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Assessing the Profitability of Hybrid Microgrids for Rural Electrification

A Multi Stage and Financial Model

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Abstract

Electricity access expansion is currently one of the main issues in the global agenda, considering the benefits that electrification brings to human society. A lot has been achieved in the past years, however, rural areas in developing countries are still lagging behind. These are usually difficult to access and not very densely populated, making project design expensive and challenging. In this context, hybrid microgrids separated from the central grid have risen as a promising and cleaner solution. Nevertheless, these require significant investment costs that, given the features of the geographies in need, will probably not be covered by the population to be served nor by the local government. This makes private investor participation the key to be able to develop these projects. Although, due to the high-risk nature of the venture the private sector is increasingly reluctant to step in. To address this issue, a multi-stage model approach feeding into a project finance-based financial model was developed in this study, with the aim of determining under which conditions it is profitable for private investors to develop hybrid microgrid electrification projects. For illustrative purposes, the models were based in a rural village in north-west Haiti, Anse Rouge. In the first stage, the village is characterized, determining the demand or electricity needed and thus the supply microgrid prototype. In a second stage, using outputs of the first, a project finance-based financial model was built from which minimum tariffs to make the venture profitable to investors were obtained. Finally, the conditions under which the tariffs obtained in the financial analysis could be charged were discussed, which will greatly depend on the efforts of the developer, the energetic potential, the acceptance of the community, and the quality of institutions. In the case of Anse Rouge, the profitable tariffs are high but feasible in relation to the past adoption of other rural Haitian settlements, however, there are relevant institutional and political risks that explain the underdevelopment of these projects in the country.

Keywords – Rural Electrification, Project Finance, Haiti, SDG7

Résumé Exécutif

L'expansion de l'accès à l'électricité est désormais une des principales priorités de développement au niveau mondial étant donné ses bénéfices démontrés pour les communautés bénéficiaires. A cette fin, les micro-réseaux, isolés d'un réseau central, offrent une solution raisonable pour garantir un accès en éléctricité dans les zones peu peuplées et difficiles d'accès. Initialement alimenté par des matières hydrocarbures, ces micro-réseaux ont évolué et de nos jours, combinent énergies fossile et renouvelables. Bien que cette alternative soit généralement plus économique sur le long terme, celle-ci nécessite également de plus larges coûts d'investissement initiaux. Dans de nombreux cas, l'implication des investisseurs privés est une composante cruciale du succès de tels projets, étant donné les moyens limités des autorités et populations locales. Cependant, il est bien souvent difficile de convaincre des investisseurs au vu des incertitudes et risques inhérents à un tel projet. Pour répondre à cette problématique, cette étude développe un modèle à plusieurs étapes visant à déterminer les conditions dans lesquelles des investisseurs privés auraient un intérêt financier à développer un projet d'électrification de micro-réseau hybride. À des fins d'illustration, ce modèle est présenté au travers de l'étude de cas de la zone rurale d'Anse-Rouge située au Nord-Ouest d'Haïti. Lors de la première étape, le modèle caractérise la géographie et future demande de la zone à couvrir en électricité ainsi que un prototype du réseau d'approvisionnement. Lors de la seconde étape, les résultats précédemment obtenus sont injectés dans un modèle financier qui dérive alors les conditions nécessaires afin de rendre le projet rentable pour des investisseurs. Au travers des tarifs de rentabilité obtenus, les exigences pour l'établissement d'un micro-réseau à Anse Rouge sont élévés mais réalisables pour des investisseurs. Pour appuyer cela, ces tarifs sont comparés à ceux de projets déjà implémentés dans la région. Dès lors, il semble que les nombreux risques institutionnels et politiques constituent le principal obstacle au développpement de tels projets en Haïti.

Acronyms

ANARSE Autorité Nationale de Regularization du Secteur de l'Energie

CAPEX Capital Expenditures

CAPM Capital Asset Pricing Model

CDS Credit Default Swap

CFADS Cash Flow Available for Debt Service

CRP Country Risk Premium

DSCR Debt Service Coverage Ratio

EBITDA Earnings Before Interests, Taxes, Depreciation and Amortization

EDH Electricité d'Haïti

EMMUS Enquête Mortalité, Morbidité et Utilisation des Services

GCF Green Climate Fund

GIS Geographic Information System

GoH Government of Haiti

HOMER Hybrid Optimization Model for Electric Renewables

HTG Haitian Gourde

IDC Interests Accrued During Construction

IEA International Energy Agency

IEC International Electrotechnical Commission

IHE Institut Haïtien de l'Enfance

IHSI Institut Haitien de Statistique et Informatique

IMF International Monetary Fund

IRENA International Renewable Energy Agency

IRR Internal Rate of Return

kWh Kilowatt-hour

LCOE Levelized Cost of Electricity

MG Micro/Mini-grids

NGO Non-Government Organizations

NPV Net Present Value

O&M Operation and Maintenance

PAYG Pay-as-you-go

PPA Power Purchase Agreement

PP&E Property, Plant and Equipment

PV Photovoltaic

RE Renewable Energy

RES Renewable Energy Sources

SDG Sustainable Development Goals

UFCF Unlevered Free Cash Flow

UN United Nations

UNEP United Nations Environment Program

USD United States Dollar

WB World Bank

WHO World Health Organization

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1 Introduction

Access to electricity for all has become one of the main priorities for the international community in the latest years, gaining more force with the United Nations (UN) Sustainable Development Goals (SDGs) set in 2015 to be achieved in 2030. Goal number seven particularly refers to the attainment of affordable and clean energy for every person in the world. The importance of this objective is evident, considering the welfare impacts that come with electrification. Many studies prove that access to electricity improves life quality, as it might offer a way out of cyclic poverty by enhancing healthcare and education, as well as by stimulating productive and income-generating activities. Furthermore, it leads to a reduction in the development gap between countries (Hubble and Ustun, 2018) (Cook, 2011).

In the period between 2010 and 2017, a lot of progress has been made. The global electrification rate passed from 83% to 89%, providing new access to a total of 920 million people. Nevertheless, several experts state that the world will not be able to reach SDG7 by 2030 at the current pace (IEA et al., 2019). As of 2017, there were still 840 million people without access to electricity, most of them located in rural areas of Sub-Saharan Africa and other poor regions. The rural factor is of utmost importance: if all the remaining population needing access to electricity would be located in urban areas, the targets would more likely be achieved over the time span proposed. On the contrary, those 840 million unserved people are mostly located in remote, difficult-to-reach areas, usually in countries with grave economic and political difficulties, meaning that the efforts to provide them electricity access will be increasingly more challenging than what has been done in the past. It is believed that by 2030, an important number of 650 million people will still be lacking electricity (IEA et al., 2019).

The solutions to tackle the rural electrification issue are either to extend the existing grid or to develop off-grid alternatives. The latter can range between individual household installations, such as Solar Lighting Systems and Solar Home Systems, up to larger, more complex solutions that serve many households (and even commercial and industrial facilities) with one unit, known as microgrids (MG). This thesis will focus on the latter, due to their resourcefulness and cost effectiveness in relation to the remaining alternatives.

MGs can be defined as *"a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A MG can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode"* (Strahl et al., 2015). Although the current market size of this technology is quite small, it has a promising potential. However, it is paired with important limitations that have prevented it from developing with the desired speed and scope.

1.1 Why Microgrids?

The first and simplest solution to address the issue of rural electrification will always be grid extension, considering the enhanced reliability, cheaper costs and economies of scale that this solution provides vis-à-vis off-grid options. However, in some cases this is not economically feasible. A grid extension comprises building transmission lines and connections which can be extremely expensive, rising to values of thousands of dollars per kilometer (USAID and ARE, 2014). Only in certain cases, when grid infrastructure is developed and demand is high enough to justify the significant costs it entails, an extension is the most cost-effective option.

Additionally, being far away from the grid adds another complication. Grid expansion projects have to be impulsed by the local utility, but in many countries where rural electrification is a prominent issue, these institutions are in a highly impoverished situation that have led to high productive and operational losses. This makes most utility companies lose money for every kilowatt-hour (kWh) they produce, making it impossible for them to fund expansion projects. This paralysis makes people who live far from the grid very unlikely to be connected by an extension, and a lot of time can be lost waiting for this to happen (Lacey, 2020).

Indeed, for rural communities far from the grid or in complicated terrains (i.e. mountains, deserts, islands), off-grid options are the most suitable solution to provide electricity access. Solar lighting and home systems are a simple and cheap alternative, given that there have no distribution or transmission costs associated, although, due to the lack of economies of scale, the total cost of energy is still high (USAID and ARE, 2014). Additionally, these are mostly convenient when population is very scattered. As they are thought to be units serving a household, capacities are low, only allowing the use of a few small home electronic items and are not capable of providing electricity for productive uses, which are key to stimulate rural communities and help alleviate poverty (Williams, 2017). Furthermore, these alternatives do not have the possibility to be connected to the central grid if required.

MGs are much more versatile. First of all, they can produce higher amounts of electricity and grid-quality power, providing capacity both for home appliances and for productive activities. Secondly, they can produce both autonomously or connected to the central grid if necessary. Finally, MGs have the possibility of integrating several generation technologies, including renewable energy sources (RES), which allows them to take advantage of the different resource potentials in the area in a cleaner way (Williams, 2017).

1.2 Why Hybrid?

Since the 1950s, many isolated communities in developing countries have depended on stand alone diesel generators for their electricity supply (Szabó et al., 2011). This is not consistent with global decarbonization goals and exposes the system to different risks inherent to fuel price volatility and high transport costs. As mentioned, MGs are well suited to use local renewable energy resources, providing developing countries with the chance of being supplied by clean energy, getting on the right track as their economy grows and starts demanding more (Williams, 2017).

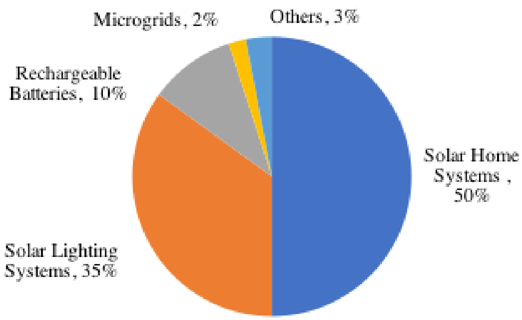
The reason why stand-alone diesel gensets have been the traditional alternative, is that they have a considerably lower upfront cost in relation with renewables. This is particularly relevant when these solutions are sought for poorer countries that usually do not count with enough funding. However, looking at the future, running costs are higher than RES due to high operation and maintenance (O&M) expenses, transport and, in some cases, import prices (USAID and ARE, 2014). This, however, depends greatly on the location of the area under evaluation and naturally the more remote, the more expensive. Schmid and Hoffmann (2004), in a study carried out in Brazil, found that diesel prices in isolated areas can increase from 15% to 45% because of transportation, depending on the place of supply. While Naude and Matthee (2007), in a study for the African continent, found that transport costs in landlocked countries can be up to 50% higher than in coastal ones.

A hybrid MG combines at least two different technologies for power generation (IEC, 2005), which are normally one or more RES, a battery and/or a diesel genset as back-up. A combination that includes all of the aforementioned elements has proven to be the least-cost solution for several locations, depending on the potential power of the RES on site. Furthermore, the need of the diesel genset and its actual use also depends on this potential: in places where renewable energy sources are abundant, they are rarely used. Nevertheless, it is useful to include them given the dispatchability of this kind of generation (USAID and ARE, 2014). Therefore, hybrid MG are a cleaner, safer and, in the long run, more cost-effective option than stand-alone diesel gensets, which is the reason why they are now taking the center stage of scholar studies on rural electrification.

1.3 Market Potential

Although MGs are a minor portion of the currently running off-grid solutions (see Figure 1.1), there is a potential market of US$ 38 billion in capital expenditure through 2030 (Bloomberg New Energy Finance, 2018). When thinking about the numbers presented in the first part of this chapter, there are 840 million people who are currently not being served. However, there is a much bigger addressable market when considering the people that have access to electricity but for which the service is unreliable. This makes the potential market grow to about two billion people (Lacey, 2020). It is estimated that MGs will serve as providers for approximately half of the new electricity access by 2030 (IRENA, 2019).

Figure 1.1: Current Off-Grid Energy Solutions Worldwide (IEA et al., 2019)



1.4 Limitations

As mentioned, most of the national utilities in countries where rural electrification action is needed are not financially or operationally capable of solving this problem. This is why the participation of the private sector is key. However, locking down these investments has been greatly unsuccessful due to their reluctance of venturing in a business model as risky as hybrid MGs. These projects are capital-intensive, particularly those with a higher penetration of renewable technologies, and at the same time, the population they serve is usually poorer, most of the times with seasonal incomes, triggering red flags in terms of payment collection. All the aforementioned jeopardize the revenue security and stability and thus, the profitability of the projects.

The good news is that there is evidence that with the right business model and sizing the right opportunities, these risks could be greatly reduced. For instance, there are many policy-support measures such as subsidies, tax incentives, climate and carbon finance, preferential lending, guarantees and public concessions. There are also different ways of increasing revenues, through demand stimulation by promoting the commercial and industrial sector in the community, setting different tariff schemes such as differentiated or flat tariffs, or applying different revenue collection systems such as pay-as-you-go (PAYG). It is key, therefore, to characterize and model the situation from the beginning, and try to reduce revenue collection risk as much as possible.

At the same time, many of the uncertainties that affect the financial prospects of a MG project can also be solved by establishing a proper policy and regulatory environment to foster and secure private investment. Naturally, a capital-intensive project in a setting of uncertain or low demand might require several years to breakeven and generate profits (Williams, 2017). Therefore, a politically changing and unstable environment is not the ideal scenario. Hence, it is important for countries to design policies that can promote private investments in these types of projects, trying to reduce corruption, instability and transparency issues. At the same time, these policies have to provide enough regulation to limit rent-seeking and opportunistic behavior in detriment of the community. This is, allowing tariffs to be high enough for private players to recover their investments but not too high to make it unaffordable for the population. These sorts of policies, unfortunately, are not very developed in emerging countries, posing an important limitation.

1.5 Research Question and Thesis Structure

This thesis intends to construct a complete and robust model, including both demand and supply side, and using these results to build a forward-looking financial model, applied to a particular village in the country of Haiti as an illustrative example. The model aims to assess the different risks and determinants of the profitability of venturing in the business of rural electrification, in order to identify the key aspects to consider when evaluating whether entering into this business. With this, the question to be answered in this study is: **under which conditions is it profitable to develop a rural electrification project via hybrid microgrids?**

This thesis will be structured as follows: first, chapter two will present a broad literature review, which will set the main phases when analyzing a potential rural electrification project. Chapter three will provide the geographical context. Chapter four will describe the multi-stage model process to determine supply and demand. Chapter five will refer to the building of the financial model, using inputs from the two previous chapters. Chapter six will discuss the results of the financial model and also refer to the limitations of the research. Finally, chapter seven will close this thesis with the conclusion and final remarks.

2 Literature Review

This study will assess the profitability of a hybrid MG through a financial modelling approach. The inputs for this task will be obtained from a multi-stage model, which has been already described in previous literature on the subject of rural electrification. This will be referred to in the first section of this chapter. The second section will be dedicated to the specific financial modelling methodology to be used, which will be reviewed using two books as main references. These are "Project Finance: Theory and Practice" by Stefano Gatti and "Corporate and Project Finance Modeling: Theory and Practice" by Edward Bodmer.

2.1 Multi-Stage Model

Most academic work regarding rural electrification seem to converge in a certain methodology to approach electrification planning. Cader et al. (2016) describes in a simple way the different stages in this methodology. First, the status of electrification stage, which comprises a geospatial analysis that can provide data on the actual electricity access and infrastructure of the geography in question. Secondly, the demand-model stage, which seeks to estimate the demand in order to adequately design a system that will cover for it. Lastly, the supply-side model stage, where a least cost analysis should be performed, determining which alternative is the most economically convenient for electricity supply.

Many of the studies that will be mentioned in this chapter have used a similar framework, analyzing the geography, the demand and finally the supply options to arrive to the optimal electrification strategy. Examples of these are Blechinger et al. (2016) and Hubble and Ustun (2018) who conducted a complete analysis, including the three aforementioned stages, to arrive to the best electrification option for 1,800 small islands and a group of 50 countries, respectively. There are also more tailored approaches, focused in one particular geography, such as Blum et al. (2013), who carry out an exhaustive multi-stage analysis based on on-site surveys for electrification in rural Indonesia, and Parshall et al. (2009) and Zeyringer et al. (2015) who use a similar methodology to determine the optimal electrification option for rural Kenya. The following subsections will talk about each step of the multi-stage process.

2.1.1 Geography Selection

When doing an electrification assessment focused on a particular geography, choosing the location involves several criteria. First of all, a geography has to be selected depending on its status of electrification. The idea is to choose an area with low or no electrification rates, outside the future plans of the national utility companies. These zones are, in turn, very problematic to identify, due to the absence of detailed information on existing electricity connections (if any), population and other demographic characteristics (Cader et al., 2016).

The most straightforward solution to characterize a geography is to execute surveys or site visits to the locations in question. The United States Trade and Development Agency (2015), for instance, uses surveys during visits in different villages in Haiti to gather significant data on different parameters deemed as essential for MG sustainability. With this, they come up with an overall score to indicate which village is more prone for successful MG development. In the same line, Gerlach et al. (2013) elaborated a worldwide country ranking regarding the adequacy to develop a MG project. The scoring is based on two main criteria, market potential and political/financial environment, using different publicly available indicators to quantify them.

In the case where there is no pertinent survey data available and site visits are not possible, many studies suggest the use of geospatial data such as GIS (Geographic Information System) to perform geographic analysis. As an example, Bertheau et al. (2015) use GIS resources such as population and school databases and night light imagery to identify population clusters in Nigeria in order to perform electrification modeling. Going further, Kaijuka (2007) uses GIS to derive demand patterns through a point-based system for each type of demand node (i.e. household, school, health center) and determine priority areas for electrification development.

2.2 Demand-Side Analysis

Demand modelling is the one of the most crucial and challenging steps in network planning. It is the milestone to determine the level of consumption the system must meet, and therefore its sizing and design. An overestimation or an underestimation can lead to important efficiency issues that can jeopardize the feasibility of the project. There are many ways in which this proves to be a difficult task. First of all, demand for electricity is dynamic, meaning that it generally increases after a community gets access (Díaz et al., 2010). Additionally, in the case of zones which have never been electrified before, it might be particularly complex to derive an accurate demand as there is no historical information, having to rely in proxies to determine a load level.

Demand projections can have a significant impact when evaluating the design of an electrification system. For instance, Parshall et al. (2009) and Zeyringer et al. (2015) both analyze the cost-effectiveness of grid extension versus different off-grid technologies in Kenya, but arrive to opposite results which can be attributed, in part, to the different approaches to estimate demand. While the former simplifies the estimation by dividing the population in different subgroups and calculating an approximate demand depending on each cluster's configuration, the latter creates a more detailed approach through a regression model for the demand per household in relation to different variables.

Proxy estimations by grouping have been used in many studies when assessing demand, such as the aforementioned study by Parshall et al., in which households in Kenya were grouped according to income and then classified into four fixed demand categories. Even though this method is less comprehensive and could miss important influencing factors associated to each geography, it has the advantage of being simple and that it can be easily extrapolated. This can be seen in the different non-tailored models that have been created using grouping proxies to determine demand. Hubble and Ustun (2018) create a model, which aims to be applicable in many geographies, in which loads are calculated based on a previous study carried out in 2015 for Rwanda. Taking two villages in said country, where load profiles had already been analyzed and modelled, the authors build fours scenarios depending of the size of the village under study and their level of activity.

Probably the most exhaustive methods to estimate demand involve the processing of survey data, but at the same time these are complicated and costly. Tatiétsé et al. (2002) and Blum et al. (2013) calculate a demand based on data of a survey carried out by them in the region in question, gathering information on appliance ownership. On the other hand, Williams (2017), Zeyringer et al. (2015) and Pachauri (2004) model individual demand per person or per household applying different regression models based on the data of existing population surveys. These models have as dependent variable an indicator of electricity demand and use independent variables that depict income and social status (such as property ownership, number of employees, size of the house, other expenses, etc.), household profile (determined by age and education of the household head and its members).

In the end, the decision of which method to use depends greatly on data availability and the scope of the study. If the research is based in a specific location and there is enough data available, a regression model or the elaboration of a typical household prototype would be the best choice. However, if the model is intended to be applied in different geographies and/or there is not enough data, a proxy-based estimation is more suitable.

2.3 Supply-Side Analysis

There is extensive literature regarding the cost-effectiveness of hybrid MGs vis-à-vis grid extension and stand-alone diesel. For the former, most of the studies use methods to obtain a breakeven distance, which corresponds to the length of transmission infrastructure in which it would be less expensive to generate and distribute electricity in a local MG than to extend the existing grid. Szabó et al. (2011) uses a spatial electricity cost model to determine the least-cost option between off-grid solutions and grid extensions to power different zones of Africa. According to the results, West African countries with more advanced grid infrastructure could consider an extension as the best mean for rural electrification. While for the rest of Sub Saharan Africa, where central grids are less developed, off-grid solutions more cost efficient.

According to the breakeven distance method, the furthest the village is from the central grid the most likely are MG to be the least cost option. As Blum et al. (2013) finds, solar-powered solutions increase competitiveness with the remoteness of the village in question. Criticisms of this approach include that breakeven distance calculations normally work specifically to a certain location, therefore it is not easily extrapolated. Additionally, Cader et al. (2016) note that least cost grid extension is not the same as shortest distance, given that this measurement does not consider necessarily the topology and difficulty of the terrain in which grid infrastructure needs to be built. Nevertheless, studies converge in the idea that for villages located the furthest from the grid, there is a point for which the costs of extension of the transmission and distribution lines becomes unprofitable, and it is best to switch to decentralized, off-grid projects. Naturally, when talking about complicated topographies such as mountainous terrains or islands, this switch becomes even clearer.

Regarding diesel, even though most countries tend to adopt this solution due to its cheaper initial costs, many studies have proven its lack of competitiveness in the longer term. Hubble and Ustun (2018) concluded that, in most cases, gensets can be phased out or create equally cost-effective RES-only solutions by adding solar and battery options. This paper also talks about the general reasons that complicate the inclusion of a diesel genset. Among them high supply chain costs, particularly in underdeveloped countries with a precarious infrastructure levels, and the need to have instructed technicians at hand whose skills are difficult to find in rural settings. However, most studies consider the addition of a diesel unit due to the importance of it as a backup.

Finally, it is important to take into account diesel subsidies, whose importance is highlighted in Szabó et al.'s study, given that their presence notoriously change the spatial results. Bertheau et al. (2015) update Szabó et al.'s spatial analysis and analyze the influence of fuel taxes and subsidies in Africa. Comparing two scenarios with international and national diesel prices (the latter incorporating subsidies and taxes) results show that Levelized Cost of Electricity (LCOE) reductions of a hybrid system compared to diesel only increase significantly in countries with high national prices. Contrarily, in countries with high subsidies, LCOE is not reduced at all by adding hybrid technologies. Lacey (2020) state that subsidies of up to US$ 8 billion a year are granted by African countries for fossil fuel consumption. This tells us that there is enough money to spend in sustainable rural electrification projects, the only missing thing is the will and trust in renewable energy technologies.

There are several decision support tools and softwares that identify economically-optimal designs. The most used are cited and compared by (Cader et al., 2016), which are HOMER, Network Planner and GEOSIM. Each of these tools have different pros and cons when being used for network planning, however, HOMER is the most suitable when analyzing MG design, as it includes availability of solar and wind resources and inputs such as demand projection and diesel prices can be added in order to get a more exact solution.

Many existing studies in the matter such as Hubble and Ustun (2018) and Rehman et al. (2007), use this tool in their network planning assessments.

2.4 Financial Model

When reviewing literature, it was noted that there were not many relevant studies that actually focused on the financing of these projects past the supply and demand planning phase. The most notable example is Williams (2017), who built financial model with the inputs of a statistical analysis carried out in the same study.

Most papers that address the financial aspects of MGs are qualitative and focus on the difficulties of obtaining funds due to the risky nature of such projects. Oueid (2019) refers to the particular barriers of the upfront capital required to develop such projects and to the lack of data on specific sources of capital and performance of existing ones that might serve as information to decrease the uncertainty of potential investors. Owens (2002) in his guide published by the USAID, talks about the general barriers driving away investments in renewable energy projects, which coincide with some of those encountered for MG projects mentioned in chapter one. Such barriers include, among others, a high capital to O&M cost ratio, a high project development to investment cost ratio and and a small total investment required.

2.4.1 Project Finance

Most renewable energy projects are financed via project finance, which is a particular way of raising funds. Müllner (2017) dissects its definition by the Basel Committee on Banking and Supervision, stating that it is *"a form of financing for the construction of a new capital installation in which the lender is usually paid solely or almost exclusively out of the money generated by the contracts for the facility's output"*, therefore making the payments depends primarily on the project's cash flow and not on the creditworthiness of the equity sponsor. Hence, the lender takes an increasingly higher amount of risk than in a regular venture and this translates into a higher cost of capital.

The important thing for debt providers is to be proven that cash flows are sufficiently stable and secure to cover debt service[1], thus, revenue certainty is key, both in terms

[1] Interest and principal payments.

of price and quantity. On the price side, at first this might seem problematic, given that MGs for rural electrification, as mentioned before, are generally aimed at poorer populations with scarce means to pay for electricity services. However, there are several studies that prove that rural people are actually willing to pay for these at levels more than sufficient to cover the costs (White, 2008), mainly due to the high level of spending that they already incur on to buy alternative solutions to cover for their energy needs such as charcoal, kerosene and candles (UNEP, 2015) (Lucky et al., 2014).

On the quantity side, this is also challenging. As mentioned in a previous subsection, it is difficult to estimate the demand for an unserved village, and it is hard to determine if it will be enough to ensure the necessary revenues. This is why the location has to be carefully studied and demand has to be estimated as exhaustively as possible. One way of choosing a more convenient location is to look for anchor customers, which secure high and reliable demand and ability to pay, such as mobile antennas, industries and public buildings (Williams, 2017). In addition, access to grid connection does not necessarily imply use of electricity for all end uses, in fact, consumption levels in newly connected households are usually lower than expected for an initial amount of time (Winkler et al., 2011). To ensure electricity use, it is necessary to implement affordability and policy interventions such as educating the community and promoting productive uses of electricity.

On another note, securing the actual revenue collection is a third additional challenge. Most authors agree that the safest way to do so is through a Power Purchase Agreement (PPA), which is a commitment between the producer and a purchaser in which the former promises to deliver a specified output over a determined period in exchange of payments at a fixed rate per unit by the latter (Owens, 2002). However, this sort of agreement is not usual for rural communities, where the counterpart would have to be the government if there is no anchor customer. Nevertheless, pay-as-you-go (PAYG) systems have proven to be an effective solution for this issue (Yadav et al., 2019). Yadoo and Cruickshank (2012) found that in Peru, pre-paid meters have allowed a 66% reduction in operational costs (collection costs). A detailed description on modeling in project finance is provided in Appendix A1.

3 Geographical Framework

This chapter will put the reader in context with the geographical framework of this thesis. The first section is dedicated to explain the geography selection, as well as to introduce the country; the second refers to the selected nation's history, geography, economy; a third and final section talks about the country's electricity sector, its challenges and why MGs might be a solution for them, and hence why this geography was of particular interest for the extent of this study.

3.1 Country Selection: Haiti

The selected geography is the country of Haiti. According to the World Bank data as of 2017, Haiti positioned itself as the least electrified country in the American continent[2], with an electricity access of 43.8% (The World Bank). In addition, an important amount of the population with access is connected illegally. The service provided to the connected population is unreliable and sporadic, most of the time not even guaranteeing electricity for a full day. The access rate has remained unchanged for 40 years (World Bank, 2017) and infrastructure has suffered severe damages due to the latest natural disasters.

It is commonly believed that Haiti is in a condition of urgency regarding electrification: it is the poorest country in the western hemisphere with little electricity access, which opens the possibility of expanding it in order to boost productivity and other development opportunities. Moreover, the little and unreliable generation facilities rely primarily on diesel, despite the fact that the country has an outstanding potential for renewable energy development. More precisely, the country depends on fossil fuels for 85% of its electricity generation, representing 7% of the country's annual GDP, making it vulnerable to volatile oil prices and exchange rate fluctuation (UNEP, 2015). The potential for renewable energies is so big, that considering just solar photovoltaic (PV) generation, only six square kilometers of panels would be able to generate as much electricity as the country produced in 2011 (Lucky et al., 2014). In addition, Haiti has been considerably understudied, with most of the existing literature being focused in Sub Saharan Africa and Southeast Asia.

The reason why this happens is very understandable. Taking the first criteria of the

[2] In terms of access to electricity as a percentage of the population

ranking elaborated by Gerlach et al. cited in the previous chapter, which addresses political and financial environment, Haiti is not very well positioned. In 2019, the country ranked 179 out of 190 in the Doing Business ranking by the World Bank, and 168 out of 180 in the Transparency International's Corruption Perception Index. This, paired with high inflation (12.5% in 2018 according to The World Bank) and high levels of political instability makes it a highly unattractive country for the private sector to venture in.

However, looking at the second component of the ranking regarding market potential, things do not look so grim. There's an overall low global electricity access rate, and this increases in the rural settings, where electrification reaches a meagre 2.7% (The World Bank). Considering the high proportion of people living in rural areas (almost five million according to the World Bank) this composes quite an important market potential. When pondering, additionally, that for many of the people that have access to electricity the service is very unreliable, this provides a much bigger market base.

3.1.1 Haiti: Background

Haiti is an island nation located in the Caribbean, occupying the western third area of the Hispanola Island, shared with the Dominican Republic. It is the third-largest Caribbean country by area and population, with over 11.5 million inhabitants as of 2018 (The World Bank). Its largest city is the capital, Port-au-Prince, located in the middle of the territory. A map of Haiti can be seen in figure 3.1.

Figure 3.1: General Map of Haiti (Enciclopaedia Britannica, 2020)

The most commonly used administrative division of the country consists in four layers, which from largest to smallest are: 10 departments (figure 3.2), 42 arrondissements, 144 communes, and 571 communal sections. Haiti has a predominant mountainous landscape: five mountain ranges (Massif du Nord, Montagnes Noires, Chaine de Mateaux, Massif de la Hotte, and Massif de la Selle) cover 75% of the country's territory (figure 3.3). Nearly all the population is of African origins, who descended from earlier slaves. The official languages are Haitian Creole and French. Two-fifths of the population live in rural areas with high density levels. Urban lifestyle is limited to Port-au-Prince and 10 other cities (Enciclopaedia Britannica, 2020).

Figure 3.2: Department division of Haiti

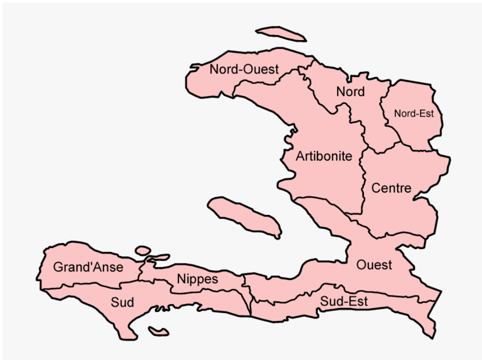


Figure 3.3: Physical Map of Haiti (Globalsecurity.org)

As mentioned, Haiti is the poorest country in the western hemisphere, with a GDP per capita of US$1,866 (PPP, as of 2018) (The World Bank) and a Human Development Index of 0.50 (2019), locating the nation at number 169 out of 185 (United Nations Development Program). Over half of the population lives below the poverty line of US$ 2.41 a day (World Bank). Poverty is more extreme in rural settings and in regions located the furthest from the capital. The country suffers from great political, social and economic instability and it is the focus of many natural disasters such as the high magnitude earthquake in 2010 and Hurricane Matthew in 2016, causing several deaths and destruction. According to Germanwatch's 2020 Global Climate Risk Index, Haiti is positioned at number three in the Long Term Climate Risk Index, raking third out of the ten most affected countries by climate impact from 1999 to 2018.

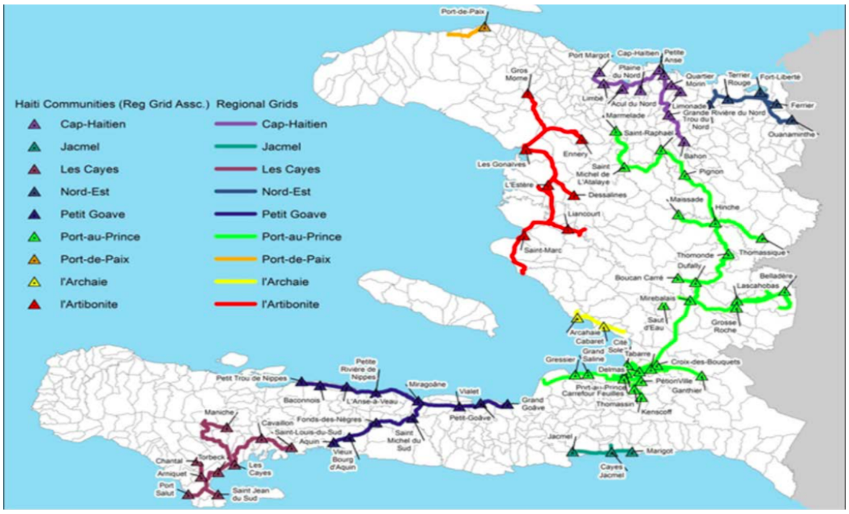
3.1.2 Haiti's Electricity Sector

The electric utility for Haiti is Electricité d'Haïti (EDH), vertically integrated, therefore essentially viewed as a monopoly in the generation, transmission and distribution of electricity. This monopoly power was given by a 1989 decree, which paradoxically also opened the possibility to outsource generation to private third parties. Due to this caveat, private independent power producers started developing generation assets in 1996, and today they are the main suppliers of electricity (Stuebi and Hatch, 2018). In 2018, the first official regulatory agency for the electricity sector was established, called ANARSE (Autorité Nationale de Regularization du Secteur de l'Energie).

The electricity system in Haiti is extremely fragmented, which leads to important inefficiencies. EDH operates one main interconnected network serving Port-au-Prince and other nine isolated grids that supply 500-20,000 customers (figure 3.4). In addition, there are more than 30 smaller, village-level, municipal diesel grids (100-500 kW), which were initially set up by EDH in its mandate to provide rural electrification, but are now owned and operated by each municipality (Schnitzer et al., 2014). These units serve 1,000-5,000 customers and are generally unreliable and costly to run. Nevertheless, they usually have more modern and complete distribution networks and could become more efficient if hybridized with other sustainable generation sources, creating a compelling opportunity for renewable energy (World Bank, 2017).

Electricity access is mostly concentrated in the Port-au-Prince area, reaching levels close to 40%, with an average consumer receiving around 15 hours of electricity per day. In rural areas, electrification rates are less than 5%, receiving power for an average of 5-9 hours per day (Lucky et al., 2014).

Figure 3.4: EDH Infrastructure



In addition, self generation through individual diesel engines has become a common method of obtaining electricity access. It is believed that the combined capacity of these generators reach 500 MW, which is more than EDH grids, municipal and private minigrids capacities combined (World Bank, 2017).

3.1.2.1 Issues with EDH

EDH is undergoing severe technical and financial challenges, mainly due to operational losses that can reach levels of 65%. Moreover, due to the important percentage of illegal connections, payment collection is ineffective, making EDH recover less than a quarter of the value of the electricity generated. This environment of continued losses have caused the utility's available generation capacity to remain stagnant for the last 10 years. Haiti's centralized electricity price is normally above the Caribbean regional average, reaching values close to US$ 0.3-0.35 per kWh (DOE and NREL, 2015). Unserved communities usually spend a higher share of money in alternative energy sources than centrally connected urban areas. Studies and surveys have determined that most unserved rural households and small enterprises pay US$ 10-20 a month for substitutes such as candles, kerosene and charcoal, reaching up to 6.5% of a household revenue (World Bank, 2017) (Stuebi and Hatch, 2018). Cost of generation per kWh, on the other hand, is usually higher than the rates charged to consumers, ranging from US$ 0.3 to almost US$ 2 per kWh (World Bank, 2017) (Stuebi and Hatch, 2018). This situation makes EDH live in a constant status of deficit, surviving out of government subsidies that can reach up to 4% of the national budget, threatening Haiti's fiscal stability.

A utility with fiscal deficit and distribution losses poses many problems in the extension of electrification. There are not enough funds to comply with the investments required, both at a utility and government level, and waiting times are too long considering the urgency of electricity access in a country like Haiti. This is why in many countries where this situation is present, private investment steps in as a more viable alternative (Lacey, 2020). Currently, there are many private initiatives carried out in Haiti by both profit and non-profit organizations, such as Earthspark, NRECA International NRG and Sigora International.

3.1.2.2 Issues with Diesel Dependency

The increasing reliance on diesel is also very dangerous for Haiti, not only because of the volatility associated with fluctuating prices and exchange rates or the high government spending in imports and logistics, but also because the country is facing a big fuel crisis.

For more than a decade, Petrocaribe, an program created by Hugo Chávez in Venezuela, guaranteed a stable oil flow to 18 countries in Central America and the Caribbean, allowing them to buy the fuel at preferential payment terms. This easy access to oil made Haiti dangerously dependent on it. In 2012, Venezuelan oil covered nearly 70% of Haiti's needs. Additionally, in 2010 Haiti halted the automatic adjustment mechanism of fuel products the country had since 1995 due to the humanitarian crisis that rose after the earthquake, fixing prices in local currencies to help reconstruct the country. However, eventually this fixed price did not cover the charges and fees to suppliers and the burden fell on the government (IMF, 2020). When Venezuela's economic situation started to deteriorate, oil production decreased substantially, and finally in early 2018, the country announced the indefinite suspension of fuel exports to several Petrocaribe nations, including Haiti (Rauls, 2019).

This unfortunate event paired up with an agreement reached by Haiti and the International Monetary Fund (IMF) in mid-2018, in which the latter promised a loan package in aid of the country's heavy debt burden, in exchange for a gradual reduction of energy subsidies.

This caused an initial spike of 48% in diesel that enraged the Haitian population, causing thousands of people to go out on the streets protesting (Brice and Orlofsky, 2018). In addition, given the fuel shortage from the fall of Petrocaribe, Haiti has been forced to turn to the global market in search of supply at notably higher prices, which has made the country fall into further debt (Perry, 2019).

This is a grim panorama that has divided international opinions. Some say that the subsidy removal policy have made Haiti accommodate to foreign priorities to the detriment of its own population; that subsidies amounted to just 2.2% of the country's GDP; and that it provided a key help to the population, specially after all the natural disasters the country has faced (Perry, 2019). Others claim that a loan such as the one to be granted by the IMF is more urgent than ever, after the accumulated debt the government has acquired with alternative oil providers. The IMF states that the actual losses related to fuel subsidies due to resource misallocation, opportunity costs of displaced productive spending and other externalities reach almost 4.7% of Haiti's GDP (IMF, 2020). Some institutions hold on to the idea that the only way to solve the situation is to do a deep energy sector reform. Continuing with the status quo of energy subsidies would ultimately deepen the country's reliance on fossil fuels instead of promoting a more sustainable shift and it will ultimately lead to higher deficits and public debt (IMF, 2020).

3.1.2.3 Renewables and Off-Grid Energy as Possible Solutions

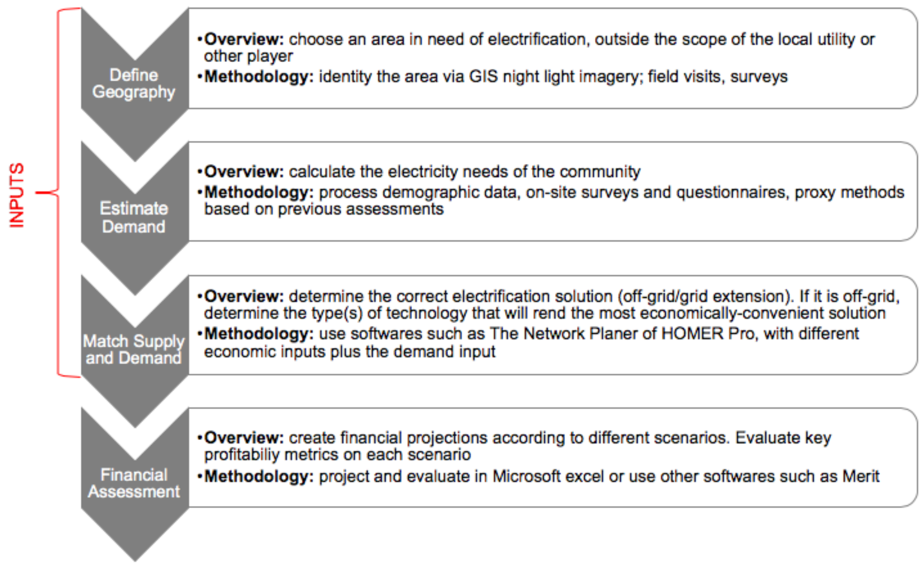
Given the aforementioned facts, Haiti is in a complicated situation regarding its electricity sector. First of all, EDH is seen internationally as inefficient financially and operationally and therefore difficult to work with; secondly, the political instability in the country makes it hard for corrective measures to materialize; thirdly, there is a significant lack of coordination between the main actors in the electricity scope, partly because of differences in aims and interests (Stuebi and Hatch, 2018). This is also why international companies that have been engaging in the electricity business in Haiti have preferred to develop independent off-grid solutions, instead of collaborating with the national utility. Finally, the country's relative isolation as well as domestic barriers, such as high import tariffs and VAT, and difficulties in financing access makes it difficult for private initiatives to grow.

However, all the aforementioned issues, particularly those revolving around diesel, plus the country's mountainous topography, make off-grid renewable energy projects practically the only feasible way of tackling rural electrification problems in Haiti. Some former Petrocaribe countries such as the Dominican Republic have been able to escape from its curse by shifting and investing in renewable energy. This is very complicated for Haiti due to its political situation and high debt, however, there are several global initiatives, such as the World Bank's Off Grid Electricity Fund that has already had some impact in diversifying Haiti's energy mix (Rauls, 2019). In addition, there are several funding opportunities, such as the Green Climate Fund (GCF), that boost international private companies to contribute with RES hybrid MGs in the country. Indeed, due to the increase expenditures by unserved population in alternative fuels, there is an opportunity of setting up RES MG projects and sell electricity at a higher rate that will both allow the private company to recover its investment and make newly electrified people save money. As of now, the regulator is not putting a cap in the tariffs to be charged by players that venture in this type of business, therefore a developer can come up with a particular tariff and have the approval of the regulator. This is a positive aspect given that it allows private operators to set their own tariffs, which are generally affordable for the population in question and at the same time let the company recover its investment, as proven by the successful cases of Sigora and Earthspark.

4 Multi-Stage Model

This chapter develops the multi-stage framework that will provide the inputs for the financial model. The first section is dedicated to the geographical selection of the particular village in which the hypothetical project would be developed. The second section describes the demand-side analysis methodology in which the demand of the village is estimated. The third and final section talks about the supply-side analysis in which the best options of MG design will be obtained. A diagram can be seen in figure 4.1 that depicts the whole process' structure.

Figure 4.1: Multi-Stage Process Diagram



4.1 Village Selection: Anse Rouge

To choose a particular location within Haiti, a study by the United States Trade and Development Agency was reviewed, which carries out a detailed analysis of 89 rural towns and their suitability for MG development. The team executed field visits and surveys on economic activities, political will, energy demand, infrastructure and strength of civic organizations for several months in 2015. The study ranks the towns using two methodologies. For this research, the second methodology was considered, which consisted in assigning scores for each town depending on four categories: (i) weekly business energy expenditures, (ii) total weekly energy expenditures and fuel consumption, (iii) economic and energy potential, and (iv) ease of access and flood risk.

For the purpose of this thesis, all the analyzed towns were reviewed and filtered according to a particular criteria. A town would be considered for the scope of this study if: (i) there was no current presence of EDH or another independent power producer, (ii) it was not located in an area where EDH or other MG operators had future plans, (iii) had good prospects of economic activity, (iv) had relatively easy access.

From this narrow-down, 30 suitable owns were filtered, with the final choice being the town of Anse-Rouge, located in the department of l'Artibonite. According to United States Trade and Development Agency, Anse Rouge possesses about 40,000 inhabitants and its main economic activities are salt mining and agriculture. Additionally, the study asserts that most businesses have their own generators and solar panels, indicating an existing demand for energy in the business sector. It already counts with the presence of a non-functional brownfield MG managed by the major's office, indicating the existence of some infrastructure.

4.2 Demand-Side Analysis

In this study, demand was derived through a two-step grouping approach. The first step consisted in analyzing the town through spatial analysis using GIS data, in which an overall number of people and buildings were obtained. In the second step, the Survey of Mortality, Morbidity and Service Utilization (EMMUS from its acronym in French) was analyzed, with the purpose of obtaining a further sociodemographic characterization of the area. In the next sections the methodology through which the demand estimate for the village was obtained will be described, along with the databases used and the subsequent results.

4.2.1 Step 1: Spatial Analysis

4.2.1.1 Methodology

To get a clearer idea of the village's demand, it is crucial to know how many potential connections there are and which are the main prospective consumers. To derive this, a simple spatial analysis was carried out using GIS in order to obtain the population and number and type of building. GIS is a framework used to gather, manage and analyze data, integrating several types of information in the form of layers. There are many publicly available GIS datasets that include a wide range of information such as administrative borders, topography, infrastructure, sociodemographics and natural resources. For this study, several open-access databases where used which will be explained in the next paragraph. In the absence of the possibility of doing a field visit to the area of interest or of having reliable and relevant survey data, GIS mapping is a very handy tool that allows us to navigate geographical information and obtain relevant data without moving from our current location.

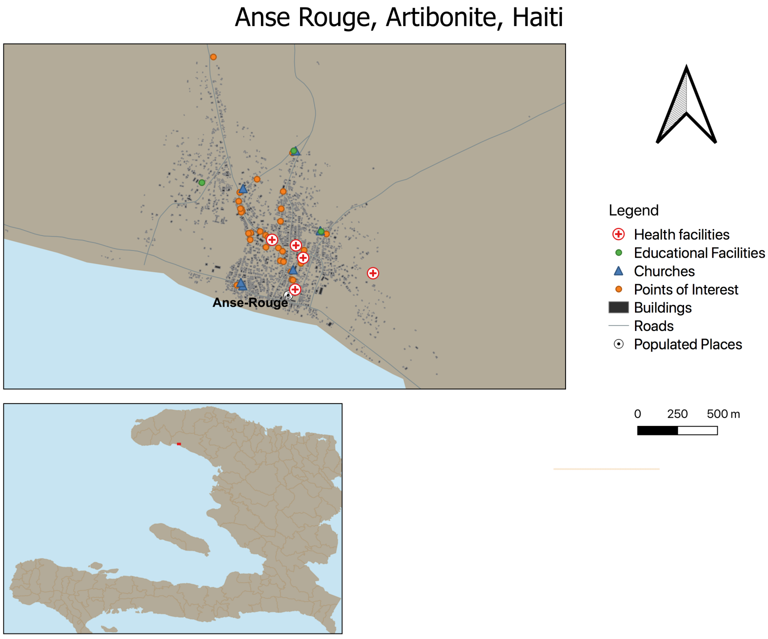
4.2.1.2 Database Description

The main database used for this analysis was obtained from OpenStreetMap, a large repository project of worldwide open geospatial data organized per country and per region and normally updated on a daily basis (Korkovelos et al., 2019). The database section for Haiti and the Dominican Republic included a wide variety of different geographic and infrastructure information. For the purpose of this study, layers that showed the different towns and their population, buildings and places of interest were used. Additionally, GIS databases provided publicly by the United Nations Stabilization Mission in Haiti, which included Haiti's administrative divisions and educational and health facilities, were brought into play.

4.2.1.3 Results and Limitations

According to the spatial analysis, the town of Anse Rouge has a total of 39,500 inhabitants and 2,499 potential number of buildings to be connected to a MG. Among these buildings, there are Non-Government Organizations (NGOs) or socially-oriented cooperatives, bars and restaurants, churches, beauty salons, shops, drinking water sources, fountains, and health and education facilities. The map obtained in this analysis can be seen in figure 4.2. A detailed table and map with the identified buildings can be found in Appendix A2. According to United States Trade and Development Agency the clinic, the churches, the morgue, an Oxfam shop (see Appendix A2) and the hotel/restaurant are the main energy consumers.

Figure 4.2: Map of Anse Rouge using GIS data



Note: "Points of Interest" includes all categories of buildings which are not health and educational facilities and churches

It is important to understand that even though GIS data is very exhaustive, it is likely that not all buildings are completely identified and categorized. For instance, doing a simple search in Google Maps for Anse Rouge, a gas station was identified, which was not present in any of the OpenStreetMap databases. The morgue and the Oxfam presence identified by United States Trade and Development Agency was also not present in the GIS databases used. For simplification, only the buildings outlined in the GIS databases were used, with the inclusion of Oxfam.

4.2.2 Step 2: Demographic Survey Analysis

The objective of carrying out this analysis is to have an idea of the living conditions and demographic characteristics of the population of Anse Rouge. The ultimate goal is to find ratios and percentages in order to be able to group the population more accurately in demand categories according to sociodemographic indicators. The neoclassical theory suggests that the primary economic variables to determine the demand for any good or service are household preferences, price of the good or service and income (Louw et al., 2008). It is believed, therefore, that having a good idea of the sociodemographics of the village will provide a rational way to group its inhabitants into different demand levels.

4.2.2.1 Database Description

The EMMUS is a survey designed to provide information on several health-related and demographic matters. The sixth version was carried out between 2016 and 2017 by the Haitian Institut of Childhood in collaboration with the Haitian Institute of Statistics and Informatics and the Demographic and Health Survey Program. For its sampling, the EMMUS targets the population of individuals that live in households throughout the whole country. 13,405 households were interviewed out of an initial selection of 13,546. The sample was stratified in order to have enough representation of urban and rural locations, as well as of the 10 Haitian departments and the metropolitan area of Port-au-Prince. The sampling is done in two stages: first, 450 enumeration areas, defined in the 2003 general census, were taken. After mapping the different households in each enumeration area, a second stage sampling process is performed in which households are selected randomly.

4.2.2.2 Methodology

The survey data was analyzed using SVY commands in the software Stata to account for the design in complex survey data. As Anse Rouge is located in Artibonite and is considered a rural settlement, a subpopulation accounting for the rural population living in this department was created. Out of the total sample of 13,405, 1,164 houses corresponded to rural households in Artibonite. The first variable analyzed was the wealth index separated for urban and rural locations. This indicator is separated in quintiles: poorest, poorer, middle, richer and richest, which had a concentration of 23.16%, 25.3%, 20.55%, 19.16% and 11.94%, respectively. Secondly, the ownership of electrical appliances was addressed and it was surprisingly low. Only 8% of the respondents in rural Artibonite declared to have access to electricity, 33.0% of them had a radio, 6.5% a television, 1.2% a refrigerator, 0.5% a land-in telephone and 0.6% a computer. This indicates that the household level of electricity demand is probably very low, which can be attributed to the small number of people with electricity access. Furthermore, 98% of the rural Artibonite population uses rudimentary fuels such as coal and wood for cooking. The exploration of this variables in a subpopulation that can be coherently extrapolated to the selected village provides a clearer idea about the potential electricity demand.

4.2.3 Result: Demand Estimation

To derive demand, the first step was to carry out a residential (household) approach, aggregating from a per capita level data. According to the World Bank, the per capita yearly electric power consumption in Haiti, as of 2014, was 39.0 kWh (The World Bank). The total population of Anse Rouge was classified according to the wealth quintile percentages of rural Artibonite. The average yearly consumption per capita was assigned to the "middle" quintile, the "poorer" and "richer" quintiles' consumption was scaled down and up in 20%, respectively, while for the "poorest" and "richest" quintiles it was scaled down/up in 50%. With this, a total residential demand of 1,437.32 MWh per year was derived. The numbers assigned can be observed in figure 4.3

Figure 4.3: Residential Demand Approximation by Wealth Quintile

Number of inhabitants	#	39,500	*Source: GIS*
Electricity consumption per cápita	*kWh/year*	**39.0**	*Source: World Bank*

Wealth Index *(source: EMMUS2016/17)*		People per strata	Per capita electricity demand per strata	Total electricity demand per strata
		#	*kWh/year*	*kWh/year*
Poorest	23.2%	9,148.2	19.5	178,600.3
Poorer	25.2%	9,954.0	31.2	310,931.1
Middle	20.6%	8,117.3	**39.0**	316,946.1
Richer	19.2%	7,568.2	46.9	354,609.5
Richest	11.9%	4,716.3	58.6	276,229.0
TOTAL RESIDENTIAL DEMAND				**1,437,316.1**

Secondly, all the "productive" electricity requirements were obtained based on the approach taken by Blum et al. (2013), in which appliances per business/institution were recorded. As the study did not have exactly the same businesses as the ones identified for Anse Rouge, some new assumptions were taken, mostly based in the appliance consumption defined by Blum et al. with the exception of two types: NGOs and cooperatives, for which a new assumption was developed, and the clinic, for which the assumption by Parshall et al. (2009) was taken. A more detailed outline of these assumptions can be found in Appendix A3. The total productive electricity requirements totalled to 44.6 MWh/year. Therefore, the total estimated demand of Anse Rouge resulted in 4,060 kWh/day or 1,481.9 MWh/year.

Figure 4.4: Non-Residential Demand Approximation

Building Type	Quantity	Electricity demand per building	Total Electricity Demand
	#	kWh/year	kWh/year
NGOs	3	500.00	1,500.0
Churches	6	766.50	4,599.0
Schools	3	3001.76	9,005.3
Hospital	2	3474.98	6,950.0
Pharmacy	2	73.00	146.0
Clinic	1	360.00	360.0
Bar	3	985.50	2,956.5
Hotel/Restaurant	1	1693.60	1,693.6
Beauty Shop	2	620.50	1,241.0
Beverage Shop	3	949.00	2,847.0
Convenience Stores	13	949.00	12,337.0
Drinking water sources	5	73.00	365.0
Fountain	2	192.24	384.5
Water well	1	192.24	192.2
TOTAL NON-RESIDENTIAL DEMAND			**44,577.1**

4.3 Supply Side Analysis

4.3.1 Methodology

Once the demand estimation is obtained, the supply system for the village in question can be properly built taking into account all the inputs derived. For this, the software HOMER Pro was used. Hybrid Optimization Model for Electric Renewables (HOMER) is a software, originally developed by the National Renewable Energy Laboratory, that allows to simulate a viable system for all possible designs or technology combinations depending on the inputs, such as geographic location, load, nominal discount rate, fuel price, and costs in general.

The location was set to Anse Rouge, Haiti, the life of the project to 25 years, the daily demand to the number obtained in the previous subsection (4,059.9 kWh/day), the nominal interest rate of 10% and the inflation rate to 1.8% [3]. Additionally, a base diesel price in USD/liter based also on the World Bank database for the year 2016, scaled up to account for remoteness and diesel issues. The scaling was done in 45% as per Schmid and Hoffmann (2004), given the remoteness of the village and its difficult access and also due to the issues regarding diesel availability. This is also more realistic considering the diesel subsidy situation in Haiti and the intentions of removing them. The last time this

[3] The value of the US dollar inflation for 2018 (The World Bank).

was attempted diesel price increased in around 50%, therefore if its not for the town's remoteness, the price markup will be for subsidy adjustments, or a mix of both. Apart of the selection of PV technology, the option of including both a generator and lithium-ion batteries were considered for this analysis.

4.3.2 Results: Microgrid Design Options

In this paragraph the results of the HOMER Pro estimation will be discussed. It is important to note that even though HOMER Pro already provides a financial analysis with present value and return metrics, for the purpose of this thesis, only the data on CAPEX and replacement costs will be taken from the software. The reason behind this is that HOMER Pro's software has tweaking limitations. For instance, it offers the possibility of doing a sensibility analysis in several of the variables but this is only for the first year of evaluation, for the rest it is assumed to be constant, therefore it was preferred to perform a separate financial analysis with more detailed projections. The results in HOMER Pro provided the most cost-effective MG design in terms of net present cost. For the inputs used, the software concluded that the most cost-effective solution is the hybrid MG design that mixes PV, batteries and a diesel genset closely followed by the 100% renewable MG composed only by PV and batteries. The option of a 100% diesel MG was the most expensive alternative, doubling the net present cost of the first two.

Table 4.1: Net Present Cost per Alternative (HOMER Pro)

Alternative	Net Present Cost
MIX	$ 6.58 M
100RE	$ 6.63 M
100DIESEL	$ 11.5 M

The first two designs will be financially analyzed in the next chapters, under the names "100RE" and "MIX", respectively. The 100% diesel alternative was left behind given that this study plans only to assess hybrid MG designs. It is important to note that for the "MIX" alternative, the base load had to be scaled up in 5% (4263 kWh/day), given that the electricity production was too low and it would have posed problems when considering a system degradation rate and a scenario of demand increase in the financial model. However, even though this option was scaled up and therefore its cost increased, it remained the cheapest option. A summary of the HOMER Pro results can be seen in figure 4.5.

Figure 4.5: Homer Pro Outputs for Financial Model

Data for Anse Rouge Microgrid

	Unit	100RE	MIX
CAPEX			
Battery	USD	1,589,075	1,031,733
PV	USD	2,883,053	1,855,109
Diesel genset	USD	-	440,000
System converter	USD	206,274	101,104
TOTAL SYSTEM	**USD**	**4,678,402**	**3,427,946**
Salvage Costs			
Battery	USD	529,692	343,911
PV	USD	-	-
Diesel genset	USD	-	133,324
System converter	USD	68,758	33,701
TOTAL SYSTEM	**USD**	**598,450**	**510,936**
Useful life			
Battery	Years	15	15
PV	Years	25	25
Diesel genset	Years	-	15
System converter	Years	15	15
Replacement costs			
Battery	USD	1,589,075	1,031,733
PV	USD	-	-
Diesel genset	USD	-	440,000
System converter	USD	206,274	101,104
TOTAL	**USD**	**1,795,349**	**1,572,837**
OPEX (O&M)			
Battery	USD	31,096	19,712
PV	USD	9,610	6,184
Diesel genset	USD	-	26,175
TOTAL SYSTEM	**USD**	**40,706**	**52,071**
Fuel costs			
Diesel genset	**USD**	**-**	**133,324**
Price	$/L	0.899	0.899
Cons	L/year	-	148,303
Electricity production			
PV	kWh/year	1,861,799	1,197,980
Diesel genset	kWh/year	-	565,472
TOTAL SYSTEM	**kWh/year**	**1,861,799**	**1,763,452**

5 Financial Model

This chapter will refer to the overall profitability assessment of the microgrid project (and different alternatives) proposed for Anse Rouge. Convenience and profitability of a project of this type is measured according to the views of lenders and equity sponsors, the first through the compliance of certain debt covenant ratios, and the second, through the evaluation of the project's equity IRR. As mentioned in chapter three, in the case of developing a project in Haiti, tariffs are set by the developer according to what seems suitable and then they need the green light of the regulator. Therefore, the objective of the financial model will be to find a tariff per kWh that would comply with both the debt and the equityholder requirements under different capital structures.

For the elaboration of this model, financial projections for the whole lifetime of the projects were constructed based on several assumptions that will be discussed throughout the chapter. In order to have a comprehensive understanding of the environment in which this model is embedded and get accurate assumptions, an extensive analysis of renewable energy financing was carried out. Some assumptions were also based on the funding proposal package for the GCF drafted by Earthspark, as well as on informal conversations with incumbent players. The chapter will be divided in several sections discussing the assumptions taken for the different parts of the model.

5.1 General Assumptions

In the hypothetical situation built around this study, the company looking at this model is an international private company based in a developed country. Additionally, it is presupposed that this company it is small-to-medium-sized and that its only business is the development of MG projects in Haiti or other underdeveloped economies. It was preferred to consider a smaller non-diversified company to set a precedent if the profitability assessment is positive. If this is the case for a company as such, with a riskier profile, then it would with a higher probability, be a worthwhile venture for any other larger company. The model was carried out in US dollars (USD), for simplicity reasons, given that it was easier to account for the risks of the country in the discount rate. The life of the project was set to 25 years, as mentioned in the previous chapter, among which one year corresponds to construction and set up (2020) and the rest to operations (2021 to 2045).

5.2 Operations

5.2.1 Revenues

The revenues depend on the electricity sold, which is equivalent to the demand, and the tariff charged per kWh. As the latter is an output of the model, in this subsection the assumptions surrounding the electricity demand are discussed. Nevertheless, there are two main assumptions that should be made at the tariff level ex-ante, these are the escalation rate and the payment collection. As tariffs are denominated in USD, the growth was set as the last reported USD inflation number (1.8%). As discussed in chapter two and as per our conversation with incumbent companies, our prototype project adopts a PAYG system to recollect payments, this prevents late payments and losses and guarantees a stabler and more predictable inflow for revenues.

5.2.1.1 Electricity Demand

The electricity sold will be equal to the electricity demanded. The initial demand, as detailed in the previous chapter, was set at 1,481,893 kWh/year[4]. As seen in the literature review, there is evidence that this demand can either grow once an unserved community is electrified, or remain flat. According to conversations with incumbents, demand will always tends to grow. However, this also depends on several actions taken from the beginning of the process. In light of this, three scenarios were considered:

- **Flat:** a pessimistic scenario where demand keeps constant during all the life of the project
- **Mid:** demand grows 0.17% per year
- **High:** demand grows 0.34% per year

It is also important to determine if the production capacity of the MG will satisfy the growing demand, taking into account the degradation rate. A degradation rate of 0.6%

[4]From 4,060 kWh/day.

was presumed for the 100RE case, as per the comparative study of both technologies by Baurzhan and Jenkins (2017), while for the MIX case said rate was taken as 0.8%. Normally, the MG should have a certain level of looseness between the amount demanded and the electricity produced.

5.2.2 Costs

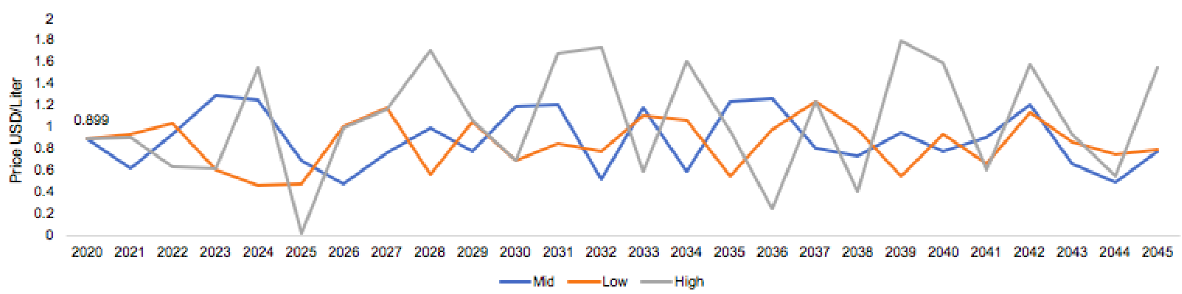
5.2.2.1 Operation and Maintenance

O&M costs were taken from HOMER Pro software. The result obtained were used for the first operating year and a ratio O&M to electricity sold was determined. For the subsequent years, the ratio was kept constant, and this determined the O&M expenses for future periods. In addition, administrative costs of 20,000 US$ per year were incorporated, which correspond to regular incurring costs such as salaries of personnel. Like the tariffs, the number was scaled up according to inflation.

5.2.2.2 Fuel Costs

For the MIX alternative, fuel costs and the uncertainties that come within must be taken into account. From HOMER Pro the level of fuel used in the first operating year was obtained, according to the price (US$ 0.9/liter), which was used as an input. For the subsequent years, the price of diesel will fluctuate according to a randomly generated number, accounting for the unpredictability of the diesel prices. Three different random paths are considered, with medium, low and high levels of fluctuation. However, there is no particular tendency for each case. Figure 5.1 shows a line graph of the diesel price under the three aforementioned cases.

Figure 5.1: Projection of Diesel Price Fluctuation



5.2.3 Working Capital

For this item assumptions were simplified. As the collection of tariffs uses a PAYG system, collection days [5] was set at zero, while for accounts payables days a common rate of 15 days was assumed. Even though normally companies exhibit a higher level of accounts payables days, as this is supposed to be a smaller company as an investor, with not so much collateral or track record, it is more reasonable to keep the number down.

5.3 Uses of Funds, Property, Plant and Equipment and Depreciation

Uses of funds correspond to all the expenses the project needs to do in the construction period. They are composed by construction costs, interest accrued during construction (IDC) and financing fees. Uses of funds will then be capitalized and registered in the balance sheet as property, plant and equipment (PP&E).

5.3.1 Construction Costs

Construction costs are the main component of a project's uses of funds. This is composed by the capital expenditures, obtained from the HOMER Pro results detailed in the last chapter, and one-time development costs. A summary of the different components for each alternative can be seen below:

Table 5.1: Capital Costs in USD

	100RE	**MIX**
Battery	1,589,75	1,031,733
PV Panels	2,883,053	1,855,109
Diesel Genset	-	440,000
System Converter	206,274	101,104

For this project, grant financing from either the Government of Haiti (GoH) or a private institution will be taken as auxiliary financing. The amount of grant is recorded as a percentage of the capital costs corresponding to the one obtained by Earthspark as per

[5] Or accounts receivables days.

the aforementioned GCF application (15% of the capital costs). The grants, therefore, serves as a "capital income", reducing the CAPEX amount and alleviating this cost item.

The development costs correspond to expenses related to the development of the project, such as capacity building for employees, building energy literacy among the community, and the promotion of additional productive uses of electricity. All these are in hope that the community will adopt the electricity access well and demand will eventually grow. Development costs were calculated according to Earthspark's application to the GCF. Each type of cost was calculated as a percentage of CAPEX. As the numbers for CAPEX for our system in question were already obtained, the different costs were derived according to the aforementioned percentages. The detail for Earthspark's costs can be seen in table 5.2. Taking these numbers into account, the development cost for the 100RE and MIX cases are US$ 224,582 and US$ 173,483, respectively.

Table 5.2: Earthspark's One-Time Additional Operating Expenses

Cost Category	**Amount (US$)**	**% of CAPEX**
CAPEX	40,639,019	100%
Employee building capacity	268,823	0.66%
Energy literacy for the community	824,992	2.03%
Promotion of productive uses of energy	316,001	0.78%
Total development costs	1,409,816	3.47%

5.3.2 Interest During Construction and Financing Costs

The remaining components of the uses of funds are IDC and financing fees. IDC are the interests incurred from the construction loan that are not paid given that there is no cash flow. Therefore, they are capitalized into PP&E instead. Financing costs are the fees charged by banks in order to provide the debt, which are also capitalized. In this model, financing fees are assumed to be 1% of the acquired debt. As both are calculated according to the final amount of debt acquired, they are determined after assessing the debt sizing.

5.3.3 Depreciation and Tax Advantages

Depreciation will be assumed to be straight-line and equal along the years of operation. The useful life of each asset was determined in HOMER Pro by looking at the year in which replacement CAPEX was incurred. In the end of the project's life, some assets are re-sold. According to Haiti's Center of Facilitation of Investments (CFI) website, the Haitian Investment Code provides several tax advantages, such as tax exemption for a period of maximum of 15 years and attractive schemes of accelerated depreciation. However, only certain industries are eligible and renewable energy is not on the list. In conversations with incumbent players this was confirmed, therefore there are no tax advantages or accelerated depreciation considered in this model.

5.4 Sources of Funds (Capital Structure)

This subsection refers to the funding of the uses of funds previously described. The first step is to size the debt, which was done according to the minimum Debt Service Coverage Ratio (DSCR) required by the lenders and the operational cash flow available for debt payment on each period (commonly known as Cash Available for Debt Service or CFADS). The formula of DSCR can be seen below, and the idea is for it to be 1.0x at an extreme minimum, however, lenders generally ask for some looseness in the threshold, depending on the industry, the business and the risks. Thus, the number used in this case was 1.3x.

$$DSCR = CFADS_t/(K_t + I_t) \tag{5.1}$$

$\mathrm{CFADS_t}$ is the CFADS in period t, $\mathrm{K_t}$ is payment of debt principal in period t and $\mathrm{I_t}$ is payment of interests in year t. From the operating profit CFADS was obtained, which corresponds to the earnings before interest, tax, depreciation and amortization (EBITDA), plus the changes in working capital and minus the tax expenses. From this formula we can obtain the maximum debt service that the operational cash flows can handle for each period, and its present value sets the maximum amount of debt the project can incur in (sculpted debt).

The second step is to compare this maximum debt capacity with the construction costs. When doing this, circularities appear in the model, given that the final debt amount required will be the one setting the rest of the components of the uses of funds (financing costs and IDC), and these will, at the same time, be funded by debt and determine the final amount incurred. These circularities are dealt with through iterative macros that will loop a copy paste operation until the amounts converge.

It is important to note that sometimes the maximum debt can result in a percentage of the uses of funds which would not be reasonable, therefore, there is generally a maximum leverage set as a percentage of the total uses of funds. A default maximum leverage 80% was set, given that we believe that a further leverage would damage the bankruptcy risks of the company. However, for the purpose of this study, several options for maximum leverage were tested. The remaining percentage of uses of funds will be covered by equity.

5.5 Debt Schedule

In the previous section the construction debt was defined. This loan will normally have a higher rate due to the higher risks of the construction period and when operations start, it is refinanced to a term loan with a lower interest rate. In our model, the term loan will be paid in yearly, depending on the cash available for principal payments (maximum debt service minus interest payments), with a maximum tenor of 18 years and a grace period of three years.

Both loans' interest rates are evaluated according to three different scenarios in order to stress or relieve the model. The logic is the following: Haiti's nominal lending rate is approximately 13.8% (The World Bank). However, preferential terms are supposed due to the benefits of the use of renewable energy. This is exhibited in Earthspark's application for the GCF in which the senior loan rate is set to 7%, despite of the high lending rate for the country. Therefore, 13% is considered to be the high and 7% the low scenarios. A value of 10%, as a midpoint, is considered as the base case scenario.

- **Low:** 7%, senior loan rate for Earthspark in its application for the GCF
- **Mid:** 10%, mid-point between high and low
- **High:** 13% an optimistic value based on the lending rate for Haiti in 2019

5.6 Maintenance Reserve Account

As seen on the previous chapter, HOMER Pro indicated that each of the alternatives required a maintenance capital expenditure in order to replace one or more of its parts. A summary of this can be seen in the table below:

Table 5.3: Replacement Costs in USD

Alternative	Component	Total Cost	Timing
100RE	Battery, converter	1,795,394	year 15
MIX	Battery, converter, genset	1,572,837	year 15

For this purpose, a Maintenance Reserve Account (MRA) was built, in order to set aside some of the operational revenues for the time when the maintenance capex expense is needed. The MRA was constructed from the cash available after debt principal and interest payments, and it was built up in equal percentages per year until reaching a 100% of the money needed one year before the expense was scheduled (year 14).

5.7 Dividends, Debt Ratios and Equity Internal Rate of Return

Dividends will finally be the cash flows that equityholders will receive in exchange of their initial contribution. Equity has the lowest priority in the cash flow waterfall, therefore, dividends are only paid if there is enough cash flow after debt interest and principal payments and MRA movements, or if there are is enough retained earning balance. Dividends will also be blocked if the debt service coverage ratio is under the level established by lenders, given that all the remaining cash and retained earnings should serve as a cushion for debt, which has higher priority. Additionally, in the end of the project, all remaining retained cash and earnings will be paid to equityholders as a dissolution dividend. Finally, the total dividends paid, including the dissolution dividend, will determine the equity sponsor inflows, which compared to the equity contribution in the construction period will determine the equity IRR of the project to be contrasted with the cost of equity discussed below.

5.8 Cost of Equity

The cost of equity determined in this section will ultimately correspond to the equity sponsors' minimum rate of return. We used Damodaran's variation of the CAPM model (Damodaran, 2003). The formula can be seen below:

$$k_e = r_f + \beta MMERP + \lambda CRP \tag{5.2}$$

Where r_f is the relevant risk-free rate; β corresponds to the levered beta, which measures the exposure to market risk; MMERP is a mature market risk premium; λ is the company's exposure to country risk and CRP is the country risk premium. The 10-year US-treasury bond yield (0.7%) (US Department of Treasury, 2020) was used as risk-free rate, Damodaran's unlevered beta calculation for the green and renewable energy industry (0.58) was used as β (Damodaran, 2020a) which then was re-levered using the capital structure of the hypothetical developer. The mature market equity risk premium (MMERP) was assumed as 6.01% as per Damodaran (Damodaran, 2020b). λ was simplified according to a study by Abuaf (2015), which catalogues the factor in three values, 0.35, 0.7 and 1.0, "low," "medium," and "high" exposure to country risk, respectively. It is believed that the project would have an overall mid-to-high exposure to country risk, however, for conservative reasons, the higher λ was initially chosen. Finally, the country risk premium (CRP) was also obtained from Damodaran's exhaustive country-per-country analysis of equity risk premiums (Damodaran, 2020b).

As it was mentioned, several financial structures were in this assessment, which ultimately affect the levered beta. As this indicator takes into account the risk that a firm acquires depending on its capital structure, a higher leverage will increase the levered beta and thus the minimum cost of equity required. This sets a trade-off in terms of maximum leverage, given that a higher leverage is good for equityholders, but at the same time it increases the risk of the company, and therefore the minimum required IRR, which makes the project less likely to be profitable.

6 Analysis and Discussion

In this chapter, the financial analysis for each of the microgrid designs previously described is performed. As mentioned in the last section, the analysis tries different capital structures and finds a tariff per kWh for which both the lender's covenants and the minimum rate of return for the equity sponsors comply. The value of the market variables was separated in three cases: Base, Upside and Downside, and for each case different maximum leverage allowances were imposed: 75%, 80% and 85%. The idea is to see the impacts in price of the trade off between increasing leverage and minimum equity IRR. The base case would be one with mid-level variables, in which a good result in the development activities for demand growth are presumed, along with a medium fluctuation in diesel prices and that the construction debt will be able to be refinanced at a cheaper term loan. The upside case assumes a very positive effect of the development activities, translating in a higher increase in demand, a low fluctuation in fuel prices and lower interest rates for both loans. The downside case assumes that the demand remains flat, therefore that no additional productive uses of electricity have proliferated, a high level of fluctuation in diesel prices and a scenario in which the construction loan was not refinanced, therefore the loan is being paid at the same rate fixed during construction. The value of the different variables for each scenario can be seen in the following tables:

Table 6.1: Base Case Variable Values

Variable	**Scenario**	**Value**
Escalation rate (tariffs & costs)	Mid	0.17% per year
Fuel costs escalation rate	Mid	-
Term loan interest rate	Mid	10.0%
Construction loan interest rate	high	13.0%

Table 6.2: Upside Case Variable Values

Variable	**Scenario**	**Value**
Escalation rate (tariffs & costs)	High	0.35% per year
Fuel costs escalation rate	Low	-
Term loan interest rate	Low	7.0%
Construction loan interest rate	Mid	10.0%

Table 6.3: Downside Case Variable Values

Variable	Scenario	Value
Escalation rate (tariffs & costs)	Flat	0% per year
Fuel costs escalation rate	High	-
Term loan interest rate	High	13.0%
Construction loan interest rate	high	13.0%

The first section in the chapter will discuss some information about tariffs. The second section will talk about the results obtained from the evaluation of the different alternatives and will include a discussion about these results. A third section will refer to the limitations of this thesis.

6.1 Tariffs

In order to put the reader in context, it is important to refer to the different tariffs observed in the analyzed environment, both at a utility level and from other incumbents. According to conversations with current players in the country, tariffs until now were set by them, as there is no clear regulation in the matter. The regulator, ANARSE, started working officially around 2018 and developers basically need to present their tariffs and get a green light from them. These negotiations have been turning more difficult with time, and there are thoughts that a maximum tariff will be established in the near future. Nevertheless, the GoH is aware of the good effects that these projects bring to the population, therefore it is believed that it would not necessarily turn into a major problem.

Stuebi and Hatch (2018) state that Haiti's electricity rates at the public utility level ranged from US$ 0.25 to 0.40 per kWh in 2015, depending on the client type (residential, commercial or industrial), although with the recent Haitian Gourde (HTG) depreciation these levels have gone down considerably. The author, analyzing electricity bills from 2017, concludes that tariff levels in said year reached US$ 0.15 - 0.25 per kWh, with a residential average tariff in relation to kWh consumed of US$ 0.185 per kWh and a midpoint of US$ 0.20 per kWh. These tariffs are significantly low and have made the public utility have continuous losses with the need of a financial bailout from the government. In turn, this suggests that in no way this is an appropriate price level to cover for the reasonable needs of the company, therefore, utility tariffs are not a good parameter for our tariffs.

Tariffs charged by the different incumbent players are undisclosed. However, in an informal conversation with one of them, it was hinted that tariffs averaged US$ 0.9 per kWh [6]. Charging this level of tariffs is quite challenging, as the clients are aware of how low their urban counterparts pay through EDH tariffs, thus it requires a lot of education to the community to make them understand the reason of this difference. Nevertheless, incumbents say that people can afford these prices given that their consumption is, in general, very low, and that the fact that in the absence of these projects they would have to buy more expensive alternatives. The savings they get from not spending on these alternatives can range from 50% to up to 80% depending on the service (phone charging, light bulbs, refrigeration, etc.) (Stuebi and Hatch, 2018) (Lucky et al., 2014)

Another challenging point is the fact that these tariffs are thought of in US dollars, which complicates things when considering the strong HTG depreciation tendency. Likewise, if tariffs were considered in HTG, the significant inflation observed in the recent years in Haiti would also imply an important yearly increase. This must be part of the education that has to be provided to the community, as they must understand that electricity is a product and just like all the others, and that its price increases in the same way.

6.2 Results

In this section the different results for each of the alternatives will be discussed, according to the different levels of maximum leverage and the aforementioned market cases. The tariffs will be presented in sensitivity tables, in which the different tariffs for the different cases will be exhibited in relation to different minimum IRRs calculated. The highest minimum IRR corresponds to the one in which the exposure to country risk is 100% (high), on the contrary, the lowest corresponds to the one in which the exposure to country risk is 70% (mid). There is an additional minimum IRR considered which is the mid point between the two aforementioned rates.

The results for the 100RE can be seen in table 6.4. The tariffs ranged from US$ 0.53 and US$ 0.72 per kWh, depending on the capital structure and the market case.

[6] They charge differentiated tariffs for daytime or nighttime, around US$ 0.8/kWh and US$ 1/kWh, respectively. They also charged different tariffs depending on the level of consumption.

Table 6.4: 100RE: Tariff Sensitivity Analysis in US$/kWh

Maximum Leverage: 85%			
Minimum IRR	*Downside*	*Base*	*Upside*
30%	0.65	0.59	0.53
32%	0.67	0.61	0.55
35%	0.69	0.63	0.57

Maximum Leverage: 80%			
Minimum IRR	*Downside*	*Base*	*Upside*
26%	0.65	0.60	0.55
27%	0.67	0.63	0.57
30%	0.71	0.65	0.59

Maximum Leverage: 75%			
Minimum IRR	*Downside*	*Base*	*Upside*
23%	0.65	0.61	0.55
26%	0.69	0.64	0.58
28%	0.72	0.67	0.62

As seen above, even though a higher leverage increases the minimum equity IRR, the lowest prices are seen for the cases where the maximum leverage is set to 85%, implying that the benefit of contributing less equity from the beginning is higher than the damage of increasing the company's risk, in the eyes of the equity sponsors.

In the case of the MIX alternative, there are lower tariff values than with 100RE, which range from US$ 0.47 to US$ 0.59 per kWh. The complete results can be observed in table 6.5. This implies that adding a diesel genset will provide an advantage in terms of tariffs.

It is important to note, for both alternatives, that the minimum IRR is not constant with the changing market cases, as displayed in the tables, given that the debt amount changes according to the cash flow, which is determined by the market conditions. However, the variation is slight at a decimal level, this is why the minimum IRR is taken into account without its decimals, in order to simplify the calculation and results.

Table 6.5: MIX: Tariff Sensitivity Analysis in US$/kWh

Maximum Leverage: 85%			
Minimum IRR	*Downside*	*Default*	*Upside*
30%	0.54	0.51	0.47
32%	0.56	0.52	0.48
35%	0.57	0.53	0.49

Maximum Leverage: 80%			
Minimum IRR	*Downside*	*Default*	*Upside*
25%	0.54	0.51	0.48
28%	0.56	0.53	0.49
30%	0.58	0.54	0.51

Maximum Leverage: 75%			
Minimum IRR	*Downside*	*Default*	*Upside*
23%	0.54	0.51	0.48
26%	0.56	0.53	0.50
28%	0.59	0.56	0.53

6.3 Discussion

Incumbent companies have stated that the tariffs they work with range from US$ 0.4-0.5/kWh in the lower end, and US$ 1/kWh in the upper end. As exhibited, the tariffs obtained from the financial assessment are within the aforementioned range, indicating that our hypothetical project would be feasible in Haiti. However, even if highest possible price is still in line with what is expected according to the current incumbents, the ideal is to charge the lowest tariff possible in order to ease negotiations with the regulator and avoid problems with the community. Furthermore, previous studies such as Winkler et al. (2011) state that affordability is the main policy that enables the proper adoption of electricity usage. This applies not only to Haiti but to developing countries as a whole.

It can be seen that increasing the maximum leverage, even though it rises the level of debt acquired and therefore the risk of the project, which translates in a higher minimum IRR, it still allows for lower tariffs to be charged in order to comply with this minimum rate. This is a predictable conclusion, given that the increase in maximum leverage will imply a direct reduction in the contribution done by equity sponsors, while the increase in risk has a more indirect effect. Therefore, under this point of view, the more debt the better.

Now, comparing between alternatives, it can be observed that there is a certain advantage in the MIX design. This has to do with the lower CAPEX required, which will make equity sponsors obtain their desired IRR with lower prices. It is also important to note the decrease in risks of this alternative due to solar intermittency, which are relevant even though they are not reflected in the financial numbers. Nevertheless, there is an important caveat with this alternative, given that the tariff required to make the project profitable can vary significantly from the values obtained depending on the diesel price. Forecasting fuel prices for the next 25 years is a challenging process and all existing projections' probabilities of being accurate are extremely low, given that diesel prices can be affected by many events which are almost impossible to predict. Furthermore, the difficulties Haiti has with its ongoing fuel crisis have already been discussed, which can even make it more costly. This issue has made some of the aforementioned current players to decide to leave out diesel gensets, due to the great level of uncertainty they add to the project. Therefore, in a scenario in which there would not be such important uncertainties regarding diesel, the addition of a genset will probably allow a developer to charge lower prices. However, in this case, it is highly likely that the costs of including the diesel genset are under-weighted, given that they are too difficult to quantify in an accurate way.

An additional point to mention is that the results could be even more favorable if the country would have tax advantages for these kind of projects. In a report carried out by KPMG in 2015, Haiti was reported to have only one out of the 12 featured regulatory and fiscal policies to advantage renewable energy (Behrendt, 2015). Further uses of grants and other sorts of aid could also have helped to obtain a better result. In the previous chapter it was mentioned that grants accounted for 15% of the CAPEX, however, a developer could try to get a higher grant or other type of help such as loans at lower rates, tariff subsidization, risk guarantees, among others.

6.4 Limitations

The first, and most important limitation of this study is the fact that in project finance models, as they are not based in historical numbers, all assumptions are made carefully with the assistance of expert advisors in every aspect. In this study, assumptions were made as realistic as possible, taking into account past experiences of incumbents in the business in Haiti and considering that there was no advisor participation. Some assumptions, however, such as the increase in demand, were made under the criteria of the author, which might differ to the ones carried out by an expert. Probably the most critical assumption in which experts in the field are needed is the diesel price projection. As mentioned, this is a challenging task and might lead to completely different results than the ones presented here.

Furthermore, the most accurate assumptions and information could have been gathered by doing a physical site visit and talking to the people involved, such as mapping the town, identifying possible "demand anchors" (such as cellphone antennas), determining the community's willingness to pay (or obtaining a more exact amount spent in alternatives to electricity that could be destined only to pay the tariff), identifying possible electricity-intense activities to boost demand, among others. This was not possible for the extent of this study and the approach taken might not be very accurate.

Secondly, information regarding this topic was excessively limited. Public disclosure of tariffs, both for the utility and for the incumbents, was difficult to obtain, therefore there are no references that can be considered absolutely exact or certain. Information was attempted to be obtained through conversations with the different actors, however, due to the high level of confidentiality and disclosure, it was difficult to get to a further level of cooperation. Given the lack of available data, a future study could be more robust if it is possible to have more cooperation from both the utility, regulators, and the other incumbents in the business.

Thirdly, there are many scenarios that can arise from a prototype project like this. A more realistic placement should include talking to real investors and lenders that can offer a more certain picture on returns expected and structures. The possibilities are infinite, particularly in terms of debt. One could try different lending rates, grace periods and even different debt instruments such as mezzanine and subordinated debt. In this case, the simplest form of debt was modeled (only senior loans) and took a non-tailored approach for average minimum DSCR and rates. In terms of equity, there are also other figures such as shareholder loans, which decrease the taxable income given that it also accrues interest even if it acts as equity in a 100% basis. This was not considered in the model, and just as with debt, only regular paid-in equity was taken into account. In addition, more complex forms of aid/grants/subsidies could be evaluated. In this model only a simple grant as a percentage of CAPEX was considered, however, there are more options possible that could also be taken into account.

Lastly, it is important to consider that the minimum internal rate of return depends on each investor. In this case a theoretical cost of equity for the country was estimated in function of a particular methodology, however, there might be differences in the return required for each investor. This would impact significantly the minimum tariff required.

7 Conclusion

The problem of rural electrification is real and pressing, and it is one of the main issues to tackle in today's global energy agenda. Off-grid MGs have proven to be a more feasible alternative under certain situations, in comparison to the ultimate goal of central grid extension. These MGs can be fueled only by diesel, combine diesel and other renewable equipment, or just use RES. MGs that combine more than one technology are referred to as hybrid, and usually the ones that include RES are the preferred option due to their environmental advantages. However, these are also more expensive given their high investment cost.

Most countries, in a very myopic way, choose to solve the problem of rural electrification with diesel, because it requires a lower capital cost. However, most of them do not count on the high costs of diesel generation, considering oil price and exchange rate fluctuations, and also logistics given the remoteness of unserved places and the usual lack of proper infrastructure. Not to mention the harm to the environment of continuing to use fossil fuel solutions as a way to tackle modern-day electricity issues. Switching to hybrid MGs, however, is not that simple, as most of the countries that suffer severe shortages in rural electrification usually do not have enough funds to develop these projects. Therefore, the participation of the private sector is essential. Nevertheless, these types of projects have a high level of uncertainty and risks that tend to drive the these investors away.

The question of this thesis was the following: **under which conditions is it profitable to develop a rural electrification project via hybrid microgrids?** and it aims to analyze under which conditions it would be attractive for the private sector to engage in the development of these projects. Throughout this study and the development of the multi stage and the financial model, the different conditions to answer this could be analysed. The first section of this chapter, talks about the general conclusions obtained from this research. The second section refers to the conclusions obtained when applying the model built to the particular geography selected.

7.1 General Conclusions

The first condition is related to the geography selection, and it is to have a situation in which off-grid electricity supply is more economically feasible than an extension of the central grid. This is the case for countries that have a very complicated topographic landscape, such as islands or mountainous terrains, or where locations are so remote and with difficult accessibility that the investment needed for extending the central grid cannot be materialized. Off-grid alternatives are also more convenient in places where the existing electric utility is operating inefficiently, with consistent losses that disable it to carry our further investments in extending the current grid infrastructure. This is a very common issue in most of the underdeveloped economies around the world.

The second condition, also related to geography, would be to choose a region where RES potential is high enough to be able to rely as little as possible on diesel. Places near the equator, for instance, have very intense solar energy potential, and there are areas in which diesel gensets are added just as a safety backup but are rarely used and in some cases not used at all. Places where renewable sources are not abundant will not take advantage of the expensive capital investments properly and will probably recur more frequently to diesel gensets in order to provide the necessary electricity. This adds uncertain fuel O&M costs on top of the high capital costs of renewable energy equipment, thus reducing the profitability options of the project.

It is ideal for the geography selected to have a relatively friendly investing environment, with not so much political turmoil, good transparency levels and advantages for these particular ventures. For instance, there are several advantages that a renewable energy project could obtain, which were commented throughout this study, such as accelerated depreciation and other tax advantages, as well as aid government programs such as subsidies or feed-in-tariffs. Also, it would be ideal to consider a country where import tariffs and other costs when dealing with international suppliers or sponsors are low and that allow an easier development.

Once the geography is selected and the developer starts planning the project and its financing, the simple answer for profitability would be when both private equity and debtholders feel secure with their investment and contribution in the project. After going through all the chapters of this thesis, it can be concluded that the most important condition is to secure revenues. For this, the first key is to have enough demand to make investment worthwhile. This can be assured if the area counts with "demand anchors" such as cellphone antennas, hospitals, schools, churches, administrative buildings and other businesses or economic activities that would need electricity as a vital element to function. Secondly, it is important to ensure the real payment of the electricity supplied, considering that the project would be serving a poorer sector of the population. This has been solved through pay-as-you-go systems (proven to be successful in several examples) and to charge tariffs that are affordable to the community.

The charging of affordable tariffs is somewhat challenging, as these are usually substantially higher than utility level tariffs. This not only poses a problem for the community, but also for the developer itself, given that normally regulators control the maximum tariff to be charged by independent power producers. The reason behind why tariffs for these projects are so high is that they are key to provide enough cash flow for equityholders (after all other obligations) and to result in an IRR over the minimum required by sponsors, which is generally high given the riskiness of these ventures. Usually, a higher level of debt contributed at the beginning will allow for lower tariffs to be charged. However, this will damage the the project's risk, making it more prone to bankruptcy, and it might compromise the debt covenants. There is usually a maximum level of leverage that a project can acquire, and it depends up to some extent on the solvency of the sponsor, therefore it would be ideal for the developer to have some track-record or a side-business in order to get a higher allowed leverage level.

A way to relieve the pressures on the capital structure is to take as much advantage as possible of all the aid possibilities that exist in the business of renewable energy, particularly in initiatives to help underdeveloped countries. Solutions such as grants and subsidies (for CAPEX or subject to operations), guarantees that might allow developers to get lower debt rates, loans with preferential rates facilitated by development institutions, government aid programs, subsidies for the population, among others. This will decrease costs and ease the tariff-setting process.

Lastly, it is also important to educate the community regarding the use of electricity. This is very relevant particularly for communities that did not have electrification at all, where they must be instructed about what they can do with electricity in order to take a better advantage of the service and also to increase demand and make the project sell more and obtain more revenues. They also must understand that electricity is a basic product just like food or anything else in their essential basket, and that the price will fluctuate just as anything else. This is particularly relevant in countries with high inflation and currency depreciation. Existing success cases have proven that with a good communication the projects would still be able to charge their higher tariffs, as evidence suggests that despite of this, the fact of not having to spend on dirty, expensive alternatives to cover for energy needs provides substantial savings to rural households.

7.2 Applied Conclusions

In this study, two different alternatives of hybrid microgrids in a rural village in Haiti were analyzed and modeled, one composed only of renewable sources, and one mixed with a diesel generator. Haiti is the poorest country in the western world, with only approximately 25% of the population having access to electricity. The poverty in the country is reflected in its institutions and in the lack of transparent information, with an electric utility that has been in deficit for a worrying amount of time. It is also going through political turmoil that has resulted in a severe currency depreciation. It is a country that ranks low in the corruption perception and ease of doing business indices, however, there are a couple of companies that have successfully ventured in the business of developing hybrid microgrids in rural areas in the country, and that have caused a very relevant impact in the society.

Haiti, as all other developing countries, has pros and cons for the development of a project as such. First, the country's difficult financial situation at a state-level and its topography make off-grid solutions practically the only way of dealing with extending electrification. In addition, the potential for renewable energy (especially solar) is huge, which allows to minimize or definitely leave behind the usage of diesel gensets, which would eliminate significant uncertainties and environmental issues. Furthermore, the regulator (until now) still has not set a maximum in the tariff level to be charged, as seen in other countries, therefore developers just need to negotiate their required tariff with the entity and get an approval. This allows players to be able to fix their tariffs per kWh rather freely On the other hand, the country has a very complicated economic and political situation that makes any possible venture in it very risky. At the same time, Haiti does not have a particular investment treatment for energy projects that allows certain advantages, as seen in other countries, such as tax exemptions and accelerated depreciation.

Analyzing the selected village's demand, the supply options and its corresponding costs, and modeling it in a project finance fashion, the minimum tariffs per kWh to be fixed by a potential private developer who would want to venture in the country were derived. The result of these tariffs were quite high, however in line with what is expected according to the experience of existing players. This does not eliminate the complexities of charging a significantly higher rate in relation to the utility and moreover in an environment of very high inflation and rapid currency depreciation. Although, previous success cases have shown that projects with these levels in tariffs are feasible. In the end, the level of the tariff will depend on a higher extent on the minimum return of the equity sponsor, rate that will always remain at their discretion.

There are many challenges to come, such as a possible tariff cap from the regulator, further economic deterioration in the country and an ongoing political instability. However, for a country like Haiti this might be the only realistic solution in the medium to long term, and there are many other underdeveloped countries facing similar situations. This is an urgent issue, particularly if the SDGs are planning to be achieved by 2030, therefore it is of utmost importance to impulse profitability conditions to make these projects proliferate.

It would be ideal for more big energy companies who already have steady revenues and whose profitability would not only depend on one project to venture in these sort of businesses. Many of them have already started to do so, such as Shell, EDF and Engie. The incursion of these players in the field will allow more experience to be acquired, which will start reducing the risks linked to lack of information. In addition, it is important to promote more governmental funding to these initiatives. There is a massive public spending in fossil fuel subsidies every year, not to mention other unsustainable activities. Channelling some of this money to renewable off-grid initiatives could be very helpful and can provide life-changing advantages for a country's population.

Renewable energy projects are expensive, as they convey a high capital to O&M ratio that will make financers uneasy. Adding on top of this the development of a project in a very unstable country and serving a really poor community makes it even riskier. It is natural to understand why this projects have not been further developed around the emerging world, even considering all their upsides. However, if there are enough initiatives and efforts to promote these sort of projects at a national and international level that might ensure a higher level of profitability for private ventures, we will hopefully be seeing much more of these projects rise in the near future.

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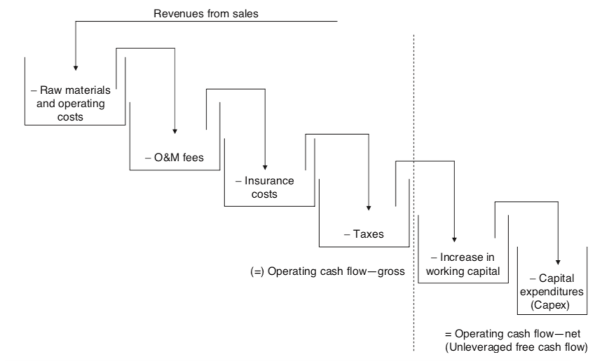
Appendix

A1 Modeling Project Finance

A1.1 Operations

As the traditional financial modeling approach computes the value of a company or project through their cash flows, the first step is to identify its operative components. This, in other words, corresponds to the operational cash flow or unlevered free cash flow (UFCF). A graphic representation its calculation, known as cash flow waterfall, is depicted in figure A1.1.

Figure A1.1: Waterfall Diagram for Unlevered Free Cash Flow (Gatti, 2012)



In order to properly calculate cash flows a series of inputs must be initially defined. These are: (i) investment timing (life of the asset, length of construction period), (ii) initial costs (CAPEX, land lease, development costs), (iii) grants (if applicable), (iv) operational revenues and costs (sale tariffs, O&M, administrative costs), (v) fluctuations in working capital, (vi) taxes, and (vii) macroeconomic variables (inflation, interest rates, etc.).

A1.2 Capital Structure

After obtaining the the cash flow, we can move on to the second key metric in project finance which is the capital structure or the optimal mix between debt and equity.

A1.2.1 Debt

In the construction phase, the financial modeler considers a loan to cover the initial capital and additional costs. There are several inputs that need to come with this consideration, such as the tenor, the interest rate and the minimum acceptable coverage ratios. Usually, the loan acquired during construction has a higher interest rate given the riskier nature of the period. When the project starts operating, this debt is normally refinanced into a term loan with a lower interest rate.

The interest rate determines the cost of debt and it depends on the risk of the project, the geography and the stage of the venture. The debt repayment follows the dynamic of the project's cash flow generation capacity. As it is initially weak, many loans are underwritten with a grace period in which repayments are not required, however, interest is. Even though this is possible and quite common, in general lenders prefer shorter repayment times in order to cut down their exposure.

A1.2.2 Equity

Given the risk associated to project finance, equity sponsors will try to invest as little capital as possible. The exact number depends on different grounds, such as on the economic soundness of the project and the level of risk equityholders are willing to take. This minimum risk tolerable has a high level of subjectivity (Cacciafesta, 2015), however there are several structured approaches that attempt to soundly estimate this rate.

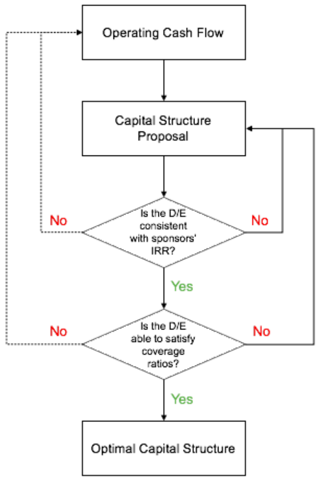
A1.2.3 Determining the Optimal Capital Structure

Once we are clear with the definition of operational cash flow, we can start the process of determining the optimal mix between equity and debt. Usually, the equity sponsor has a number in mind and this is the starting point. This ratio of debt to equity has to comply with two requirements in order to declare it well-suited for the project. First, the equity internal rate of return (IRR), the rate at which the net present value (NPV) of the cash flow received by equityholders (Free Cash Flow to the Equity or FCFE[7]) is zero, is obtained. If this is higher than the minimum return required by the sponsors, the capital structure goes to the next step. In the second step, the proposed ratio is tested to ensure

[7]The FCFE has the same rationale as the UFCF except for the fact that it incorporates debt issues and repayments

that the cash flows can cover the debt service. If not, it is rejected and a new proposal with a lower level of debt must be tried. A diagram of the decision process can be found in figure A1.2.

Figure A1.2: Trial and Error Decision Process for Optimal Capital Structure (Gatti, 2012)



A1.3 Minimum Internal Rate of Return

The minimum equity return for equity sponsors is also known as the cost of equity, and it is challenging to determine due to the larger share of uncertainty that equity returns possess (Donovan and Nuñez, 2012). The Capital Asset Pricing Model (CAPM), initially presented by Sharpe (1964) and Lintner (1965), is the most widely used method in corporate finance to obtain the cost of equity, which can be seen in equation .1.

$$k_e = r_f + \beta[(E(r_m) - r_f] \tag{.1}$$

Through traditional CAPM, the cost of equity is based on a risk-free rate (r_f), the measure of systematic risk (or the covariance of the asset's return versus the market) (β), and the expected market return ($E(r_m)$).

However, many scholars have pointed how this model is not very accurate when applying it to emerging economies, as it assumes that all countries face the same market risk premium, and therefore all the differences in risk fall on the variances in the systematic risk measure or betas (Damodaran, 2019). Academic evidence has proven that these variances are not capable of measuring country risk (Damodaran, 2019), which led some academics to conclude that the model was not applicable for developing geographies (Cheung et al., 1993), (Mobarek and Mollah, 2004), (Gupta and Sehgal, 1993).

For these reasons, many variations of the CAPM have been established. For instance, Donovan and Nuñez (2012) propose a downside-beta approach accounting for when returns do not follow a normal distribution. In a simpler approach, Walker (2016) assesses how to do an extension of the CAPM by including country credit risk as a second factor in the traditional equation, based on a model proposed in 2003 by Damodaran (Damodaran, 2003). This model has been widely adopted by its simplicity and greater accuracy when working with emerging countries.

A2 Detailed Building Analysis for Anse Rouge

Table A2.1: Buildings of Anse Rouge

Type of Building	**Number**	**Names (if available)**
Bar	3	Bon Samaritain Bar, Feullie Bar Resto
Beauty shop	2	Studio de Beauté Unisex, Detty Studio de Beauté
Beverage shop	3	n.a.
Churches	6	Église Catolique Bon Samaritain, Église Baptiste de Platon forcelis, Premiere Église Baptiste Evangelique d'Anse-Rouge, Église Alliance Chretienne d'Anse-Rouge, Église Baptiste Independante d'Anse Rouge, Église et École Pradel Pompilus
Clinic	1	Clinique Afos
Convenience store	13	Polo Épicerie, Épicerie la Sagesse
Drinking water source	5	n.a.
Fountain	2	n.a.
Hospital	2	Hôpital Anse Rouge, Centre de Sante d'Anse Rouge
Hotel/Restaurant	1	n.a.
NGOs*	3	OXFAM, ODECAR, GREFACOOP
Pharmacy	2	Betty Pharma, Maggy's Pharma
Schools	3	École Philadelphie, Institution Mixte les Frères Pierre, École Nationale Nan Tiyo

*Note: Oxfam is a confederation of 19 independent charitable organizations focusing on the alleviation of global poverty, founded in 1942 and led by Oxfam International. ODECAR is an organization that focuses on improving both rural and urban infrastructure around Anse-Rouge. GREFACOOP is a women's cooperative that works on economic and social causes.

Figure A2.1: Detailed Map Anse Rouge Buildings by Type

A3 Detailed Approach for Non-Residential Demand

Figure A3.1: Detailed Approach for Non-Residential Demand based on Blum et al. (2013) and Parshall et al. (2009).

Kiosk - Drinking water source - Pharmacy

Appliance	Pwr Consumption (W)	Qty per hh	Usage per day (hrs)	kWh per day
Light bulb	25	2	4	0.2
			per day	0.20
			per year	73.00

Restaurant

Appliance	Pwr Consumption (W)	Qty per hh	Usage per day (hrs)	kWh per day
Light bulb	25	10	6	1.5
Refrigerator	100	1	24	2.4
Mixer	100	1	8	0.8
Blender	180	1	8	1.44
			per day	4.64
			per year	1693.60

Bar

Appliance	Pwr Consumption (W)	Qty per hh	Usage per day (hrs)	kWh per day
Light bulb	25	2	6	0.3
Refrigerator	100	1	24	2.4
			per day	2.7
			per year	985.50

Convenience store & Beverage shops:

Appliance	Pwr Consumption (W)	Qty per hh	Usage per day (hrs)	kWh per day
Light bulb	25	2	4	0.2
Refrigerator	100	1	24	2.4
			per day	2.6
			per year	949.00

Beauty Salon

Appliance	Pwr Consumption (W)	Qty per hh	Usage per day (hrs)	kWh per day
Light bulb	25	2	2	0.1
Hair dryer	800	2	1	1.6
			per day	1.7
			per year	620.50

Churches

Appliance	Pwr Consumption (W)	Qty per hh	Usage per day (hrs)	kWh per day
Light bulb	25	10	6	1.5
Stereo (speakers)	20	5	6	0.6
			per day	2.1
			per year	766.50

Schools

Appliance	Pwr Consumption (W)	Qty per hh	Usage per day (hrs)	kWh per day
Internet	8	1	8	0.064
Desktop computer	60	8	8	3.84
Indoor light	15	12	8	1.44
Outdoor light	15	24	8	2.88
			per day	8.224
			per year	3001.76

Hospital

Appliance	Pwr Consumption (W)	Qty per hh	Usage per day (hrs)	kWh per day
Vaccine refrigerator	60	1	12	0.72
Vaccine refrigerator/free	60	1	12	0.72
Indoor light	15	10	7	1.05
Outdoor light	15	4	7	0.42
microscope	15	1	2	0.03
Centrifuge nebulizer	150	1	2	0.3
Vaporizer	40	1	2	0.08
Oxygen concentrator	300	1	2	0.6
Overhead fan	40	4	7	1.12
Water pump	100	1	2	0.2
Electric Sterilizer	1500	1	2	3
Desktop Computer	60	2	7	0.84
15" LCD monitors	25	2	7	0.35
Multifunctional scanner/p	17	1	2	0.034
Satellite phone	5	1	0.1	0.0005
Internet	8	1	7	0.056
			per day	9.5205
			per year	3474.98

Fountain + Water Well

Appliance	Pwr Consumption (W)	Qty per hh	Usage per day (hrs)	kWh per day
Water pump	45	1	12	0.54
			per day	0.54
			per year	192.24

Clinic

	Source: Parshall	
	per day	0.98630137
	per year	360