst part of it, but according to the interviewee, they are making a huge effort to find a way to retribute them, but with no success so far.
In the case of Cumaribo, the calculations were done on the premise that capital investment costs are fully covered by the government, which would be the actual case if the project is implemented. These costs include panels, civil works and installation. On average the cost of these implementations is around 2 USD/Watt. An opportunity cost of 13% was utilized, with 11% corresponding to the discount rate, and 2% inflation. This is done according to the guidelines of the Ministry of Energy and Mines.	This rates and assumptions will be used when performing a business economical analysis from the government perspective, to see how close the model holds to what is stated here.
Cumaribo energy system features 3 diesel plants. Two of 750W and another one of 900W. However, is never the case were there are two plants operating at the same time. This over-sized design can be explained on reliability grounds, taking into account that is a remote area with access difficulties and the municipality cannot afford to go without energy for weeks at at time if an unexpected failure presents itself. Another reason is the extremely high transport costs, and carrying 3 at one time might have been an strategy to lower them.	Since the model is done in an optimization program it is unlikely that the minimum cost system can follow this oversized structure. However, In many regards the difference is not so critical provided that the diesel generators never operate at the same time, and they would probably last more, so the investment in three generators at time zero could be equated to some extent with the replacement cost every 20 thousand hours of operation.

The institution that is promoting hybridization in the case of Cumaribo is IPSE. But the motivation is more economical than environmental or otherwise. The main objective is to decrease the costs related to diesel generation in NIZ. Fuel costs and fuel transport costs are ultimately covered by the state and there is a great interest in changing this situation through renewables, given that they are expected to lower the operation costs of diesel systems.	This is an example of how renewables not necessarily need externalities to make case for investments. In this particular case the very nature of renewables to have low operational costs is the one driving their implementation. With a financial drive as the main motivation. In other cases renewables need to make room against more profitable options through social welfare and environmental arguments.
The principal actors to be taken into account for an hybridization project in Cumaribo would be; The national government, IPSE, the energy operator (generator and distributor are one and the same company in this case, Electrovichada S.A.), and the municipal government, which despite having relatively low interest in the project, still have the influence to greatly affect its implementation. Some of these actors were contacted with IPSE as an intermediary and some haven't been contacted because the project is still not approved, so it would be ill advise to create expectation without certainty.	These actors are the principal ones from an administrative stand-point. The end-users and inhabitants of Cumaribo are also central from a social stand-point, but as is mentioned later in the interview the users in this case may have a neutral disposition towards hybridization because neither the benefits nor the consequences affect them in a significant way.

In order to understand the interest of the government in hybridizing NIZ systems, the following aspects of the situation should be taken into account; On one side, there exists funds exclusively reserved for capital investments in NIZ. Every year these funds display excess resources. On the other hand, there is a solidarity fund, which is meant to protect energy users in NIZ from high electricity prices. It experiences deficit every year and the government is forced to use the national treasure to cover it, because direct transfers of money from the former funds to the latter are forbidden by law. This means that the government requires an indirect mechanism to transfer capital, and hybridization is just the perfect tool, because it lowers the cost of energy, hence decreasing the need for subsidies.	So in this case the capital investment is taken from the funds destined to it, and used for hybridizing the energy system in Cumaribo. In turn, the prices per kWh drop for the energy produced using solar energy. Hence, the gap between the legal maximum that can be charged to the population and the actual energy price also shrinks, and the money that have to be taken from national treasure diminish as well.
From the perspective of the energy operator hybridization impacts the economics of the operation in two ways; First, there are fuel savings, which diminish the generation costs. And second, the energy generated from photovoltaic panels is charged with a different tariff formula. Because the tariff drop is bigger than the fuel savings. Overall the operator perceives looses.	The idea is to proof this by means of a simulation. And quantify, if ever from a case study perspective, that this is true. Hence, showing that from the energy operator perspective hybridization is actually not a good option, even if the capital costs of the hybrid implementation are zero.