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Examining the Role of Diesel Generators for Microgrid Bankability in India and Southeast Asia

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Abstract

Since the introduction of Edison's lightbulb over one-hundred years ago, humanity has struggled to keep up with electrification for all. With global attention now aimed at sustainable energy production, the struggle becomes more complex by not only obliging energy access, but access to clean energy. The concept of microgrids has been promising for filling in the demand, but not quickly enough to meet global electrification targets due to lack of private investment in key areas. This study explores how one of the microgrid components, the diesel generator, affects financing for microgrid development. Data for the study was collected through the use of mixed methods and included documentation review, interviews, and microgrid simulations using HOMER Pro software. Information was analyzed across the data types by using triangulation.

The research revealed that private financing for microgrids is perceived to have highest risk in the initial investment phase. HOMER analysis showed that within microgrid configurations, a diesel generator can lower the capital needed but this will be offset with higher operational costs and possibly penalties from environmental policy. The diesel generator also lacks providing added value to systems; value which often makes a project economically feasible. Although the diesel generator is not an ideal component in all configurations, it could serve as a catalyst to acquiring funding for microgrids with uneconomical capital costs or complexity. The anchor-business-community model for microgrids is suggested as a way to capitalize on existing gensets in large enterprises to create an affordable community microgrid. Energy policy must adapt to accommodate various microgrid configurations, especially how they will interact with the main grid. Improvements in policy, design, and financing mechanisms for microgrids will ultimately help in proliferating the technology to areas of critical importance.

Keywords: microgrids, rural electrification, diesel generator, energy policy, renewable energy

Executive Summary

So far, the modern 21st century economy has been dominated by the need for electrification and ensuring access to the electrical network. Over 6 billion people use electricity in some capacity to maintain their healthcare, industries, agriculture, home life, and nearly everything. However, this still leaves a gap of 1.1 billion people worldwide without access to electricity (International Energy Agency, 2017). Diversity in policies, geographies, and economic power has made global electrification difficult to achieve. Problems aside, electrification is still moving forward to address three main tasks in the future of energy. The first challenge is expanding electricity access to regions that are not connected to the main electric grid. The second challenge is creating enough new production to keep up with the accelerating demand. Once a user is added to the electrical grid, the user's demand for electricity increases tremendously. This can be seen in the difference of energy use between more and less affluent countries. Beyond expanding access and improving power capacity, there is a need to develop this energy system in a sustainable manner. This means using renewable energies and responsible technologies to generate and harness clean power.

The concept of a microgrid has been used to address these obstacles through the use of remote, sustainable, and dynamic power systems. Microgrids have the potential to integrate a higher mix of renewable energy through a reliable system that is much better at providing energy to off-grid communities. Providing specialized services to a smaller market usually requires energy prices to be higher for the microgrid compared to traditional main grid generation. High costs are one of the greatest barriers to spreading microgrids to underserved areas. Microgrids are each novel in their design and therefore can represent varying cost levels. The component costs of a microgrid are scrutinized based on the operating philosophy chosen for the system. Typically, microgrids that operate with higher renewable energy generation will have higher upfront costs. The diesel genset component has been a staple in microgrids and its use is extensive in the electrification of the developing world due to its simplicity and cheap initial costs. The price of fuel and high emissions from diesel have led microgrid developers to incorporate more renewable energy into the mix to make the projects more attractive for investment. It is apparent that renewable energy and storage have their own roles in microgrid bankability. The diesel genset is a vital component in many microgrids and is forecasted to still be a major part of project design in the future. This is attractive to competitive companies, such as Volvo Penta, who are often interested in emerging markets and technologies. The microgrid concept was especially interesting to Volvo Penta within the context of the Indian and Southeast Asian context, as these markets are quickly growing.

The dilemma between the need for more sustainable energy but also more access and increasing demand requires more knowledge on microgrid financing if it will be part of the future solution. Each component needs to be examined to understand how it contributes to the whole system and if in fact there is a better replacement. The problem generated the following research question to guide the thesis:

How does the diesel genset component affect the financing and investment opportunities of microgrid projects in India and Southeast Asia?

The microgrid concept has received much research attention with the introduction of cheaper renewable energy. The research question was answered by evaluating different types of data about the microgrid design, value, costs, and energy policy. The methodology was determined by reading previous studies that were engaged in similar research. This consisted of documentation period and a more quantitative case study research. The documentation phase was used to collect general data on microgrids that would be useful in generating a case study. The energy policy of each country in the scope was researched to find interactions with microgrid development. Some of this data was used in part with the case study phase of the project. The case study phase used data collected to run a microgrid simulation using the specialized HOMER Pro software by NREL. Existing microgrid case studies were examined for their configurations and operating models to help determine the correct parameters for the simulation. Component data was provided by Volvo Penta and other publicly available databases. The case study was simulated to provide an optimized microgrid system based on a given size of diesel generator. A sensitivity test was then used to examine how the system configuration changed based on diesel prices and projected lower battery costs.

The resulting information on microgrid policy is displayed in two figures. The first figure shows how each country is approaching microgrid policy through financing and frameworks. The second figure shows certain policies for each country and to what degree they would affect microgrid development as well as the legitimacy of diesel gensets. This was determined by the potential for a policy to change funding or political motivation towards microgrid projects and diesel gensets. The documentation phase also provided findings on the value chain of microgrids in these countries. The value chain showed that added value from the diesel genset was rather low in comparison to the services that could offered by renewable energy and storage. The diesel genset does create the added value of redundancy power for a system, but this is more in the case when it is used more for storage purposes. Microgrid finance is heavily dependent on the return that can be made on investment. It was found that the initial phases of a microgrid project carry the most risk for investment due to the higher likelihood that it will not be completed. Therefore, capital expenses are the most difficult to secure private funding for. The case study simulation showed that the introduction of a diesel genset lowered the capital expenses of a microgrid, but came at the increase of operational costs due to fuel needs. During the sensitivity tests, the simulation found that the gensets provided enough economic value to be used throughout all sensitivities except the highest. When diesel prices were at the highest, then diesel generation was greatly reduced in favor of more photovoltaic energy and battery storage. These findings were then analyzed together to provide a better answer to the research question. The simulation showed that the diesel genset can lower capital costs, which are the hardest to fund privately. However, the economics of the diesel genset can prove less viable with the introduction of environmental penalties or renewable energy credit schemes. This practice is less common as of now in the countries of scope.

The study was performed across multiple data types to develop a stronger picture of microgrid financing and policy in India and Southeast Asia. The results show that the diesel genset has a dynamic role in microgrid financing. It can help to secure initial private funding through lowering capital costs, as long as there will still be investment or tariffs high enough to cover the increased operational costs. Policies that remove subsidies for diesel fuel, seek to further subsidize renewable energy generation, or include environmental degradation penalties will reduce this financing potential for gensets in microgrids. Overall, microgrids are developed on a case-by-case basis in various geographical and economic conditions, thus each requires its own special form of configuration and financing. This complexity makes it difficult to apply the findings of this study to all microgrids, but improves the knowledge base of the genset component.

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Abbreviations

ABC – Anchor Business Community

BS – Battery Storage

BOOM – Build Own Operate Maintain

CAPEX – Capital Expenditure

COE – Cost of Energy

DG – Diesel Genset

EV – Electric Vehicle

HOMER – Hybrid Optimization of Multiple Energy Resources

LCOE – Levelized Cost of Energy

MG - Microgrid

NPC – Net Present Cost

OPEX – Operational Expenditure

O&M – Operation and Maintenance

PCC – Point of Common Coupling

PPP – Public-private Partnership

PPA – Power Purchase Agreement

PV - Photovoltaic

RE – Renewable Energy

REG – Renewable Energy Generation

ROI – Return on Investment

1 Introduction

This study is built around the technological concept of microgrids and how they are used to electrify rural areas. Microgrids are complex and contain varying levels of technology, therefore one component was given emphasis – the diesel generator. Microgrids are relatively small capacity electrical grids whose key function is to provide electricity beyond the main power grid. These smaller grids have proved useful in providing other capabilities to customers apart from sole generation. Microgrids can help facilitate access to high quality power for users that are unelectrified, suffer from frequent outages, or require more dynamic needs of electrification. The following subsections serve to introduce the topics that will be of greatest focus in this research.

Configurations

In the case of rural microgrids, which are typically more geographically isolated, a specific type of microgrid is commonly deployed: the hybridized microgrid. This grid consists of multiple generation types and some sort of energy storage option (Khodayar, 2017). The hybrid microgrid is the configuration type at focus for this research. Hybrid configurations are especially relevant because they are proven to be effective in rural areas as well as their inclusion of the diesel genset component (Goel & Ali, 2014). The demand for leap-frogging technologies has discouraged the use of diesel generation and storage for energy in favor of renewable generation. This begs a greater inquiry into the targets of achieving greater electrification versus the proliferation of renewable energy and how both can be done together most efficiently (IRENA, 2015).

Components

The diesel generator component has been at focus because of its commonplace use in rural electrification and its evolving role in the microgrid industry. A generator was traditionally used as either backup power or to cover daily loads, but now includes more ambiguous functions to serve system complexity. The functional role of diesel gensets gains even more ambiguity from the effects of new policies and business models. This research is especially of interest to those in the diesel generator industry. The industry had a global market value of 17.51$ billion in 2017 and is expected to grow with a compound annual growth rate of 17% until 2022 (Grand View Research, 2017). Microgrids will help to account for a portion of this growth, but just how much will depend on the relationship between diesel generation and project financing.

Financing

Acquiring an adequate level of financing requires that a project meet certain criteria set forth by the financer (World Bank Group, 2010). It was unclear how the component mix within a hybrid microgrid affects the level of financing that can be received. This research investigated the relationship between component mix and funding possibilities for microgrids, seeking to emphasize the effect of the diesel generator.

Investment

The incentive mechanisms for microgrid investment are lacking. This is due to the low payback rates of energy projects in rural areas as well as other fiscal instabilities (Long, Wang, & Pan, 2018). Investment is crucial for having enough capital to cover startup and operational costs, but can be difficult for new technologies and concepts like hybridized microgrids (Williams, Jaramillo, Taneja, & Ustun, 2015). Considering that the component at focus is a comparatively old technology that is trusted by investors to be reliable, there prompted a further look into how the component mix would affect investment in the scoped countries.

Energy Policy
The policy aspect of microgrids is constantly evolving and energy governance seems to be shifting towards a high rate of renewable energy mix (International Energy Agency, 2018). Policy sentiments towards technologies will affect how the market perceives them as well. This sentiment towards diesel gensets and the consequential effect to hybrid microgrids is not understood (Tongia, 2018).

Business Models
To better achieve better project economics, proper business models have been studies and tested. However, even with the local or regional success of some models, there still remains a lack of decisive models that are effective enough to be applicable in a majority of environments (Balijepalli, Khaparde, & Dorbariya, 2010). Even more, there is a lack of sufficient study into how the diesel genset component can improve or hinder business models beyond backup power (Franz, Peterschmidt, Rohrer, & Kondev, 2014).

1.1 Background

For much of the world living in modernized economies little thought goes into flipping on a light switch, but panic arises when the light flickers or fails to turn on. Conversely, a significant portion of the global population gives little thought when the light flickers or fails to turn on, but praise arises when the room illuminates. This is the reality for the 1.06 billion people worldwide who lack access to electricity. The numbers are unequally distributed as 80% of those live in just 20 countries. Southeast Asia bears around 65 million without access and India represents a staggering 240 million people without any sort of electricity (International Energy Agency, 2015) (International Energy Agency, 2017). Furthermore, the overwhelming majority of the population without electricity access lives in rural areas; achieving only a 73% electrification rate in 2014 (United Nations, 2018). This number has slowly been rising globally but many are still being left behind while the world economy continuously becomes more electrified.

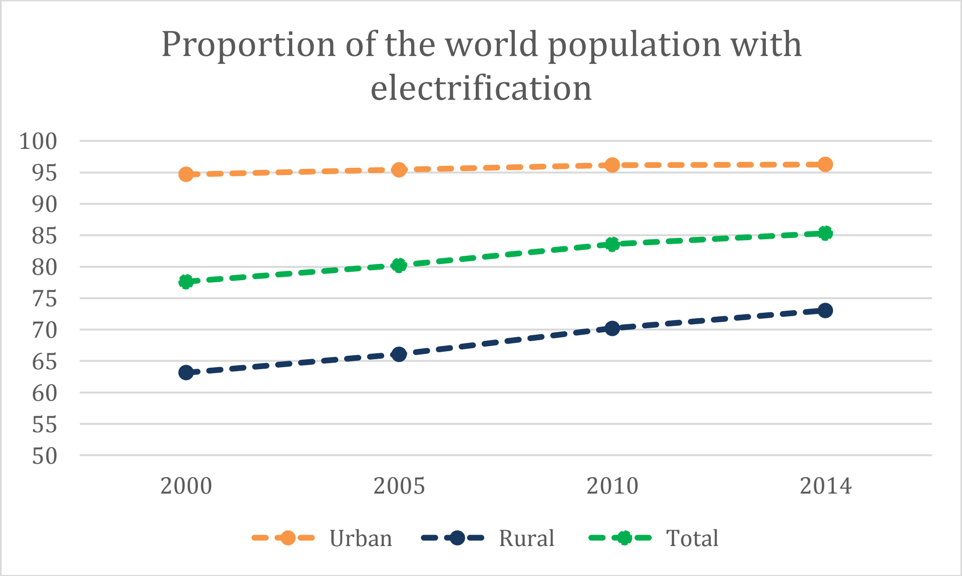

Figure 1 Electrification rates in the world measured by residence of urban and rural populations.

Electricity is key in meeting the many societal goals set out by the United Nations, such as Sustainable Development Goal 7: ensure access to affordable, reliable, sustainable, and modern energy for all (United Nations, 2018). Those who are reading this document on an online format already realize the tremendous impact that electrification has on our daily lives. From education, industry, commerce, health, and increasingly transportation, electricity powers the progress of society. It is instrumental in overcoming poverty barriers. It extends the hours that children can spend studying and provides flexibility in working for adults as well as increased hours of operation for businesses. Industries can expand and utilize more advanced technology for improved output, making them more competitive (Samad & Zhang, Benefits of Electrification and the Role of Reliability: Evidence from India, 2016) (World Bank, 2018).

Achieving higher electrification rates is only one solution. It has been observed that once communities do gain access to electricity, demand increases. As these regions achieve greater GDP, consumption levels go up and peak demand curves shift. This puts a burden on the energy infrastructure, especially if it had not been designed with the anticipation of future loads (Charrada, 2016). The Environmental Kuznets Curve can be utilized to represent the causal link between increased economic growth and increased environmental degradation. This is especially true in the case of India, which is one of the fastest growing populations and GDP per capita in the world (Tiwari, Shahbaz, & Adnan Hye, 2013) or in Southeast Asia whose energy demand has grown 65% since 2002 and projected to grow again by another two-thirds as its economy triples by 2040 (International Energy Agency, 2017). It is estimated by the International Renewable Energy Agency that if we are to achieve the goal of universal electricity access by 2030 with the current trend of grid-extension, almost 60% of additional electricity generation will have to come from off-grid sources (International Renewable Energy Agency, 2017).

Sustainable Development Goal 7 (SDG7) is especially relevant in this study of microgrids. By dissecting the wording of SDG7 the importance of what is termed a 'Microgrid' (MG) becomes apparent. The first part of the goal, "…ensure access…" implies that it is vital to expand electricity access to everyone. The second phrase "…affordable…" recognizes that high tariff costs for electricity are not conducive to bringing everyone electricity. Most often the case of transmitting and distributing electricity to rural or remote communities costs substantially more than urban and peri-urban customers. Typically, onsite generation also incurs greater costs than tapping into the macrogrid. The third part of SDG7 is nearly as important as access, "…reliable…" electricity. Having access to the electricity grid is one piece to the puzzle, but having stable and reliable access is vital for economies to grow or healthcare to operate efficiently. The next important part of the phrase is "…sustainable…" which has been cemented into so much discussion in the 21st century. The global realization for the need to shift from polluting and environmentally taxing energy sources is now deeply rooted. Not only has society shifted its focus from fossil fuels, but macro economies have also begun to feel the benefits of 'green' energy through a reduced levelized cost of energy (LCOE) of renewable energy generation (IRENA, 2018). The final part of the SDG7 is "…modern…" electricity. This is often seen in parts of the developing world where leapfrogging technology is taking place. Rather than upgrading generation from coal or other unsustainable source, societies are investing in green technologies identical to those being used in modern economies.

All of these buzz words: accessibility, reliability, affordability, and sustainability are incorporated into the operating philosophy of microgrid technology. Microgrids are designed to meet one or many of the problems that plague traditional macrogrid expansion to rural and remote areas. Electricity systems are beginning to decentralize, decarbonize, and democratize, known as the “three D’s”. Microgrids offer better solutions to incorporate renewable energy generation (REG) and provide reliable electricity to regions that haven’t developed energy infrastructure, all the while balancing generation and storage to bring down the price of energy (Hirsch, Parag, & Guerrero, 2018). It would seem that this technology should be displacing traditional macrogrid philosophy at break-neck paces, but with many new technologies, there is the Diffusion of Innovations Theory, which proposes that the early stages of adoption will be slow followed by exponential growth.

Multiple barriers stand in the way of microgrids reaching the underserved regions, such as sub-Saharan Africa, South Asia, and Southeast Asia, all of which stand to benefit the most. The technology for microgrids is present and becoming more advanced every year. The main barrier for the proliferation of microgrids is investment. These microgrids tend to charge a higher LCOE than energy purchased from the macrogrid. This makes projects tricky to fund due to the high risk for ROI when coupled with the poor economic conditions in many of the remote areas that are in need of this technology. Apart from investment financing, there are policy barriers that can either disrupt or slow the growth of the microgrid trend. Regional energy policy has traditionally favored expansion and subsidization of the macrogrid, which can conflict with the microgrid. Finally, a lack of viable business models has made the concept of microgrids unattractive to entrepreneurs and energy ventures. Fortunately, these barriers are being eroded year after year as the microgrid proves itself a viable competitor to the status quo of energy markets (Microgrid Investment Accelerator, 2017).

1.2 Problem Description

This research has been conducted to provide insights into the bankability of microgrid projects. Due to the various problems that this technology faces in the form of acquiring financing, there is a need to explore different approaches to business models, policy reform, and configurations in detail. Since this study is being conducted under a partnership with Volvo Penta, most emphasis will be on the diesel genset component in the microgrid.

The study will gain insights on how this component can affect the bankability of a microgrid by either making the investment more or less attractive to investors and business models. To arrive at these findings, the thesis will also seek to explore the subtopics of microgrid financing, government and institutional policy mechanisms, and microgrid configurations featuring diesel generators as a component.

The incorporation of renewable energy generation into microgrids has helped to undercut costs associated with diesel generation and enhanced the economics of systems. Financing for microgrids has typically been for systems that involve the use of diesel generators as core components, but is now shifting to more hybridized energy systems. The problem is the gap of knowledge in how traditional financing of microgrids that contain diesel gensets will be affected as microgrids utilize more types of hybrid generation.

The regions of India and Southeast Asia are hubs for microgrid development. India suffers from large gaps in energy access and quality, whereas Southeast Asia has similar problems but coupled with the disadvantage of island geography. These economies are growing at high rates, creating new surges in energy demand and funding to match. Governments and markets are stabilizing, creating a more welcoming atmosphere to energy project investment. This atmosphere makes the region an incubation chamber for how microgrids will be successfully managed in future cases.

1.3 Research Question and Objectives

This study has one overall research question that is determined by the scope:

How does the diesel genset component affect the financing and investment opportunities of microgrid projects in India and Southeast Asia?

This research question requires the investigation of subtopics in components, financing, investment, policy, business models, and microgrid configuration optimization. Therefore, research objectives were used to better guide the process. Apart from guiding the overall research process, the objectives provide a framework for organizing information that might be relevant to each other. Often, while exploring one objective there will come information that is useful to a different objective. The organizational structure of the research objectives I meant to reduce the loss of information by allowing data to be expedited from one objective to another.

1. Identify the main components and services of a microgrid, carefully mapping out where value is added as well as accounting for capital and operational costs.
2. Investigate where microgrid financing comes from as well as drivers, facilitators, and barriers.
3. Explore the policy drivers, facilitators, and barriers of the countries within the scope and compare.
4. Record microgrid business models and demonstrate how they are effectively used in distinct markets.
5. Perform microgrid configuration optimization of case study projects to evaluate the fluctuations in capital and operational costs of various scenarios.

1.4 General Scope

Microgrid projects vary in size from small systems of a single photovoltaic panel and battery, to huge multi-component systems capable of powering city sectors. Smaller systems are less attractive for investment and yield smaller profit margins for suppliers, so the minimum range of projects examined was approximately 400 kW. The enormous complexity of larger systems was far beyond the capabilities of this thesis alone, therefore the largest systems that were examined had been designed to deliver <5 MW of generation capacity (Hossain, Kabalci, Bayindir, & Perez, 2014).

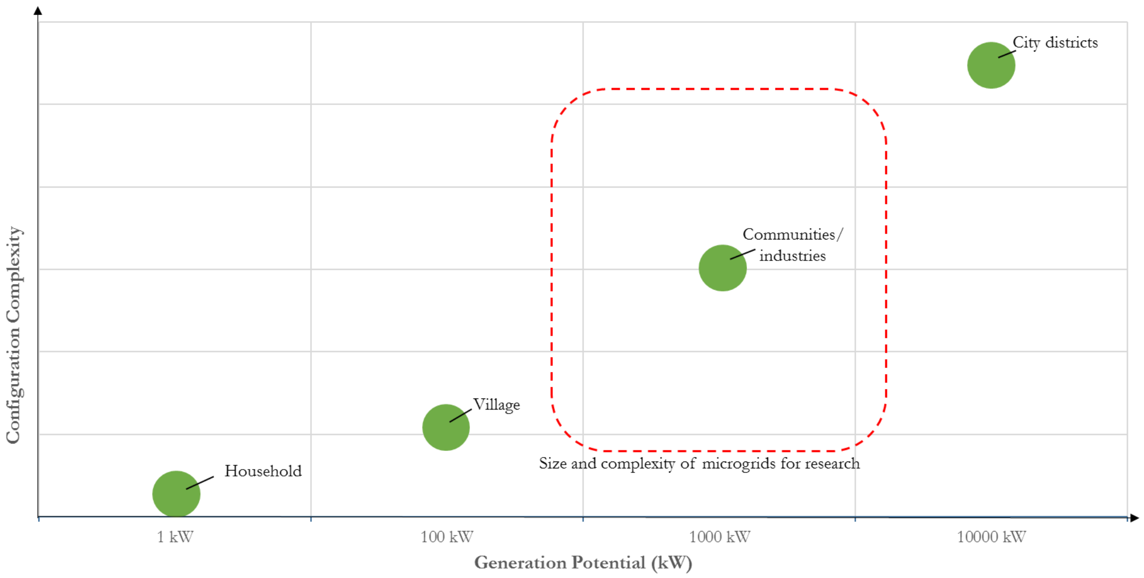

Figure 2 The scope of system covered in terms of size and complexity.

Microgrid market growth is projected to be highest in the Asia-Pacific region through 2022, though North America still dominates the highest market revenue through 2025 by expecting to account for roughly 70 percent of global microgrid project revenue (Grand View Research, 2017) (Market Research Future, 2018). This makes Southeast Asia a particularly interesting region for its market potential for investment, along with the data resources that were provided by Volvo Penta's headquarters in Singapore. India is also prime for the microgrid market with an off-grid energy systems market value estimated at $10 billion by 2020 (Microgrid Investment Accelerator, 2017). South Asia, India more specifically, has aggressively pursued policy to achieve higher electrification rates. This policy includes support for renewable energy based microgrids, showing government acceptability for the need of the technology (Ministry of New and Renewable Energy, 2012). India was chosen specifically out of South Asia, rather than the others, because of the data available for this study. Volvo Penta has a headquarters in Bangalore, along with many suppliers and customers in the region. This provides a wealth of information that would not be comparable to the data available in countries such as Nepal, Bhutan, or Bangladesh.

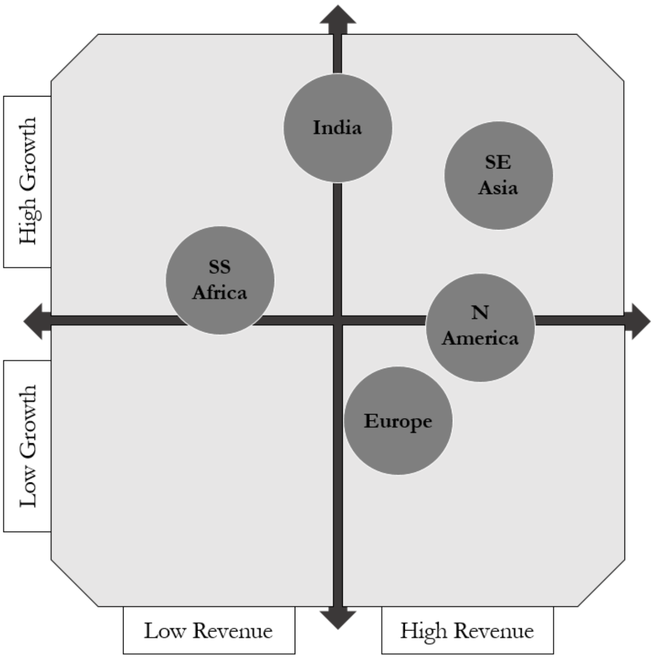

Figure 3 Quadrant Matrix displaying the most prominent microgrid markets worldwide. Placement is determined by market growth vs. project revenue in the region.

1.5 Limitations

This thesis has been limited by three main factors throughout the research process: data availability, data consistency, and microgrid variability.

1. Microgrids may not be a new technology, but their role has greatly expanded since their first conception in 1955[1]. Most microgrid research that was has been within this decade. Data sources were rich and well documented, but given that the topic is young, there is relatively limited research available. Data availability is also limited in this subject because large databases are often used for market analysis and therefore require the purchase of private user rights. Limitations in the thesis budget held back acquiring this private data.
2. Government sources of data within the selected scope were not always consistent with each other. India has several ministries that each work in some way with energy development. This wide diaspora of data meant that some departments were publishing results with old data while others may be using updated data and yielding another result. For example, Myanmar recently consolidated several ministries and the new umbrella has failed to update its databases to reflect the absorbed bodies.
3. There is no true template for a microgrid. Each is designed according to an operating philosophy to reflect user needs. This makes it difficult to paint all microgrids with one brush. What is said to be true of some grids may not exactly be the same for others. This is especially true for the microgrids across the huge variance in climates and geographies in countries scoped.

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[1] The first instance of a modern microgrid used on an industrial scale was at the Whitling Refinery in Indiana, United States. It was constructed in 1955 and provided 64 MW of electricity. (Wolf, 2017)

Limitations due to data quality were anticipated from the beginning. To mitigate discrepancies within the data, it was important to compare multiple sources. Where possible, data retrieved from local or government sources was backed up against the World Bank archives of electrification, population, energy, development, and commodity prices. In the case that data was absent, then archived data from the World Bank was used in place.

It is difficult to compare all microgrids when each is unique to its own case. Therefore, a simulated microgrid was created to capture the generic workings of a hybrid system, which is the central system at focus. Beyond the differences in system design are the variables of geography and governance. These are the most limiting factor to the study, as governing practices are constantly in flux and geographies vary greatly between the scoped countries.

1.6 Audience

This thesis was written for the intended audience of the supervisors at Lund University, Volvo Penta strategy development, microgrid developers, policy makers trying to understand microgrid structures, and peers in the environmental and sustainable energy fields. The target is especially for those involved in rural electrification strategies in the regions of South Asia, Southeast Asia, and could even pertain to Sub-Saharan Africa.

1.7 Ethical Considerations

This thesis was conducted in cooperation with Volvo Penta's New Business Development division in Gothenburg, Sweden. Pursuant to a non-disclosure agreement, all data that is considered sensitive to the company and its stakeholders has been omitted and only information that would be suitable for the publishing of this thesis to the public has been included. Names and positions of those within the companies interviewed have been omitted to avoid any implicating claims, and information obtained from interviews was used only as leads to find publicly available data. During the process of this thesis, it was taken into account that the regions studied vary greatly in ideologies, cultures, politics, and values. Therefore in no way do the findings of this research seek to impose personal views or to disregard the diversity of the countries at study. Academic integrity was held up throughout the research and writing process for this thesis to ensure that information was accurate and the written product genuine.

1.8 Outline of Thesis

Chapter 1 introduces the encompassing problem of rural electrification and sustainability, while showing the microgrid market as one of the solutions.

Chapter 2 explains the methodology used in collecting data from literature, documentation, and case study simulation.

Chapter 3 contains the first part of the data collection through literature review. The initial introduction to this section provides a brief overview of the type of microgrid at focus.

Chapter 4 deviates from documented data collection into more quantitative approach through the use of a microgrid simulation software.

Chapter 5 brings together all of the resulting data to be analyzed. It provides a triangulation approach to get stronger insights to the research question. It discusses the results and their meaning to the broader microgrid industry and policy direction for electrification.

Chapter 6 concludes the study by providing a direct answer to the research question. The final section of the chapter discusses the implications for further study into the topic.

2 Methodology

The data needed to perform this thesis required insights from both industrial and government sectors. Much of the information found is publicly available through previously published papers, government reports and databases, and large international agencies. Insights into industry trends were not always publicly available, but rather secured through unstructured interviews with professionals in the industry, including at Volvo Penta. Due to the sensitivity of the interviews, no data within them is published but rather used at gateway to acquiring further information or to verify knowledge that was publicly found.

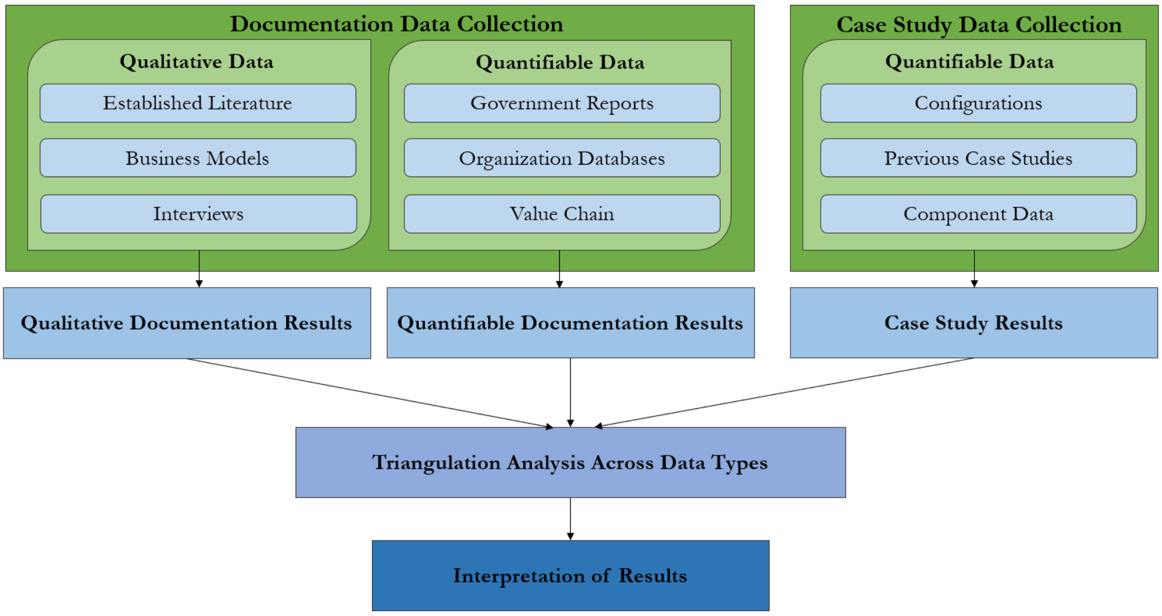

Figure 4 Model of the methodology employed throughout the research process.

The initial step to this methodology begins with a documentation of existing literature on microgrids, bankability, and policy (figure 4). This helped to identify what has already been explored, specifically in India and Southeast Asia. It also helps to contextualize the problem further and give the reader a stronger understanding of the subject. After a review of the literature, further information was needed about government policy and user data from each country in the scope. The final part of the data collection consisted of examining microgrid case studies and load profiles that would be used for analysis.

Table 1 List of research subtopics and the chosen methods of obtaining attributed data.

Research Subtopic	**Method of Acquiring Data**
Identify the main components and services of a microgrid, carefully mapping out where value is added as well as accounting for capital and operational costs.	- Documentation of case studies - Interviews with microgrid developers - Volvo Penta internal data - Case Study Research
Investigate where microgrid financing comes from as well as drivers, facilitators, and barriers.	- Documentation of previous literature - Government data and reports - Interviews with microgrid

	developers
Record microgrid business models and demonstrate how they are effectively used in distinct markets.	- Documentation of case studies - Documentation of previous literature
Explore the policy drivers, facilitators, and barriers of the countries within the scope and compare.	- Documentation of previous literature - Government data and reports
Perform microgrid configuration optimization of case study projects to evaluate the fluctuations in capital and operational costs of various scenarios.	- Documentation of case studies - Documentation of previous literature - Government data and reports - Volvo Penta internal data - Case Study Research

2.1 Documentation

2.1.1 Interviews and Inquiries

To gain access and insights to certain information, unstructured interviews were used. Inquiries into certain information were also performed within Volvo Penta to gain access to knowledge about components and market information. Relevant actors were suggested through Volvo Penta as well as the author's own communication. A full table of interviewees is available in the appendix, figure 15.

2.1.2 Literature Review

There already exists a wealth of documentation on microgrid research within the study area scope. The aim of this section is to refine the definition of concepts and present established finding from previous research. Main concepts defined in this section are microgrids, rural electrification policies, microgrid policies, and bankability. Since the definitions of each concept are not arbitrary for all cases, they are explained based on the scope of this thesis. First, the definition of a microgrid is made clear and distinguished from other common nomenclature. The basic information on microgrid configurations and philosophy is presented to show how they contribute to a project's value stream. After setting this basis, a brief overview of rural electrification is given within the context of India and Southeast Asia. Data obtained through international reports and databases is arranged in way to quickly provide comparative information to the audience. Electrification policies are introduced between the countries to build a case for the need of microgrids to fill the gaps in rural electrification. The concept of bankability is defined for the use throughout the thesis. Previous literature on project bankability is summarized to show the consensus of the greatest aspects to financing. The final section aims to present the gaps in research and the connections that still need to be made pertaining to diesel gensets, electrification policy, and financing.

2.1.3 Government Reports, Policy, and Data

Data was required on the policies, frameworks, and overall energy market of each country within the scope. The policies explored were based on the recommendations from the literature on what can have an effect on microgrid uptake and bankability. Main policies are rural electrification schemes, renewable energy policies, and off-grid energy policy. After gaining a further understanding of the effects that these policies have, it was determined financial investment policy should also be examined. Countries were then researched to explore how their current policy frameworks would affect the capital investments into energy projects.

Microgrids grow based on the policy sphere that surrounds them. Information on country policies was important for realizing how policy would affect components and business models, which have further implications to bankability. The International Renewable Energy Agency recommends that the most important political pressures to affect microgrids are rural electrification strategy and energy market regulation. All of the countries were scrutinized for their rural energy policies and openness of energy market (International Renewable Energy Agency, 2015). Details on the country's past policy were also explored to get an idea of the direction for future policy related to microgrids. Financing policy was explored and divided into funding categories for a microgrid project. This was to show where there is political backing for government finance in off-grid energy solutions. Since fuel is a main issue of costs in microgrids with diesel generation, it was important to also explore how each country plans to regulate subsidies on fossil fuels in the future, or where its renewable energy targets are. The information gathered is presented as a matrix (table 2) to see how countries compare and trends in the microgrid policy framework for the regions.

Table 2 Matrix used to determine the impact of country policies on microgrids and diesel generators

	Strong Negative	Negative	Neutral	Positive	Strong Positive
Diesel Effect	Actively denounces use of diesel with fiscal measures and policy	Policy denounces use of diesel	No significant effect	Provides incentives that could increase instances of diesel use	Promotes the use of diesel in energy projects or provides funding subsidies
Microgrid Effect	Reduces funding and policy towards microgrids	Reduces the funding towards microgrids	No significant effect	Framework or funding to encourage microgrid projects	Framework and funding for microgrid projects
Magnitude of Effect	N/A	N/A	No significant effect	Moderate targets and funding	High targets and funding

Data from the energy market was needed to analyze things like energy cost, electrification rates, etc. The World Bank Group has a collection of data from 2016 that served as a good starting point for each country. However, electrification rates are constantly changing so government databases provide updated figures when available. Energy costs were found by exploring the utilities within each country that have information available on historical pricing. These same utilities contain data on demand and growth statistics that help to show the changes in energy patterns. Customer load profiles were gathered from the utilities that would later be used within the study's own case study profile. Load profiles were available in the form of spreadsheet data that was reworked into visual data representations.

2.1.4 Microgrid Profiles

Microgrids vary in all capacities, so it was important to understand how the configurations are based. Articles and reports were examined for microgrids that were within the project scope. Previous studies were vital for understanding the most optimal configurations of microgrids, common project challenges, and recommendations for future research. Optimal microgrid configurations were important for understanding if there was a role for diesel generation within the most efficient systems and what that role would be.

Microgrid market data was mostly available through public resources, though some information was provided by companies interviewed. Market data was used to determine which sector has the highest growth in microgrids. It was also used to gain an understanding on the frequency and size of components in common profiles for the regions. Company actors interviewed were able to give primary information as to how they perceive the microgrid market in their respective operating spheres. Information on specific customers and sales was unfortunately prohibited, but would have been even more useful for the study.

2.1.5 Value Chain Map

After real case studies were evaluated, information was reformatted to identify the value chain of microgrids. The emphasis of the thesis is the effect of a component on microgrid financing, so it was necessary to account for the value that each component adds to the system. The first priority was to map the entire value chain of an optimized microgrid to gain insight into where a microgrid adds value beyond energy generation. Costs of components and services were found in Volvo Penta's product specifications, former microgrid market studies, and case studies on systems.

2.2 Case Study Research

The HOMER Pro software was used to analyze the data of various microgrids in this study. HOMER (Hybrid Optimization of Multiple Energy Resources) Pro was chosen because of its reputability in the professional world of microgrid development as well as its collective database on microgrid components. It has been used many times in previous microgrid case studies to explore optimization techniques. The HOMER model is used in three steps: simulation, optimization, and sensitivity analysis (Lambert, Gilman, & Lilienthal, 2006). The simulation is run with the system's base input information such as components and load profile. The model is optimized through thousands of simulations and reports the best configuration. Optimization is evaluated through sensitivity tests for multiple variables.

Several studies contributed to the development of a simulation in HOMER for this research. Three studies in particular were used to create the simulation based on their previous findings. They were based on microgrids in Sri Lanka, Malaysia, and Canada. The Sri Lankan and Malaysian case studies were used because they represent real microgrids that have been developed and optimized through the HOMER software (Givler & Lilienthal, 2005) (Halabi, Mekhilef, Olatomiwa, & Hazelton, 2017). The Canadian case study provides the most detail in the process used to evaluate system optimization using HOMER (Hafez & Bhattacharya, 2017). The National Renewable Energy Laboratory published a report in 2003 that characterized all combustion technologies used in distributed energy generation. This report provides specifications, estimated costs, and challenges of each piece of technology used in the microgrid (NREL, 2003). The data yielded from the report helped to verify component cost trends and technology shifts to formulate a better idea of the direction of microgrid development.

Data gathered on microgrid components and configurations was run in a simulation through HOMER to provide an optimized design of the system based on operating philosophy, cost, and sensitivity of selected variables. A visual model of the simulation can be seen in figure 5. The simulation was then used to determine the cost of energy (COE), net present cost (NPC), OPEX, and CAPEX of the project per system configurations:

A. The most optimal hybrid system based on lowest COE and configuration feasibility (the system must function realistically).
B. The most optimal hybrid system consisting of 100% renewable penetration through a PV+BS design.
C. A system consisting of only the two DG components providing power with some BS incorporated to improve efficiencies of the DG (excess power capture).

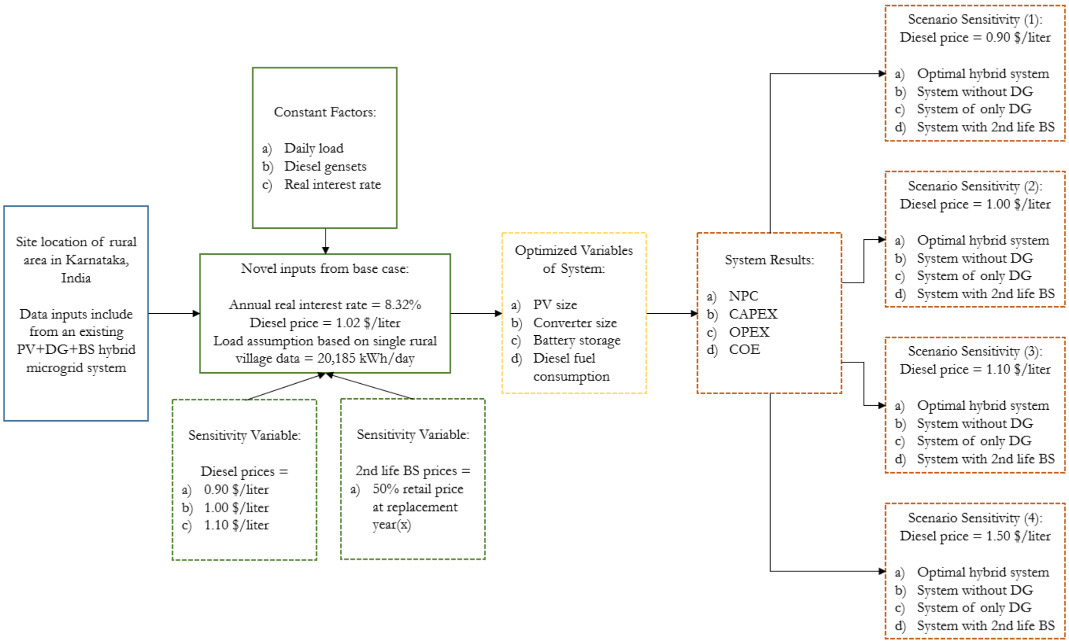

Figure 5 Process model for optimization and results of hybrid microgrid using HOMER software.

The simulation was run with example load data based on a survey of sample residential loads throughout the region of Karnataka, India. Data was gathered through the Karnataka Power Transmission files (Karnataka Power Transmission Corporation Limited, 2018), Bangalore Electricity Supply Company (Chunekar, Varshney, & Dixit, 2016), and a joint initiative between the Government of India and Government of Karnataka (Crisil Infrastructure Advisory, 2016). The load used in the simulation has been increased to reflect the hypothetical usage of a residential cluster of 1000 households, i.e. retrieved sample load data unit multiplied by 1000. This method of load data runs on the assumptions that all households will have similar power demand structures throughout the day, which is uncommon considering the wide wealth gap in India. However, the daily load curve used is a reflection on the average of 1000 households surveyed by Bangalore Electricity Supply Company and verified through the other sources mentioned. The simulation was given the site specific location of the outskirts of Hubballi within the Karnatak region. Site specific coordinates are used by the software to incorporate solar global horizontal irradiance, temperature, and weather data provided by

NASA Surface meteorology and Solar Energy database[2]. The coordinate location is important because the mentioned factors will have an effect on the efficiency and lifetime of system components.

This model remains most applicable to the Indian context of rural or peri-urban settings. The model does provide an accurate look at data behind a potential project as well as an effective way to gather meaningful results from minor variabilities in the system. The same model could be used in other countries as long as the cost accounting and geographic parameters are adjusted accordingly.

A sensitivity analysis is used to account for the variability in costs, one of which in this case study is represented by the price of diesel fuel across regions. The price of diesel fuel in the region fluctuates daily along with the local currency (Indian Rs). The 2010-2016 average price for diesel across India was 0.85$/liter (German Agency for International Cooperation, 2016), but currently stands at 1.15$/liter (Bank Bazaar, 2018). Due to this gap range of 0.30$/liter, a sensitivity of 0.10$/liter was used in the scenarios at: 0.90$/liter, 1.00$/liter, and 1.10$/liter. An outlier sensitivity of 1.50$/liter was also to examine the effects of possible large fluctuations in fuel prices.

The next sensitivity scenario was the projected costs of the storage component of lithium ion batteries throughout the 25 year lifespan of the project. Information on lithium ion batteries was available in the form of batteries used in electric vehicles. Lithium ion batteries used in large-scale microgrid projects are similar to those used for ultra-modern electric vehicles (EV). The battery size for this microgrid was determined to be in the form of those that will be commissioned in truck-size electric vehicles. A series of 100 kWh capable lithium ion batteries was chosen as the series size for the MG due to its frequency of use in modern passenger and truck-size EVs (Iclodean, Varga, Burnete, Cimerdean, & Jurchis, 2017). The replacement costs of the batteries are based on their 8 year lifespan before being replaced, with the assumption that the batteries will have reduced their maximum state of charge to 70% of original capacity. After the 8 years from the installation of the first batch of batteries, the costs for replacements have been determined by the projected lower costs of the same batteries in the year 2025 (figure 5). The EV industry has been posed with the problems of waste in the form of spent batteries from the growing fleets around the world. One such application was proposed as using second-life lithium ion batteries for cheap storage capabilities in microgrids. The model is then run with the sensitivity to include the lowered cost and storage of reused batteries. The sensitivity scenario uses a 50% price reduction in the cost of second-life batteries as well as the assumption that these components will have only 70% original capacity.

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[2] GHI, temperature, and weather patterns can have a large effect on the efficiency of solar PV units and battery cells.

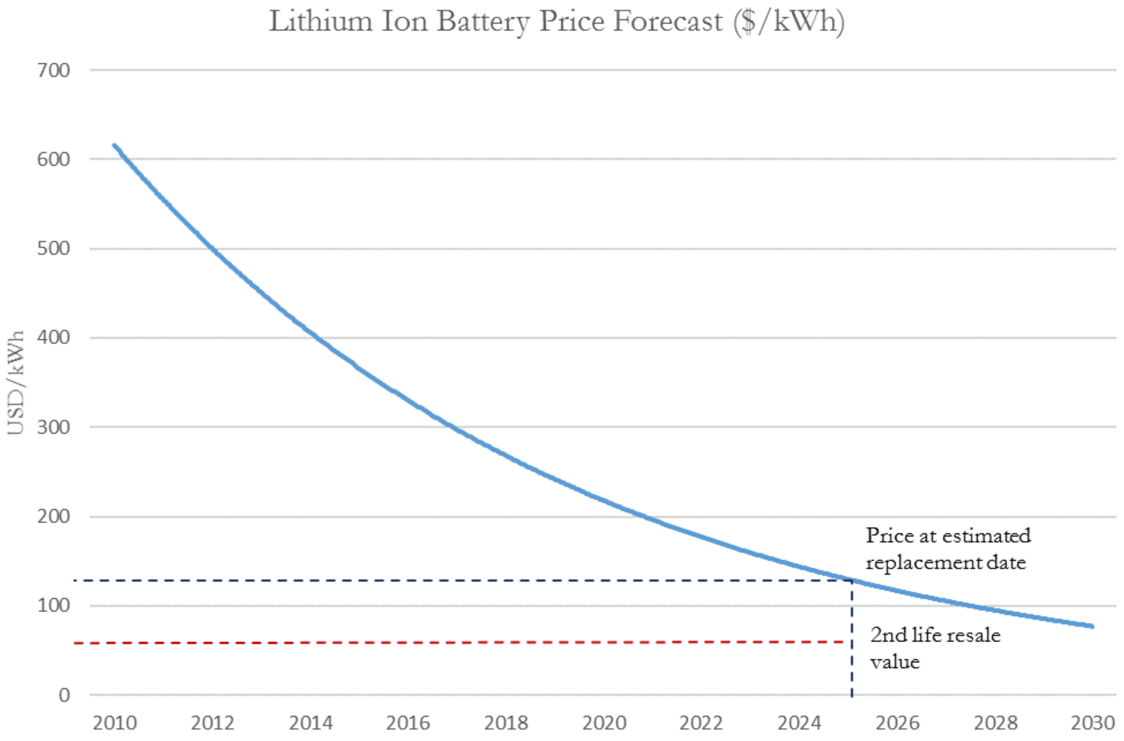

Figure 6 Lithium ion battery price forecast with the industry target price of 125-150$ by 2030.

Source: 1 (Hayward & Graham, 2017) (International Finance Corporation, 2017) (IRENA, 2017) (Union of Concerned Scientists, 2017)

The installed size of PV (kW) is variable in the model. Based on the sensitivity of the other components, the PV will be optimized by the HOMER software. The PV component was not chosen to be run through a sensitivity analysis because of the lifetime limits of the model. Prices of utility-scale PV installations have fallen dramatically and are projected to continue (see appendix, figure 15). However, this model runs on the assumption that the lifetime of the modules installed initially will have a lifetime of 25 years, the same as the duration of the project. Therefore, no new installed capacity is accounted for and replacement costs are negligible. In real life applications, the reduced costs of installed PV will have an effect on total system costs due to the expansion of the system and replacement of damaged or defective panels throughout the lifetime. The base case for the HOMER model with the attributes is represented in table 3.

Table 3 Component list of example large hybrid microgrid in rural India.

Component	**Attribute**	**Value**
Generic PV	Rated power (kWp)	Variable
	Efficiency (%)	13
	Lifetime (years)	25
	Operational temperature (°C)	47

Volvo Penta 716 kVA-50Hz Diesel Generator x 2	Rated power (kW)	573
	Minimum load ratio (%)	30
	Minimum running hours (h)	30,000
	Lifetime (h)	90,000
Generic System Converter	Rated power (kW)	Variable
	Inverter efficiency (%)	90
	Rectifier efficiency (%)	85
	Lifetime (years)	15
Generic Lithium Ion Battery Pack	Nominal capacity (Ah/battery)	167
	Nominal capactiy (kWh/battery)	100
	Nominal Voltage (V/battery)	600
	Lifetime (years)	8
	Conversion efficiency (%)	85
	Minimum discharge state (%)	20

The components in the system were given values (2018 USD) according to data based on existing microgrid case studies, Volvo Penta product information, IRENA reports, IEA reports, databases from the Government of India, and various literature. The values associated with system costs per components can be seen in table 4.

Table 4 Costs of components over the project lifetime based on set parameters and existing microgrid projects (prices reflect USD value in 2018)

Component	System Cost	Value
Generic PV	Capital ($)	770/kW[3]
	Replacement ($)	770/kW
	O&M ($)	10/year

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[3] Cost pertains to installed utility scale PV above 100 kW in India 2018 (Ministry of New and Renewable Energy, 2018) (Fu, Feldman, Margolis, Woodhouse, & Ardani, 2017).

Volvo Penta 716 kVA-50Hz Diesel Generator x 2	Capital ($)	90,000
	Replacement ($)	81,000
	O&M ($/operation hour)	0.03
Generic System Converter	Capital ($)	890/kW
	Replacement ($)	800/kW
	O&M ($)	10/year
Generic Lithium Ion Battery Pack[4]	Capital ($)	27,000/battery
	Replacement[5] ($) 2nd Life Replacement ($)	12,000/battery 6,000/battery
	O&M ($)	4000/year

2.3 Analysis of Findings

This study contains two major sources of information to be analyzed: documentation review and case study data. A documentation analysis was chosen to evaluate the data gathered through documentation review. The documentation phase yielded data from reports, articles, literature, and primary sources. The documentation format of review was advantageous because it analyzed the various forms of the data based on content and theme (Bowen, 2009). The results of HOMER were scrutinized using a deductive analysis. The data was displayed according to the affected variables and analyzed for differences and patterns between the sensitivity scenarios and microgrid configurations.

2.3.1 Triangulation of Data

The documentation results and HOMER analysis yield data in different formats. The documentation results remain in a qualitative format whereas the HOMER analysis provided data in a quantitative form. The use of data triangulation was chosen for two reasons. The first was to use the advantages of triangulation to enable the comparison across two types of data sets. The triangulation method is useful in comparing data when the basis of comparison is not easily recognized between the data types, especially with the use of mixed methods. The second reason was to establish greater credibility within the study by using multiple methods and corroborating the results (Jonsen & Jehn, 2009).

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[4] Based on full solution costs with the battery account for 40% of total expenditure (International Energy Agency, 2018, s. 67) (Allruwaili, 2016).

[5] Replacement costs are determined by the future projected costs of lithium ion batteries at the expected end of life. (IRENA, 2017)

3 Literature Review

The literature review section of this study presents data on the main topics of research. Microgrids are covered first to establish the concept and introduce the various configurations and components involved. The business case for microgrids is presented to provide context to the problem of financing while introducing business models common within the scoped regions. Rural electrification within India and Southeast Asia is given in greater detail to highlight particular problem areas and build the relationship between energy access and adoption of microgrids.

3.1 Microgrid Overview

3.1.1 Microgrids

The precise definition of what constitutes a microgrid is often a subject of interpretation. Verbiage can change depending on the system's size, design, and level of connectivity to the macrogrid. For this thesis, the definition from (Hossain, Kabalci, Bayindir, & Perez, 2014) will be used: "a localized group of electricity sources and loads that it normally operates connected to, that acts as a single controllable entity and in a synchronized way with the conventional utility grid, but can be disconnected and independently operated according to physical and/or economic conditions". This definition covers the most important principles of microgrid structure and operation. First, a microgrid must consist of *localized* electricity sources that work to achieve a common goal of meeting normal loads or achieving demand-response. For this research, the electricity sources can come from either renewables or traditional means of generation. The next part of the definition is perhaps the most important element of a microgrid's purpose, which is being *controllable.* An aggregate of energy-production sources is an easy task to achieve, but incorporating intermittent renewable energy generation (REG) while meeting various load profiles is no walk in the park. The element of control in a microgrid allows it not only to balance between production sources, but also to shift to and from storage options when needed based on the operating philosophy. The last part of the definition is flexible when speaking about microgrids. Definitions include the principle that a microgrid must have a point of central coupling (PCC) with the macrogrid, but can operate in an islanded mode if required/requested (Vine, Attanasio, & Shittu, 2017). This aspect of the microgrid creates some obscurity because we often observe microgrids to be in remote areas that have no connection to the macrogrid whatsoever. The International Renewable Energy Agency (IRENA) delineates this confusion by addressing microgrids without a PCC as an "off-grid" microgrid. These off-grid microgrids have the same constituents, but differing operating philosophies due to the lack of access to the macrogrid (International Renewable Energy Agency, 2015). Many of the setups to be discussed in this paper are seen as off-grid microgrids, but due to rapid new expansions of the macrogrid in these areas, it is difficult to know whether this may still be the case. Therefore, throughout this thesis the term microgrid will constitute both off-grid systems as well as those with a PCC to the macrogrid, with the occasional delineation in reference to "remote microgrid" systems. The terms "minigrid", "mini-grid", and "micro-grid", are often used interchangeably in international reports, but shall take specific meanings in this thesis.

Microgrids can be designed for various purposes and sizes of generation. As such, nomenclature has been used to distinguish the size and complexity differences, although it differs greatly between research bodies. For example, the United Nations Framework Convention on Climate Change refers to mini-grids (aka microgrids) as having a total capacity not exceeding 15 MW of generation (United Nations Framework Convention on Climate

Change, 1992), whereas another report regarding distributed vs centralized energy projects uses the maximum capacity generation limit of 1 MW (United Nations Framework Convention on Climate Change, 2015). The maximum generation of 5 MW for a microgrid will be used as per the scope of the study, which was determined by the regulation of independently operated isolated energy systems in the countries at study varying from 1-10 MW. Smaller-scale microgrids have been assigned the names "nanogrid" and "picogrid" so as not to categorize grids generating 5 MW with grids having only 1 kW capacity. Going beyond the 5 MW scale, there has been discussion of connecting multiple large microgrids together to form what has been coined an "ecosystem". A microgrid ecosystem consists of centralized generation or the utility grid, distributed generation from residential or commercial microgrids, energy storage, and controller-enabled appliances. All components and actors in the ecosystem are optimized to share infrastructure for achieving the best ROI (Jiang & Fei, 2014). Table 5 serves as a reference to the size and capabilities of each respective microgrid.

Table 5 the classification of various microgrids according to size and complexity. Information based on.

	Size (kW)	**Complexity**	**Cases**
Stand-alone	0-0.1	• Single generation unit	• Single DC connection • Serves one household
Picogrid	0-1	• Single controller • One to a few generation units	• Not grid-tied • Remote system • Serves a single or a few households at small loads
Nanogrid	0-5	• One to multiple controller • Multiple generation units	• Grid-tied or remote • Serves multiple households • Favors DC connections
Microgrid	5-5000	• Multiple generation and storage components • Controllers manage local energy supply • Provides quality and reliability options • Operates in multiple philosophies	• Grid-tied or remote • Supplies villages, large islands, city sectors, or industrial power needs • Can sell excess power to macrogrid for better economics
Ecosystem	5000<	• Multiple interconnected microgrids • Large-scale generation components • Highly complex controllers optimize demand-response and economics of generation/storage	• Interconnected customers • Industrial parks, multiple village or city sector microgrids • Mission-critical infrastructure with similar power needs

Source: 2 (International Renewable Energy Agency, 2015)

3.2 Business Case for Microgrids

The first major use cases for microgrids were seen in military operating bases to ensure reliability and security in power supply. Now, microgrids are seen everywhere due to their many useful applications. An International Energy Agency report on energy investment found that global investment in microgrids was USD 14 billion in 2017. Off-grid microgrids accounted for 25% of total all microgrids installed in 2017 (International Energy Agency, 2018, s. 75). The most common source of electricity in these systems was from small-scale diesel generators. Figures by another market analysis peg the microgrid market to reach USD 38.99 billion by 2022 with a compound annual growth rate of 12.45%, while revenue generated through off-grid microgrids and nanogrids to exceed USD 25 billion by 2024 (Khodayar, Rural electrification and expansion planning of off-grid microgrids, 2017, s. 68).

3.2.1 Operational Philosophies

Microgrid systems are designed to fill the needs of users that cannot be met through the traditional macrogrid. The macrogrid provides customers the service of access, where it is applicable. In areas like India and Southeast Asia, basic access is lacking through the traditional grid, leaving a gap to fill. Access is one of the most prevalent operational philosophies for nanogrids and microgrids in Southeast Asia and India. Often places with little or no access were supplied by diesel generators run for a few hours a day, but the introduction of renewable energies can increase the penetration of access to these areas.

Having access to electricity is not enough to generate the huge economic potential of electrification, there must also be a reliable supply. While the access to supply has increased, the quality of electricity delivered still varies. The quality of power received can have constraints on the size and types of enterprises that develop (Samad & Zhang, 2016). In a World Bank survey of firms worldwide, those in Southeast Asia and India were found to be significantly affected by poor quality of electricity (table 6). The trends reveal that large percentages of the firms suffer from electrical outages for hours at a time, some for multiple times per month. It should also be noted that a fair percentage of firms own or share a generator, especially in India and the Philippines where the populations are high.

Table 6 World Bank Enterprise survey of firms in various countries to represent the effects of electricity quality.

Country	**Firms experienced electrical outages (%)**	**Number of electrical outage per month**	**Average duration of outages (hours)**	**Firms owning or sharing a genset (%)**	**Average proportion of electricity from genset (%)**	**Firms identifying electricity as a major constraint (%)**
Cambodia (2016)	35.3	1.4	1.3	40.0	9.0	6.1
India (2014)	55.4	13.8	2.0	46.5	8.8	21.3
Indonesia (2015)	22.5	0.5	5.7	11.7	16.5	14.5
Lao PDR (2016)	51.9	0.9	3.3	3.4	71.8	23.3
Malaysia	18.9	0.1	3.8	10.8	20.7	9.4

(2015)						
Myanmar (2016)	94.9	11.0	1.3	52.3	15.4	6.8
Philippines (2015)	39.9	0.1	3.0	42.7	38.9	19.6
Thailand (2016)	8.6	0.2	1.7	0.4	20.0	23.7
Vietnam (2015)	26.3	0.2	7.5	25.2	1.6	3.7

Source: 3 (World Bank Group, 2017)

Beyond just reliability, there are markets that seek the value of microgrids through their added resiliency to a power system. Some services and infrastructure require uninterrupted power supply (UPS) that is mission critical. Hospitals, water treatment centers, data centers, research facilities, and military operating bases require power to be delivered even in the situation of extreme weather events or security attack. This driver is seen more often in developed markets but is becoming increasingly used in all areas, especially in coastal or island regions sensitive to the extreme weather events associated with climate change. Microgrids were characteristically high in cost and unavailable to customers without heavy amounts of capital investment. With the recent fall in lifetime energy prices of REG, microgrids are becoming a more attractive option for their affordability. Most often, this occurs in energy markets where fuels costs are relatively high. Adding local REG into the mix, typically alongside an already established diesel generator, can significantly reduce fuel costs and ultimately lower MG operating costs. It is important that microgrids with REG incorporated be designed accordingly to maximize utility of the renewable energy sources locally available rather than a one-size-fits-all approach. Another driver, and more so a facilitator, for microgrid value is sustainability. The international call for clean energy has some customers looking for ways to integrate higher amounts of REG into their profiles. Microgrids can add REG into the system as well as utilize the benefits for effectively than the macrogrid. The variable generation of renewable energy sources such as wind and PV are controlled through storage technologies to avoid over-generation. Sustainability is demonstrated as a facilitator of MGs through its continued subsidization from government schemes. A highly advantageous trait of MGs is the ability to support the macrogrid through its PCC. Systems can be optimized for increased demand-response and help the macrogrid better control production in times of peak loads. This provides economic opportunity for the system by selling energy to the macrogrid when energy is most expensive, while also producing cheaper power for operators. Ancillary services beyond demand-response include support in the case of black starts, which can be costly when done solely through the macrogrid. This tends to represent savings on infrastructure in the macrogrid by reducing the need for expensive beaurocratic projects (Hirsch, Parag, & Guerrero, 2018).

3.2.2 Optimization

The various user needs for MGs require that most systems be optimized differently. Traditionally, off-grid energy was provided primarily with diesel gensets. The diesel genset was a way to achieve high volumes of electricity with low capital costs. The shift away from diesel-only generation is due to volatility in fuel prices/availability, high degree of technical maintenance, and environmental degradation. These costs attributed to the operational phase of the diesel genset offset the savings in capital costs (Khodayar, 2017). The most attractive and economical systems have similar components: renewable energy generation (REG), diesel generators (DG), and battery storage (BS). Optimization models take into account the operating philosophy of the system, and attempt to find the most cost-effective configuration. This proves difficult considering the geographic, market, and governance differences between regions. For example, when calculating the amount of photovoltaic (PV) generation needed, the variable average sunlight, weather patterns, and temperature will all affect the kW_p for the array, which can also vary by manufacturer. Hybrid systems consisting of PV+DG+BS are common because of the low operating cost of PV coupled with the redundancy and low capital cost of DG. Battery storage options create flexibility in the system and capture the nearly free energy produced by REG. The BS also acts as a way to smooth out the minor fluctuations in demand-response, which can be expensive when done arbitrarily by the genset (figure 7).

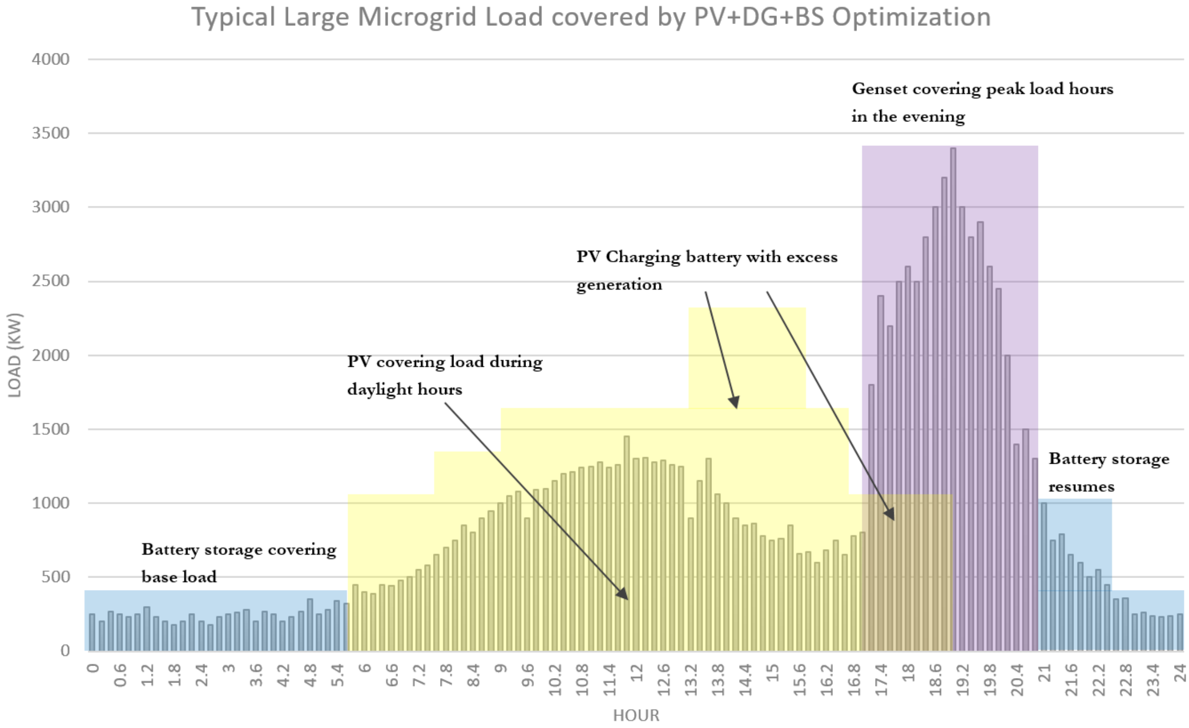

Figure 7 Representation of the daily electricity production and charging of an optimized microgrid based on a common daily load curve.

The inclusion of BS may represent high capital expenditure (CAPEX) but can reduce the operating expenditure (OPEX) of a system throughout its determined lifetime. This hybrid system can cut the LCOE roughly in half compared to DG only systems in areas with high fuel costs[6] (Danley, 2017) (Goel & Ali, 2014).

Table 7 Common components that make up a hybrid microgrid with energy storage options

System Component	Common Sources	Benefits	Challenges

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[6] The common price of diesel used for modelling is 1.0-1.06 $/liter.

Reciprocating Internal Combustion Engines	• Diesel Fuel • Biodiesel (HVO)	• Easy to dispatch/small footprint • Reliable technology • Less mechanical expertise required	• Air and noise pollution • Expensive operating costs • Requires refueling
Storage	• Batteries (lead acid, lithium ion, nickel cadmium) • Flow batteries (vanadium redox, zinc-bromide) • Fuel cells (hydrogen, methane-based) • Kinetic energy (fly wheels, pumped hydro)	• Reactive 'smart' power • Clean energy can be stored • Allows systems be more flexible	• End of life concerns • Reduced efficiency by converted energy • Life-time is short and sensitive to many factors • Expensive and in early development stages
Renewable Energy Generation	• Mini-hydro • Wind turbines • Solar (concentrated, PV) • Biogas	• Zero fuel costs • No need for access to fuel supply chain • Low environmental impact • High public and government support	• Requires storage for full functionality • Intermittent generation compared to peak load • Variable energy production complicates ROI for financers

Source: 4 (Danley, 2017)

The notion of optimized microgrids with DGs is further reiterated in a study using NREL's HOMER Software. The case study investigates the role of the DG specifically in small-scale solar power systems. Using the modeling software, the researchers were able to identify the most cost-effective configurations based on a hypothetical load in a scenario in Sri Lanka. The results found that PV+BS configuration was the most optimal configuration for very small loads, up to 13 kWh/d, depending on the right conditions of the other variables. Beyond this load, the PV+DG+BS hybrid model was the most cost-effective and reliable configuration. The study is similar to the HOMER analysis that was conducted in this thesis, but the regions at focus and system sizes are far different. However, this Sri Lankan case study is an interesting example of the role of the DG in picogrid configurations (Givler & Lilienthal, 2005).

3.2.3 Business Models

A business model is a tool that is used by companies to deliver a value that its customers will pay for, which is translated into a profit. For microgrids, a business model covers the services that are provided, how they are translated into value for the customers, and how this value is generated beyond the expenses incurred. Business case models need to be developed, specifically for the microgrid at hand, which aims to minimize capital and operational costs while still providing valuable services (Balijepalli, Khaparde, & Dorbariya, 2010). Generally, the microgrid aims to cover the basic services that the macrogrid provides: power generation, transmission[7], and distribution. The traditional macrogrid uses a static model that consists of just producers and consumers. The utility builds, owns, operates, and maintains (BOOM) the energy network to charge the consumers with an energy based on market demands. In contrast, microgrids require a much more dynamic business model to deal with the various actors in its value chain. A third party is generated in the microgrid business model that is

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[7] Transmission is often not needed in the case of microgrids due to the intrinsic on-site locality of the system. However, some larger microgrids must provide transmission infrastructure, especially in the case of larger ecosystems.

termed the 'prosumer'. The prosumer acts as both a provider and consumer of energy in the instance that the microgrid either sells or buys energy from other actors. An example of this would be a small microgrid that is owned and operated by a community. The community uses the MG for its own energy consumption, but sells the excess production back to the macrogrid. The community not only consumes the energy it produces, but also acts as an energy producer on the market (Rodriguez-Molina, Martinez-Nunez, Martinez, & Perez-Aguiar, 2014).

Multiple stakeholders within a microgrid system creates the challenge of delineating which parties take over the BOOM responsibilities that the utility-owned macrogrid once did. There are four major business models that are observed to take place in the microgrid prosumer market to manage the BOOM aspects (Franz, Peterschmidt, Rohrer, & Kondev, 2014).

Utility Operator Models

Similar to the traditional macrogrid business model, the local utility is responsible for microgrid development. Funding typically comes from government sources in an attempt to secure the MG services for public needs. Energy is fed back into the distribution network and to the utility's customers at a cross-subsidized rate similar to that paid for energy from the macrogrid. The potential for MGs in rural electrification schemes through the utility is high, but often not within the core functions of the utility.

Private Operator Models

Microgrid systems are solely planned, built, operated, and owned privately. Funding is entirely through either private equity and loans, or a combination of private equity and some sort of public grants or subsidies. The former is often rare due to the relatively high investment risk of microgrid projects combined with the private sector's typical aversion to low or negative project ROI. Some successful private sector models are the Anchor-Business-Community (ABC) approach, clustering approach, and local entrepreneur approach. The ABC approach involves finding an established anchor customer (usually telecom tower in the case of India) that can deliver reliable energy payments, extending the grid to local businesses that have a potential for high payback rates, and finally delivering connections to other customers that may have created too large a financial risk by themselves. The clustering approach uses economies of scale to reduce the operational costs of multiple microgrids in local area by utilizing the same labor and overhead costs. The local entrepreneur approach establishes local workforce that operates and owns part of the system. Local entrepreneurs have greater social network, self-investment, and influence in the community served allowing for better security, money collection, etc.

Community Based Models

A local community engages in the ownership, operation, and maintenance of the MG. The system is planned and built through third parties since the community might lack the local expertise. Community models are heavily financed through grants and subsidization, but operational costs can be somewhat recovered through community contributions. Local decision-making structures are used for smaller systems to avoid conflicts, but larger systems tend to be more formalized.

Hybrid Operator Models

The hybrid model uses a combination of the above three. All aspects of BOOM, including financing, can be carried out by different partners. Responsibilities as well as power purchasing must be clearly delineated before the planning stage. Hybrid models allow all parties to take on less financial risk by diversifying ownership of the system and engaging the strengths of different actors.

3.3 Rural Electrification

3.3.1 Electrification Rates in Rural Areas

Rates of electrification in urban and peri-urban areas have achieved far better success than that of rural areas. This data is not surprising due to the difficulties of expanding the macrogrid to rural customers. Some countries, such as Singapore and Peninsular Malaysia, have been highly successful in aggressively expanding transmission and distribution to its rural areas. Others, such as Myanmar and Cambodia, have not achieved high rates of electrification yet (figure 8).

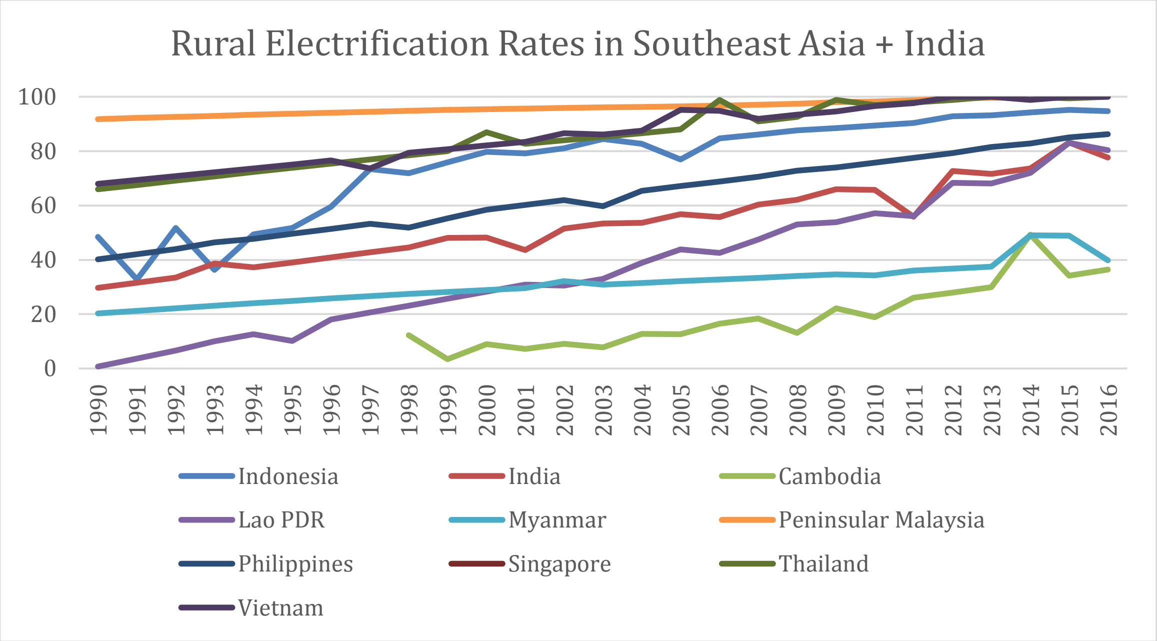

Figure 8 Rural electrification rates (%) of the countries within the selected project scope.

Source: 5 World Bank. 2018. "Electrification rates, rural".

Growth rates of rural electrification are promising, even if they fall short of achieving the Sustainable Development Goal 7: electricity for all by 2030 (United Nations, 2018). Percentage rates of the population do not illustrate the entire picture of the problem, as will be further shown in section 2.3.2. Definitions of 'electrification' vary by country, as well as large population differences among the Southeast Asia and India countries. Countries such as Indonesia and India have reduced their percentage of unelectrified rural areas, but this still leaves massive gaps in population without access.

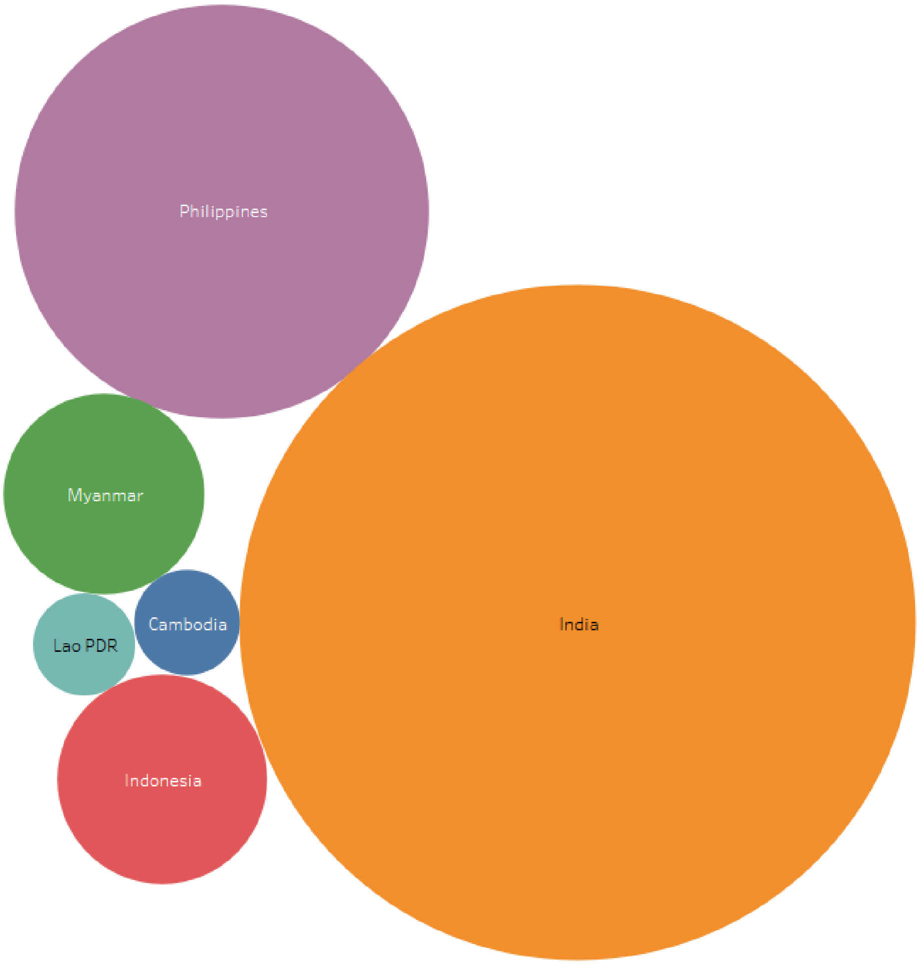

Figure 9 Packed bubble map with size corresponding to the number of rural population within the country without access to electricity (ref: Lao PDR = 5.46 million)

Source: 6 (World Bank, 2018)

Rates of rural electrification are lower than urban counterparts for a variety of reasons that differ between countries. Geography, technical solutions, financial incentives, natural resources, and economic capacity of individuals are just some of those reasons. According to the ASEAN Guidelines on Off-grid Rural Electrification, there are certain factors that are indispensable to rural electrification strategies:

- Predictable policy framework
- Sustainable business models
- Community involvement
- Support and financial mechanisms
- Appropriate technology
- Training and capacity building

The most influential way to strengthen the rural electrification strategies is through a strong, long-term commitment to policy framework (ASEAN Centre for Energy, 2013).

3.3.2 Policy Incentives

The Indian government set out its energy reform process by creating the Electricity Act 2003. The Act set policy guidelines, standards, and regulatory framework to accelerate the development of a market-based electricity system. Private sector participation was encouraged by unbundling vertically integrated utility structures, enabling a more competitive market. Transmission and distribution infrastructure was widely invested upon and remained the only components to be fully regulated by state-owned utilities. However, this opened up the deregulation of generation and market competition. The next major policy milestone was the National Electricity Policy 2005, which aimed to provide greater open access to for the availability of power. To tackle the problems with electricity quality and costs, the Indian government created the Tariff Policy 2016. These policy incentives were effective in urban and peri-urban areas, but still did not meet the task of achieving sweeping electrification rates (Power System Operation Corporation Ltd., 2017).

To meet the high demand for electricity in rural areas, the Indian government created the Saubhagya program. Saubhagya was set into action in September of 2017 by Prime Minister Modi in an effort to monitor and accelerate energy distribution through free energy connections. Households targeted by the scheme include unelectrified rural villages where grid extension is financially unfeasible and economically poor urban households without access. The former of the two is also provided with LED lamps and supplemental battery packs. The main generation through this scheme is through photovoltaic-based standalone systems (India Government Ministry of Power, 2018). Results of the electricity distribution policies are dependent on which statistics are used. Looking at only the village electrification rate, the Indian government announced in 2018 that the target of 100% was nearly achieved. However, the definition of village electrification in this context requires that a minimum of 10% of households have access to electricity. This still leaves huge gaps over the household level and makes no mention on reliability or quality of power. When looking at 100% household connectivity within 'electrified' villages only about 1,424 of the 18,374 villages are fully connected (India Ministry of Electronics and Information Technology, 2017).

All countries in Southeast Asia have adopted some form of rural electrification policies. Government ideas of best strategies are remarkable different though. In Vietnam, rural electrification is assigned to each province with support from a bottom-up approach, but with one central financing mechanism. In the Lao PDR Rural Electrification Master Plan, affordability is the most important aspect of the program but there is also a strong emphasis against off-grid energy projects based on the timeframe of grid extension. It is also prevents energy projects from being funded in areas where customer ability to pay is less than 50%, leaving financing out of the equation for the poorest of rural areas (Ministry of Energy and Mines of Lao PDR, 2010).

3.4 Bankability

3.4.1 Concept Definition

Microgrid projects are not shy when it comes to requiring upfront capital investments. As with any investment of capital, there is a desirable return to the financer. The term 'bankability' means various things depending on which entity is doing the financing. For this thesis, the term takes on the definition of: the willingness of a financial lender or investor to finance an energy project with a reasonable acceptance of risk. In the case of microgrid financing, bankability entails the risk that the lender is willing to take on to achieve a desired ROI from the lifetime of a project. Bankability of microgrid projects is ultimately up to the financers of the project and how they perceive risk. Private financers of microgrid projects tend to view the concept of bankability through a more monetary lens, such as a higher ROI. Whereas government funded projects might be considered more bankable if it generates revenue that can sufficiently carry the operation and maintenance costs of the system, or if it reaches certain policy goals. In some cases the customers are expected to provide some of the capital costs of the system, either up front or in the form of increased energy tariffs. In this case, the consumer accepts one or many of the values that microgrids create as the return their investments (Siemens, 2015).

3.4.2 Financing and Investment

Financial support is needed to increase the uptake of microgrids in rural areas. Obtaining full funding from government subsidies and support is often unfeasible and slow to reach lower income demographics. Projects funded solely on government aid tend to be small-scale standalone systems, such as the result of the Saubhagya program in India. Despite the potential for microgrids in rural electrification, government and private efforts have so far not contributed highly to alleviating energy poverty. The process of electrification takes large sums of capital, especially when customer density is low. Major lending institutions such as the World Bank and Asia Development Bank help in filling the funding gaps, but still fail to reach some projects (World Bank Group, 2010).

Further funding from private sources can improve the viability of these projects into strong assets for the power sector. Private lenders are advantageous for a number of reasons. First, they alleviate the cost burden on the government by reducing the need to fully subsidize a project. Privately-contracted energy projects usually benefit from the speed and efficiency that comes with business interests. Publicly funded energy projects can suffer from lack of technical expertise, which has even led to the de-electrification of some areas. Finally, projects developed within the private sector can have stronger managerial performance and improve the lifetime throughput (Williams, Jaramillo, Taneja, & Ustun, 2015). However, private financing in microgrid projects can have an effect on the overall LCOE. The German automation conglomerate Siemens is one of the largest players in the microgrid industry. The company has done extensive research into microgrid project development and provides detailed information on private investments. The private investors expect a specific ROI depending on which stage of the project they are financing. Project funding in early stages presents a high risk for investors due to the intrinsically higher probability of the project becoming unrealized from this point. Early stage investments tend to require an ROI between 12-15% to make the risk acceptable (Siemens, 2015). This higher ROI requirement for a project translates to higher LCOE costs for the consumers. The MG projects with higher LCOE costs are typically more successful in areas where electricity tariffs are already high, or alternatives (grid connection) are not feasible (ASEAN Centre for Energy, 2013).

Microgrid financing can be negotiated between public and private actors through a range of mechanisms. Public subsidies can encourage microgrid financing through the use of capital subsidies, tariffs, loan and risk guarantees, tax incentives, and land or operating concessions. These subsidies can be further broken down into direct and indirect subsidies. Public-private partnerships (PPP) are formed through the favorable cooperation of resources between the government and private sector. The mentioned subsidies can contribute to a project either directly or indirectly by providing public assistance in the form of capital or subsidized loan, or in indirectly such as reduced fees for grid connection costs or technical assistance. In most rural electrification projects, the operation and maintenance costs of a system will be taken on by the private partner. Financing mechanisms from the public sector can come through legislative obligations from the power utility towards rural customers. Power utility financing requires the main utility in a region to invest in rural electrification schemes through off-grid financing. The utility then cross-subsidizes tariffs, allowing for a lower COE to rural customers. Policy measures are also used to define roles in microgrid development, train local workers, provide monitoring capacity, and develop regulations that are conducive to MG uptake. Beyond governance and financing, the public sector can provide development assistance in the form of technical expertise. Industry standards including components and construction can be developed to improve technical efficiency. Site surveying and permitting assistance can reduce the need for extra privately-contracted resources (Schnitzer, o.a., 2014).

Perhaps the most powerful financing tool available for microgrid development is the Power Purchase Agreement (PPA). Power Purchase agreements ensure a stable revenue stream to the microgrid owner through a fixed tariff rate or load agreement. The PPA allows investors to calculate the projected revenue from a microgrid while assuming far less risk. Without the use of a PPA, power producers and customers are susceptible to the imbalances of the production-demand complex. Too much power results in cheap COE, deterring interest in investments, whereas too expensive COE will cut off the average consumers. However, a PPA in general does not equal bankability. Based on a report produced by the Overseas Private Investment Corporation (OPIC), there are several elements that create a bankable PPA. Not only must there be a fixed tariff, but there should be other financial and political securities included. Foreign currency exchange should not affect the prospects from a good PPA. Risk mitigation should be provided through protection from tax law changes, political instability, and natural disasters. Financial risk is mitigated through the use of only credit-worthy off takers in the case that the project defaults on payments. A more recent addition to a bankable PPA element is the inclusion of connection responsibility in the case of grid interconnection. This designates which party pays for connection fees and what the tariff structure will look like (OPIC, 2014).

3.4.3 Barriers and Facilitators to Investment

Investment barriers are compiled from various sources, but the main documents that this thesis works upon are from a white paper by Navigant Consulting, a report from the United Nations Environmental Programme (UNEP), an International Renewable Energy Association (IRENA) microgrid development tool, a 2018 report from the International Energy Agency's (IEA) World Energy Investment, a report by the Brookings Institute in India, and a report by the Rocky Mountain Institute.

A synthesis of information in these reports yields a trend in what are considered barriers to bankability.

Table 8 Literature review matrix corresponding to documents researched that cover microgrid investment risk.

Publication	**Perceivable Risks to Microgrid Investment**
2018 World Energy Investment (International Energy Agency, 2018, s. 76)	- Regulatory framework for ownership and operator models - Nation grid extension - Availability of public funding - Electricity tariffs
Navigant Consulting White Paper (Strahl, Paris, & Vogel, 2015, ss. 11-17)	- Technology risks (proven v unproven) - Developer reputation

	- Interconnection agreements - Unstable local energy demand - System support during operation - Valuation of ancillary services - Mitigation strategy for fuel costs - Business models
IRENA Project Navigator (International Renewable Energy Agency, 2017)	- Regulatory framework for private ownership - Policies for clear roles, responsibilities, and procedures - Cost recovery for private operators - Access to finance - National grid extension
UNEP Microgrid Report (Finlay, Ali, Camenzuli, & Dobriansky, 2014, ss. 1-4)	- Developer and financer reputation - Clear roles and responsibilities through project lifetime - Technology complexity, future reduction of costs undercut value of expensive new components - Unstable local energy demand - Lack of stable energy regulations - System support during operation - System security and safety
Brookings Institute India (Tongia, 2018)	- National grid extension - High capital costs - Electricity tariffs - Cost recovery for private operators - Unstable local energy demand - Interconnection agreements
Rocky Mountain Institute Minigrid Design Charrette (Rocky Mountain Institute, 2018)	- High capital and operational costs - Unstable local energy demand - Financing is expensive or unavailable - Regulatory policy is unpredictable

IRENA provides a comprehensive guide for developing the most bankable microgrid project for financers (IRENA, 2018). This guide provides insights to the advantages and disadvantages of using certain technologies for the project. The guide focuses on project components' effect on bankability and is used in conjunction with the literature synthesis to highlight key areas. A compilation of the documents reveals trends in the most pivotal areas of microgrid bankability.

Predictable policy and regulations

Microgrid developers expressed the complications that arise when policy surrounding their venture is uncertain. Power sector regulation is impactful to the operations and revenue streams of an energy project. Regulations can change responsibilities between actors and shift financial obligations in unpredictable ways.

Proven technology and reliability

There is a risk that technologies could be unavailable or unfamiliar to developers and financers. New technologies that haven't been proven in the field or frequently tested within the complex MG framework can seem risky to invest in. Reliable information on renewable energy must be available for microgrid project developers, but is often fragmented across government agencies and private actors. Investors also fear the risk of new technologies losing much of their value over time when adopted too early (i.e. cutting-edge batteries or thin film solar PV).

Environmental/social impact assessment

The environmental impact of certain technologies can be a determining factor in energy projects. Projects must clear an environmental impact assessment, and even so may still face penalties for environmental degradation.

Site specification and land leasing

Land requirements are an important part in creating a microgrid. Land citing can be impeded due to high land values, land use codes, or emissions requirements for an area. It can be difficult for a system with many components to adhere to all of the guidelines.

Grid Creep

The eventual connection to the macrogrid is inevitable in many places, making investments into some microgrids risky. The LCOE in most microgrids is higher than the macrogrid, so once the macrogrid "creeps" onto the microgrid, energy tariffs become complicated. Energy purchased from the microgrid will have to compete with the macrogrid, lowering the ROI predicted by investors[8].

Complexity of design

Systems that have complex design with many components require certain technical expertise that may not be available locally, or within a reasonable proximity. There tends to be a lack of inventory accounting for components and manufacturers of local renewable energy infrastructure/services[9].

Existing Infrastructure Available

In many cases the cheapest component to use is the one that already exists in the infrastructure. This point mainly highlights the use of DGs already in place would help to lower the overall capital costs of a microgrid. It also goes for transmission and distribution equipment.

Subsidies and Government Partnerships

The most often mentioned bankability aspect was support from the government. Outside of regulations, the government plays a huge role in providing financial and technical support to projects throughout the lifetime. Investors require inexpensive and credit-

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[8] Grid creep is more prominent in countries like India where the national grid is being quickly expanded. The arrival of the macrogrid is not always bad, as the microgrid can benefit from selling ancillary services to the main grid. (TFE Consulting, 2017).

[9] Many of the larger competitors in the microgrid industry are on the forefront of offering plug-and-play solutions which provide generation and storage in one package, though it is still costly in upfront capital. (Dörfler, Simpson-Porco, & Bullo, 2014)

worthy finances be made easily accessible. Microgrid financers are concerned about the level of public support a project receives during operational phase as well.

Capital expenditures
The upfront costs for microgrids can be the most challenging part of financing a microgrid project. A microgrid project requires intensive design and contracting to be bankable, but it also requires upfront capital for good engineering and contracting.

Operational expenditures
In microgrids with a DG that comprises a large portion of the generated electricity, fuel costs will dominate operating expenses. The fluctuation in diesel fuel prices causes changes in operating expenses of a project. This sensitivity is usually accounted for within PPAs, but the uncertainty ultimately induces risk in a project. Operational costs also come from maintenance of technology and funding overhead costs.

Unstable Energy Demand
Microgrids are sensitive to local energy consumption due to the relatively low aggregate of consumers compared to larger regional grids. This is especially difficult when factoring in the variability of generation in renewable energy sources. Systems designed with the capacity to meet peak demand are at risk of being oversized and consequentially, over-budgeted. The problem of undersized systems can lead to blackouts or brown outs. Ventures are less risky when revenues can be accurately projected, especially throughout the lifetime of the project.

Valuation of Ancillary Services
The added value services that a microgrid provides are difficult to calculate and often misunderstood by project investors. The lack of concrete and uniform valuation for ancillary services of a microgrid can affect the revenue streams of a project. This tends to underappreciate the overall value that a microgrid can provide to customers.

3.4.4 Relationship between Diesel Gensets, Policy, and Finances

The major effects to microgrid bankability are already available from prior research. However, the weight of each effect on specific microgrids can vary due to the novelty of design and interests of different investors. Even in this case, common trends of these effects can be extrapolated and further explored. Research can provide the link between policy's effect on bankability as well as investor requirements for the framework and design.

The missing piece of the puzzle lies in how each component, determined by system design, affects the overall bankability of the project. Specifically, the effects that a diesel genset component as storage and generation can have on bankability aspects. Direct causal relationships can be made between components and overall system prices, but bankability is beyond the most optimal price. Components also need to be explored for their added value to systems, which could outweigh their nominal costs. A component may be inexpensive to use in a system, but may not bring much extra value. Whereas a component might be more expensive upfront, but provides enough added value to warrant the costs. Overall component and system value can be affected by shifts in legislation as well. Policies can drastically change the prices of components and even the way in which they are allowed to operate in power systems. This adds extra variability to the true effects on microgrid bankability. Therefore, not only does a MG project bankability need to be examined by its component make up, but also how sensitive the financing is based on policy directed at DGs.

4 Research Findings

4.1 HOMER Findings

The results of the HOMER model showed which configurations of microgrid were most suitable depending on diesel price sensitivity and incorporation of second life batteries. The findings based on each sensitivity against the four preset configurations are represented by figure 10. Costs are displayed as either CAPEX, operation and maintenance (O&M), or fuel. Capital costs cover the primary expenses of the system during year zero, as in the initial acquisition and setup costs of each component. The O&M costs cover the maintenance and replacement of each component. Fuel costs are attributed to the diesel used by the gensets throughout the lifetime[10].

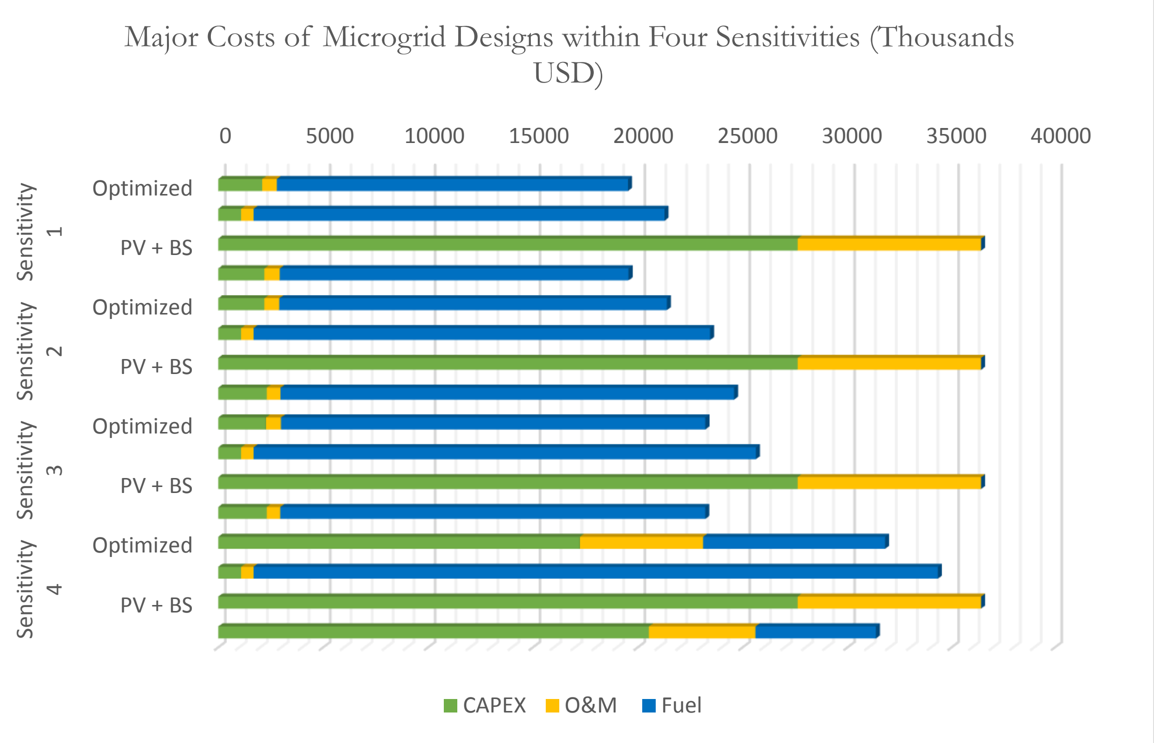

Figure 10 Results of the microgrid system optimizations as simulated in the HOMER Pro software. Costs are represented under the main groups of microgrid project finances.

Source: 7 HOMER Pro Software. Created by Author

Sensitivity 1 (s_1), Sensitivity 2 (s_2), and Sensitivity 3 (s_3) all yielded similar results. They each found that the most optimal configuration was the primary system of PV+DG+BS. System costs were dominated by fuel for the gensets throughout the lifespan. This was the same for the same for the DG+BS configuration which had even higher lifetime costs. The removal of the DG in the PV+BS configuration resulted in higher overall costs due to the high amount of CAPEX required from the extra RE penetration to make up for the lost gensets. The

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[10] The cost of diesel fuel remains constant throughout the 25 year lifetime of the project. It is not uncommon for energy projects to secure fuel purchase agreements under the power purchase agreement for bulk quantities of fuel (World Bank Group, 2017).

PV+BS configurations also required greater O&M costs based on the frequent replacement of large amounts of batteries and the maintenance costs of both components. Sensitivity 4 (s_4), with the highest cost of diesel, had much different results. The optimized system still consisted of PV+DG+BS hybrid configuration, but the software removed the second DG and reduced the base loading of the remaining genset. The new system relied on a much higher amount of RE penetration (see table 9) and BS units compared to the systems of s_1, s_2, and s_3.

Table 9 Results of HOMER Pro sensitivity testing. Listed are the optimal configurations based on the price of diesel fuel.

Diesel Fuel Price ($/L)	PV (kW)	DG 1 (kW)	DG 2 (kW)	BS (units)	Converter (kW)	COE ($/kWh)	NPC ($)	OPEX ($/yr)	CAPEX ($)	RE Fraction (%)
0.9	1359	573	573	13	587	0.251	19.5M	1.65M	2.10M	16.5
1	1456	573	573	12	653	0.275	21.3M	1.82M	2.21M	17.3
1.1	1550	573	573	12	651	0.299	23.2M	1.98M	2.28M	17.7
1.5	12568	573	-	214	1908	0.405	31.4M	1.34M	17.2M	75.7

The introduction of the plausible scenario which included the use of second-life lithium ion batteries had unexpected effects on the systems. In s_1, s_2, and s_3, the software found that even with the reduced replacement costs of the second-life batteries, it was still more economically suitable for the system to remain on DGs for the base load. However, in s_4 the system found that the second-life batteries reduced the overall cost of the system even with the reduced capacity of used batteries. System costs were reduced by $431,034, a total of 1.36% over the project lifetime.

4.2 Value Chain

Information collected on microgrid development was used against the costs of components and services to provide an overview of the microgrid cost structure. The model in figure 11 represents the core costs of a microgrid project. Component costs, installation, and other overhead service costs are captured within the CAPEX. Staffing overhead, fuel, and other operational costs are accounted in OPEX. In the case that the project is funded privately, the return investment must be accounted for within the intrinsic cost. The right side of the diagram breaks down the financing of the project into the main four mechanisms: government subsidies, government-backed loans, private investment, and tariffs passed onto the consumer. Project costs and funding can vary. The weighted bands of the diagram are based on information provided through the Rocky Mountain Institute (Rocky Mountain Institute, 2018). The microgrid project under focus is a hybrid PV+DG+BS system that uses diesel for covering some generation.

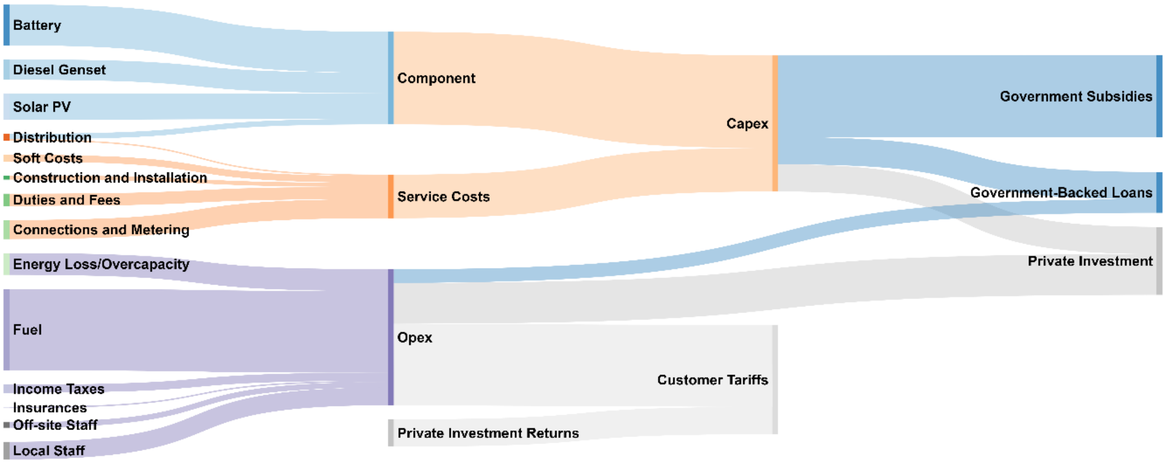

Figure 11 Sankey diagram mapping the costs of an optimized microgrid project and the sources of funding.

Source: 8 based on information by Rocky Mountain Institute (Rocky Mountain Institute, 2018)

It is observed from the diagram that each development actor plays a specific role in microgrid funding. Financing in the form of initial capital is shared between the government and private investors. The government tends to take on a large portion of this funding through subsidies or providing low-interest loans to private investors. Private investors are expected to provide upfront capital and development support. Customers are rarely included in the initial fundraising phase of a project, unless the customer is also seeking to take ownership of the system such as in the case of a microgrid for a campus park. In contrast, the operational costs of a project are very rarely supported by the government and almost solely provided by private investment and customer tariffs. The government can provide support in the form of tax relief or maintenance expertise, otherwise governments are apprehensive to increase subsidies for costs like fuel and overcapacity issues.

After the costs of the project are calculated, the value added is examined to determine the feasibility of financial ROI. The completed microgrid project, depending on its design and philosophy, will add value in a multitude of functions. The most obvious of those being its base value as a completed microgrid system. This is because, after all, the whole of a microgrid's parts is greater than the sum. A microgrid that is coupled with the main grid has more capabilities to expand its added value than isolated microgrids. Extra energy produced can be either stored and sold to the macrogrid during peak pricing, or sold directly to the macrogrid as long as production exceed consumption. The grid-connected microgrid adds its support services to the macrogrid, such as black-start capabilities and renewable energy integration, which can be reimbursed through the utility. Value can be measured by the savings that the system represents. The demand-response capabilities of a MG result in energy and fuel savings, which translates into direct financial savings. In some cases, renewable energy credit schemes can add value to REG sources within the microgrid. The difficulty of measuring the true value of MG lies in the subjective value added to the consumer and society. Services like access and power quality may not be measurable in some instances, but still bring value to a customer. Resiliency for a customer may come at a high cost, but must be calculated for each power consumer. These more abstract added value services are being factored into lenders' appraisals increasingly more often and with greater accuracy (Industrial Economics Incorporated, 2015).

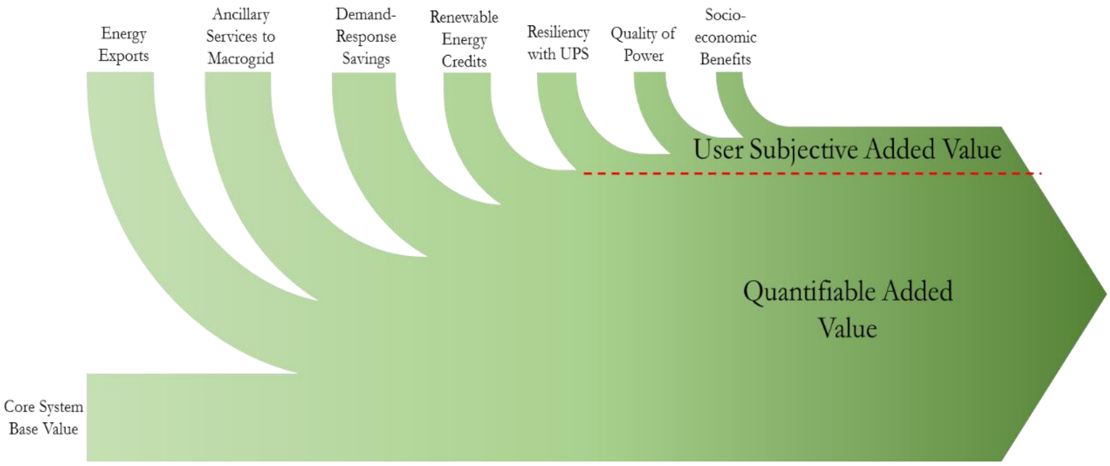

Figure 12 Accumulation of added value for a microgrid to combine quantifiable and less-quantifiable values.

Source: 9 Generated by the author

However, the metrics of such services are still difficult to capture and often undervalued, complicating the investment risk of a project. In the case of an off-grid microgrid, the financial value of added values is higher. The 'no alternative' or 'grid connection alternative' are too expensive compared to the microgrid option, creating a greater willingness to pay for access or other added values.

4.3 Documentation

The literature review provided ways in which policy can affect the bankability of a microgrid, but the scope required further exploration into the specific countries. Direct policy effects on bankability were found by using combinations of key search terms, such as: 'national energy policy '+'country name'. Government reports revealed each country's energy development plans. Policies were examined for their relevance on the effects of bankability. Beyond the direct effects of policy on microgrids, it was also explored how policy might affect the incorporation of diesel generation into the country's energy mix. Thus, it could assessed how country policies are not only affecting the expansion of microgrids, but also how these policies are influencing the generation types within the microgrids.

4.3.1 Policy Effects on Bankability

Government policy can affect every part of microgrid development from costs to designs and business models. The policies that are most influential towards microgrids were found to be regarding energy framework and subsidies. These policies are broken down even further into subcategories that have more direct effects on microgrids. Energy markets in each country were evaluated to determine whether or not they were deregulated or state-owned, though some markets were found to be only partially regulated. Energy market deregulation is vital for microgrids to be competitive against conventional generation. The second subcategory searched for was the inclusion of a rural electrification policy. All countries have adopted this sort of policy to seek expanding energy access to underserved areas. Rural electrification projects usually present a design chosen to achieve the goals. The design could be from expanding the transmission network or to increase funding for off-grid projects. Countries were then screened to see if there were any already existing policies that directly relate to microgrids. Many countries do include a specific framework for microgrid policies, though some are included in the rural electrification frameworks. It must also be mentioned that the direct inclusion of a microgrid policy may not make it more effective, but surely more comprehensive which was determined to be a key piece to influencing bankability.

Policy was found to have a strong direct effect to the financing of microgrids. The main effects from policy are in the forms of grants or subsidy schemes. They are further subdivided into whether the microgrid project itself receives funding or if the project's renewable energy components receive subsidies. Policy directed toward microgrid financing was examined for its effects on electricity tariffs, capital cost subsidies, and operational cost subsidies[11]. All countries, with the exception of Singapore's absolutely deregulated energy market, have a specialized type of electricity tariff in place for off-grid energies relative to the macrogrid. Most countries also have a grant scheme in place to help offset the capital costs. In contrast, only India and Philippines have grants in place for funding the operational phase of off-grid projects. This reestablishes the bankability aspect of riskiness in microgrid projects that do not have government support for the operational phase. The last policy scheme searched was the subsidization of renewable energies. Since most microgrids utilize some type of renewable energy, any government support would reduce the overall private costs of the project. It is the assumption that subsidizing renewable energy then would reduce the economic feasibility of diesel generation. Each country has a different mix of renewable potential, so subsidies for certain technologies might not always be equal. Subsidy schemes often incorporate biodiesel as a fuel or within the already existing fuel mix. Also, not all countries take the same approach to renewable energy investment, as some are conservative and others have optimistic targets.

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[11] Operational expenditure subsidies do not include subsidies that a country sets to manipulate the price of diesel.

Table 10 Matrix displaying the constituents of each country's energy policy.

Country	Deregulated Electricity Market	Rural Electrification Policy Framework	Microgrid Specific Policies	Grants and Subsidies			Renewable Energy Subsidies
				Tariff Subsidies	Capex Subsidies	Opex Subsidies*	
Cambodia	x	✓	✓	✓	✓	x	✓
Laos	x	✓	x	✓	✓	x	✓
Malaysia	x	✓	✓	✓	✓	x	✓
Myanmar	x	✓	x	✓	x	x	x
India	✓ **(state owns 45%)**	✓	✓	✓	✓	✓	✓
Indonesia	✓	✓	✓	✓	✓	x	✓
Philippines	✓ **(state owns 50%)**	✓	x	✓	✓	✓	✓
Singapore	✓	✓	x	x	✓	x	x
Thailand	✓ **(state owns 47%)**	✓	✓	✓	✓	x	✓
Vietnam	✓ **(state owns 68%)**	✓	x	✓	✓	x	✓

Table 11 Sources attributed to research on each country's energy policy

Country	Source of Energy Policy
Cambodia	(World Bank Group, 2009) (Deshmukh, Gambhir, & Carvallo, 2013, s. 10)
Laos	(Pillai, 2014)
Malaysia	(Malaysia Ministry of Energy, Green Technology, and Water, 2012)
Myanmar	(Asia Development Bank, 2016)
India	(India Ministry of Power, 2009)
Indonesia	(Indonesia Ministry of Energy and Mineral Resources, 2018)
Philippines	(IRENA, 2017)
Singapore	(Singapore Energy Market Authority, 2018) (Francesch-Huidobro, 2017)
Thailand	(Thailand Provincal Electricity Authority, 2014) (Hoonchareon, 2013)

Vietnam	(Menke, 2013) (Wold Bank Group, 2011)

Each country was scrutinized for its specific policies that could affect microgrid development. The first and most apparent for each country was if it had a direct policy on microgrids and interpret this as either strong or weak. Another factor that was taken into account was the plan for renewable energy in the future generation mix. Policies with strong targets for renewables were seen as being negative towards diesel generation (unless otherwise noted), but as an overall facilitator of microgrids. Fuel subsidization schemes were important to gauge as they would have a large overall effect on project operational finances. Low fuel tax or high subsidization were seen as positive for diesel generation as well microgrid development since it lowered the overall project cost. Investment policy is important in energy project financing. Skepticism of foreign finance can limit the amount of capital available for projects, lowering feasibility for projects that require high CAPEX. Policies that limit the amount of foreign investment available for energy projects were considered negative. The culmination of the specific policies is seen in figure 13.

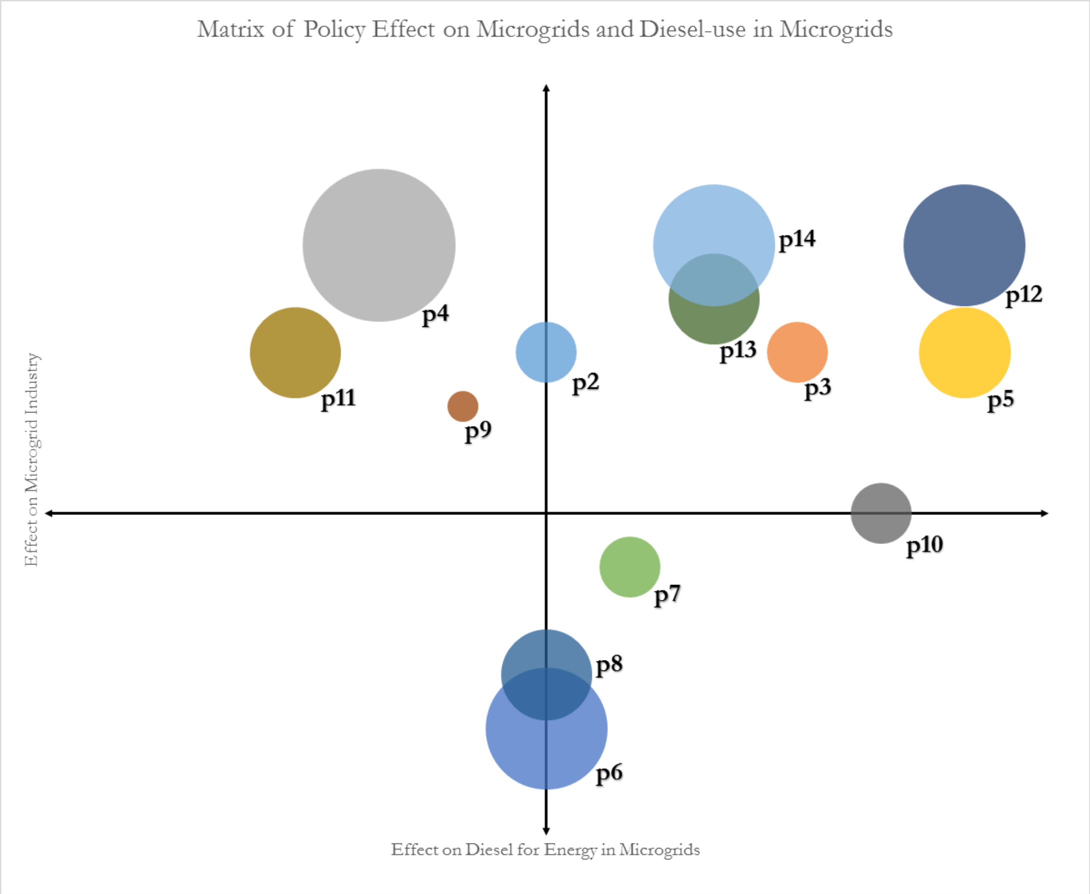

Figure 13 Matrix mapping out the major energy policies of each scoped country. Policies are displayed based on their perceived effects on microgrid development and diesel fuel as an electricity source.

Table 12 Policies and descriptions attributed to figure 13.

Policy Code	**Name**	**Country**	**Description**

p2	United Nations SDG: Goal 7 (United Nations, 2018)	Worldwide	Ensure access to affordable, reliable, sustainable, modern energy for all.
p3	Electricity Act 2003 (India Ministry of Electronics and Information Technology, 2017)	India	National Initiative to spread electricity access to rural areas by means of grid extension and minigrid set ups. Included provisions for all types of generation
p4	Draft National Policy on RE Based Mini/Microgrids (India Ministry of New and Renewable Energy, 2016)	India	Pertaining to systems 10 kW and above. The Ministry targets to achieve deployment of at least 10,000 RE based micro and mini grid projects across the country with a minimum installed RE capacity of 500 MW in next 5 years (taking average size as 50 kW)
p5	Rural Electrification Fund (ASEAN Centre for Energy, 2013)	Cambodia	Part of the Renewable Energy Action Plan. Grant assistance for connections in rural areas. Subsidies on solar and hydro home technologies of up to 25% capex. High expansion of diesel minigrids
p6	Presidential Regulation No. 44/2016 "Indonesia Negative List" (REEEP Policy Database, 2012)	Indonesia	FDI for power projects less than 1 MW is prohibited. From 1MW - 10MW must be less than 49% FDI. Above 10MW must be <95%
p7	National Energy Policy 2014 (IEA, 2016)	Indonesia	Push towards using domestic energy rather than exporting resources. Increases the use of RE as well as fossil fuels. Reduces the subsidies for fossil fuels and electricity. Aims for 100% electrification by 2020.
p8	Socio-economic Development Plan (Lao PDR Ministry of Planning and Investment, 2016)	Laos PDR	Improve the rural electrification rates through funding for RE projects, and hybrid projects when hydropower isn't available. Promote great use of biofuels.
p9	National Renewable Energy Policy and Action Plan (Malaysia Ministry of Energy, 2010)	Malaysia	Targets energy efficiency and uptake of renewable energies. No specific address of microgrids or off-grid development.
p10	Diesel Fuel Subsidy Reform (Li, Shi, & Su, 2017)	Malaysia	In 2014, fuel subsidies were abolished due to the low prices worldwide. With a new administration in 2018, promises of reinstatement of the subsidy were filled

			with hopes to better target poorer populations.
p11	Myanmar Energy Master Plan (Myanmar National Energy Management Committee, 2015)	Myanmar	Set targets for the country to increase its renewable energy mix to 15-20% by 2020, and above 60% by 2030. Energy projects are targeted at rural electrification increases.
p12	Philippine Energy Plan 2017-2040 (Philippine Department of Energy, 2017)	Philippines	Plans to increase energy production through all generation types. Support for the increase in diesel generation for off-grid power, and more RE for grid-connected power. Creation of a new department to expedite the permitting process for new energy projects.
p13	Alternative Energy Development Plan (Peerapong & Limmeechokchai, 2017)	Thailand	Increase Renewable energy portfolio to 25% by 2021. Extremely promote the utilization of Bioenergy and Biofuel (Biomass/Biogas/MSW/Bioethanol/Biodiesel), Creation of B20 (80/20 biodiesel mix) as well as community and Enhance the participation of community for RE generation (solar rooftop/solar PV for agri. Co-op/ DGG/ community CBG).
p14	National Power Development Plan (Vietnam Ministry of Industry and Trade, 2011)	Vietnam	Promotes a much larger increase in renewable energy mix for the country. Advocates for more investment in rural off-grid energy infrastructure, primarily hybrid microgrids.

The matrix shows that most policies aimed at microgrid governance tend to have a positive effect on the proliferation of microgrids, as can be seen in the two upper quadrants. There was no significant information to show that positive microgrid policies translated into negative outcomes for diesel generation. Rather, negative outcomes for diesel were through policies that increased targets for renewable energy generation or provided subsidization for generation technologies other than diesel. Negative effects on microgrids came from policies that limit investment, or create an obscure operating environment for off-grid generation.

5 Analysis and Discussion

This section is meant to investigate and present the relationships between the data collected. The findings of this thesis are categorized into two data types: documented data and quantitative data. The documented data is a result of the compilation of literature review and government database research. Results of the documentation have shown the major aspects of bankability in microgrid financing, the effects of policy on bankability, and the value creation in microgrid projects. The results of the HOMER case study showed how the optimization of a simulated microgrid might change with the variability of fuel prices. This revealed the cost trends associated with the major components. The results of both methods are analyzed to determine the true role the gensets have in MG bankability.

5.1 Triangulation of Data

The analyzed data is both in documented and quantitative formats. Both types were used to analyze the relationships between the results. Bankability aspects of microgrid financing are examined against the value added potential of components and the system expenditures of components.

5.1.1 Documentation Analysis

Policy results are examined through the matrix presented in figure 13 and the data from table 10. The results showed that all countries within the scope have varying policy mechanisms to promote microgrids. A deeper look into specific policies revealed that these mechanisms also have various depths of efficacy. Of all the countries within scope, India was alone in meeting all of the study's research criteria in microgrid policy frameworks. However, India is also in the lower range of electrified rural population along with countries like Myanmar and Cambodia, who had gaps in government microgrid policy. This study does not seek to find correlation between the amount of microgrid frameworks and the development of microgrids, but rather builds off of the notion that comprehensive and feasible policies are needed for a classical 'quality over quantity' case. From figure 13, we can see further into specific policies that are having direct effects on microgrids and diesel gensets. Policies that are more favorable towards microgrids tend to result better for diesel gensets as well. Though, the opposite cannot be said for positive effects on diesel having the same effect on microgrids. This could be due to the high level of competition between generation sources.

The results of the microgrid value chain showed that the DG component does not bring a significant added value to the system. The genset does serve as a vital component for systems that seek extra redundancy beyond added battery storage. In these cases, diesel generation is used primarily for backup purposes and rarely for daily generation. Other components bring more added value to the system by improving the range of operating efficiencies. For example, battery storage may reduce bankability by using untested technologies but will improve the overall system economics through the use of demand-response or selling energy to the macrogrid.

5.1.2 HOMER Systems Analysis

The results of the HOMER case study showed the relationship between system configuration and major costs. A deeper analysis can be used to breakdown the costs even further into components.

Each sensitivity scenario resulted in an optimized system. The sensitivities 1, 2, and 3 all included the two DG components in the most optimized systems. As the $/liter cost of diesel increased across the sensitivities, the amount of RE penetration also increased. This trend continued until the highest sensitivity of 1.5$/liter of fuel. The configuration in s_4 found that the fuel costs of two gensets was too great, so instead reduced the system to one DG and the rest would be covered by large increases in PV and storage. This fuel cost threshold for a system will vary based on the operating needs, but the HOMER simulation confirms that such a threshold is not far off from current prices. Furthermore, each sensitivity found that the 100% renewable energy system had a fixed LCOE of 0.44$/kWh. This signals that, for this system, if the attributed costs to the diesel genset increase the LCOE above the 0.44$/kWh of the 100% REG scenario, then the gensets become less favorable.

Another pattern emerged from the data collected through HOMER. The systems created in s_1, s_2, and s_3 all used two gensets to achieve the lowest LCOE. However, each scenario produced a system similar to s_4 in which it dropped one genset in favor of increased PV and BS. These suboptimal systems were projected to have a slightly higher LCOE than the most optimized system (table 13).

Table 13 Comparison of system energy costs based on optimal configurations and suboptimal configurations with high RE penetration.

Sensitivity_x	Optimal System LCOE ($/kWh)	Suboptimal System LCOE ($/kWh)	Difference in LCOE (%)
s_1	0.25	0.373	32.97
s_2	0.274	0.377	27.32
s_3	0.298	0.382	21.98

The 'suboptimal' configurations achieved a renewable energy fraction of 84% for each sensitivity, compared to an average of 17.65% for the most optimal. Two accounting measures that are not calculated into HOMER Pro software are for emissions penalties and system added value. The optimal systems with relatively low RE capacity have consequentially higher emissions over the lifetime. The true costs of a system with such high emissions would be greater based on taxes through environmental regulations. Aside from true costs, the true added value of the system cannot be fully calculated through the HOMER Pro software. The suboptimal systems with higher REG and BS are far more flexible than the optimized system, allowing for greater potential of value streams and ROI. It is ultimately up to the consumer/prosumer as to the aggregate of perceived added value. The willingness to pay for certain services might warrant the added costs of a more dynamic system.

5.2 Role of Diesel Genset Component

The microgrid has been shown to be complex in nature, requiring actors and components to be flexible. Designating the wrong design or component can result in the loss of revenues or even full funding for a project. This yields especially true for the diesel generator component.

It was found that the diesel genset can affect the bankability of a microgrid project through varying means.

The results across both data types are used to examine the impact of the genset on the previously found microgrid bankability aspects. The role of the genset was determined as either positive or negative for bankability depending on the anticipated effects in (table 14). Effects are determined as positive or negative depending on whether or not they will improve the likelihood of project financing. The impact on project financing was accounted for based on the relationships between costs, policy, and system design. The potential impact on bankability is provided for the diesel generator and is relative to other generation sources.

Table 14 Aspects that affect the bankability of a microgrid project and how the diesel genset impacts those aspects.

Bankability Aspect	**Positive or Negative Role**	**Description of Impact**
Predictable policy and regulations	-	Policies promoting a shift away from diesel fuel create more uncertainty in the true lifetime operational costs of a DG component.
Proven technology and reliability	+	The DG has a proven history of effectiveness in microgrids. The use of the technology is less risky than some newer alternatives.
Grid creep	+	The low capital cost associated with a DG reduces the project's risk of losing ROI through the introduction of the macrogrid. A genset is more capable than REG technologies at being removed from a system and used elsewhere to recover expenses.
Complexity of design	+	The simplicity of a genset reduces the need for extra components and engineering. This translates to lower overall costs and maintenance, but less complexity can reduce the flexibility of a system.
Existing infrastructure available	+	Gensets are already heavily deployed in rural electrification and could serve to be incorporated into growing microgrids, lowering capital costs and reducing the need for outsourced technical knowledge.
Site Specification and land leasing	+	Renewable energy generation typically requires a permit for a larger tract of land than would be needed with a genset. Areas with land scarcity or high value could have a significant effect on the final costs of land citing.
Environmental/social	-	The most contentious drawback of the genset is its extensive reliability on diesel fuel. Emissions standards

impact assessment		are making DGs less attractive, especially in peri-urban, urban, and environmentally sensitive areas.
Subsidies and government partnerships	-	Government subsidies typically favor renewable energy generation and promote frameworks to improve the amount of REG capacity. Many instances of energy development investment do not include diesel generation for funding or grant programs.
Capital expenditures	+	Upfront costs for DGs are far below those for REG and storage.
Operational expenditures	-	Lifetime costs to operate a DG are variable depending on fuel costs. The low capital costs for a genset are overshadowed by the need for fuel and a reliable supply chain.
Unstable energy demand	-	As with any system, a change in local demand can risk that the system is oversized or undersized. No component configuration has been explored that addresses the problem of fluctuations in local energy demand, rather this problem is solved through various types of business models.
Valuation of ancillary services	-	The only added value that the DG component brings to a microgrid is reliability. This service is vital for UPS, but other generation and storage capabilities are far more dynamic for the system's value.

Diesel gensets can potentially improve the bankability of a project. The HOMER case study revealed how the inclusion of a genset, rather than 100% REG, lowered the projected LCOE for the system when diesel prices were low. The inclusion of gensets resulted in a much lower capital cost for the system, even if operational costs were higher. Lower capital costs can help improve microgrid bankability to private investors by reducing the principle needed for the riskiest phase of investment. This would then lead to less financial obligation from government funding. Capital costs could be even further reduced if existing gensets are incorporated into projects. Diesel gensets are common place and represent a significant capital cost to smaller microgrids, which could be averted entirely if a system is retrofitted or built around an existing piece of infrastructure.

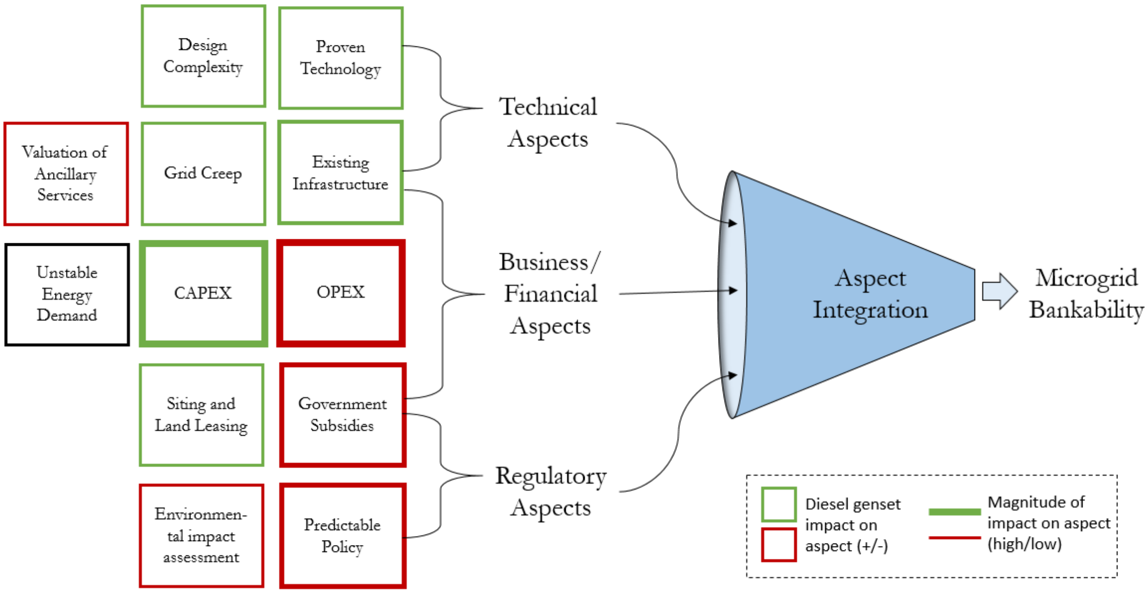

Figure 14 Visual representation of diesel genset impacts on bankability aspects.

The diesel genset was found to include many negative impacts to bankability. Perhaps the most determinant factor in the applicability of gensets is the policy surrounding diesel fuels. First, one of the main barriers to bankability was the lack of predictable policy and legislation. Policy around fossil fuels has been rapidly changing and the future of legislation is not concrete. This creates a great uncertainty over a major generating source for the microgrid operator. The further implementation of carbon taxes and other environmental legislation can even increase the costs to operate a diesel genset, translating to an increase in overall costs. In addition, rival generation sources are subsidized with far greater willingness, creating another disincentive for incorporating diesel generation. Gensets also struggle to meet the performance capabilities of other technologies. Renewable energy and storage provide far more value to a system beyond the roles of generation and redundancy that a genset maintains. Though some added values may be difficult to project, the concrete values such as demand-response and energy exports can be calculated and added. Such added values are not applicable to a system dominated by diesel generation.

5.2.1 Within Business Models

Certain business models for microgrid operation in rural electrification were shown to be successful. The most relevant business model that could benefit from diesel gensets is the ABC model. The Anchor-Business-Community model is desirable because it defines an anchor customer as the central demand source. In many cases this anchor customer is a large business or industry that already possesses the means of producing energy. This serves as a vital piece of existing infrastructure to lower the upfront costs of the system. The anchor business is much more likely to provide additional upfront costs if the capital required is lower, which could be achieved through a diesel generator. The anchor customers are also more attracted to the added value provided through a microgrid, such as UPS or quality power. In the case of India, anchor customers are being seen as telecom towers. Telecom towers in India are projected to rapidly increase to meet the growing data demand in the country. These stations are typically in rural areas, have fixed energy demands, and are backed by creditworthy companies; making telecom stations perfect anchor customers (Ramchandran, Pai, & Parihar, 2016).

5.2.2 Policy Implications

Whether a country's energy market embraces or disapproves of microgrids, the systems are proliferating and require better policies to govern them. Even if markets are apprehensive, there is still a strong need in the ability to manage electricity generation across platforms. It was found that microgrid policies in India and Southeast Asia are surrounded by obscurity, especially when they have a PCC with the macrogrid. At the minimum, policy makers need to provide clear delineations as to the responsibilities of each actor in the project.

The extent of microgrid legislation depends on the overarching goals of a country's electrification policy. For example, the countries of Lao PDR, Malaysia, and India all have different targets set for electrification. Lao PDR is most interested in expanding bottom-line electricity access, whereas India has expressed most interest in expanding access through increased renewable generation, and Malaysia is focused most on increasing its share of renewable energy in the overall generation mix. In the case of Lao PDR, microgrid policies should be supportive to any generation technology and proven business models to expand bottom line access. In India, where renewable energy is favorable, policies should aim to promote the increased use of REG in microgrids but not so much that it hinders bottom-line access. Malaysia, a country that has already made large strides in rural electrification, should carefully evaluate how its policies will affect the economics of microgrids that are already in place.

Policy must be comprehensive enough to allow for flexibility of components in microgrid configurations. Previous studies have shown that the component mix will vary depending on system philosophy. The case study research revealed that subdivided system costs are determined based on types of generation employed. Costs associated with generation are sensitive to legislation, such as renewable energy subsidies or emissions penalties. Microgrid bankability can be severely limited when components are improperly regulated. Microgrids that derive bankability through the use of diesel gensets could stand to be unrealized if project costs become too high or unpredictable due to heavy-handed legislation.

Of course, the ideal policy would spread high-quality renewable energy access to all with the cheapest cost. However, the reality is that project logistics and financing risks make this leapfrogging policy difficult to achieve in developing regions. Governments that have made insufficient gains in electricity access must acknowledge the facilitators and barriers of private financing if greater achievements are to be realized in the future.

5.3 Validity of the Results

The results of this study are most valid within the delineated project scope. Microgrids in regions such as North America and Europe face different financing challenges and therefore may not find as much validity. The case study research covered three common system configurations, but microgrids come in a large variety. The results are most pertinent to the systems that include or consider including diesel generation beyond backup power.

Policy mechanisms for supporting microgrids varies between countries. Though the scope focused on two regions, the policy implications can be used worldwide. The countries within the scope use various policy mechanisms to achieve electrification and could possibly be translated to other countries.

6 Conclusion

6.1 Central Findings

Various microgrid bankability data was examined for relationships between financing and components. The diesel genset component has a uniquely adapted role in system design based on operating philosophy. Advanced systems tend to use the diesel genset as a final means of redundancy for backup power, whereas many smaller off-grid systems for rural electrification use genset for base power. In the role of backup power, the effect on microgrid bankability is clearer because of its single purpose in the operating philosophy. Using a genset for covering daily loads can change the economics of a system both positively and negatively.

The genset component was found to be beneficial to microgrid financing in certain scenarios. The most difficult part of funding a microgrid development project is acquiring the initial capital for system design, components, and installation. In India and Southeast Asia, a large portion of initial capital funding comes from government subsidies and grants, whereas the operational funding is covered by private costs and consumer tariffs. Renewable energy technologies and storage devices can significantly increase the capital costs, but reduce lifetime operational costs. Private investment is apprehensive in funding large portions of initial capital because of the high risk at this phase. The diesel genset will reduce the amount of initial capital needed to begin the project, which in some cases may be enough to bring the project to fruition. Need for capital is lower due to the genset's low installation costs, reduced complexity, and the possibility of utilizing existing hardware. Incorporating a diesel genset could also lower the perceived risk of investors who are lacking knowledge and trust in newer technologies.

A number of characteristics that were harmful to bankability aspects were discovered. The most recognized drawback of incorporating the diesel genset was the price of fuel. High fuel costs can have a large effect on systems that are not robust enough in their generation mixes. Beyond high price scenarios, the fluctuations in the price itself creates conditions of unpredictability, which is very impactful to bankability. Systems receive far more added value benefits from REG and BS than from diesel generation, aside from backup power. These added value services can be essential to systems with specific operating philosophies.

Proper policies and business models are needed to address the complexity of microgrids. Policies can shift the favor from one type of generation to another, which could completely change the economics of an established microgrid with multiple generation types. Improper or impotent policies could even cause some projects to be unfeasible due to reduced bankability, having an opposite effect on electrification access. Business models have adapted to meet the evolving policy and technology around microgrids. The ABC model was suggested as the most efficient way to manage hybrid microgrids with multilevel stakeholders and to achieve to lowest LCOE across all customers.

6.2 Further Research

Beyond this thesis, more research is needed in developing policy around distributed generation. Ultimately, the component design of a microgrid will change as the market cycles through cheaper technologies. Therefore, policy must be created to acknowledge the use of microgrids in energy security and provide a supportive environment. Policy should be examined for the best balance of subsidization for energy projects while still enabling market competition. Successful frameworks still need to be identified that will encourage domestic and foreign private investment.

When looking at the component level of microgrids, it became apparent that there is a need for greater research on how to design a microgrid for certain business models. There are a few documented versions of successful business models for microgrids, but the difficulty is designing an economical system whose philosophy will also fit the purpose of the business model, i.e. designing a system around an anchor customer in the anchoring business model.

The field of microgrid research could benefit from exploring the evolution of microgrid ecosystems. A better understanding of how a microgrid develops from a small isolated system to a greater ecosystem will help with designing projects with the future in mind. It is currently challenging to design a project to meet future capacity needs without being too uneconomical. Building a system for overcapacity is not preferred, but the system should rather be able to easily accommodate added generation and storage. Knowledge of demand increase within users of these microgrids coupled with experience in best practices of system expansion will shed light on this gap.

7 Bibliography

Allruwaili, A. (2016). *The Impact of Different Battery Technologies for Remote Microgrids.* Open Public Research Access Institutional Repository and Information Exchange.

ASEAN Centre for Energy. (2013). *ASEAN Guideline on Off-grid Rural Electrification Approaches.* ASEAN Renewable Energy Support Programme.

Asia Development Bank. (2016). *Myanmar Energy Sector Assessment, Strategy, and Roadmap.* Asia Development Bank.

Balijepalli, M., Khaparde, S., & Dorbariya, C. (2010). Deployment of Microgrids in India. *Institute of Electrical and Electronics Engineers*, 1-7.

Bank Bazaar. (2018, August 9). *Diesel Price in Karnataka Today.* Retrieved from www.bankbazaar.com/fuel/diesel-price-karnataka.html

Borghese, F., Cunic, K., & Barton, P. (2017). *Microgrid Business Model and Value Chains.* Schneider Electric.

Bowen, G. (2009). Document Analysis as a Qualitative Research Method. *Qualitative Research Journal, 9*(2), 27-40.

Charrada, H. B. (2016). *Electricity Demand in ASEAN: Modeling and Forecasting.* University of Munich, Department of Energy Systems.

Chunekar, A., Varshney, S., & Dixit, S. (2016). *Residential Electricity Consumption in India: What do We Know.* Prayas Energy Group.

Crisil Infrastructure Advisory. (2016). *24x7 Power for All-Karnataka.*

Danley, D. (2017). *Optimization of advanced energy storage for solar-diesel hybrid microgrids.* 2017 IEEE Global Humanitarian Technology Conference.

Deshmukh, R., Gambhir, A., & Carvallo, J. (2013). *Sustainable Development of Renewable Energy Mini-grids for Energy Access: A Framework for Policy Design.* University of California Berkely.

Dörfler, F., Simpson-Porco, J., & Bullo, F. (2014). Plug-and-Play Control and Optimization in Microgrids. *Institute of Electrical and Electronics Engineers*, 211-216.

Finlay, J., Ali, S., Camenzuli, A., & Dobriansky, L. (2014). *Microgrid/Minigrid Finance and Investment Risk.* United Nations Environmental Programme.

Francesch-Huidobro, M. (2017). *An Analysis of Singapore's Market-based Tools for Energy Policy.* Konrad Adenauer Stiftung.

Franz, M., Peterschmidt, N., Rohrer, M., & Kondev, B. (2014). *Mini-grid Policy Toolkit: Policy and Business Frameworks for Successful Mini-grid Roll-outs.* European Union Energy Initiative Partnership Dialogue Facility.

Fu, R., Feldman, D., Margolis, R., Woodhouse, M., & Ardani, K. (2017). *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017.* National Renewable Energy Laboratory.

German Agency for International Cooperation. (2016). *Pump Price for Diesel Fuel.* World Bank.

Givler, T., & Lilienthal, P. (2005). *Using HOMER® Software, NREL's Micropower Optimization Model, to Explore the Role of Gen-sets in Small Solar Power Systems.* National Renewable Energy Laboratory.

Global Data. (2018). *Diesel Generators, Update 2018 - Global Market Size, Competitive Landscape, Key Country Analysis, and Forecast to 2022.* Global Data.

Goel, S., & Ali, S. M. (2014). Cost Analysis of Solar/Wind/Diesel Hybrid Energy Systems for Telecom Tower by Using HOMER. *International Journal of Renewable Energy Research, 4*(2), 305-311.

Grand View Research. (2017). *Microgrid Market Size Worth $17.51 Billion By 2025 | CAGR: 17.0%.*

Hafez, O., & Bhattacharya, K. (2017). Optimal planning and design of a renewable energy based supply system for microgrids. *Renewable Energy, 45*, 7-15.

Halabi, L., Mekhilef, S., Olatomiwa, L., & Hazelton, J. (2017). Performance analysis of hybrid PV/diesel/battery system using HOMER: A case study of Sabah, Malaysia. *Energy Conversion and Management*, 322-339.

Hayward, J., & Graham, P. (2017). *Electricity Generation Technology Cost Projects: 2017-2050.* CSIRO.

Hirsch, A., Parag, Y., & Guerrero, J. (2018, July). Microgrids: A review of technologies, key drivers, and outstanding issues. *Renewable and Sustainable Energy Reviews, 90*, 402-411.

Hoonchareon, N. (2013). *Thailand Smart Grid Policy Plan and Roadmaps.* Chulalongkorn University.

Hossain, E., Kabalci, E., Bayindir, R., & Perez, R. (2014). Microgrid testbeds around the world: State of art. *Energy Conversion and Management, 86*, 132-151.

Iclodean, C., Varga, B., Burnete, N., Cimerdean, D., & Jurchis, B. (2017). Comparison of Different Battery Types for Electric Vehicles. *Conference Series: Materials Science and Engineering, 252.*

IEA. (2016). *National Energy Policy (Government Regulation No. 79/2014).* International Energy Agency.

India Government Ministry of Power. (2018). *Saubhagya Dashboard.* Retrieved from Saubhagya: www.saubhagya.gov.in

India Ministry of Electronics and Information Technology. (2017). *Progress Report of Village Electrification March 2017.* Retrieved from National Informatics Center: visualize.data.gov.in

India Ministry of New and Renewable Energy. (2016). *National Policy for Renewable Energy Based Micro and Mini Grids*. India MNRE.

India Ministry of Power. (2009). *Guidelines for Village Electrification through Decentralized Distributed Generation under Rajiv Gandhi Grameen Vidyutikaran Yojana in the XI Plan - Scheme of Rural Electricity Infrastructure and Household Electrification*. Government of India.

Indonesia Ministry of Energy and Mineral Resources. (2018). *Renewable Energy Purchase Policy* . International Energy Agency.

Industrial Economics Incorporated. (2015). *Assessing the Benefits and Costs of Developing a Microgrid: Model User's Guide*. IEC.

International Energy Agency. (2015). *India Energy Outlook*. Special Report. Retrieved from https://www.iea.org/publications/freepublications/publication/IndiaEnergyOutlook_WEO2015.pdf

International Energy Agency. (2017). *Southeast Asia Energy Outlook 2017*. Retrieved from https://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_SoutheastAsiaEnergyOutlook.pdf

International Energy Agency. (2017). *World Energy Outlook 2017*. Retrieved from https://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_SoutheastAsiaEnergyOutlook.pdf

International Energy Agency. (2018). *World Energy Investment.*

International Finance Corporation. (2017). *Energy Storage Trends and Opportunities in Emerging Markets*. IFC, ESMAP.

International Renewable Energy Agency. (2015). *Off-grid Renewable Energy Systems: Status and Methodological Issues*. IRENA.

International Renewable Energy Agency. (2017). *REthinking Energy 2017: Accelerating the global energy transformation*. Abu Dhabi.

IRENA. (2016). *The Power to Change: Solar and WInd Cost Reduction Potential to 2025*. IRENA.

IRENA. (2017). *Accelerating renewable mini-grid deployment: A study on the Philippines*. International Renewable Energy Agency.

IRENA. (2017). *Electricity Storage and Renewables: Costs and Markets to 2030*. IRENA.

IRENA. (2018). *Project Navigator Bankability Checklist*. Retrieved from IRENA Project Navigator: https://navigator.irena.org/inside/pn/Pages/default.aspx

IRENA. (2018). *Renewable Power Generation Costs in 2017*. Abu Dhabi: International Renewable Energy Agency.

Jiang, B., & Fei, Y. (2014). Smart Home in Smart Microgrid: A Cost-Effective Energy Ecosystem With Intelligent Hierarchical Agents. *IEEE Transactions on Smart Grid, 6*(1), 3-13.

Jonsen, K., & Jehn, K. (2009). Using Triangulation to Validate Themes in Qualitative Studies. *Qualitative Research in Organizations and Management: An International Journal, 4*(2), 123-150.

Karnataka Power Transmission Corporation Limited. (2018). *Daily Load Curve.* Bangalore. Retrieved from http://218.248.45.137:8282/LoadCurveUpload/lcdownloadview.asp

Kempener, R., Lavagne d'Ortigue, O., Saygin, D., Skeer, J., Vinci, S., & Gielen, D. (2015). *Off-Grid Renewable Energy Systems: Status and Methodological Issues.* International Renewable Energy Agency.

Khodayar, M. (2017). Rural electrification and expansion planning of off-grid microgrids. *The Electricity Journal, 30*, 68-74.

Khodayar, M. (2017). Rural Electrification and Expansion Planning of Off-grid Microgrids. *The Electricity Journal, 30*, 68-74.

Lambert, T., Gilman, P., & Lilienthal, P. (2006). Micropower System Modeling with HOMER. In *Integration of Alternative Sources of Energy* (pp. 379-418).

Lao PDR Ministry of Planning and Investment. (2016). *8th Five-year National Socioeconomic Development Plan* . Lao PRD MPI.

Li, Y., Shi, X., & Su, B. (2017). Economic, social and environmental impacts of fuel subsidies: A revisit of Malaysia. *Energy Policy, 110*, 51-61.

Long, Y., Wang, Y., & Pan, C. (2018). Incentive Mechanism of Micro-grid Project Development. *Sustainability, 10*(163), 2-6.

Malaysia Ministry of Energy. (2010). *National Renewable Energy Policy and Action Plan.* Malaysia MOE.

Malaysia Ministry of Energy, Green Technology, and Water. (2012). *Malaysia Rapid Assessment Gap Analysis for Sustainable Energy for All Initiative.* Government of Malaysia.

Market Research Future. (2018). *Microgrid Market Research Report - Global Forecast to 2022.*

Menke, C. (2013). *Smart Grid Activities in Vietnam.* Deutsche Gesellschaft für Internationale Zusammenarbeit.

Microgrid Investment Accelerator. (2017). *Microgrid Market Analysis & Investment Opportunities in India, Indonesia, and Tanzania.* Allotrope Partners.

Ministry of Energy and Mines of Lao PDR. (2010). *Rural Electrification Master Plan of Lao PDR.*

Ministry of New and Renewable Energy. (2012). *Draft National Policy on RE Based Mini/Micro grids.*

Ministry of New and Renewable Energy. (2018). *Memorandum No. 318/38/2018-GCRT.* Government of India.

Myanmar National Energy Management Committee. (2015). *Myanmar Energy Master Plan.* The Government of the Republic of the Union of Myanmar NMEC.

NREL. (2003). *Gas-Fired Distributed Energy Resource Technology Charazaterizations.* United States Department of Energy.

OPIC. (2014). *Important Features of Bankable Power Purchase Agreements For Renewable Energy Projects.* Overseas Private Investment Corporation.

Peerapong, P., & Limmeechokchai, B. (2017). Optimal electricity development by increasing solar resources in diesel-based micro grid of island society in Thailand. *Energy Reports, 3*, 1-13.

Philippine Department of Energy. (2017). *Philippine Energy Plan 2017-2040 and Executive Order No. 30.* . Philippine Energy and Policy Planning Bureau .

Pillai, G. M. (2014). *Lao PDR National Sustainable Energy Strategy Report on Enabling Environment and Technology Innovation Ecosystem for Affordable Sustainable Energy Options.* UNESCAP.

Power System Operation Corporation Ltd. (2017). *Indian Electricity Market Data Analysis.* New Delhi: Government of India.

Ramchandran, N., Pai, R., & Parihar, A. (2016). Feasibility assessment of Anchor-Business-Community model for off-grid rural electrification in India. *Renewable Energy, 97*, 197-209.

REEEP Policy Database. (2012). *Indonesia Profile.* Reegle Info.

Rocky Mountain Institute. (2018). *A Design Charrette To Achieve 20 cents/kWh By 2020.* Nigeria.

Rodriguez-Molina, J., Martinez-Nunez, M., Martinez, J.-F., & Perez-Aguiar, W. (2014, 9 9). Business Models in the Smart Grid: Challenges, Opportunities and Proposals for Prosumer Profitability. *Energies, 7*(9), pp. 6142-6171.

Samad, H., & Zhang, F. (2016). *Benefits of Electrification and the Role of Reliability - Evidence from India.* South Asia Region, Office of the Chief Economist. World Bank Group.

Samad, H., & Zhang, F. (2016). Benefits of Electrification and the Role of Reliability: Evidence from India. *World Bank Group*, 1-14.

Schnitzer, D., Lounsbury, D., Carvallo, J., Deshmukh, R., Apt, J., & Kammen, D. (2014). *Microgrids for Rural Electrification: a critical review of best practices in seven case studies.* United Nations Foundation.

Siemens. (2015). *Microgrid Start Up: A Guide to Navigating the Financial, Regulatory, and Technical Challenges of Microgrid Implementation.*

Singapore Energy Market Authority. (2018). *Singapore Energy Story.* Singapore Government.

Stadler, M., Cardoso, G., Mashayekh, S., Forget, T., Deforest, N., Agarwal, A., & Schönbein, A. (2015). *Value Streams in Microgrids: A Literature Review.* Lawrence Berkely National Laboratory.

Strahl, J., Paris, E., & Vogel, L. (2015). *The Bankable Microgrid: Strategies for Financing On-Site Power Generation.* Navigant Consulting.

TFE Consulting. (2017). *Kenya: The World's Microgrid Lab.* Retrieved from https://www.tfeconsulting.com/_website/wp-content/uploads/2017/09/TFE_Report-Kenya-new.pdf

Thailand Provincal Electricity Authority. (2014). *Rural Electrification in Thailand: Policy and Implementation.* Government of Thailand.

Tiwari, A. K., Shahbaz, M., & Adnan Hye, Q. M. (2013). The environmental Kuznets curve and the role of coal consumption in India: Cointegration and causality analysis in an open economy. *Renewable and Sustainable Energy Reviews*, 519-527.

Tongia, R. (2018). *Microgrids in India: Myths, Misunderstandings, and the Need for Proper Accounting.* Brookings Institution India Center.

Union of Concerned Scientists. (2017). *Accelerating US Leadership in Electric Vehicles.* UCS.

United Nations. (2018). *Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all — SDG Indicators.* (United Nations Department of Economic and Social Affairs) Retrieved July 16, 2018, from Sustainable Development Goals: https://unstats.un.org/sdgs/report/2017/goal-07/

United Nations Framework Convention on Climate Change. (1992). Indicative simplified baseline and monitoring methodologies for small-scale CDM project activity categories. *25*, p. 1. UNFCCC.

United Nations Framework Convention on Climate Change. (2015). *Facilitating Technology Deployment in Distributed Renewable Electricity Generation.* Technology Executive Committee. UNFCCC.

Vietnam Ministry of Industry and Trade. (2011). *Master Plan for Power Development for the 2011-2020 with the Vision to 2030.* The Socialist Republic of Vietnam.

Williams, N., Jaramillo, P., Taneja, J., & Ustun, T. (2015). Enabling private sector investment in micro-grid based rural electrification in developing countries: a review. *52*, 1268-1281.

Vine, D., Attanasio, D., & Shittu, E. (2017). *Microgrid Momentum: Building Efficient, Resilient Power.* Center for Climate and Energy Solutions.

Wold Bank Group. (2011). *Vietnam State and People, Cental and Local, Working Together the Rural Electrification Experience.* Asia Sustainable and Alternative Energy Program.

Wolf, G. (2017). A Short History: The Microgrid. *T&D World - Digital Innovations.*

World Bank. (2018). *Access to electricity, rural*. World Bank, SE4ALL Database.

World Bank. (2018). *Access to Energy is at the Heart of Development*. Retrieved from The World Bank: Understanding Poverty: https://www.worldbank.org/en/news/feature/2018/04/18/access-energy-sustainable-development-goal-7

World Bank Group. (2009). *Cambodia Rural Electrification Strategy and Implementation Plan.* Cambodia Ministry of Industry, Mines, and Energy.

World Bank Group. (2017). *Enterprise Surveys: Infrastructure.* Retrieved from http://www.enterprisesurveys.org/data/exploretopics/infrastructure

World Bank Group. (2017). *Fuel Supply/Bulk Agreement.* Retrieved from https://ppp.worldbank.org/public-private-partnership/sector/energy/energy-power-agreements/bulk-fuel-supply-agreements

Appendix

Table 15 List of actors interviewed as well as general information provided through the interview.

Informant	**Information Provided**
Fluidic Energy – CEO	- Microgrid markets in Africa, India, and Southeast Asia - Technical specifications for batteries used in microgrids - Financing in public-private microgrid projects
Gram Oorja – Engineers and manager	- Project development in rural India - Financing microgrid projects through government funding, private grants, and tariff structures - Technical specifications of community microgrids in India
Volvo Penta – Director New Business Development	- Research process guidance - Organizational structure - Market information on microgrid industry
Volvo Penta – Director Industrial Sales	- Diesel generator specifications - Pricing of various generator models at retail values
Volvo Penta – Director Sales Southeast Asia	- Market information in Southeast Asia - Leading information into regional case studies
Volvo Group India – Vice President	- Market information for India - Business models for microgrids - System specifications with a DG component

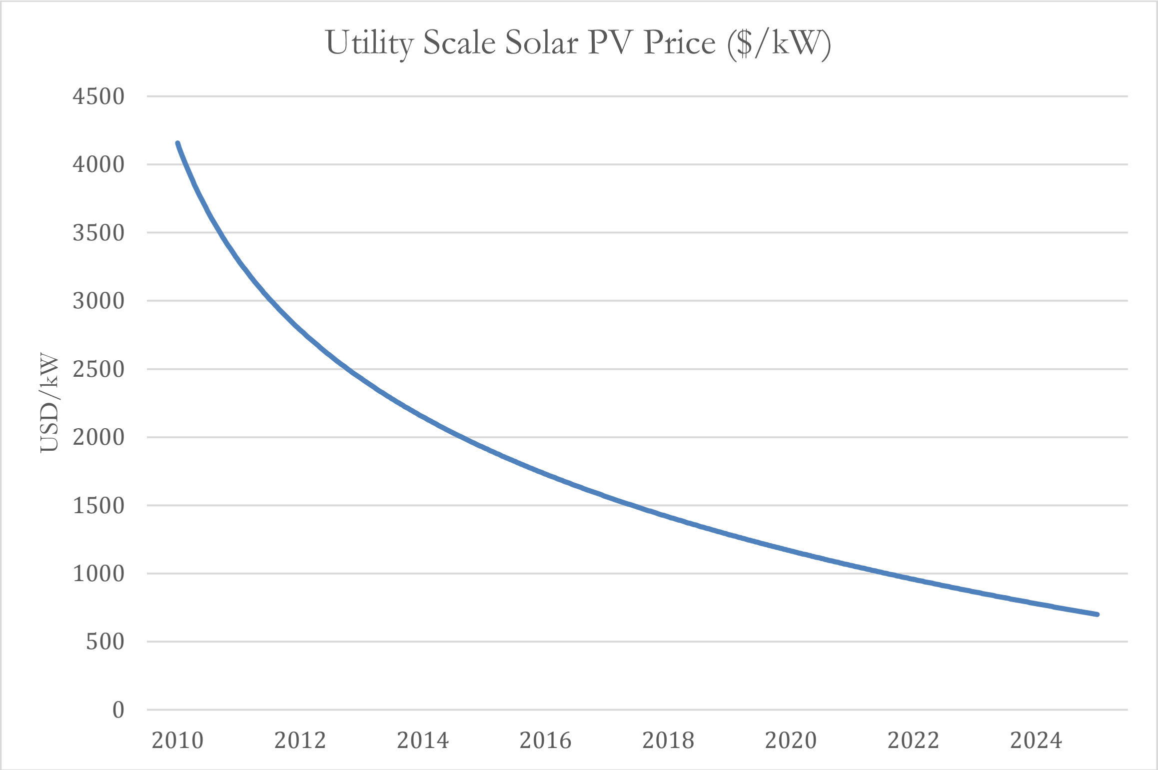

Figure 15 Costs of utility scale solar PV including total installation, module, and inverter costs. Pure costs of the module only are projected to be much lower. This is a world average and not entirely reflective of the scoped study area.

Source: 10 (IRENA, 2016)