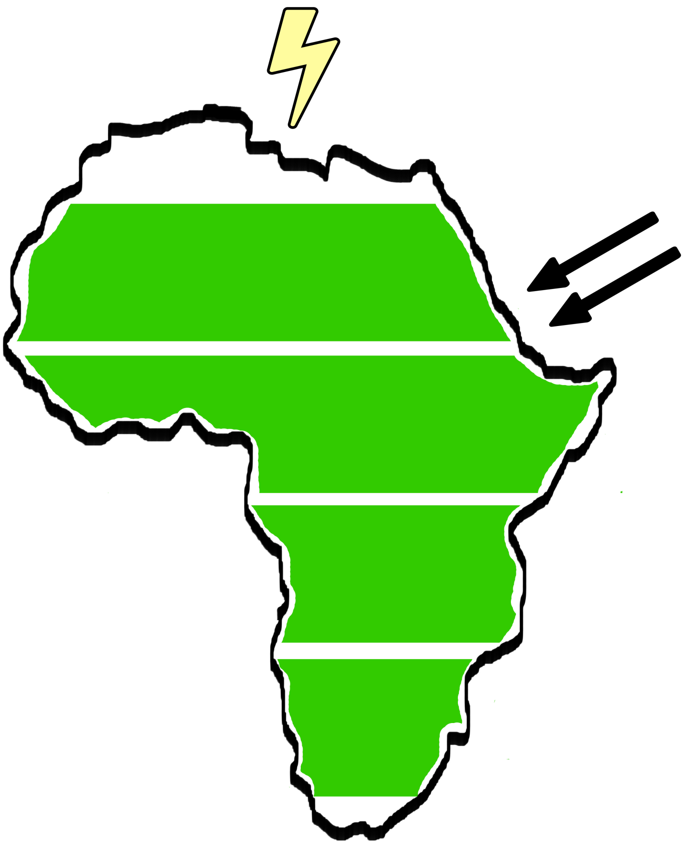

Utility from Battery Energy Storage Systems in rural Sub-Saharan African solar PV microgrids

Master's thesis in Industrial Ecology

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CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2021

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Cover: Illustration of the African continent as a battery fully charged from solar PV generated power.

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Abstract

Almost 800 million people on the planet does not have access to a reliable supply of electricity. Universal access to modern sources of energy is a necessary step for poverty alleviation in many regions concentrated around the equator. Solar PV is often used because of the high solar irradiance in these areas but will imply difficulties for delivering a stable and continuous supply of electricity, some of which the addition of a battery energy storage system eventually could solve.

This study was made with the intent to find how utility could be created from an additional battery energy storage for a solar PV microgrid application in a rural Sub-Saharan African context. A method was designed to translate improvements in the electotechnical attributes of peak capacity, availability and reliability in to social, economical and environmental utility from household, productive and community use.

The results showed that social utility from more energy supplied by an improved availability and reliability of electricity will see the most amount of utility, where high environmental utility by reduced emissions will follow as a result of this. Some economical utility could be seen, but requiring longer periods of time before any major differences can be distinguished. The overall utility from added battery energy storage was concluded to be high and the amount of utility a battery energy storage system creates is dependent on its ability to supply either additional power and energy.

Keywords: microgrids, rural, solar PV, utility, battery energy storage systems, sub-saharan africa.

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Anton Bergman, Gothenburg, June 2021

"Alles Vergängliche
ist nur ein Gleichnis;
das Unzulängliche,
hier wird's Ereignis;
das Unbeschreibliche,
hier ist's getan;
das Ewig-Weibliche
zieht uns hinan."
—Goethe, *Faust II*

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1 Introduction

The global electricity access rate has accelerated over the last decade, having seen an increase from 83 to 90 percent between 2010 and 2018 and is currently outpacing the rate of global population growth [1]. Although the high rate, the remaining percentages leave an estimated number of 789 million people without access to a reliable supply of electricity [2]. At current electrification rates, projections indicate that the 100 percent ensured universal access to electricity by 2030, imposed within Goal 7 of the UN Sustainable Development Goals, will not be achieved [3].

Challenges in ensuring an adequate energy supply across the world consists of the hitherto unequal technosocial and urban development over regions, this has been specifically concentrated to Sub-Saharan Africa where 59 percent of the population live in rural areas located far from a main grid connection [4]. The unavailability of a main grid connection implies that there will be high infrastructural, maintenance and tariff costs to connect single and remote villages to a sometimes unreliable and expensive main grid connection. The process of rural electrification is a substantial and sometimes down-prioritized expenditure among many other, still relatively, underdeveloped public services of nations within the region.

A suggested solution to provide rural communities in Sub-Saharan Africa with electricity is the development of independent off-grid solar powered microgrids. These are able to utilize the high solar irradiance associated with regions around the equator, promoting a carbon neutral energy source in developing countries.

Benefits that access to electricity could imply are numerous from a social, economical and environmental perspective. The most basic microgrids, consisting of a single power source to supply all end users, will be restricted to the delivery of electricity during hours when there is enough power produced and not to many simultaneous loads within the grid. The addition of a technology able to store power produced by solar PV and address some of its shortcomings is of interest in this context. As improvements on electricity access are made, further benefits for the end users could be found and studied.

1.1 Aim

This study aims to identify impacts of adding a battery energy storage system (BESS) to a rural solar PV microgrid in Sub-Saharan Africa by developing a methodology able to identify why, how and where utility occurs as a result of the addition. The ways a BESS could result in electrotechnical changes that eventually create differences in social, economical and environmental utility for end users of the microgrid will be identified and discussed.

The purpose of this report will be to reach an inductive understanding on where and how utility from the addition of a BESS can be created from performing a underlying study and assessing its findings, as well as acting as an qualitative introduction to further quantitative research.

1.2 Limitations

The lack of data on real experienced social, economic and environmental differences in utility the added battery storage specifically contributes to needs to be taken into consideration. This will yield inductive and general conclusions throughout the study.

Components of the microgrid such as the solar PV generator, BESS and inverters will be generalized and in some cases overlooked as the aim of the study is to make inductive assessments on changes in the system based on descriptions from the literature rather than based on calculated quantitative differences.

1.3 Research question

- How, where and to what extent are differences in social, economic and environmental utility created for end users when battery energy storage systems are introduced to solar PV microgrids in the context of rural Sub-Saharan Africa?

1.4 Background

To achieve an understanding of the ideas used in this study, the background section will cover some of the electrotechnical concepts to be used such as rural electrification, microgrids and BESS as well as what the concepts of utility in relation to electricity access implies.

1.4.1 Rural electrification

Approaches to electrifying rural areas will all have their opportunities and obstacles [5]. For small household demand in villages that are not grid connected, solar home systems (SHS) with stand-alone PV panels can be used. The SHS is able to supply electricity at an amenity level and allow for high customer flexibility as their design inherently gives the option to choose the most suitable capacity for their needs. This comes with a high net cost per kWh combined with restraints on the type of appliance it can power. Pico PV is the cheapest option for low electricity demand households, but is naturally limited by the very small power supply dimensioned to power or charge single sources of light, radios or phones [6].

1.4.2 Microgrids

A microgrid can be described as a number of lower voltage loads connected to distributed energy resources within the boundaries of a single technically and spatially defined entity, either operating connected to the main grid where the possibility to disconnect in to "island mode" exists, or as a standalone and decentralized smaller electrical grid [7]. In rural areas where a main grid is not yet developed and out of reach, fully off-grid and independent microgrids are common. The distributed generation from local renewable energy sources results in lower line losses when the power demand is near the supply. The term minigrid can sometimes be used analogous to microgrid, where a commonly used definition differentiates the two terms with regards to the total capacity of the grid [8]. A microgrid has in turn been characterized as having a capacity lower that 10 MW, using suitable intermittent technologies.

Wind and solar PV power generation are intermittent sources of energy, meaning that they are variable and partially unavailable depending on hours of the day, weather and season. Solar generation has a lower but relatively predictable variability over days, seasons and weather conditions as it generates a constant amount of energy when the sun is shining, ceasing production whenever it sets. Wind power is on the other hand a more variable source of energy dependant on factors that are more difficult to forecast than those associated with solar power, such as wind speed, air density and temperature which all can fluctuate more on shorter time scales.

Sub-Saharan Africa has high levels of global horizontal radiance potential, which meters the solar energy an area is exposed to on average [9]. The amount of solar irradiation is in turn related to the potential amount of power a solar PV panel is able to convert from the sun, making it a natural and appropriate choice as a renewable source of energy in the context of rural microgrids in Sub-Saharan Africa.

The absence of power generation during dark hours of the day in a microgrid with solar PV as a primary source of power generation will introduce some complications. A solar PV microgrid will be vulnerable to high levels of load that could occur when too many appliances draws power at the same times, as well as larger load fluctuations when heavier appliances draws more power from the grid than it is capable to supply. These factors can cause voltage mismatches, in turn resulting in power losses and damage to electrical components of the system when high enough currents forms and the microgrid shuts down. The apparent drawback of not having any electricity available after sunset is also an issue, as evening hours commonly constitutes the second daily peak of power demand when people return from work or school and want to use lighting for cooking or studying and household appliances for leisure or entertainment.

1.4.3 Battery energy storage systems

A BESS is commonly used in most microgrids to overcome some of the difficulties associated with intermittent sources of power supply. Depending on the capacity of the BESS, it should be able to contribute to a variety of services in the microgrid, most notably by storing energy during hours of high supply and low demand [10].

The concept of charging the BESS during hours of high power production and low demand that can be discharged in support of the microgrid when the power generated becomes insufficient to cover periods of high demand is known as load shifting. Load shifting can contribute to a more stable load, higher power quality as a result of avoided irregular voltage frequencies and transients [10]. To cover for periods of solar irradiance dropping during PV generation, the BESS is able to smooth out dips or peaks of power production to further stabilize the system.

There are a variety of specifications for energy storage solutions, with Li-ion batteries currently being one of the most viable options because of their life span and energy density. Although relatively expensive at the moment, recent years of high production volumes and further research has made Li-ion batteries increasingly cheaper and prices per kWh of energy stored is expected to drop even lower in the near future [11].

1.4.4 Utility

Utility originates from the moral philosophic theory of utilitarianism, which stems from the English economists and philosophers Jeremy Bentham and John Stuart Mill [12]. The term initially referred to the amount of pleasure that could be derived from an action, where an action is right if it leads to pleasure and happiness and bad if it leads to pain and unhappiness. The concept has over the years moved away from its purely philosophical applications to be adapted in to neoclassical economics [12].

Methods of deciding utility could be divided in to either cardinal and ordinal utility [13]. Cardinal utility uses quantifiable and objective measurements to rank utility from the consumption of goods and services, giving an objective magnitude on how much more utility an option results in when compared to other options.

Ordinal utility ranks the utility from the consumption of goods and services comparatively, putting every option in relation to each other whether a higher, lower or equal utility is experienced from it. The ordinal utility is suitable for ordering preferences, but is not able to put a number on how much more or less utility a choice quantitatively results in when compared to another, which should be more useful for real world evaluations.

1.5 Literature review

To establish the aim and purpose of this study in relation to current and previous research, some relevant findings from the literature will be presented. The following initial literature review will be thematically based, moving from general to more specific approaches towards the subject. A literature review that overviews previous methodological approaches to similar research questions will be featured in the methods chapter later in this study.

Literature was found by using keywords relevant to the study (different combinations and formulations of *solar PV, battery storage, rural electrification, microgrids, off-grid, electricity access, socioeconomic development, utility from electricity use, benefits of electricity, indicators, Sub-Saharan Africa*) on various search engines and databases such as Web of Science, Google Scholar and ResearchGate. Perusing references used in research papers that was found to fit the scope of the study well was another procedure used to find additional reoccurring sources of information.

There have been plenty of reports made on the energy access situation in developing countries around the world. The efforts needed to provide sufficient access to modern energy solutions in poor and rural areas are highlighted as a necessary step for achieving many of the global goals regarding poverty and health.

The importance of electricity for delivering a higher quality healthcare in rural areas has also been thoroughly researched, further consolidating the access to an adequate and reliable supply of electricity [14]. The crucial role of access to modern energy as a precondition for human development and the many benefit it entails is established in another report that also develops a framework to create a non binary metric for defining electricity access [15]. A multi-tier framework of energy access is applied and reviewed by three case studies carried out in India and Nepal, finding evidence on beneficial development of lighting, time spent on income generation for women and appliance ownership rates in correlation to better access to electricity [16]. This study also finds that access to electricity is only one aspect behind socioeconomic development, describing many other contributing exogenous factors and suggests that metrics on electricity access has the possibility to be refined even further.

A study made on the general hazards of kerosene as a source of light and heat for cooking finds a scarcity of epidemiological research, concluding that many direct (poisoning, fires and explosions) and indirect (impairing lung functions, risk of cancer and emissions of carbon monoxide, nitric oxides and sulfur dioxide) hazards can be related to household kerosene use [17]. A large amount of deaths per year in rural areas without access to electric lighting and cooking appliances are attributed to respiratory deceases from indoor pollution caused by the use of combustion fuels [18].

Impact evaluations of microgrids and how they could be a solution for establishing electricity access in an off grid rural context have also been made. An increase in study time for children, higher flexibility in time use and a significant decrease in kerosene use as a result of electrification could be found in one study [19]. The same study could also show that the impact of electricity access as a way to improve productive activities was limited. A survey based study made on rural households in India quantify the benefits of electrification and finds positive effects on flexibility in time allocation, income, expenditures and education, all contributing towards contemporary and future poverty alleviation [20]. The same study also found that there are some economical barriers for adopting electricity as household connection rates are significantly lower than the rate of villages that has access to electricity.

A considerable amount of research exists on the electrotechnical functions and optimization of solar PV microgrids, as well as on the role of proper dimensioning for an energy storage system. Conclusions have been made regarding the necessity of energy storage and energy management to meet the intermittent generation patterns of solar PV [21, 22], advantages and disadvantages between different types of storage solutions [23, 24], supply and demand profiles mismatch [25, 26, 27] and load shifting strategies [28, 29]. The need for proper energy storage systems supported by adequate control and energy management is highlighted throughout as a crucial factor for the implementation of solar PV in both grid and off grid connected microgrid context. A study on how different attributes of the microgrid can be maximized describes the optimal sizing and energy scheduling for different tariff structures, finding a preference for large scale PV-systems with no, or as small as possible, battery systems in two cases studied [30].

Other research papers has made comparative valuations of the willingness-to-pay for a main grid connection compared to a microgrid, finding an preference among users in the order of power, reliability and price while also valuing the reliability of a microgrid higher than the higher amount of available hours of electricity from a main grid connection [31]. An experiment on the socioeconomic effects of electrification and the difference in utility a grid connection implies has found that the social and economic impacts on households from electrification are slow processes, showing improvements after 18 months connection as the initial demand is too low [32]. The slow adoption rate and limited socioeconomic impacts of accessing electricity by the main grid in comparison to having a pre-electrified off grid connection are affirmed in a case study for a Tanzanian village, seeing the most significant positive impacts in lighting and lighting quality and to some extend TV ownership rates and use [33]. Another study gives experimental evidence on the impact of solar lamps with phone charging to cover a very basic energy need, finding positive effects on income, general well-being and health within treatment groups of the experiment [34].

The productive energy use and what socioeconomic impacts that it can contribute to is the focus of one paper [35]. There are also reports discussing the relation between electricity cost and load profiles of a microgrid from a technical and system dynamic approach, giving an overview on the function and abilities of the technology [36, 37, 38].

2
Method

In order to structure, collect and systematize the data required for the purpose of this study, a suitable methodology must be developed.

2.1 Method design

The method of this study should be able to capture some type of measurement on changes in utility and how it can be related to more explicit differences in the electrotechnical domain. Methods from previous studies found as likely to be applicable in this context will be presented, ranked and discussed in order to find an approach that could be suitable for the purpose of this study.

2.1.1 Literature review of methods

To complement the initial literature study that was made to get a background and better understanding on the purpose of this by a more categorical approach, an additional literature search with the intent of finding previous research that has made suggestions on how these types of studies could be conducted from a more methodological approach will be made.

Many research papers builds their methodological basis on surveys which examine real world valuations towards different attributes of electricity access by factors such power, reliability and cost in a typical off-grid village from an user perspective. Total loads within villages varies and can be based on tiers according to appliance ownership in households [39] and measured or estimated load profiles [36, 35]. Data on actual power consumption is often described as difficult to measure in this context due to the absence of metering equipment and actual power ratings of appliances.

The concept of deciding the amount of utility associated with electrification is in one research paper simplified as an economy comprised of consumers with an income influenced by goods and services in the form of food and electricity, creating a utility function dependant on the food and electricity variables [40]. The same paper also performs a cost benefit analysis to assess if the deviations in WTP for different electrification technologies are high enough to cover the changes in required investment costs for the technology.

Another study has gathered data related to household utility such as building material, toilet and water availability and energy source used for cooking together with weekly energy expenditures and daily mean usage time of appliances, comparing the grid-electrified households with not yet grid-electrified households [33]. Propensity score matching is then used to estimate the effect a grid connection has on household activities and appliance usage.

One study finds the most financially viable configuration of a hybrid energy microgrid through an extensive techno-economic analysis, as well as by weighting the environmental impact of every option for powering an off-grid telecom tower in rural Nigeria [41]. The study shows that a PV-diesel-battery system is the most sustainable both in terms of economical and environmental impacts after calculating the solar and wind potential of the site as well as describing control parameters and components of the system and how they influence the simulation results.

Another research paper delves deeper into the techno-economical modelling of a microgrid through a multi-objective optimisation framework applied to two residential cases in the Netherlands and US [42]. Key takeaways from this study is the impact solar potential has on the sizing of battery relative to the rated power of installed PV and how the dimension of a system can be derived to fit battery power rating and capacity, although modelled after a main grid connected microgrid.

There are some variations on how the method generally is conducted, mostly depending on if the base data emanates from qualitative surveys or quantitative measurements on load and technical models of the microgrid. Another field of research has explicitly developed frameworks to gather, systemize and decide how changes in electricity access impact the benefits for end users. A review on some of these and their eventual usefulness for the purpose of this report will now follow.

The use of indicators is a suggested tool for measuring utility in two studies [43, 44]. The general idea of indicators are to track progress towards a desired outcome, such as increasing utility from electrification by measuring and observing contributing characteristics and how these change over time. A challenge in this type of methodology is the need to create well-defined and specific indicators.

By establishing a toolkit to be used for the monitoring and evaluation of social impacts caused by microgrids, one paper suggests a variety of indicators that can be used to standardize data collection and analyses from the operation of a microgrid [44]. Core and optional indicators are given, all which are contributing towards a Key Performance Indicator based on measurements in the categories of technical, tracking customers, household, productive uses of energy, gender, education, health and social indicators. This type of methodology will result in an output consisting of measurable and comparable values on the utility from electricity access.

Ilskog evaluates the sustainability of rural electrification projects through a method based on 39 indicators covering the five dimensions of technical, economical, social/ethical, environmental and institutional sustainability [43]. This paper gives procedures on how to calculate the suggested indicators using data that should be possible to collect through field studies and surveys, while acknowledging the complexity and large amount of work required to acquire the data.

A World Research Institute (WRI) study assess and compare how households and small enterprises benefit from electricity from either the national grid, SHS or microgrids for rural communities in India and Nepal [16]. The framework of the study is in turn based on a multi-tier framework for determining electricity access developed by the Energy Sector Management Assistance Program (ESMAP) which is a subdivision of the World Bank [15]. Differences in service conditions between different types of electricity supply are analysed and suggestions on how the multi-tier framework can be refined are made, where the complexity of aggregating varying dimensions of electricity access into a single score is seen as the main difficulty.

The ESMAP multi-tier framework [15] partly used in the aforementioned study has been developed as a tool to defined and measure the non-binary characteristics of electricity access, as well as for presenting underlying assumptions on how it is connected to socioeconomic development. Using a final index on overall energy access, the framework is able to hierarchically aggregate sub-indices from the bottom up. The sub-indices are in turn separated into three different locales: households, productive engagements and community facilities, each having separate multi-tier matrices for deciding a rank on energy access.

The multi-tier methodology allow qualitative and quantitative data to be combined and assigned a tier (between 0 and 5) according to the predefined electrotechnical attributes within each locale. Some shortfalls brought up in this methodology are the complexity and need for data. The complexity is addressed by giving suggestions on a simplified framework that can be used when survey data is missing. Thresholds for tiers are based on subjective considerations of technological break-points and the power supply required to use various appliances and services, and might not be universally true or applicable for all cases.

2.1.2 Ranking methods

In order to get an overview of previous methodological frameworks that could be beneficial when designing a method to find the utility created when adding a BESS in a solar PV microgrid, Table 2.1 will rank four methodological approaches to decide the utility from electricity use. These approaches will be compared in relation to each other and ranked according to four parameters, 1 being the most and 4 being the least suitable methodological approach to apply for this study. The four approaches was found during the literature review of methods. Two of the approaches were explicit frameworks for the use of indicators to decide utility from electrification as a contrast to the two others, the first being a procedure for how a multi-tier framework for electricity access has been created and the second an application of the same multi-tier framework on a case study with suggestions on how the method of deciding electricity access to find utility from electricity use could be further improved upon.

The *Complexity* score will rank how extensive the method has to be in order to achieve a significant result, *Data* ranks the amount of data gathering required in combination with the presumptive availability of relevant data, the *Generality* of a method ranks how applicable it might be across different cases and how much of it that can be carried over into further studies and *Indicators* signifies the need to create and use indicators to achieve a result. If each score is weighted equally for the purpose of this ranking, the method receiving the lowest total score should contain an approach to the method that is more suitable for the purpose of this study than the others.

Table 2.1: Ranks of suggested methodological frameworks that have been found in the literature. A lower total score should imply a framework more suitable for the purpose of this study than a high score.

	Complexity	Data	Generality	Indicators
Ilskog [43]	4	4	1	4
Eales [44]	3	3	3	3
WRI [16]	1	2	4	1
ESMAP [15]	2	1	2	2

2.1.3 Analysis of method choice

Drawing from Table 2.1, it is obvious that the previous methodologies depending on the use of indicators [43, 44] will require extensive data gathering and classification in order to reach an adequate result. The construction of indicators causally impacted by the electrotechnical and economical changes a BESS entails would from a top-down perspective need large amounts of technical and surveyed data from many different cases, making it difficult to make general conclusions on how, when and where utility has changed.

Another difficulty with methods set to create definitive indicators able to reflect contributions from a large amount of sub-indicators is the need to compare "apples and oranges". This can be solved by trying to find a common unit to be used for all measurements of the system, often an unit-less ratio. The subsequent need to adapt every indicator in to a quantifiable measurement might inhibit the qualitative dimension of some indicators as well as overlooking the relations between them that this study will require.

Using an absolute indicator approach to find an ultimate measurement on change in utility by the addition of a BESS will have a high level of complexity, as survey data to be used for weighting the indicators in an already complex system most likely will be difficult or impossible to source. This might create biases towards aspects of utility that does not reflect the real world preferences and interpretations of what utility is, as only aspects with a sufficient access to data can be assessed. The need to translate qualitative data in to quantitative indicators and then back again will most likely not be able to capture some of the interlinking characteristics between attributes in the system, possibly overlooking many of the qualitative features utility is associated with.

Rather than identifying and creating indicators for causal impacts on utility as a result of added BESS, a comparative approach as seen in the two methods with a lower score [16, 15] could be used to find the statistical differences it could represent. By motivating and discussing the use of a smaller amount of carefully selected measurements, representative and reflective of the expected utility gained and explicitly able to capture how they eventually are impacted by a BESS, the differences could be statistically presented and thereafter qualitatively discussed.

The study and identification of differences that can be made in utility by adding BESS to a rural solar PV microgrid will require a methodological framework that is able to capture and connect the quantitative changes on how power and energy can be supplied to the qualitative differences in utility as a result of its use.

By selecting and motivating the use of some quantitative electrotechnical attributes whose expected changes in function inductively can be estimated from the literature, a foundation on which a qualitative analysis on the impacts caused by these changes can be laid. The impacts on utility will need to not only be analysed from a household point of view, as utility from the BESS extends beyond domestic electricity access. By also addressing and defining utility from productive and community use, a broader understanding on the overarching utility for all users in the microgrid can be found.

The method should be able to make general conclusions on changes in utility in relation to the inductive differences made to the electrotechnical functions of the microgrid as a result of added BESS. Drawing from gaps identified from the previous methodologies, a framework can be adapted to fit the research questions of this study.

2.2 Method framework

To get an overview on how the subsequent method of this study will be performed, a suggested framework will be presented and described in the following paragraphs.

The method will begin by identifying and motivate the use of some electrotechnical attributes that if changed, could have an impact on the utility from improved electricity use. By establishing these attributes in a first step, a basis on how functions of power and energy could relate to electricity use should be attained. A section on the concept of utility will follow. By creating a definition on what utility is and how it will be used in the context of this study, some indicators that should be able to reflect how social, economical or environmental utility occurs can be chosen and discussed. By identifying the locales where electricity could be used through the given indicators on utility, these can in turn be divided in to the locale where they inductively should see most use and the potentially largest changes in utility.

When indicators on utility and locales of electricity use have been decided, how and where utility is created within each locale can be assessed. By giving a rank on how much potential utility the indicator, with inductive support from the literature, should experience from the additional power and energy that the BESS is able to supply. The changes in electrotechnical attributes and subsequent function of power and energy supply as a result of the additional BESS will be discussed in the last section of the method. A characterization on whether the changes in an attribute from added BESS primarily contributes to power or energy will also be made.

Ranks on the potential level of utility from an indicator by its dependence on additional power or energy and how the added BESS primarily change the electrotechnical attributes in relation to power or energy could then be decided. The combination of these ranks should then be able to output how much social, economical and environmental utility is created by additional access to power and energy from improvements in the electrotechnical attributes.

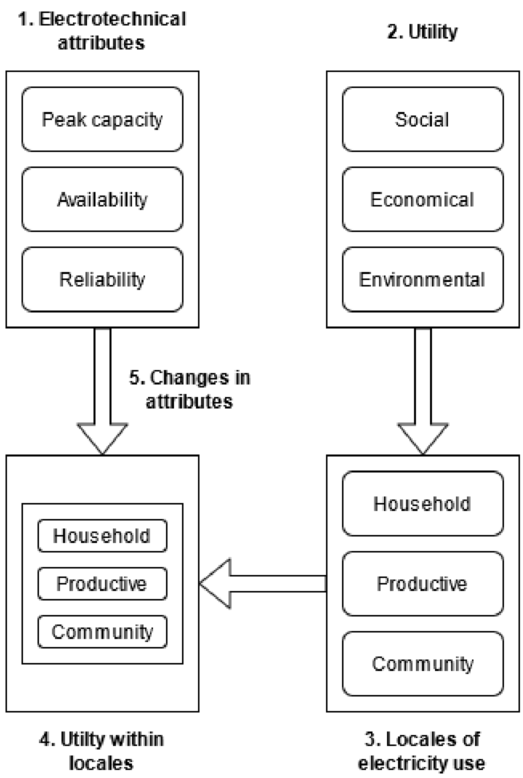

Figure 2.1: A visualization of the presented framework with each step subsequently ordered.

A graphic representation of this methodological framework can be seen in Fig. 2.1, where the first step is to motivate and describe each of the three electrotechnical attributes. The second step of the framework will be to motivate and describe the indicators chosen to measure utility within the social, economic and environmental dimensions. The third step is to identify and describe locales where electricity use creates utility. The fourth step places all indicators from the second step of the framework within the locales from the third step in order to assess how much utility contextually could be created within it. The fifth step will look at changes to the electrotechnical attributes eventually caused by the addition of a BESS and if it these can be characterized as improving either the power or energy supply. A last step will then be able to rank the relative amount of ordinal utility from each indicator within the locales.

2.3 Electrotechnical attributes

The electrotechnical attributes used in this method will be based on some of those suggested in the ESMAP technical report with further support from literature [15]. The attributes should be able to reflect factors that influence how electricity is used and where eventual improvements through the addition of battery storage are most likely to occur. Electrotechnical attributes in the microgrid used for this method are peak capacity, availability and reliability.

2.3.1 Peak capacity

The maximum amount of power that the microgrid is able to supply, measured in kW. Peak capacity impacts the quantity and load of electric appliances that can be used simultaneously and mainly depend on the amount of installed power generation and the efficiency rating of the microgrid. The peak capacity of solar PV power generation is related to solar irradiance, following a bell shaped curve as the sun rises in the morning and sets in the evening.

Higher peak capacity in a microgrid will allow for an increased overall amount of loads in the system, implying that additional and heavier loads are allowed to be used at the same time as the ability to deliver more power is improved.

2.3.2 Availability

Availability will be a measurement on how large share of the day electricity from the microgrid is available for consumption [15].

The duration and timing of a sufficient capacity of generated power can be supplied will have an impact on the availability of a microgrid. An electricity demand that is higher than what the microgrid is able to supply will have low availability, as some loads in those cases are unable to run simultaneously.

2.3.3 Reliability

A microgrid that is unable to match the supply and demand of power is prone to outages. The type of outage where loads are disconnected because the available amount is insufficient is characterized as a planned outage. Unplanned outages are on the other hand results of malfunction or failure of components in the microgrid, such as erroneous human interference, weather or accidents.

The frequency of outages as well as their duration constitutes a measurement on the reliability of supplied electricity in a microgrid.

2.4 Utility

The concept of utility will in the context of this study be used to establish a measurement on the notion of how the daily life of an individual will benefit from electricity use. When introduced to the system, the eventual changes in electrotechnical attributes caused by the BESS and how these changes could relate to differences in the conceptions of utility can be identified and further discussed. As a result of the general and inductive approach towards finding the benefits of added BESS, the ordinal utility for each separate indicator can be discussed and compared.

Utility will be divided into a social, economical and environmental dimension for which some relevant indicators when BESS is been added will be described. As some of the suggested indicators possibly impact utility in more than one aspect, their specific contributions will be described for every case. A summary of the indicators on utility to be used for each aspect can be seen in Table 2.2.

Table 2.2: Selected indicators and how they relate to the three aspects of utility established for this study.

Utility:		
Social	**Economic**	**Environmental**
Lighting	Business appliance and ICT use	Kerosene use
Public lighting	Household income and expenditures	GHG emissions
Appliance and ICT use	Business income and expenditures	
Health centers with electricity access		
Schools with electricity access		

2.4.1 Social utility

Social utility will be represented through factors related to education, safety, leisure, health and social equality. The social utility from electricity use will in this method be lighting, public lighting, appliance and ICT use, access to health centers improved by electricity and access to health schools improved by electricity.

Lighting
Can be used for indoor tasks such as cooking, reading and writing and allows for an extended amount of active hours during the day. Kerosene lamps are commonly used if and when no electric light sources are available. Available lighting during evenings can increase the amount of open hours for businesses during the day and enables labour that require an adequate light source when performed.

Public lightning
More outdoor areas covered by lighting can contribute to increased night time safety for women, higher and safer mobility during dark hours and more opportunities of evening socializing within communities [15].

Appliance and ICT use
TV, radio and mobile phones are sources of news, entertainment and communication. ICT usage contributes to a sense of social connectiveness across communities, as well as on a regional, national and global level. TV and radio are sources of information that updates and educate people on current events while also being able to bring leisure by showing movies and sport events. Fans can increase comfort by indoor cooling and electrical appliances can be used for convenience while also saving time when performing household chores.

Access to health centers improved by electricity
Electricity is crucial for many functions of health facilities in order to deliver a proper care. Electric lighting enable adequate medical assistance during all hours of the day and refrigerators can store pharmaceuticals which otherwise have to be discarded. The occurrence of modern energy and appliances is a major contributing factor for attracting qualified medical personnel.

Access to schools improved by electricity
Electric lighting allow for more hours of studying during early morning and evening hours. Education can be enhanced by the use of electronic aids such as video and computers.

2.4.2 Economic utility

Economic utility will treat factors that impact the balance between money spent and money earned for households and business, representing utility as the eventual improved possibility of financial opportunities and gain. The economical utility in this method will be based on the indicators business appliance and ICT use, household income and expenditures and business income and expenditures.

Business appliance and ICT use
Business income can be enhanced through the use of ICTs as it is able to connect vendors and customers, lowering the entry barrier for creating markets covering a larger area. Adoption of ICTs has been shown to have direct relations to economic development [45]. Mobile communication and internet access are important factors for financial inclusion and participation as a result of wider access to electronic cash and online banking services [15]. Unlike household appliance and ICT use that primarily have an impact on social utility, business appliance and ICT use will for this study contribute to aspects of economical utility because of their relatively contrasting applicability.

Electric appliances can be used in the production of goods and services, either by making existing practices more efficient or by enabling the creation of goods and services that are dependant on a certain level of power from the electricity accessed. This could in turn lead to a higher business income and the creation of new revenue streams.

Household income and expenditures
Electrification can lead to longer hours of operation for home businesses as well as shift and extend working hours of the day, prolonging the period of time available for income generation. Households with electricity access will use less kerosene and batteries for handheld torches which will save money on a monthly basis. The investments associated with installing, managing and upgrading the microgrid will impact connection fees and tariff costs for the end customer.

Business income and expenditures
The output and subsequent revenue of goods and services for productive businesses is in many cases dependant on electricity, varying from sources of light to heavier use of machinery and tools. Reoccurring power outages are obstacles for business expansion and operations, where backup generators and the fuel required to run them becomes a fixed expense with high opportunity cost when electricity from the microgrid is unavailable. The cost of upgrading and maintaining the microgrid might result in impacts on the electricity price and connection fee for business users.

2.4.3 Environmental utility

Environmental utility is in this method represented by the possibility of reducing local and global impacts on health and the environment. The environmental utility will be based on the indicators kerosene use and greenhouse gas emissions.

Kerosene use
The reduced use of kerosene for lighting and cooking can be related to improved indoor air quality and various adverse respiratory health effects. Kerosene lamps are sources of light associated with flickering that puts strain on the eyes of its user as well as being a direct fire hazard if left unattended [17].

Greenhouse gas emissions
Kerosene lamps are sources of black carbon that is a potent greenhouse gas at a local and global scale as well as emitting CO_2 [46]. A reduced use of kerosene for lighting could result in utility as these emissions decrease. Diesel generators used for load intensive productive machinery as well as for backup power in cases of power outages causes emissions of CO_2, nitrogen oxides, black carbon and ozone, causing adverse effects on a the local and global environment that could be avoided when a lower use of these types of generators are required [47].

2.5 Locales of electricity use

The locales where utility from electricity use can be created will in this study refer to a broad characterization of physical locations where end use of electricity and any eventual differences in the social, economic and environmental utility as a result of changes in the electrotechnichal attributes occurs. As suggested by ESMAP, household, productive and community use of energy will constitute the three locales of electricity use [15].

By assigning each indicator on eventual changes of utility from section 2.4 to a locale of electricity use, why and how these changes occur as a result of eventual differences in the electrotechnical attributes from adding BESS could be found. The following paragraphs will describe the locales, assign the indicators to a locale and give a brief motivation on why and how utility could be impacted from electricity use within it. A summary of the indicators and their assigned locale will be presented in Table 2.3.

Table 2.3: Indicators on utility divided in to locales of electricity use.

Locale of electricity use:		
Household	**Productive**	**Community**
Lighting	Business appliance and ICT use	Public lighting
Appliance and ICT use	Business income and expenditures	Appliance and ICT use
Household income and expenditures	GHG emissions	Health centers with electricity access
Kerosene use		Schools with electricity access

2.5.1 Household use

Households are the locales in which the first step on the energy ladder often is made as lighting and mobile charging constitutes two of the most desired and basic uses of electricity [15]. Direct impacts on utility from household electricity use will mainly be seen in the **household lighting** and **appliance and ICT use**, who both indirectly could have an impact on the **household income and expenditures** and **kerosene use**.

Lightning
Electric sources of light can be used to extend the amount of active hours in a household during a day, which are hours that can be spent on reading, studying or socializing that in turn can be attributed to acquiring new knowledge and staying informed, increased levels of education, an overall well-being and feelings of general happiness [34].

Appliance and ICT use
Electricity access enables the use of various household appliances and ICTs, which progressively is becoming a basic human need as rural populations of developing countries enter the digital age [45]. The possibility to watch TV and listen to radio allow for further household participation in current news and entertainment. The

availability of consistent phone charging within the household can be expected to increase phone use and in turn the individual and household connectiveness and social participation. Other electrical appliances such as fans and refrigerators improve the quality of life in households.

Household income and expenditures
Home businesses with the possibility to power lighting and electrical appliances could extend productive hours while making some tasks less strenuous by the aid of more efficient electric tools, increasing the throughput of goods and services which in turn can result in higher household income. As more domestic activities could take place later during the day, more hours can instead be spent on daily wage labour during hours of natural light [34]. Connection fees and tariff costs of electricity will constitute a recurring household expenditure that might increase with the electrotechnical specifications of the microgrid.

Kerosene use
The use of kerosene based household services such as lighting, cooking and heating can be related to indoor pollution, health problems and a risk of acute accidents from fires or explosion [16, 17]. The need to travel for purchasing kerosene is an inconvenience as well as a reoccurring expenditure. Kerosene fueled lights can put strain on eyes while cooking or reading, as kerosene lightning is more dim and flickering compared to electric lights [46].

2.5.2 Productive use

Productive use of energy can be defined as activities that are able to directly enhance productivity and income generation by adding value to goods and services [48]. Settings where productive use takes place could in the context of this study for example be found in manufacturing workshops as welding, carpentry or in the processing of grains by milling machines. Direct impacts on utility could for productive use of electricity stem from **business use of appliances and ICT**, which indirectly will have impacts on the **business income and expenditures** and **greenhouse gas emissions**.

Business use of appliances and ICT
Support for heavy use electrical machines is essential in many medium sized businesses, having an impact on efficiency and the flexibility of when tasks requiring high power can be carried out. Business ICT use can create new and extend current markets while also enabling further interconnections between workers, other business owners and customers.

Business income and expenditures
Extended hours of income generating activities are possible if machines and lighting can operate without interference from limitations in the electrical grid. Depending on connection and monthly tariff fees, the cost for business electricity consumption will be an reoccurring expenditure.

Greenhouse gas emissions
Diesel generators used to support load heavy electrical machines in business applications are sources of emissions with adverse health and environmental effects. Greenhouse gases contribute to global warming and harmful substances on a local level.

2.5.3 Community use

Electricity dependant services for community use could have large indirect impacts on socioeconomic development by contributing to increased human capital through enhanced education in schools, adequate care at health centers and administrative resources from government buildings [15]. The existence and functions of other community buildings such as clubs, bars and places of worship are able to tend to the local social, cultural and religious needs [15]. Safety and mobility can be improved by introducing outdoor lighting that can be used during dark hours of the day [15].

Community use of electricity mainly relates to the utility indicators of: **public lightning**, **appliance and ICT use**, **access to health centers improved by electricity** and **access to schools improved by electricity**.

Public lighting
Outdoor lighting sources during dark hours of the day contribute to increased safety for women and increased mobility as lit streets are easier to walk or drive on. Public lighting can also have an important healthcare aspect as emergent night time transportation of unwell individuals from their home to the healthcare facilities can be dangerous without lighting [15].

Appliance and ICT use
Medium sized businesses such as grocery stores, barbers, community centers, video entertainment and bars will all require access to specific appliances to deliver some of the goods and services customers demand [15].

Access to health centers improved by electricity
Electricity access is crucial for the function of health centers. The ability to provide proper care and handle emergencies with sufficient lighting during all hours of the day, refrigeration of pharmaceuticals and the ability to sterilize equipment are some factors dependant on sufficient electricity access [15].

Access to schools improved by electricity
Electricity can extend the amount of hours students spend at school by lighting as well as enhancing learning through the use of ICTs. Educational facilities with proper access to electricity are more appealing when attracting better educated teachers [15].

2.6 Utility within locales

The following section will use the previously established indicators to find where and how utility is created within each of the three locales. With support from the literature, a scale to inductively assign the potential utility of each indicator to a rating from none to high potential utility will be created. A primary dependence on either power or energy to create the most utility from a time and load aspect will also be identified.

A summary of evidence for the utility of electrification within each indicator will be presented along with a short discussion and motivation on how it is placed in the scale. **None** will in the scale imply that there is none or an insignificant amount of impact on utility as a result of increased electrification described in the literature. **Low** signifies an impact on utility where there are evidence in the literature that either suggests a small impact or being described as able to have both negative and positive effects on utility. **Some** implies that an explicit increase in utility can be found in the literature, but that evidence for these impacts have been studied relatively infrequently and that some negative impacts on utility also have been found. For the rating of **high** utility, the utility from electrification within an indicator is assessed and validated over many different research papers and in a variety of contexts. The potential utility from all indicators within each locale is summarized in Table 2.4.

Table 2.4: Indicators within each locale with ranks on the potential for changes in utility. As no indicators received the rank of **none** or **low**, these ranks have been omitted from the final table.

Potential utility:	Some	High
Household		
Lighting		x
Appliance and ICT use		x
Income and expenditures	x	
Kerosene use		x
Productive		
Appliance and ICT use	x	
Business income and expenditures	x	
GHG emissions	x	
Community		
Public lighting	x	
Appliance and ICT use	x	
Health centers with electricity access		x
Schools with electricity access	x	

The characterization of an indicator to be either primarily dependant on energy or power for use within each locale will in the same way as for the potential utility be summarized and will be presented in Table 2.5. In cases where the utility from an indicator could be dependant on both power and energy, an evaluation will be made to decide which selection should be the most applicable.

Table 2.5: Indicators and their dependence on either the supply characteristic of power or energy for creating utility within each locale.

Dependence:	Power	Energy
Household		
Lighting		x
Appliance and ICT use		x
Income and expenditures		x
Kerosene use		x
Productive		
Appliance and ICT use	x	
Business income and expenditures	x	
GHG emissions	x	
Community		
Public lighting		x
Appliance and ICT use		x
Health centers with electricity access		x
Schools with electricity access		x

2.6.1 Utility from household use of electricity

The following paragraphs will present previous findings from the literature on how and where utility can be created from household electricity use and whether the potential differences in utility are primarily dependant on power or energy from the microgrid. By summarizing the evidence and frequency on studies related to each indicator, a rank can be given on the amount of potential utility that should be able to occur as well as if the indicator is primarily power or energy dependant.

Lighting

As the most studied benefit as a result of electrification [49], household lighting has been established as the first step and most basic need on the energy ladder as electricity becomes available [50, 51]. Higher quality lighting sources increases comfort within households [49] and an adequate source of light during evenings lead to extended periods of time during the day that can be spent on studying, reading or socializing [52, 16, 50]. The availability of lighting outside hours of natural light increases the flexibility of when domestic chores can be performed [53, 50, 19]. The added flexibility can result in more time for women to participate in income generating activities [16, 39]. Household lighting creates a **high** amount of potential utility by being the most desired and studied primary use of electricity.

Lighting will in the microgrid constitute many small loads to be used during relatively long periods of time and when there is no electricity actively being generated by the solar PV. This will make it primarily dependant on **energy**.

Appliance and ICT use
Household use of appliances and ICT is the second most studied benefit of electrification as well as the next most desired use of electricity after lighting [49]. Increased productivity and efficiency of household tasks by higher rates of appliance ownership saves time that instead can be spent on leisure, household chores or income generating activities instead [16, 50]. Digital communications will improve as flexibility and unrestricted access to charging allow for a more widespread use of mobile phones [49]. TV and radio provide sources of entertainment and news [39, 50]. Other appliances that can be used to increase quality of life within households could be fans, water pumps and refrigeration [39, 54].

With TVs being the second most desired and studied use of electricity for households, the ability to generate utility through a variety of home appliances and by contributing to better news and entertainment, connectivity and communications, the potential utility from household appliance and ICT use can be deemed as **high**.

Appliance and ICT use within households will primarily depend on **energy** supplied from the microgrid. TVs are medium sized loads that are used during some hours of the day, concentrated to evening hours as people come home from work. The total load that TVs and appliances constitute will to some extent also depend on available power during hours when many households run them at the same time, but because of the relatively low load and long time frame of use it should to a greater extent be dependant on **energy** rather than power.

Household income and expenditures
Some positive impacts on household income following increased electrification has been studied, mainly as a result of longer working days and higher employment rates, especially for women, combined with higher productivity from more efficient electricity dependant tools [55, 50]. It has been reported that male wages tend to increase while female wages decrease with electrification [55]. As electricity becomes more available, expenditures will increase to cover tariff costs [55]. Less money will be spent on purchasing kerosene as electric light becomes more widely used [19].

There will be **some** impacts on the potential utility of household income and expenditures. Many studies presents an overall increase in income per capita as a result of more available working hours and increased productivity from electrification, while also reporting on relations between increased expenditures from the adoption cost of household electricity access and higher overall energy use.

This indicator will be more difficult to assess as it is dependant on factors of both power and energy, with increased power tending to result in more efficient work while energy extends the amount of time during a day that can be spent on labour. The decreased use of kerosene when energy dependant electric lights are introduced will indirectly imply reduced expenditures. Because of the higher amount of available work hours and avoided kerosene costs, household income and expenditures will be seen as primarily dependant on **energy** supplied from the microgrid.

Kerosene use
Reduced household kerosene use as a result of more electric sources of light has been studied in many research papers and is a reoccurring potential utility as it improves indoor air quality when exposure to pollutants and particulate matter decreases, avoiding many adverse health effects [49, 50, 17, 19]. Reduced household kerosene use also lowers the risk of acute accidents from fires or explosions [16, 17]. Kerosene displaced by electricity access results in lower emissions of CO_2 and black carbon which both are greenhouse gasses [17].

The health effects of poor indoor air quality caused by kerosene light use have been documented. Electric light sources replaces kerosene lights at the primary stages of electrification, resulting in many health benefits by avoided respiratory diseases, cancer and eye strain. Effects of reduced kerosene use and the impact on the potential utility is rated as being **high** and because of its strong correlation to available sources of electric light, kerosene use will indirectly be dependant on the **energy** that can be supplied from the microgrid.

2.6.2 Utility from productive use of electricity

The following paragraphs will present previous findings from the literature on how and where utility can be created from productive use of electricity and whether the potential differences in utility are primarily dependant on power or energy from the microgrid. By summarizing the evidence and frequency on studies related to each indicator, a rank can be given on the amount of potential utility that should be able to occur as well as if the indicator is primarily power or energy dependant.

Appliance and ICT use
Electrification of productive use processes and machines will allow for a higher quality of existing commodities and to some extent the creation of new goods and services that previously has not been available [55, 49]. This type of electrification has also been shown to increase productivity as it enables the access to more powerful and efficient tools [55, 56]. Increased ICT use from a higher flexibility and availability of phone charging can expand, as well as creating new markets as business owners, workers and customers becomes increasingly interconnected through mobile phone and internet communication.

Depending on existing preconditions such as the presence of high powered machines and tools for the production of services and goods, the potential utility from electrification varies for this indicator. There are no studies suggesting that market expansion is causal to increased ICT use alone, rather as being one of many other factors contributing to it. Because of the differences in potential utility connected to the size and required electricity of businesses and the rather indecisive impacts of ICT use, the rating for this indicator will be **some**.

The power required for load heavy productive use will by itself be able to cause short but high peaks of electricity demand in the microgrid during working hours of the day. These peaks could be answered by having more **power** accessible at the time.

Income and expenditures
Electrification of machines has the potential to make productive processes and services more efficient, resulting in lighter strain on workers and higher productivity. The increased productivity can in turn have a positive impact on business revenue and the amount of available working hours [55, 56]. Improved electricity access reduces the need for running backup diesel generators, saving money as less fuel is consumed at very high opportunity costs [55]. A relatively large share of reports studying the impact of electrifying productive use are inconclusive on the utility created outside of providing light for businesses that are not dependant on any heavier use of machines and tools, assessing that the electricity cost is not worth it if the scale of production is not large enough [55]. Extended hours of operation for businesses as a result of having more available light will also give an opportunity for additional revenue.

A reliable supply of electricity allowing the productive use of load heavy appliances can create large amounts of utility from a higher productivity and potential revenue. Some businesses that mainly rely on electric lights will also be able to experience utility from having it available for longer periods. A majority of the research reports small to no impacts on business income and profits, ranking the potential utility of income and expenditures from electrification of productive use to be **some**.

New and more load heavy machines that tend to an increase in production and efficiency for productive use of electricity is related to the previous indicator of appliance and ICT use. Income will be closely related to the amount and quality of goods and services that can be delivered, which should increase with a wider use of load heavy machines. This implies that business income and expenditures primarily will be dependant on **power** supplied by the microgrid when utility is created.

Greenhouse gas emissions
The use and reliance on electric machines and tools for production of certain goods and services will need backup diesel generators at times of no electric supply. These generators are associated with emissions on both a global and local level from GHG contributing towards global warming and pollution from particulate matter affecting people in proximity of the generators [47, 57].

The health benefits of reduced exposure to local emissions from diesel generators are evident and has been documented in several previous studies. Impacts on global GHG emissions can also be attributed to this type of backup generator use. Reduced local and global emissions from lower diesel generator use as a result of electricity access will be ranked as **some**, as the impacts on potential utility are less explicit for the end user in relation to many other of the indicators.

Reduced GHG emissions will indirectly originate from the decreased use of backup generators when the power available either is insufficient or unavailable because of an outage. As backup power most frequently sees use as a complement to the power supplied by the microgrid when heavy load machinery is run, GHG emissions should depend more on the ability to receive additional **power** as needed.

2.6.3 Utility from community use of electricity

The following paragraphs will present previous findings from the literature on how and where utility can be created from community use of electricity and whether the potential differences in utility are primarily dependant on power or energy from the microgrid. By summarizing the evidence and frequency of studies related to each indicator, a rank can be given on the amount of potential utility that should be able to occur as well as if the indicator is primarily power or energy dependant.

Public lighting
Public lighting promotes safety and mobility during dark hours of the day. Movement at night time is often avoided, especially by women, out of fear for robbery, attacks or wildlife [15, 49]. Socializing is also made easier as lighted areas outside work and the household allow for people to meet and children can safely play outdoors for an extended amount of hours during a day. Other commercial activities such as small businesses and markets benefit from public lightning as potential customers can be active during later hours [50].

There are few quantitative accounts on the potential utility from public lighting, but some mentions of the qualitative benefits it can entail. The many social and safety related impacts public lightning can have in combination with lacking deductive evidence could be able to create **some** potential utility from public lighting in a community context. As public lighting constitutes a small and constant load that has the inherent need for electricity during dark hours of the day when there is no solar PV supply, **energy** stored is required for its basic function.

Appliance and ICT use
Electricity can maintain or create new services that impact the utility within a community. Rather than manufacturing goods by electric appliances and tools in a productive context, community appliance and ICT use is more indirect and could for example constitute the fridge to cool drinks and the audio system of a bar, a place to watch movies and sport events or a small grocery store [15]. As a contributing factor to leisure and quality of life related to socializing and entertainment, although often only based on anecdotal evidence, community appliance and ICT use has **some** potential utility.

Community use of appliances and ICTs is in the same way as its household equivalent primarily dependant on **energy**. A higher total load from community appliance and ICT could eventually be seen during later hours of the day, but as these load occurs during relatively long periods of time they should not require a high supply of power.

Health centers with electricity access
Access to electricity in health centers is critical for many of the medical interventions that require modern equipment to deliver adequate care and save lives [58]. Poor lighting makes it difficult to provide health care services after sunset, unreliable refrigeration can spoil vaccines that have to be discarded, ICT for administration, spreading information about health and communications can be unavailable during periods of the day and proper devices are needed to sterilize equipment [14]. These amenities are some of the most essential uses of electricity in health facilities. A higher presence of more advanced medical devices is able to attract more skilled health workers in rural areas [14].

The possibility of receiving proper healthcare is a necessity for the well being of all people and integral for socioeconomic development in rural areas. The potential utility of having health centers with electricity access is apparent from the literature and at a **high** amount.

Health centers should be dependant on electricity that is available and uninterrupted during as many hours of the day as possible. Depending on the types of tools and machines that are used, a certain demand for short periods of additional power could be seen but as the access to electric lights and refrigeration is the most essential use of electricity when providing adequate health care, a primary dependence on **energy** should be seen.

Schools with electricity access
Electricity access can be linked to higher educational enrolment [18]. Electric lights increase the hours students spend at school and improve the conditions for reading and writing [15]. Many of the basic requirements for higher quality education are strengthened by electricity access [15]. Education can be greatly enhanced by the support of ICTs, enabling the use of computers and audiovisual aid during lessons. Electricity access in school can also be used by teachers to better prepare and create study materials by sufficient lighting or computers and printers, a factor that in the same way as for health centers with electricity access, can attract teachers with higher qualifications to rural schools.

Electricity will have **some** potential utility for schools. The long term benefits of high quality education are evident and studied in depth, but the relative and explicit impacts on utility might not be as notable. Basic functions of schools are available without electricity, while having the possibility to be improved by it. The improved lighting and education enhancing electrical tools will constitute a low total load during some reoccurring hours of the day which should be dependant on **energy** for a constant and uninterrupted supply of electricity.

2.7 Changes in electrotechnical attributes from added BESS

The following section will identify eventual changes in the electrotechnical attributes from adding a BESS to the solar PV microgrid with support from the literature. A characterization will be made to establish whether improvements in each attribute primarily contributes to the delivery of power or energy and which improved attribute each indicator will benefit the most from.

2.7.1 Peak capacity

The addition of a BESS should allow for the storage of unused generated power to be dispatched during periods of either no power production from the solar PV, or as support at peak demand hours of the day [27, 23]. Momentary bursts of high power demand that otherwise would exceed the available generation can also be addressed by drawing power from the BESS [59].

Peak capacity should as a result of added BESS see a definite increase, having a maximum supply otherwise limited by the momentary power level generated by the solar PV [26]. Loads that are shifted to better match the daily power supply from solar PV will lead to a higher flexibility in electricity use as more loads could be connected at the same time during periods of an otherwise insufficient power supply. The improved peak capacity will be able to resolve many of the difficulties imposed by the high productive uses of power during the period of relatively low overall demand between the morning and afternoon peaks [59, 26]. Depending on the dimension of the BESS, the amount of power that can be discharged over a day will have to be balanced against the demanded availability of energy for hours where there is no generation from solar PV [26].

The changes in peak capacity with the addition of BESS will be related and characterized by how much **power** that is available during some periods of time over a day. The power that can be supplied will in turn be dependant on the amount of energy stored in the BESS at the given moment, limiting the discharged power so that energy stored as the solar PV generation becomes unavailable is enough to handle demand peaks and supply electricity as sun sets. The power that can be supplied will therefore vary over time and with the amount of energy currently stored in the BESS.

2.7.2 Availability

The availability during hours of solar PV power generation should see an increase as the higher peak capacity from added BESS gives higher flexibility in electricity use, as it to a greater extent can be used without overloading the system and therefore allow more connected loads during longer periods of time [60]. Availability during evening hours should have the potential to drastically increase by the implementation of BESS, as energy that has not been used during the day can be stored for use after sunset depending on its dimensions.

The availability of electricity will primarily depend on the amount of **energy** stored in the BESS off peak demand. As the BESS is used to increase the peak capacity and provide power as needed, the net sum of energy left as the solar PV stops generating at sunset will decide how much and for how long power can be supplied.

2.7.3 Reliability

Without backup generation there will be no electricity available during outages in the microgrid. As supply and demand can differ, planned outages as a result of breakers going off to protect the microgrid connections can occur at varying frequency and length. Unplanned force majeure outages could always be a possible cause of lost electricity access.

The reliability of the microgrid should increase as a BESS is introduced [60, 27]. Preventive efforts to avoid planned outages can be attributed to improved peak capacity and availability as supply and demand is better matched, reducing the risk of overloading the microgrid which should lower the frequency of outages. Increased reliability should primarily come from an improved access of **energy** stored that can be used for backup electricity as outages occur. The energy level in the BESS when power generation becomes unavailable in combination with the following power demand will then determine for how long the outage can last before the BESS is depletes and no source of electricity is available.

Table 2.6: A characterization of the improvements to either power or energy that each electrotechnical attribute primarily will be able to provide as the BESS is added.

Primarily improves the supply of:	Power	Energy
Peak capacity	x	
Availability		x
Reliability		x

2.8 Ranking utility

The following section will present a mathematical procedure to relatively rank the amount of ordinal utility each indicator is able to create by cross-reference the evaluations on potential utility from an indicator within a locale (Table 2.4), its primary power or energy dependence (Table 2.5) and improvement of power or energy in the electrotechnical attributes by added BESS (Table 2.6).

For the ranks presented in Table 2.4, a value of 0 will be given to the option of **some** utility and a value of 1 will be given to the option of **high** utility. This value could then be assigned to the variable $P_{potential}$.

To achieve a value for the power or energy dependence (as the variable $P_{dependence}$) and to what extent the addition of a BESS should be able to meet the demand for either of them (as the variable $P_{attribute}$), a logic equivalence operator will be used.

The **power** dependence of an indicator in Table 2.5 and the electrotechnical attributes that corresponds to improved **power** from Table 2.6 are assigned the binary integer 0. The same is done for the corresponding **energy** dependence and attributes, which are assigned to the binary integer 1. The logic equivalence operator will output a 0 when the value of $P_{dependence}$ does not match the value of $P_{attribute}$ and a 1 whenever they do match. This will signify that a higher rank of utility is achieved when the indicator demand of either power or energy can be met by the corresponding improvements of these characteristics in the electrotechnical attributes.

The descriptions on how an utility rank could be calculated results in Eq. 2.1. The equation will be able to assign the three different rank integers from Table 2.4, 2.5 and 2.6 to an utility variable U, which by itself does not represents an intrinsic value of the indicator utility, rather a rank that can be compared to other values of U with 0 being the lowest and 2 the highest amount of relative utility from an indicator within its locale.

$$P_{potential} + (P_{dependence} \odot P_{attribute}) = U\{0, 1, 2\} \tag{2.1}$$

The relative amount of social, economical and environmental utility created from improvements in how each electrotechnical attribute is able to primarily supply power or energy by the addition of a BESS could now be found and ranked.

3
Results

This chapter presents how much relative social, economic and environmental utility was created within each indicator and locale by the differences in electrotechnical attributes from an added BESS.

3.1 Social utility

Social utility was defined as improvements and benefits made in factors that could be related to education, safety, leisure, health and equality. Utility from the social indicators by added BESS will be presented in the following paragraphs.

Table 3.1: The relative amount of social utility created from improvements of each electrotechnical attribute. Green signifies a high utility, yellow some utility and red small or no utility.

Social utility	Peak capacity	Availability	Reliability
Lighting			
Public lighting			
Appliance and ICT use			
Health centers with electricity access			
Schools with electricity access			

Lighting
Potential utility from lighting within the household locale was ranked as high and as primarily dependant on energy. Lighting was able to create a high amount of social utility from the improved availability and reliability. A higher peak capacity resulted in some social utility.

Public lighting
The potential utility from public lighting by a community use was ranked as some, with a dependence on energy. Improved availability and reliability corresponded to this demand by providing the energy required which created some utility. An increase in peak capacity resulted in small amounts of utility.

Appliance and ICT use
The potential utility from household and community appliance and ICT use was ranked as high. As the use was dependant on energy, a high amount of social utility was created from improved availability and reliability. An increased peak capacity

resulted in some utility.

Health centers with electricity access
The potential utility from health centers with access to electricity was ranked as high and primarily dependant on energy. Improved availability and reliability resulted in high amounts of social utility while an improved peak capacity would result in some utility.

Schools with access to electricity
Some potential utility could be seen in schools with access to electricity. With a primary dependence of energy, improved availability and reliability created some social utility. Increased peak capacity resulted in small amounts of additional utility.

3.2 Economic utility

Economic utility was defined by indicators that could impact the balance between income and expenditures for households and businesses.

Table 3.2: The relative amount of economic utility created from improvements of each electrotechnical attribute. Green signifies a high utility, yellow some utility and red small or no utility.

Economical utility	Peak capacity	Availability	Reliability
Business appliance and ICT use			
Household income and expenditures			
Business income and expenditures			

Business appliance and ICT use
The business appliance and ICT use was ranked as having some potential utility for a power dependant productive use. An increased peak capacity resulted in some amounts of economic utility due to more power available, while improved availability and reliability had a small impact on the utility.

Household income and expenditures
Economic utility from household income and expenditures was seen as having some potential utility with a primary dependence on energy. Increased availability and reliability therefore had some impact on economic utility while a higher peak capacity only made a small difference.

Business income and expenditures
Business income and expenditures was ranked as having some potential utility from a primary power dependence. A higher peak capacity resulted in some economical utility while additional energy from increased availability and reliability made small differences.

3.3 Environmental utility

The environmental utility was defined as impacts of local and global emissions from emission fuels, mainly by diesel fueled generators and kerosene lamps.

Table 3.3: The relative amount of environmental utility created from improvements of each electrotechnical attribute. Green signifies a high utility, yellow some utility and red small or no utility.

Environmental utility	Peak capacity	Availability	Reliability
Kerosene use			
GHG emissions			

Kerosene use
Decreased kerosene use was ranked as having high potential utility with a dependence on energy. Increased availability and reliability resulted in high environmental utility while a higher peak capacity was able to create some utility.

Greenhouse gas emissions
Potential utility from decreased GHG emissions was ranked as some, with a primary dependence on power availability. A higher peak capacity could create some environmental utility while the increased availability and reliability created a small amount.

4

Analysis

The results of this study was presented by exhibiting how, where, why and to what extent utility changes with the addition of BESS for each indicator. The following analysis section will put the results in relation to the research questions and principles from the background in order to interpret, explain and compare the social, economical and environmental utility that the addition of a BESS was able to create by improving the electrotechnical attributes.

4.1 Social utility

Indicators on social utility will experience the largest overall improvement by the addition of BESS, where the highest amounts of utility originates from lighting, appliance and ICT use and health centers with electricity access as additional energy from the increased availability and reliability can be expected when the BESS is added.

Social utility from lighting is high because of its ability to drastically improve the convenience when performing a variety of activities within all of the locales and by being a highly valued first use of electricity when introduced. The benefits of access to electric lights include a higher flexibility of work as active hours of the day are shifted and increased, the possibility to read and study with adequate lighting conditions and the extended amount of active hours that can be spent on socializing, chores or income generating activities, all of which are primarily dependant on energy from the improved availability and reliability.

Electric lighting constitutes a relatively small share of the total loads in the microgrid over a day. The BESS should be able to supply a certain amount of electricity during periods when no solar PV is available, allowing the uninterrupted use of some amount of electric lights during some hours of unavailable natural light and as outages occur. The period of time that lighting could be used during dark hours and the duration of an outages that can be handle will be dependant on the dimension and charge level of the BESS.

Access to electric sources of indoor light with a high availability and reliability during all hours of the day could be a catalyst for increasing the utility within many of the other indicators, such as higher income from more available hours of work and home businesses, lower expenditures and adverse health effects from reduced kerosene use, children study time and performance in school and quality of health care received.

Public lighting will be able to create a smaller amount of utility from the energy added compared to its indoor equivalent. The difference in social utility from public lighting is caused by its relatively low demand, but could see use when the BESS is able to supply enough energy required to keep it available and reliable when needed.

Improved access to and wider use of electric appliances and ICTs will function in the same way as electric lights that also are dependant on energy, but should constitute a somewhat heavier total constant load from TVs and fans. Other home appliances are associated with a high power momentary use that saves time and make household activities more efficient and less strenuous.

The possibility to watch TV or listen to radio when coming home from school or work is a highly desired use of electricity which could create utility from increased leisure, education and entertainment. Gathering at a community locale to watch sporting events, movies or news together will add to the social utility by allowing people to meet through common interests. Flexibility in phone charging will create social utility from the increased opportunities of participating in digital communication.

Access to health centers improved by electricity is crucial for the physical well-being of an individual as large amounts of social utility is created by being healthy and not affected by any serious deceases. The improved availability and reliability of electricity will be able to ensure the prerequisites for delivering the best care possible as an uninterrupted supply of energy during all hours of the day will be needed for adequate lighting and refrigeration of vaccines and pharmaceuticals. More energy could also allow for a wider use of ICTs to spread information on how to stay healthy, promoting utility by increased preventive care which puts a lower stress on health centers and its personell. Power from a higher peak capacity could be required for the short use of some load heavy appliances such as sterilization chambers that ensure clean medical tools that are safe to use for a long period of time.

Schools with electricity access will experience some utility by available lighting and ICTs by extending the periods of time that could be spent in school and the possibility of ICT enhanced education. Higher quality and more opportunities for education contributes to utility because of an increased level of educated individuals, a major factor for improving an individuals livelihood and community. A higher peak capacity and ability to supply power has no explicit effects on the social utility in schools.

The high level of social utility is achieved because of the relatively direct differences the addition of a BESS will cause for the end use of electricity. The benefits of higher quality lighting for more hours of the day, the ability to charge phones at home, read or socialize with your family for longer after work or watching more TV are some of the social utility generating activities that primarily depend on the energy from an improved availability and reliability of electricity. Social utility is for this type of electricity use directly experienced and closely related to what the end users demands.

4.2 Economical utility

The improvements made in the electrotechnical attributes creates some overall economical utility by mainly allowing a wider and more flexible use of load heavy machines and tools during the production of goods and services during a day as more power becomes available with the addition of a BESS and a higher peak capacity.

Labour can be made more simple and efficient by electrification, reducing the overall strain experienced when working. A higher peak capacity supports the short and to some extent simultaneous use of more productive heavy loads by providing additional power when required, increasing the overall productivity within the microgrid as well as allowing the creation of new goods and services whenever more advanced and capable electrical machines and tools are introduced. ICT use for businesses improves the possibility of having mobile phones available at more hours of the work day, leading to better communications and the possibility to extend or create new markets.

Some economic utility from increased appliance and ICT use is created from the improved support of running machinery associated with higher loads to increase the productivity and output of businesses. New services and goods are created more efficiently while the amount of tiring labour that workers are exposed to decreased. The further ability to connect with customers, employees and other businesses by ICT use also increases utility as a better overview of market supply and demand is achieved while also being able to find new markets for the goods and services that was created.

Some economic utility from household income and expenditures will also come from the increased possibility to earn more money as more hours of the day could be spent on income generating activities. Improved lighting availability and conditions as a result of the ability to use energy stored in the BESS can be attributed to this increase, as home business are able to remain open for customers after the sun sets and members of a household could go to bed later and wake up earlier as electrical lighting replaces natural light.

As periods where domestic chores could take place shifts, the amount of hours that could be spent on labour and subsequently the possibility to earn additional income every day increases. Higher electrification rates and overall electricity use could result in more household expenditures towards new appliances, installation costs and tariff fees. As kerosene use for lighting diminishes with the introduction of electricity, the reoccurring expenditure that the purchase of fuel constitutes could be significantly lowered.

Some economic utility for business income and expenditures can be seen as closely related to the possibility of increased appliance and ICT use due to the increased ability to supply larger amounts of power as needed. Electrification of manufacturing and repairing processes along with the introduction of new load heavy machines that are supported by a higher peak capacity and the ability to supply additional power during periods of otherwise insufficient generation can increase production rates as tasks are made more efficient. A higher output of goods and services that are produced at a faster pace will be able to increase business revenues.

The cost of new machines and increased electricity use could on the other hand increase expenditures. Access to electricity extends the possible amount of work hours by an increased availability of lighting, creating more hours where production and business could take place. A microgrid improved by BESS will see shorter duration and frequency of outages, which in turn could contribute towards avoiding high opportunity costs for running backup diesel generators in order to maintain production.

The overall economical utility is rated as low because its differences will take longer to be noticed while also having more indirect impacts. Many of the productive uses of electricity will make explicit changes in economic utility that at most only will be directly experienced by workers and business owners. The impacts of improved electrotechnical attributes will result in the increased utility for end users whenever services and goods are of a higher quality, lower price or as new goods and services become available from improved electricity access. An increased income could eventually be noticed after some period of time for both households and businesses because of more available working hours or higher output of commodities.

4.3 Environmental utility

Increased access to electricity during the day and especially energy after sunset will allow kerosene fueled lighting sources to be replaced by electric equivalents, improving the quality of light and significantly reducing indoor pollution. A high amount of environmental utility is gained from not using flickering and poor lighting that put strain on eyes and by improvements on general health health as exposure to fumes and particulate matter that have adverse effects on health decreases. Safety will also improve because of the lower kerosene use as the risk of fires, explosions and poisoning decreases as the need to store fuel in the immediate vicinity of people and buildings is lower.

A reduced use of diesel generators to support households and businesses during periods of outages or insufficient power supply is linked to lower GHG emissions as energy stored in the BESS increases availability and reliability of electricity. Small amounts of environmental utility is created as local and global emissions reduces, resulting in a large impact on the health of people living in proximity of generators and to some extent global warming. Kerosene used for lamps and cooking is the source of a variety of combustion emissions with high global warming potential that will reduce as energy becomes more available and reliable with the addition of a BESS.

The environmental utility will be dependant on the changes an added BESS makes within other indicators. Reduced kerosene use is directly dependant on an increased use of electric lights which in turn depends on energy from the BESS and lower GHG emissions can be attributed to a reduced need for backup power from diesel generators when the supply is insufficient or the loss of energy during an outage.

5

Discussion

The following chapter will discuss the findings from the results and analysis, the design and use of methodology and the relevance and suggested further research for the study. A short reiteration and presentation of major findings will first be presented.

The aim of this study was to find how, where, why and to what extent utility could be created by the addition of BESS to a solar PV microgrid. In order to do this, a method able to translate quantitative changes in electrotechnical attributes in to a qualitative and objective measurement on utility from the end use of electricity was developed.

The method began with a literature review of previous similar studies and a rank of approaches for finding utility from electrification was made and later discussed. A framework for the method of this study was then developed where peak capacity, availability and reliability were established as electrotechnical attributes likely to be improved by additional energy and power from a BESS. The concept of utility and how it could be applied from a social, economical and environmental aspect was discussed and indicators that should reflect electricity use was decided for each aspect of utility.

Locales of electricity use was then determined, finding that household, productive and community use of electricity would be sufficient for the scope of the method. The indicators on social, economical and environmental utility was then divided across the three locales and a rank was assigned on how much potential utility they inductively should be able to create. This was done to get an understanding on how and where utility from electricity use originates.

The changes in electrotechnical attributes by added BESS and whether they primarily tended towards increased power or energy was found. A mathematical procedure was then able to create a relative rank on how much utility each indicator should be able to generate when either peak capacity, availability or reliability was improved. Adding a BESS to a rural solar PV microgrid was able to create a varying amount of utility across all indicators, where the highest utility was experienced from the use of lighting, appliance and ICT use, health centers with electricity access and reduced kerosene use as availability and reliability of electricity increases by having more energy available from the BESS.

5.1 Results

The largest share of utility came from the improved social indicators on electricity use. This could stem from a higher availability of previous research on the benefits implied by lighting, appliance and ICT use and health centers with electricity access which increased how much potential utility should be expected. The reason for this should be that these uses previously has seen a high introductory demand as electricity first becomes available or when allowed to be used more widely.

It can also be noted that these indicators will create the most utility when the BESS makes improvements on availability and reliability, showing that there will many benefits of having access to energy for additional uninterrupted hours of the day and as no generation from solar PV is possible.

High utility from a decreased use of kerosene will also be seen. The utility created by this decrease is somewhat different as it is a indirect result of an increased use of electric lights. Reduced kerosene use will in turn have an effect on household expenditures. This relationship could be used to first of establish the access to adequate electric lighting as a catalyst for further positive impacts on utility in many of the other indicators, and secondly as a manifestation of the somewhat complex interconnections that are made between the indicators as more power and energy becomes available from the BESS.

The lower amount of utility from economic indicators will mainly depend on increases in productive use as increased power from the BESS will allow for heavier and more efficient machinery and tools. The procurement of new and more refined appliances will have a large economical barrier which could creating a disinclination to adapt new technologies that allows for higher income in the future. There will also be a risk associated with creating new markets for services or goods without having an initial demand. The lower amount of direct and short-term utility that is experienced by end users with the improved electricity access should be a reason for the relatively low rate of utility from productive electricity use.

The access to higher power at more hours does not necessitate an increase of its use. Many of the indicators on economic utility will instead benefit from the addition of a BESS after a longer period of time, but there are a variety of factors exogenous to the electrotechnical attributes that might have an even bigger positive or negative impact on income and expenditures for the economic utility.

Increased environmental utility could be related to improvements across all three electrotechnical attributes. More power available during moments of high demand within the microgrid decreases the dependence on diesel backup generation, resulting in some utility by lower emissions of greenhouse gases. A higher availability and reliance on electricity supplied will also lead to lower emissions as diesel generators becomes increasingly redundant when the BESS is able to dispatch energy stored during hours of insufficient supply from lacking solar PV generation or outages. As previously mentioned, a higher amount of household with access to electric sources of light will be able to reduce kerosene use and in turn remove a source of potential greenhouse gasses with many adverse effect on the local and global environment.

The amount of utility experienced by the end use of electricity will largely depend on the time frame during which changes in the electrotechnical impacts occur. An immediate increase of energy and power that can be supplied by the microgrid will not necessarily be followed by an equal increase in demand with higher rates of appliance ownership, heavy productive use and patterns on the general use of electricity is more likely to be adapted over longer time periods. The inert adaption of new technologies that demand a high level of power to function has previously been studied [20, 32], again implying that the highest amounts of potential utility from electricity use should be acquired by improved availability and reliability from additional energy stored in the BESS.

Improvements made in the electrotechnical attributes tending towards a higher availability and reliability by offering a higher amount of stored energy is overall contributing more towards a directly experienced utility for end users compared to the peak capacity attribute that could increase the amount of power that can be delivered. This would imply that a BESS designed to primarily address a high energy demand rather than the supply of high amounts of power will generate the most overall utility after a relatively short period of time.

Some self-evident benefits and subsequent utility from the addition of BESS to a solar PV microgrid were expected and confirmed by the results. Obvious contributions to utility were speculatively believed to originate from the ability of storing power during hours where the supply from solar PV was higher than the actual demand, dispatching whenever the demand could not be met by the power produced. The study showed that this assumption was reasonable to make.

The possibility to create new and improved uses of electricity by offering power and energy during hours of the day where it previously was not available was also expected to make major contributions towards utility. Electrical sources of light and access to ICTs were seen as very likely factors to improve the utility for individual households. Some long-term improvements in productive load heavy electricity use from an increased peak capacity was also expected at the beginning of the study.

Many of the results found in this study has been in line with previous research, consolidating the importance of electricity access as a step towards alleviating poverty and increasing the overall well being in developing areas of the world. The large amount of direct utility represented by the various social indicators of electricity use can also be reaffirmed by the results of this study. Contributions to the current discourse within energy access for developing areas and the role of BESS by this study, can be seen as the attempt to inductively systematize and rank how much utility could be gained by improvements in some of the earliest and most principal uses of electricity.

The study has compiled and discussed some of the previous approaches for assessing utility from electricity access, creating the outline and premise for a mixed general methodology able to output the relative amount of utility from some different uses of electricity. The methodology has also been able to inductively decide if most utility is created from a BESS optimized to supply either power or energy which could be of use for deciding the scope of further studies.

5.2 Method

The method was limited to the use of inductive assessments from previous research on how utility should change as electrotechnical attributes are improved rather than using actual data. This resulted in general and uncertain results that will be dependant on the type and amount of research that the inductive reasoning is based on.

By only using a few selected indicators, much of both the positive and negative impacts on utility from the addition of BESS have been overlooked. Many of the economical aspects of utility was disregarded as their impacts was seen as too complex and long-term, which in reality most likely would effect the overall utility.

The use of only three electrotechical attributes also constituted a limitation of the method, as there are many other attributes that could have had an impact on how electricity is accessed and used with the addition of a BESS. This limitation could be seen as a necessity to maintain the scope of the study by restricting the amount of factors, reducing its overall complexity as the peak capacity, availability and reliability was able to highlight differences in how the microgrid could operate by adding a BESS.

An aspects of the method that could be improved is how the indicators are carried over and divided. One of the steps could be removed if a better procedure to establish indicators and find how and where they are used was thought out. How the rank of potential utility was used could also be replaced in order to allow a more stringent and transparent method and a better understanding on how the results were achieved and what they imply.

A primary condition for this study was the need to use qualitative descriptions of electricity use as inputs for the method. This made it difficult to achieve quantifiable measurements that later could be used to compare any explicit differences in utility when BESS was added as output, instead relying on the inductive reasoning that had been made in previous studies. The need to transform qualitative data in to comparable and quantitative measurements of utility was the main difficulty of this study and the failure to find a better methodology turned this need in to a major limitation of the methodology. Conclusions that have been made in the literature are based on specific cases that cannot be held as universally true enough to make more than very general, rather uncertain and somewhat vague conclusions on how, where and to what extent utility is created by the addition of BESS in a rural solar PV microgrid.

6

Conclusion

The addition of a BESS to a rural solar PV microgrid in a Sub-Saharan African context will be able to create utility from an improved and increased access to electricity. The highest amount of utility will come from the possibility to store energy for use during periods that previously has had insufficient or no active generation at all from the solar PV.

Social utility will see large positive impacts within households when energy dependant and highly desired uses of electricity such as lighting, phone chargers and TVs can be used for longer periods of time and without interruptions. Health centers will be able to deliver a better care if more and reliable energy is available during all hours of the day and schools are given better preconditions for education, which attracts better trained medical and educational staff.

There will be some economical impacts on utility as extended periods of available lighting shifts and extends the amount of active hours of a day which can be spent on labour. Increased peak capacity from a BESS could supply additional power for heavy machines and tools for short periods of use that make work more efficient, increasing the production rate of goods and services.

Improved environmental utility depends on reduced emissions from kerosene and backup generator use. Electric lighting and the ability of the BESS to supply additional power as required and some amount of energy during dark hours or outages should be able to reduce the type of emissions associated with kerosene and backup generator use.

This study was able to show where the most amount of utility from improved electricity use should be seen and how a certain use of electricity generates a certain type of utility.

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