Impacts of solar energy projects in rural areas

A case study in Kenya

Master's thesis in Industrial Ecology

ANNA GÖRAS AND CHRISTOFFER MOHAJER

Department of Energy and Environment
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

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Abstract

Currently there are around 1.3 billion people in the world living without access to electricity and about half of them live in Africa. The majority of these Africans without access to electricity live in rural areas and to overcome this issue rural electrification by solar photovoltaic (PV) has emerged as one of the possibilities to alieve this energy poverty.
This is a case study researching two different off grid solar PV projects in Kenya, a microgrid in Sidonge A' and Solar Home Systems (SHS) in the rural areas surrounding Bungoma/Kitale. The aim of this case study was to do an impact assessment of gaining access to electricity via microgrids and SHS and to find out what differences there were in impacts between them. A case study approach was chosen where semi-structured interviews and observations from a field study was the input method into rural sustainability indicators that were compared with pre-electricity indicators. The rural sustainability indicators of the different solar PV systems were also compared with each other to help answer the aim of this study.
The results showed that access to off grid electricity had positive effects related to health, safety, economy, education, mobile phone and internet usage. The differences between the different off grid electricity solutions were that SHS had less environmental impact and was cheaper to use, however microgrids had positive impacts regarding business investments, gender equality and social activities which Solar Home Systems did not have.

Keywords: Impact assessment, solar PV, microgrid, Solar home system, SHS, rural electrification, sustainability indicators

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Anna Göras & Christoffer Mohajer, Gothenburg, June 2016

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Abbreviations

CIGRÉ	The International Council on Large Electric Systems
EDI	Energy Development Index
EKC	Environmental Kuznets Curve
FDI	Foreign direct investment
GDP	Gross Domestic Product
GNI	Gross National Income
GWP	Global Warming Potential
HDI	Human Development Index
HDR	Human Development Report
LDC	Least developed country
ODA	Official Development Assistance
PV	Photovoltaic
POCP	Photochemical Ozone Creation Potential
SHS	Solar Home System
UN	United Nations
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

Two of the greatest global challenges are eliminating both climate change and poverty. An important part of stimulating the economy in rural areas where poverty is widespread and people live mostly on agricultural earnings is to enable them access to electricity (United Nations Development Programme, 2015). Around 1.3 out of the world's 7 billion people live in energy poverty and about half of these in Africa. In sub-Saharan Africa 620 out of 940 million people lack access to electricity and this is also the only region in the world where the number of people living without electricity is increasing (International Energy Agency, 2014).

Kenya is a country that is currently placed very low on the United Nation's (UN) Human Development Index (HDI), at 145th place out of the 188 countries included. (United Nations Development Programme, 2015) Only 20% of the population is connected to the national grid, making eliminating energy poverty a big challenge.

As sub-Saharan Africa aims to eliminate poverty, and therefore also energy poverty, it is of a great significance globally that the energy form is renewable in terms of preventing climate change. There are currently many renewable energy forms being developed and used, an important one in sub-Saharan Africa could be solar photovoltaic (PV) as this region receives a lot of radiation from the sun.

In rural areas where access to the national grid is often distant, it can be a start to use an off grid-solution which enables people to access electricity and perhaps helps lessen the gap between rural and urban areas. Therefore it can be interesting to investigate what socioeconomic and environmental impacts there is from off-grid solutions using solar PV in rural areas.

1.1 Aim

The mission with this thesis is to do an environmental and socioeconomic impact assessment of two different solar PV projects. One of the project provides electricity by connecting the villagers' homes to a microgrid and the other provides electricity with a so called solar home system (SHS). Both projects involves providing electricity to people who previously lived without it. The aim of the impact assessment is to find out which of the different solutions of providing electricity to people gives the most positive impacts regarding the amount of socioeconomical and environmental effects. The aim of the project will be fulfilled by interviewing and observing in the villages and then analysing the gathered data.

1.2 Limitations

The study focuses primarily on off grid solar PV-solutions in rural areas in Kenya, therefore only indicators that is applicable on rural areas will be used, which also means that only effects in Kenyan rural areas will be observed. Off grid was defined as electricity systems that are not connected to the national grid.

For the interviews there are some limiting factors. On site in Sidonge A' the number of households connected will limit the number of possible participating households that has gained access to electricity. Another limitation is budget constraints.

1.3 Research questions

- What is the socioeconomic and environmental impact of gaining access to off grid electricity via solar PV in rural areas?
- What main differences regarding socioeconomic and environmental impact can be observed between the different solar PV off grid electricity solutions for rural areas?

2 Background

In order to understand and relate to the results and findings of this project the background covered several different areas. First is an overview of sustainability in the world and its relation to electricity and electrification. This is then later followed by more specifics related to solar PV and rural electrification.

2.1 Situation in the world regarding sustainability

Today's world is facing many problems regarding sustainability and more specific regarding sustainable development (United Nations, 2015). Billions of people live in poverty and are denied a life of dignity and not forgetting the challenge which climate change presents us with. But it should not be forgotten that this is also a time of great opportunity. The millennium goals which proceeded the sustainability goals (described below) made some progress in a lot of areas regarding sustainability even if there is still a long way to go.

In September of 2015 the UN set an agenda for sustainable development. In order to achieve this agenda the UN set up 17 goals regarding sustainability and sustainable development which are to be fulfilled by 2030 (United Nations, 2015). The goals can be found in Appendix. These goals are set to achieve what the millennium goals did not and also to go even further.

2.2 Welfare in a global perspective

Welfare can be measured in a variety of ways. The welfare of a country is connected to the quality of life which can be measured in two ways, either by objective- or subjective indicators. (United Nations Development Programme, 2015) A commonly used objective indicator is the HDI, developed by the UN. An example of a subjective indicator is Subjective wellbeing (SWB), it is used to measure how happy each individual feels. The HDI of nearly all countries is included in the annual Human Development Report (HDR) which is published by the United Nations Development Programme (UNDP). The HDI consists of three dimensions: *Health*, measured as life expectancy at birth, *Education*, measured in both expected years of schooling and mean years of schooling and *Living standard*, measured in Gross National Income per capita (GNI/capita, 2011 PPP $). PPP stands for Purchasing power parity and all the figures are PPP adjusted to account for the difference in price levels between countries. The HDI is also divided into four different groups: Very High Human Development, High Human Development, Medium Human Development and Low Human Development.

The GNI is very close to another way of measuring national income, Gross Domestic Product (GDP). (United Nations Development Programme, 2015) The GDP measures the value that is produced within a country's borders, as opposed to the GNI that is the value produced by the country's citizens. The most significant difference is thus that the GDP is based on location, and the GNI is based on ownership. They are however both well suited and respected measures of a country's national economy, or welfare.

Historically speaking, as the GDP of a region or country increases, there are a lot of patterns that can be observed. (Stern, 2003) There is a hypothesis based on income per capita and the amount of environmental degradation called the Environmental Kuznets Curve (EKC) hypothesis. This states that the stage of economic development has a clear connection to the amount of environmental degradation of a specific region or country as the income grows. It is formed as an inverted U, and the amount of economic development is divided into pre-industrial economies, industrial economies and post-industrial economies. The turning point is in the middle of the stage industrial economy, where the amount of environmental degradation starts to decline as the economic development approaches the stage post-industrial economy.

This hypothesis should however be used with caution as it is not always entirely correct. In (Stern, 2003), it is stated that *"It seems unlikely that the EKC is a complete model of emissions or concentrations"*, meaning that the EKC is not always applicable on all pollutants. Despite these flaws, the hypothesis is a good model to show the current challenges regarding greenhouse gases, where the industrial economies of the world, i.e. developed countries, will have to strive for lowering their emissions. The pre-industrial economies, i.e. developing countries, will also need to keep their turning point as low as possible to reach the global goals. A simple but not always possible way of reaching these goals could be to grow their economy using clean and renewable energy sources.

A term called decoupling is often used to illustrate that the aim regarding a regions sustainability is to not let economic activity increase the resource use or environmental impact. (Fischer-Kowalski, et al., 2011) As can be seen in Figure 1 below, decoupling is about detaching an increase in economic activity from an increase in resource use, called Resource decoupling, or environmental impact, called Impact decoupling. *"Decoupling at its simplest is reducing the amount of resources such as water or fossil fuels used to produce economic growth and delinking economic development from environmental deterioration".*

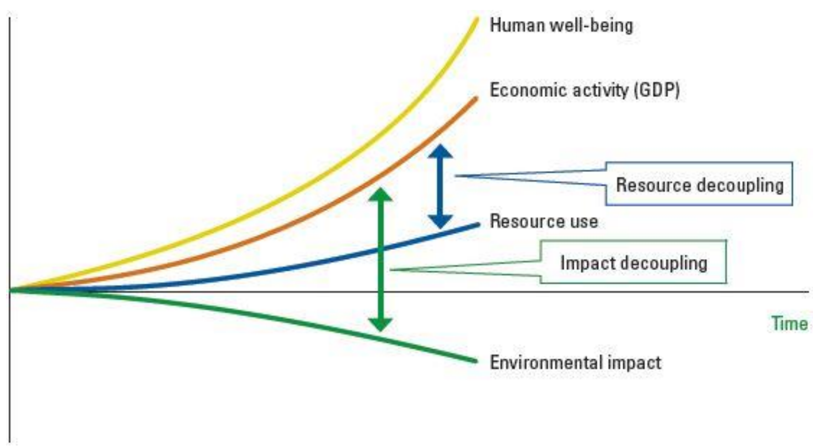

Figure 1. Resource decoupling and Impact decoupling.

2.2.1 Welfare in connection with electricity

"There is a strong positive association between energy consumption and the Human Development Index for developing countries" (United Nations Development Programme, 2015).
As the Human Development Report 2015 states, there is a connection between the Energy development Index value and the Human Development index value which can be observed in Figure 2 below.

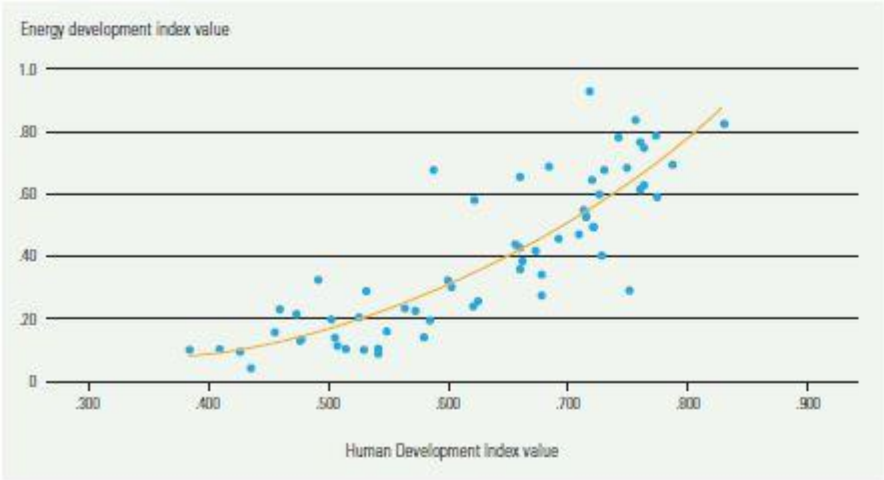

Figure 2. Graph of Energy Development Index and Human Development index.

This indicates that a step towards an increased HDI within a region can be to increase the Energy Development Index (EDI) which consists of two types of indicators: Household- and Community-indicators. (International Energy Agency, 2012) Both these indicators consists of two indicators of their own where the Household-indicator includes *"Share of population with electricity access and per-capita residential electricity consumption"* (Electricity indicator) together with *"Share of modern fuels within the residential sector"* (Clean cooking indicator), and the Community-indicators two values consists of *"Per-capita public sector electricity consumption"* (Public services indicator) and *"Share of productive uses in total final consumption"* (Productive use indicator). From this the conclusion can be drawn that an increase in a population's energy access results in a direct increase in the EDI, which will most likely result in a positive influence on the HDI.

2.2.2 Current welfare situation in Kenya

More than two thirds do not have access to electricity in Africa, despite having all the resources needed to fulfil the energy demand. (International Energy Agency, 2014) Africa is most often divided into North Africa and sub-Saharan Africa. There are huge differences between the regions, for example the GDP in North Africa is about two and a half times larger than the GDP in sub-Saharan Africa, and also only about 1% in North Africa is without electricity while energy poverty in sub-Saharan Africa is much more widespread. This is also the only region in the world where the number of people living without electricity is increasing.

Despite these negative figures, there are some quite positive trends that can be observed in sub-Saharan Africa (International Energy Agency, 2014). The economy is growing as well as the income per capita, also the life expectancy is increasing. However there are some factors that contribute to the lack of business markets investments: widespread poverty and inequality, lack of development in infrastructure, corruption, low levels of political stability in some parts, and low productivity- and skill-levels. Although the economy is rising and has helped many which has resulted in less percentage of people in sub-Saharan Africa living on less than $1.25 a day (defined as absolute poverty), rapid population growth has actually increased the number of people living in absolute poverty. The increase of population has been concentrated in mainly West and East Africa, from about 270 million people in year 2000, to about 940 million in 2013.

The current welfare situation in Kenya is that the GDP per capita (2011 PPP $) 2013 is only $2705 which is well below the World average of $13964. (United Nations Development Programme, 2015) For comparison with a highly developed country, Sweden has a GDP of $43741 which is more than 16 times higher. In terms of HDI, Kenya has been placed at 145 out of 188 countries measured with a HDI of 0.548, which also places the country into the group Low Human Development. The world average is 0.711 and would be placed in the group High Human Development. To again compare with a highly developed country, Sweden has a HDI of 0.907 which is ranked 14th and is placed in the group Very High Human Development.

2.2.3 Current energy situation in Kenya

In Kenya about 35 out of 44 million people live in energy poverty. (International Energy Agency, 2014). The EDI of Kenya is as low as 0.1 out of the maximum value 1, where the major contributor of this number is the Productive use indicator. The country has established a Rural Electrification Authority in 2006, which has the goal of, among others, achieving universal access to electricity in 2030. In 2013 about 90% of their public facilities had access to electricity while the household's access rate still was very low.

There is also an initiative called the Kenya Vision 2030 which is *"A national long-term development blue-print to create a globally competitive and prosperous nation with a high quality of life by 2030, that aims to transform Kenya into a newly industrializing, middle-income country providing a high quality of life to all its citizens by 2030 in a clean and secure environment*". (Vision 2030 Development Board, 2015) The initiative supports many new projects mainly focused in infrastructure and has three main pillars: Economic, Social and Political. One of the main goals is to, starting from 2017, achieve an annual 10% increase in GDP.

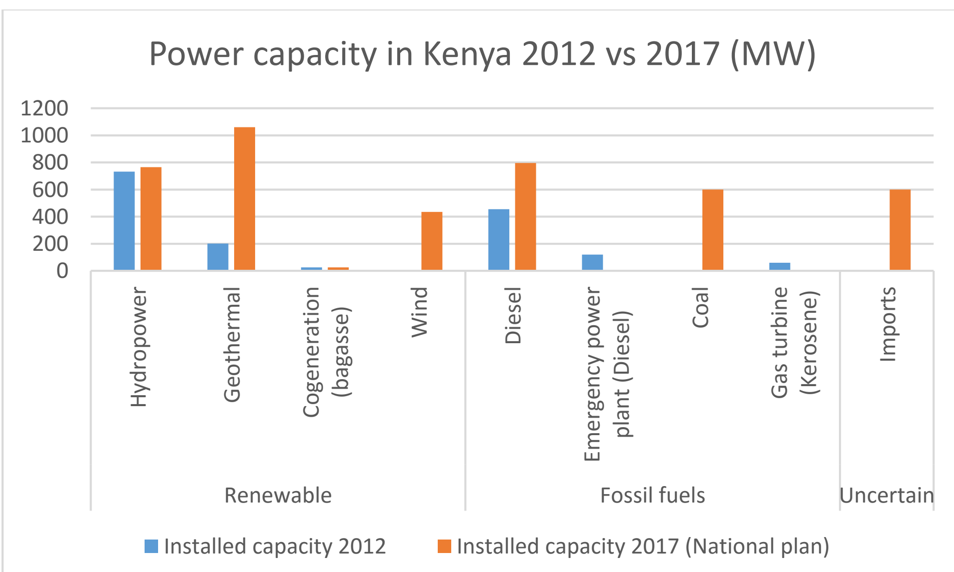

Figure 3. The power capacity of Kenya in 2012 compared to the 2017 National plan (Rose, et al., 2016).

In Figure 3 above Kenya's plans for the coming years can be viewed, where there will be significant changes in both the installed capacity, 1600 MW in 2012 vs 4280 MW in 2017, and the composition of the power generation sources. (Rose, et al., 2016) As solar is used mainly off grid and for self-sufficient households, there is no mentioning in the plans for the National grid as early as 2017 as it is not yet economically feasible.

2.3 Deforestation

Deforestation is when large parts of a forest is harvested and not replaced on a massive scale. (National Geographic, u.d.) This is done a lot today and every year the amount of forest in the world decreases. With the current decreasing rate there will be no forests in the world in a hundred years. Deforestation has several negative environmental effect. One being that millions of species loses their natural habitat. Deforestation is also one of the drivers of climate change which makes it important to prevent.

2.3.1 Deforestation in Kenya

There are several effects caused by deforestation in Kenya, both within and outside of the country. (Crafford, et al., 2012) Both the local climate, in terms of changes within ecosystems, and the global climate are affected. Other areas where deforestation cause problems are water regulation, erosion regulation, water purification and disease regulation. Most valued are Kenya’s montane (mountain) forests areas, often referred to as Kenya’s “Water Towers”, mostly located in the middle and western areas of the country. The total economic effect of deforestation of the montane forests in Kenya was in 2009 estimated to generate a profit of 1308 million KES per year while on the other hand resulting in direct losses in other economic sectors of total 4606 million KES per year where the largest sector was *Growing of crops and horticulture* (-3595 million KES). The indirect effects were estimated to a loss of 1951 million KES resulting in a total impact in other economic sectors of 6557 million KES. Non-consumptive use values are monetary speaking hard to estimate but may include areas such as recreation, species or landscapes different cultural and spiritual importance.

2.4 Kerosene use in developing countries

Globally 500 million households rely on kerosene for lighting. (Lam, et al., 2012) In eastern Africa (including Kenya) 60% of the population relies on kerosene for lighting purposes. It is a well-known fact that kerosene use is linked to a number of different hazards including, fires, explosions and poisoning. It is also shown in studies that emissions from kerosene use can cause lung function impairment, increased cancer risk and asthma to name a few effects. Therefore it is crucial to minimize the usage of kerosene in these areas in order to avoid these problems.

2.5 Solar PV systems

This study has focused on two different systems for providing electricity to rural households. The two are described below.

2.5.1 Solar Home Systems

Solar Home Systems (SHS) is an off grid system providing electricity via solar power mostly in rural areas. It has a limited supply of energy and therefor can only fulfil the households’ basic electrical needs such as lighting, phone charging and powering a radio or small TV. (Energypedia, 2015)

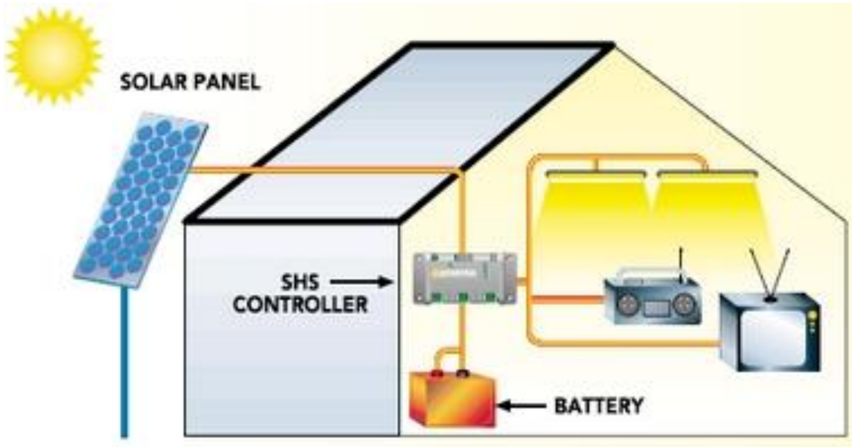

Figure 4. Schematic picture of a solar home system.

A solar home system consists of a solar panel fitted on top the household roof or on a pole as can be seen in Figure 4, a battery and a charge controller. It differs from different suppliers but can also contain lightbulbs, phone charging and ability to connect other small appliances. The SHS is not portable and is used for only one household (Wheldon, u.d.).

2.5.2 Microgrids

The International Council on Large Electric Systems (CIGRÉ) defines microgrids as "…electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded." (Marnay, et al., 2015) This study evaluates a system which is islanded, not connected to the national grid and provides electricity via solar PV.

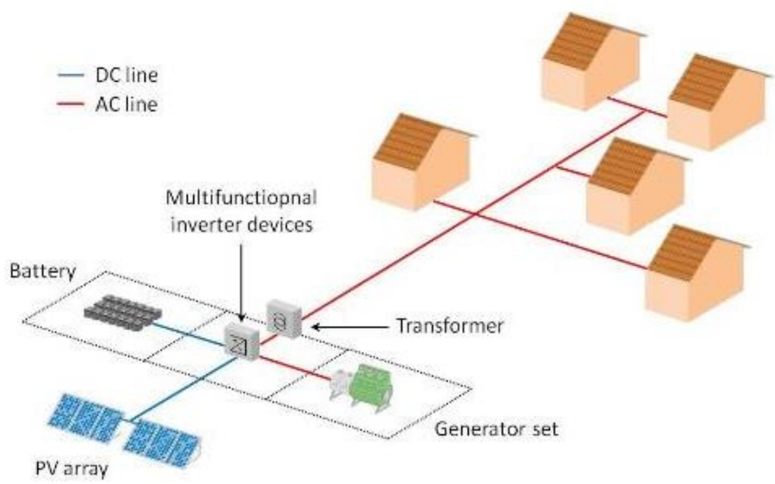

Figure 5. Exemplification of an off grid microgrid with a backup generator, similar to the one in Sidonge A'.

As can be seen in Figure 5 a microgrid consists of solar PV arrays, batteries, multifunctional inverter devices, a transformer and powerlines connecting to the households. (Léna, 2013) As seen in this picture there can also be a connection to a generator providing backup when the energy from the solar arrays is not enough to power the energy needs of the grid. The solar array converts solar energy into electrical energy and the batteries store the energy for later use.

2.6 Rural electrification by solar PV

Many reports show that gaining access to electricity via solar PV gives positive results in many different aspects, socially, economically and environmentally. Below five studies and their results are presented. There are not a lot of studies on this matter to present since this is a field which has not yet been subject to so many studies. A study very similar to this one was done in Kenya in 2013 by (Okello, et al., 2013), who, based on a case study in the Kisumu area in western Kenya, investigated the impact of a technology change in rural households.
The change in technology was, more specifically, going from a household without electricity to gaining access to electricity via SHS. They found that the household first of all started saving money when they started using SHS since they no longer needed to buy kerosene or at least as much kerosene. The researchers found that the households decreased their kerosene use with between 31 and 69 percent. They also saved money since they no longer needed to pay to charge their mobile phones. Some even earned some money by letting other people charge their phones for a small fee in their homes. The women in the households stated that they could keep a cleaner house since they could keep doing chores even after dark. The children were able to study for longer time during the evening and the children also stated that they saved time since they no longer needed to go get kerosene since it was their duty to buy it for the household. They also stated that the families spent extra time together in the evenings chatting and interacting. One thing that was found and that had a big significance was that the SHS had played a major role in improving communications for the households.

A very recent study on rural electrification in South Asia gave some interesting and contemporary results. (Palit & Ranjan Bandyopadhyay, 2016) The study researched if grid extension or off-grid solutions (mainly solar PV but not exclusively) was the most beneficial way to go when electrifying rural areas. The study does not actually promote one over the other but presents five key issues to take into account before deciding between grid extension and an off-grid solution.

- The first key emphasizes that none of the systems are superior to the other when taken all aspects into account. There are different aspects of both systems where they are weak and the best way in the long run might actually be that they both are in to play to complement one another when one system fails.
- The second key is independent from the two different systems and says that the key to success of electrification in rural areas is the government creating a helpful environment by creating for example creating enabling policies like subsidies.
- The third key they mention is that when the demand of electricity (mostly in remote rural villages) is low it might be favourable with small islanded systems like minigrids[1] since they are usually more economically viable in these areas. This since extending the grid far would be costly both by investment and maintenance.

[1] There is no specified definition between micro and minigrids. Some define microgrids as slightly smaller than minigrids but it is not a general definition and not of any real significance in this case.

- The fourth key states that there is a lack of communication and collaboration between stakeholders of the two different systems. In some cases collaboration between grid extension and off- grid solutions could help the development of a region more than simply invest in only one of the options.
- The fifth and last key targets the off-grid solution. It states that if these systems is to be a significant solution energy poverty the whole off-grid community needs to coordinate. The community needs to set up benchmarks for quality and monitoring in order to get rid of the problems it is now facing. Some problems are low quality equipment and some organisations just putting up systems and then leaving the monitoring and management for people without the right knowledge to manage it. If like these went away it could in the future entice major investors which could lead to a real significance of off-grid systems to the problem of rural electrification.

The conclusions from a report which summarized lessons learned and some problems which have emerged from several projects involving off-grid solar PV systems gave some insight in the problems involving rural electrification. (Reiche, et al., 2000) The report divides the problems into the demand side, the supply side and the financing and institutional level. On the demand side it stated that off-grid rural electrification will only work if it involves the community as much as possible in the process. Both via decision-making and by ownership. On the supply side the biggest problem is how the suppliers can ensure the quality and reliability of the system they provide. On the financing side the biggest insurance of success seems to be if there is some sort of prepayment involved. For example prepaid meters, fee-for-service provision or leasing. On the institutional level it is important to make sure that it is an “even playing field.” That distorting subsidies are reduced and that communication between the stakeholders is present.

Even though some studies show that there are positive results in some aspects there are still critics who claim that the results from rural electrification by solar PV in these studies are exaggerated. (Jacobson, 2006) They claim that it does not alieve the population from poverty since the poorest people in the rural areas, who are most in need of poverty alleviation, cannot afford it and therefor solar PV is only for the richest people in the rural areas. They also state that it only plays a minor role in generating income. These critics acknowledge that it can play a big role in increasing the study time for children but that it is not as big a role as some might claim. This is because sometimes the household prioritize to allocate the electricity to appliances such as TVs rather than letting the children study for longer periods of time. One thing that even the critics agree on is the solar PVs effect on communication. The solar PV helps the people connect to relatives, friends and helps business connections which plays a major role in the importance and significance of solar PV for rural areas.

3 Methods

Below the methods that were used in this study are presented beginning with general theory about case studies and systematic combining, followed by the methods for which results were obtained such as interviews, indicators and weighting. Lastly, the calculations used in the study are presented.

3.1 Case study and systematic combining

In order to fulfil the objective of this study a case study approach was chosen and more specifically an approach called systematic combining. This approach to case studies can be described as an abductive approach were the initial theory is developed over time as more knowledge is gained from the data gathering (Dubois & Gadde, 2002). The changes made to the initial theories is done after gaining knowledge from empirical data. As (Dubois & Gadde, 2002) describes it "Systematic combining can be described as a nonlinear, path-dependent process of combining efforts with the ultimate objective of matching theory and reality." This method is described visually in Figure 6**Error! Reference source not found.**.

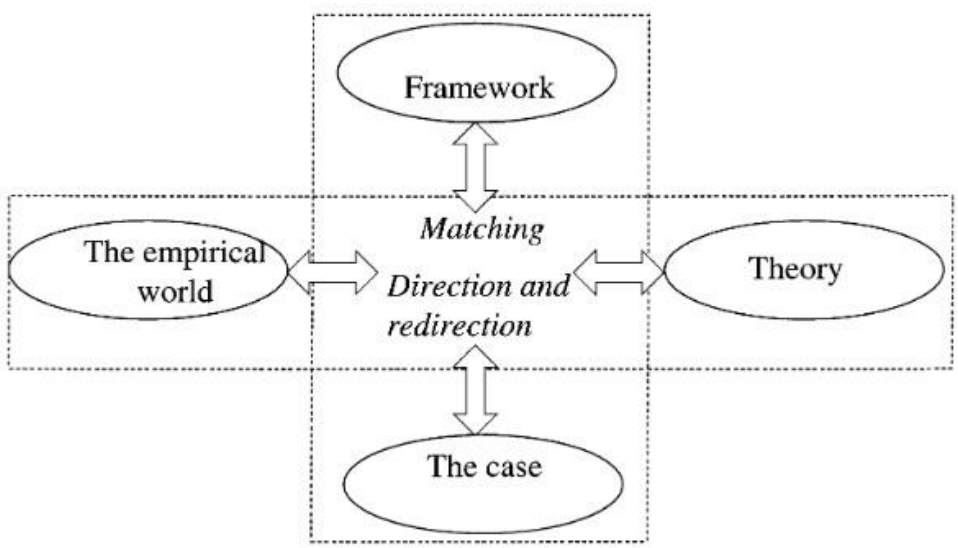

Figure 6. Systematic combining and how it works.

3.2 Interviews

The rural area of Bungoma/Kitale and the village Sidonge A' was chosen for the interviews because of their close proximity to one another in order to keep down costs for transportation. Both of these rural electrification projects also has a Swedish collaboration partner [2] based in Gothenburg which this study did a collaboration with. This made it easy to find channels of communication with project managers in Kenya since a base for communication already had been established. On site in Sidonge A' and the rural area of Bungoma/Kitale, the goal was to gather as much useful information as possible both for the socioeconomic and environmental impact of gaining access to electricity. The environmental and socioeconomic impact assessment consisted of interviews, which were held with people affected by the projects, in order to identify the rural sustainability indicators and how they have changed from pre-electricity to post-electricity and

[2] Trine, a company using crowdfunding to bring clean energy project to developing countries.

this was partly also done by observations from the time spent in the villages. The post- and pre-electricity sustainability indicators were easy to find due to the current situation in Sidonge A', where there were both households with electricity, and those that did not have access to electricity. People from both groups were interviewed and the households with electricity, including the SHS-users in Bungoma/Kitale, were asked about their behaviour and habits from their pre-electricity-time. In Sidonge A' teachers from the village's primary school were also interviewed in order to confirm and get more information regarding how the electrification effected the children's studies.

The questions and indicators that were used during the semi-structured interview can be found in Appendix and are also presented in 5 Results. Before the questions were used they were tested in a pilot interview in order to identify weaknesses in the questions and the interview method.

3.2.1 Interview method

The interviews were be conducted in a semi-structured nature (Longhurst, 2010). Semi structured interviews is when you have predetermined questions to be answered but you still allow both the informant and interviewer to be flexible in the interview process allowing for a more conversational interview style than a structured interview. In the interview the questions used were be kept as open as possible in order to avoid steering the interview-participants in any direction making the interview as unbiased as possible.

3.2.2 Sampling

In this study both a quota sampling- and convenience sampling method was chosen. Quota sampling is when there is a fixed number of categories and a minimum number of interview-participants from each category. (Robinson, 2014) Convenience sampling is when the interview-participants of a study is chosen by their proximity to the researcher and also for their willingness to participate.

The participants in the interview were mainly planned to be chosen through quota sampling. The focus of the categories was amount of time they have had the system and occupation. This was to get a good spread over the interviews where effects could actually be measured as the interview-participants would not be entirely new to the system, and also that the interviews would incorporate people from different types of income-amounts.

Though there were some limiting factors (see 1.2 Limitations) which resulted in some usage of convenience sampling. Convenience sampling were to be implemented as a backup plan if all else would fail, however that was not entirely the case. The convenience sampling was a good complement where the quota sampling was not, due to limitations, possible to carry out fully.

3.2.3 Observations

On site in both villages, observations were made to serve as complementary input to the rural sustainability indicators. This was done through talking to several villagers independent of one another and asking them general questions about their habits and of the local community. Also, observations and documentations were made of the surrounding environment, with numerous different inputs such as distances to nearby towns, cooking possibilities, sanitation access, water access and appliances.

3.3 Rural sustainability indicators

The sustainability indicators used in this study were selected from a list of indicators from the United Nations. (United Nations, 2007) The United Nations did an inventory of different indicators used to assess sustainability in rural areas. Below the indicators chosen to assess rural sustainability in this study are shown see Table 1. They were chosen to cover all aspects of the study but to still be closely related to the limitations of the study so that effects on the indicators could easily be identified and verified. The interview questions were formed with the indicators in mind in order to get data related to all indicators.

Table 1 Rural sustainability indicators which were used to indicate sustainability in a project.

Theme	Subtheme	Indicator
SOCIAL	Health	Water access and water quality
		Vaccines
		Deadly diseases
	Education	Time to study
		Primary school enrolment
		Primary school completion
	Housing	Mobile phone usage
		Internet usage
		Improved sanitation access
		Cooking possibilities
	Gender equality	Women in agriculture
		Women in business
		Primary school gender ratio
ECONOMICAL	Labour force	Participation rate
	Employment	Employment
	Productivity	Work contribution
	Investment	Private: appliances, basic consumption Business: businesses, shops etc.
	Sectoral Share	Occupation (agriculture, industry etc.)
ENVIRONMENTAL	Climate	Contribution to climate change
	Land Use	Amount of agricultural land
		Deforestation
		Population growth
	Surrounding environment	Soil and water
	Air quality	Inside air quality
		Outside air quality

3.4 Weighting

In order to quantify the results the rural sustainability indicators were to be weighed against each other by the stakeholders.

3.4.1 Stakeholder identification

The stakeholders in the two different solar PV systems were identified to be the users of the systems, the investors and the Swedish company Trine.

3.4.2 Weighting

The stakeholders were all given a list of the indicators and asked to weigh them on a scale from one to five based on how important the indicator was to them. One indicated not important at all and five indicating extreme importance. They also rated the themes and subthemes.

3.5 Calculations

Below follows a short explanation of the calculations that have been made. The calculations were made to help determine environmental and health effects that are related to the combustion of fossil fuels. The emission factors were obtained for kerosene use (United States Environmental Protection Agency, 2014) and for gasoline use (Tillman & Baumann, 2004). The gasoline use is included since the microgrid has a backup generator driven with gasoline. Without the microgrid the gasoline generator would not have been there. After which, emission factor was quantified with the use obtained from interviews and observations. The substances were then used to determine the Global Warming Potential (GWP) and the Photochemical Ozone Creation Potential (POCP), both tables with calculations are presented in Appendix as A.9 and A.12 (Tillman & Baumann, 2004). The POCP is seen as a local contribution to the air quality, however the total outside air quality including combustion of waste and firewood etc. will not be examined. Below the equations for calculating GWP and POCP are presented.

Contribution to GWP= Substance [kg per household per month] GWP 100 years emission factor*

Contribution to POCP= Substance [kg per household per month] POCP High NOx emission factor*

4 Case description

In this study two different areas in western Kenya were visited, see Figure 7. Bungoma and Kitale are two different towns but their rural areas are connected so it can be seen as one area for this study. The Sidonge A' village and the rural areas in Bungoma/Kitale were chosen because they were both targeted with different solar PV solutions for rural electrification. Sidonge A' with microgrids and Bungoma/Kitale with SHS.

Figure 7. Map over Kenya where the areas visited in this study (Sidonge A', Bungoma and Kitale) are indexed in red. The rural areas in Bungoma and Kitale is in this study seen as one area.

4.1 Solar Home Systems

The SHSs were sold by a company[3] based in the Bungoma/Kitale area and the areas and the systems are presented further below.

4.1.1 Bungoma/Kitale rural area

In the rural areas of Bungoma/Kitale the people work mostly with farming or work at the sugarcane factory. The crops which are mostly grown are the cassava, maize and bananas but some people also grow tealeaves which they supply to the local tea factory. In the rural area where this study took place it was rather far too the nearest town with about 10km to nearest shops and charging stations (for mobile phones) but the primary school was in very close proximity to the village so it was easy access for the children.

The households in the studied area had an average of six people living in them. Most of the people in the rural area lived in cottages with two rooms, one living room and one bedroom, see Figure 8 and Figure 10. The cooking was done either outside or in a separate small cottage next to the main

[3] The company is called Mibawa and operates in many different parts of Kenya and Bungoma/Kitale is one of these places.

one. The cottages were made of clay mixed with cow dung and only those who could afford it had brick houses (which were only one of the interview-participants in Bungoma/Kitale). The cow dung is added for durability since without it the cottage would fall apart every time it rained. No one had improved sanitation in the area that we observed.

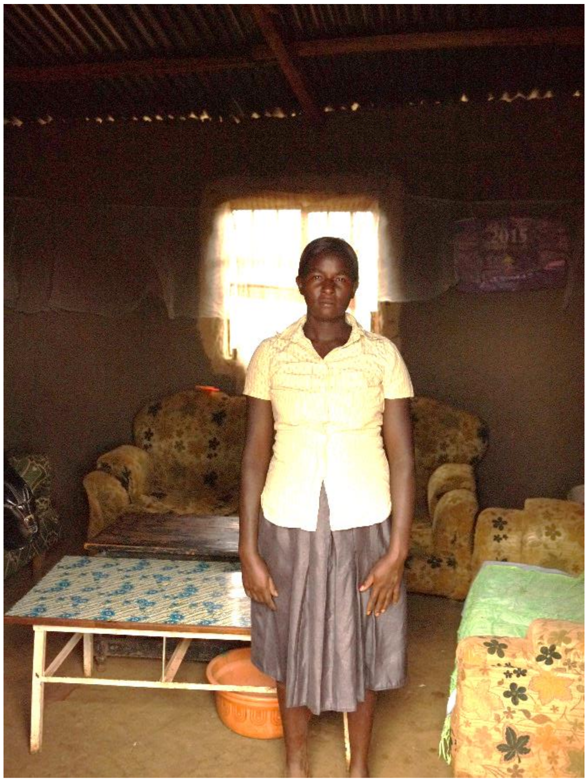

Figure 8. Typical living room for people in rural Kenya. Picture taken in Kitale with a proud owner of a SHS.

4.1.2 Solar home system

The SHS in this study are sold from a small shop in Kitale and also by going out to people directly where there are large people gatherings, for example when there was the sugarcane harvest. At the sugarcane harvest there are workers from the sugar factory in the Bungoma who are specially targeted since they have a stable income. These earn only in average 10000 KES[4] per month (900 SEK per month) but at least has a stable income making it easier for them to pay for the system than others without stable income.

A number of different brands of SHS was sold at the store In Kitale and at the gatherings but one brand in particular was promoted (and was almost exclusively sold) which also was the far cheapest alternative which also came with a radio which the other brands did not. This SHS consists of a 3W solar panel, a 4000mAh battery pack, two 0,9W bulbs with switches, a mobile phone charging pin and a small chargeable radio. This SHS is called *Mibawa solarpack 3* see Figure 9. It is sold for 7500 KES. The solar panel is fitted on top of the household's roof by the company to ensure that it was installed and used properly from the beginning. It also came with a two year warranty which gave them another edge compared to other brands of SHS. With the

[4] Kenyan shilling. 1 KES = 0.09 SEK (Forex, 2016)

Mibawa solarpack 3 the customers can light two separate rooms and charge their mobile phone and the accompanying radio.

Figure 9 The SHS promoted for rural usage.

4.1.3 Future plans

The company MIBAWA has a plan to provide SHS (and solar lanterns[5]) to 30000 people in Kenya. They have also identified a new market so more people can access clean energy. The new market consists of households and businesses already connected to the national grid. But the national grid is not reliable and power cuts are for some periods of the year a daily problem. Therefore people who rely on having constant access to electricity can buy SHSs as a backup system.

4.2 Microgrid

A microgrid was installed in Sidonge A' to give this village access to electricity and clean water this projects and specifics regarding the village is presented below.

4.2.1 Sidonge A'

It is a village located near (almost on) the west border to Uganda. Since it is only a short walk without border control there is a lot of trading between Sidonge A' and the closest village in Uganda. Sidonge A' lies approximately 10 km from the nearest town Funyula. In the village there is a Primary school where all children go. The main source of income for the people living in the village is farming. They mostly grow for themselves to consume but sell the excess to generate income. The crops mostly grown are maize, beans, cassava and sorghum.

643 people are living in Sidonge A' divided in 120 households making the average household size 5.3 persons. Most of the people in the area lived in cottages with two rooms, one living room and one bedroom, see Figure 8 and Figure 10. The cooking was done either outside or in a separate small cottage next to the main one. The cottages were made of clay mixed with cow dung and only those who could afford it had brick houses (which were only three in Sidonge A'). The floors were all made of the clay and cow dung mixture but the once with brick houses had put a plastic mat

[5] Lamps with a small solar panel on top. Charges by putting whole lamp outside in the sun.

over it. No one had improved sanitation access and only had very small cottages with a hole in the ground which several households shared see Figure 11.

Figure 10. Typical house in the village of Sidonge A'. The houses looked very similar in Bungoma/Kitale also.

Figure 11. To the left is the small cottage where the toilet is located. For reference it is too small for anyone but children to stand upright in. To the right is the inside of the toilet cottage. Leaned on the back wall is the stick with a metal sheet on which is put on top of the hole to prevent smell.

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4.2.2 Kudura

This study evaluated a microgrid which was islanded, not connected to the national grid and provided electricity via Solar PV. The system which provided the electricity was called Kudura. It was launched as a pilot project in 2011 and completed the same year when 12 households where connected. If the pilot project worked out it was to be expanded to 50 households in 2016. It had a centralised station with solar panels where the controlling and monitoring was done, see Figure 12. It is a container where the solar panels are fitted on top and the batteries and other monitoring appliances are fitted inside. It provided the households and a few surrounding businesses with 50-250W of power which was enough to cover the households basics needs of electricity i.e. powering lighting, mobile phone charging, a radio and a small TV. The system only allows the households to get power from 18-23 o'clock but the businesses enjoys the benefits of having electricity 24-7. The households pay 380 KES per month to get electricity and does not pay any connection cost. The households that are connected to the microgrid has a transmission box fitted on their wall in the house with two sockets where one could charge their phone, radio or small TV or similar appliances. Bigger appliances or appliances which needed large amounts of electricity are not allowed to be plugged into the system. From this box the lights in the house where also powered. The businesses around the systems were a barber shop where you could also charge your mobile phone and a video-hall where the kids in the village were shown movies etc. and they showed football and movies for adults in the evenings. When the solar power was not enough to power the households and the surrounding businesses the system was backed up by a gasoline generator. The Kudura system also provided the local community with clean water via a purification system.

Figure 12 The area where the Kudura system is located. The blue container being the Kudura system itself and the white building being designated for future businesses.

4.2.3 Future plans

There are plans to expand the system in Sidonge A'. These plans are being implemented at the time this thesis is written and it is supposed to be finished sometime in 2016. The plan is to install more solar panels to the system so there is enough power for 4 more businesses and a total of 50 households. The power is supposed to cover the households need for lighting throughout the day so not only in some hours as it is at the time this thesis is written. The new businesses that they are planning for are a milk-cooling facility, a salon, a general shop and a water shop where they can store and sell water from the purification part of Kudura. As of now there are no refrigerator at all in Sidonge so the milk the kettle farmers get from their cows and goats go to waste if it is not consumed the same day. Another plan the village has is to open a small library where children can spend time after school. This also presents employment opportunities.

4.3 Comparison of SHS and microgrid

In order to get a better grip of the specifics regarding the both researched technologies a descriptive table on the specifics is presented below in Table 2.

Table 2. Comparison of a number of specifics between the different solar PV solutions.

	SOLAR HOME SYSTEM	MICROGRID
Number of connected households	NA[6]	12[7]
Capacity/ household	3W	50-250W
Types of lights	LED	LED
Lamps per household	2	2
Wattage per lamp	0,9W	5W
Backup generator, type	No	Yes, gasoline
Socket	USB	Type G
Mobile phone charging	Yes	Yes
TV- plug in	No	Yes

[6] Mibawa claim on their website that they have transformed 110000 lives in Kenya but does not indicate how many households they have connected.
[7] Plans to connect up to 50 households were in progress in 2016.

5 Results

Below, the subtheme of each indicator is presented and the case results of each subtheme will be presented under the technology, starting with SHS. Directly after the subthemes the interview questions and observations related to the indicators are also presented. The final parts of this chapter contains indicators where no information was obtained after which the weighting results are mentioned.

5.1 Health

Interview questions:
Have you or anyone in your family had any health problems during the latest years?
What kind of diseases have you had during the latest years?
Have you noticed any improvement in your health since you started using electricity?
What kind of vaccines have you gotten?

Observations:
Water access
Water quality

5.1.1 Solar Home Systems

Water access and water quality
As there was a nearby river that water was taken from the access was good. However the water was cleaned using chlorine instead of a purification system which means that the water quality was poor, as seen in Table 3.

Vaccines
As vaccine programs were handled by the government there was no influence in the amount of vaccines by gaining access to electricity to be observed in Bungoma/Kitale.

Deadly diseases
No information was obtained regarding the amount of deadly diseases in Bungoma/Kitale.

Other
Less coughing mentioned by six out of eight people. Less runny nose mentioned by four out of eight. Less eye problems mentioned by two out of eight. No improvement in health mentioned by one out of eight. Three out of eight mentioned that it was much safer to handle the lighting instead of kerosene lamps where there were risks of burning and fire hazards.

5.1.2 Microgrid solar installations

Water access and water quality
With the water purification facility included in the Kudura-container, villagers in Sidonge A' could purchase water that was completely purified, which is of good quality, instead of buying water that was purified using chloride. The water could be bought at the same price, 0.5 KES per litre water, from both the Kudura-container and for chlorinated water.

Vaccines
As vaccine programs were handled by the government there was no influence in the amount of vaccines by gaining access to electricity to be observed in Sidonge A'.

Deadly diseases
When conducting the interviews, there had according to the interview-participants been a decrease in deadly diseases such as malaria[8] where three out of twelve people had experienced less malaria. It was also told that since starting to use the Kudura-system, the cases of typhoid fever[9] and cholera[10] had decreased. This was however only mentioned by one person.

Table 3 summarizes in a short matter the results obtained in the subtheme Health. For full explanatory texts see 5.1.1 and 5.1.2.

Table 3. Summarization of the health related indicators and their impacts. An upwards pointing arrow indicates a positive influence from solar electrification which means less cases of diseases.

INDICATOR	SHS	MICROGRID
Water		
Water access	Good	Good
Water quality	Poor	Good
Deadly diseases		
Malaria	-	↑
Cholera	-	↑
Typhoid fever	-	↑

Other
Less coughing mentioned by six out of twelve. Less eye problems mentioned by four out of twelve. No more bad smell mentioned by three out of twelve people. A better health in general mentioned by two out of twelve people. An increased amount of stress mentioned by one out of twelve people. Three out of twelve mentioned that it was much safer to handle the lighting instead of kerosene lamps where there were risks of burning and fire hazards. A nearby house had burnt down the year before due to a kerosene lamp that fell, also severely hurting one person.

5.2 Education

Interview questions:
Villagers:
Are you/your children going to school?
How many hours of studying do you/your children do per day from home? Can your children study longer at home since you've gained access to electricity? How many minutes/hours?
Teachers:
Have you noticed any changes since parts of the village gained access to electricity?

[8] Caused by mosquito bites, around 214 million per year infected and 438 000 deaths annually (World Health Organisation, 2015).
[9] Infection caused by contaminated food or drinking water, approximately 21 million cases and 222 000 typhoid-related deaths annually (World Health Organisation, 2014).
[10] Infection caused by contaminated food or drinking water, 1.4 to 4.3 million cases and 28 000 to 142 000 deaths annually (World Health Organisation, 2012).

How big part of the children in the community goes to school?
How many years in average do people go to school?
What are the main reasons for not completing school?
What is the ratio between boys and girls in classes?

Observations:
Gender ratios in general in different areas of the community (agriculture, school, business, household chores).

5.2.1 Solar Home Systems

Primary school enrolment
Among the interview-participants, all eight of eight had children that went to school.

Primary school completion
No results were obtained that were directly related to the completion rate.

Primary school gender ratio
According to the teachers interviewed in Sidonge, the gender ratio was about 50:50. No results were obtained for Bungoma/Kitale. This was however not seen as anything that was influenced by the SHS or microgrid solar installations.

Time to study
In Figure 13 below the number of hours per day children study can be viewed as it was obtained from the interview-participants, to the left the average study time before purchasing the Solar Home System is shown and to the right the average time studied since purchasing the system.

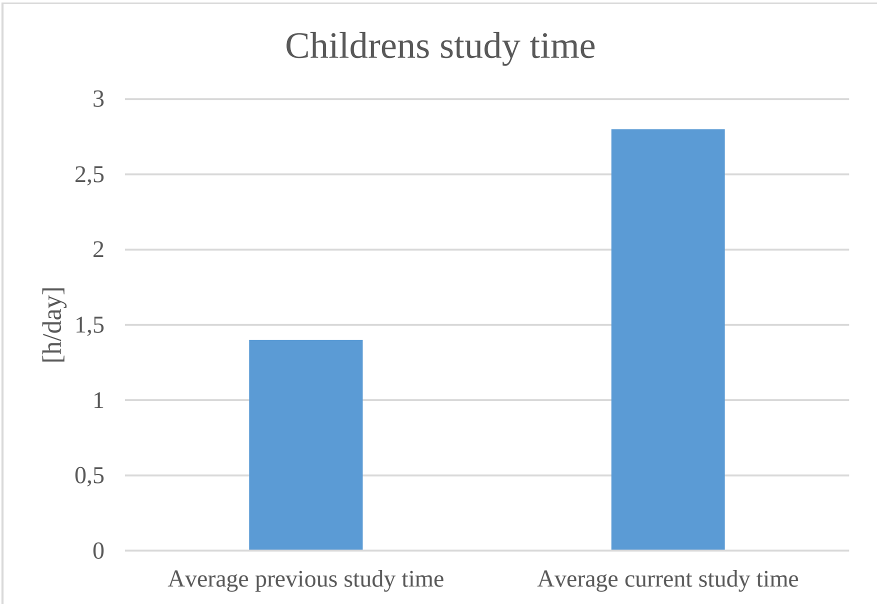

Figure 13. The number of hours children studied per day before and after purchasing the Solar Home System.

5.2.2 Microgrid solar installations

Primary school enrolment

Of the interviewed in Sidonge A', three had no children in the household, one household had children that were yet too young for school and the remaining eight had all of their children in school.

Primary school completion

The two teachers that were interviewed were united in concluding that children with access to electricity perform better than children without access to electricity because of the fact that they were able to study more. Other aspects mentioned was that studying with electricity lamps was more efficient in terms of getting more work done, also more people could study at the same time instead of 1-2 children gathering around one kerosene lamp. One of the teachers had also noticed that children with electricity were more advanced, had a lot of different views and were better of putting Kenya in perspective to other countries.

Time to study

In Figure 14 below the number of hours per day children study can be viewed based on information obtained during the interviews, to the left the average study time before subscribing to the microgrid solar installations is shown and to the right the average time studied since purchasing the system. The results are accumulated from interviews both with the teachers and the children's parents.

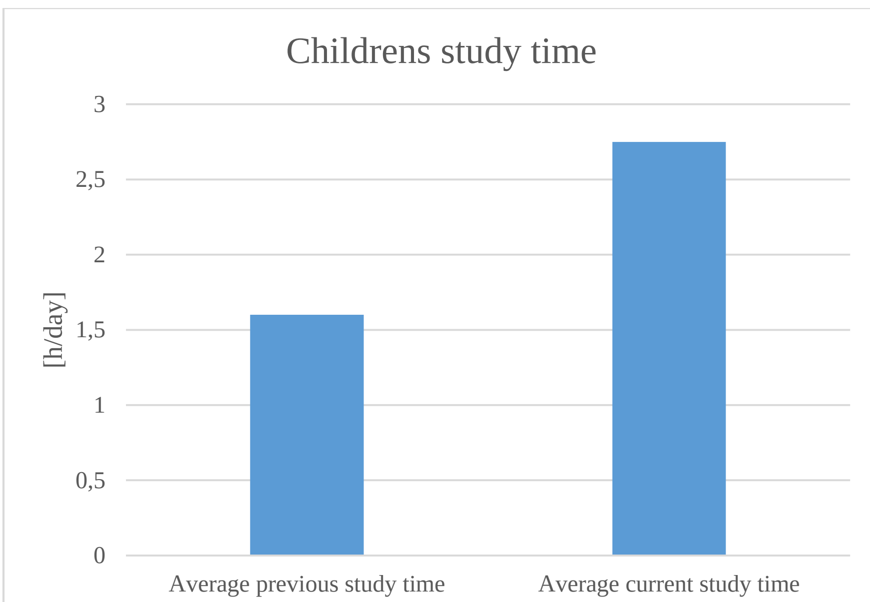

Figure 14. The average number of hours children studied before and after subscribing to the microgrid solar installations.

5.3 Housing

Interview questions:

How do you cook your food? Do you use coal or wood when you cook? Where do you get it from? Do you have a mobile phone? What do you use it for? Have you been able to use it more than before?

Do you have access to the internet? What do you use the internet for? Have you been able to use it more than before?
How many people live in your household?

Observations:
Improved sanitation access
Appliances

5.3.1 Solar Home Systems

Mobile phone usage
All of the interview-participants, eight people, currently used a mobile phone. The main reasons were to call relatives and friends, also to use M-PESA[11]. All eight people answered that they had been able to use their phones more now since they could charge it at home. This was also cheaper since a fee of 20 KES was charged each time to charge it, this also had to be done at the market at least 10 km from their homes.

Internet usage
Out of seven people (since one interview was cancelled due to an accident nearby), three people answered that they did not use the internet and four people answered that they did. Main reasons for using the internet were to use social media and M-PESA.

Improved sanitation access
No access to improved sanitation is shown either before or after purchasing SHS for all of the eight households.

Cooking possibilities
There was no change in cooking possibilities influenced by gaining access to electricity through SHS.

5.3.2 Microgrid solar installations

Mobile phone usage
Eleven out of twelve people answered that they used a mobile phone. The main reasons were communication but also to use M-PESA. All eleven people were able to use the phone more after gaining access to electricity since they could charge it at their homes instead of the nearby town Funyula about 10 km away, with a fee of 20 KES per charge.

Internet usage
Only two out of twelve people used internet. The main reason was to use social media.

Improved sanitation access
No access to improved sanitation was shown either before or after using microgrid solar installations for all of the twelve households.

Cooking possibilities

[11] M-PESA is a mobile money transfer service (Safaricom, 2016).

There was no change in cooking possibilities influenced by gaining access to electricity observed as an effect of microgrid solar installations.

5.4 Gender equality

Observations:
Gender ratios in general in different areas of the community (agriculture, school, business, household chores).

5.4.1 Solar Home Systems

Among the interview-participants seven out of eight were women. The reason there were mostly women interviewed was because the men were off in bigger cities bringing in income.

Women in agriculture
It was observed that the main caretaking of the household including agriculture were taken care of by women. Most women in the village were working with agriculture of different sorts.

Women in business
None of the seven women interviewed ran a business of her own and none of them were business employees.

5.4.2 Microgrid solar installations

Among the interview-participants eight out of twelve were women.

Women in agriculture
Most of the women in the village seemed to be working in agriculture. Seven out of eight women interviewed stated they worked with farming.

Women in business
Three out of eight women interviewed had a business. Two of these were started after gaining access to electricity. Also the village in Sidonge A' has an agenda of empowering women by getting more of them into businesses. Therefore the businesses built around the Kudura-system were dedicated to females so only females were allowed to run these businesses. This is a vision the project managers had and it may be that there is no females who want to run the businesses but they at least are the first to get the chance of running them. But the ones there now (the video hall, barbershop and mobile charging shop) are not run by females.

5.5 Economy

Interview questions:
Do you feel that you have saved money from switching to solar power? If so, have you been able to purchase anything you've wanted with the money you have saved?

Observations:
Unemployment and contribution
In Figure 15 the monthly costs for lighting and phone charging is shown for SHS-users, microgrid solar installations-users and people without access to electricity. This includes payment of the

different systems for the electricity-users, but also current kerosene use. For people without electricity it was based on charging their phones every five days and the kerosene use was based on both how much the SHS- and microgrid-users had used before but also from how much the people interviewed without access electricity currently used, to an average of 5.05 litres per month for each household. All costs of the kerosene use was based on the current kerosene price obtained from the interview-participants, which was 90 KES/litre.

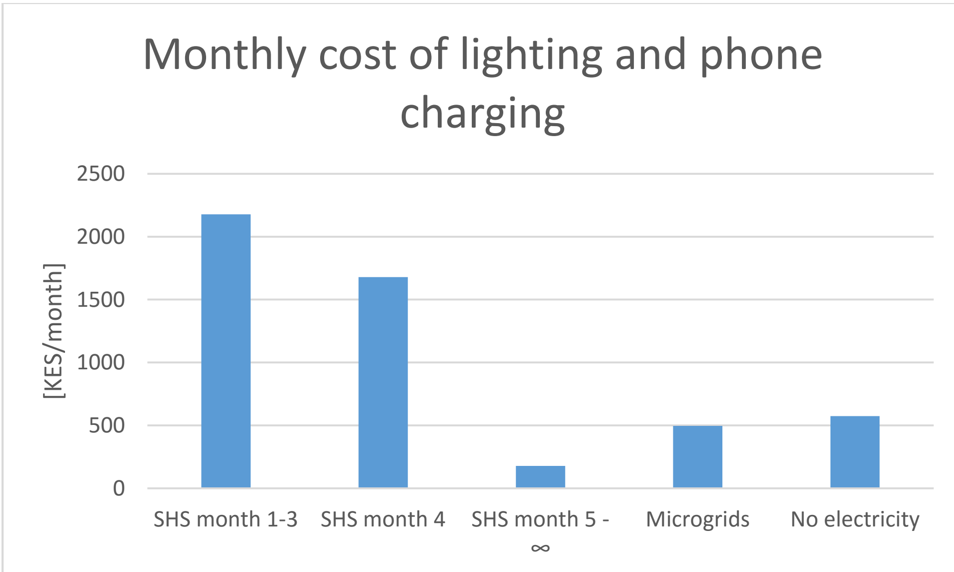

Figure 15. Monthly costs for lighting and phone charging.

5.6 Investment

Interview questions:

Do you feel that you have saved money from switching to solar power? If so, have you been able to purchase anything you've wanted with the money you have saved?

Observations:

Appliances

5.6.1 Solar Home Systems

Private investments: appliances, basic consumption etc.

All eight households claimed to have more money left since installing the SHS, which according to the interview-participants had increased their consumption pattern in general. As different types of consumption had increased, the most common use of the money that was found to have been spent on their children, providing them with books for school, going to a better school, clothes, presents, money and also providing them with better food. Two of the households invested in more animals such as sheep, chickens and cattle. One of the interview-participantss built a better house.

Business investments: businesses, shops etc.

No business investments in the local area was found that was related to people gaining access to electricity through SHS.

5.6.2 Microgrid solar installations

Private investments: appliances, basic consumption etc.

Twelve out of twelve interview- participants claimed to have saved money. The most common investment was in home appliances where six people had made purchases such as kitchen tools, TVs and radios. The second largest private investment was in home improvement, which includes chairs, a better house and better food. Other areas of investments was private businesses, where more people could be employed in for instance help with farming, buying more animals and buying and selling products. Also one household mentioned paying for the children at school.

Business investments, businesses, shops etc.

There was a number of business investments that was observed and that was found as a direct correlation to the microgrid solar installations within the community[12]. A video hall and a barber shop was observed in the village, there was also a milk cooling facility, a small shop, a saloon and water bottle storage that was under construction.

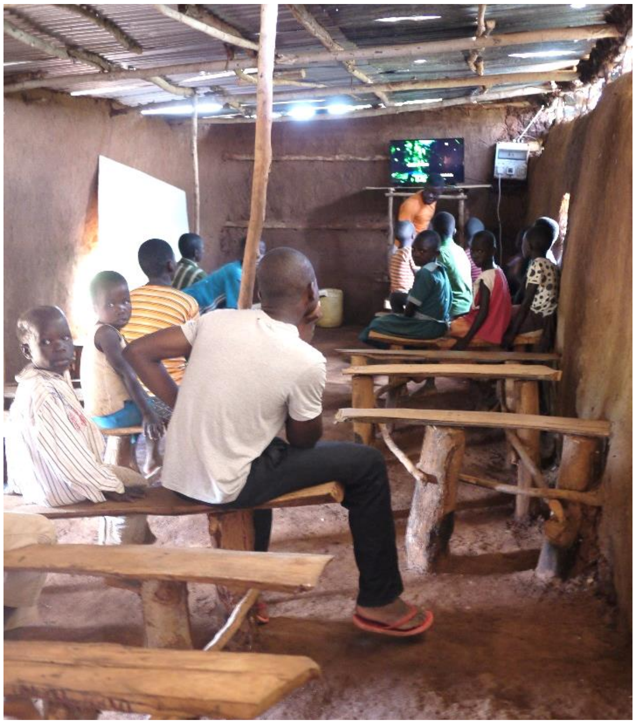

Figure 16. The video hall in Sidonge A'. Next to the TV in the picture there is also room to put up a projector screen for bigger events.

[12] These were both built and financed by RVE.SOL and Trine.

Figure 17. The barbershop in Sidonge where men can come and get their head shaved.

Figure 18. One of the buildings where the businesses allocated for women will be located.

5.7 Sectoral share

Interview question:
What do you do for a living? (Part of the introduction/small talk)

Observations:
Sectoral shares

In Table 4 the Sectoral share is presented for SHS and microgrids.

Table 4. *Sectoral share* of SHS and microgrids.

SUBTHEME	OCCUPATION	SHS	MICROGRIDS
Sectoral share	Farmers	4 of 8	10 of 12
	Teachers	2 of 8	0 of 12
	Business employee	1 of 8	0 of 12
	Housewives	1 of 8	1 of 12
	Business owners	0 of 8	4 of 12

5.8 Climate

Interview questions:
How much kerosene do you use per day/week/month?
When do you use kerosene and what do you use it for? How much did you use before you started using electricity?

5.8.1 Solar Home Systems

Contribution to climate change
As can be seen in Figure 19, the kerosene use has decreased with approximately 67% for SHS-users.

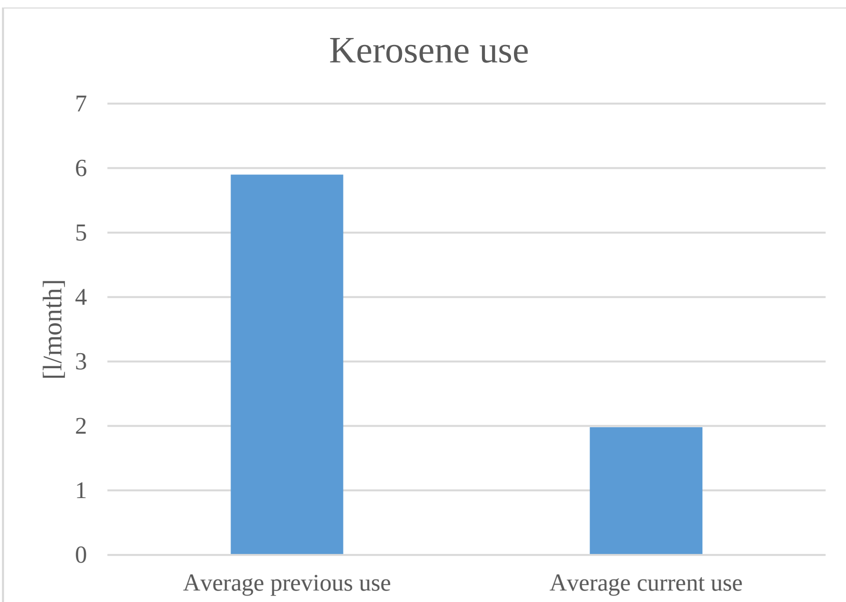

Figure 19. Previous and current use of kerosene for SHS-users.

5.8.2 Microgrid solar installations

Contribution to climate change
As Figure 20 shows, the kerosene use of microgrid solar installations-customers has decreased with approximately 70%.

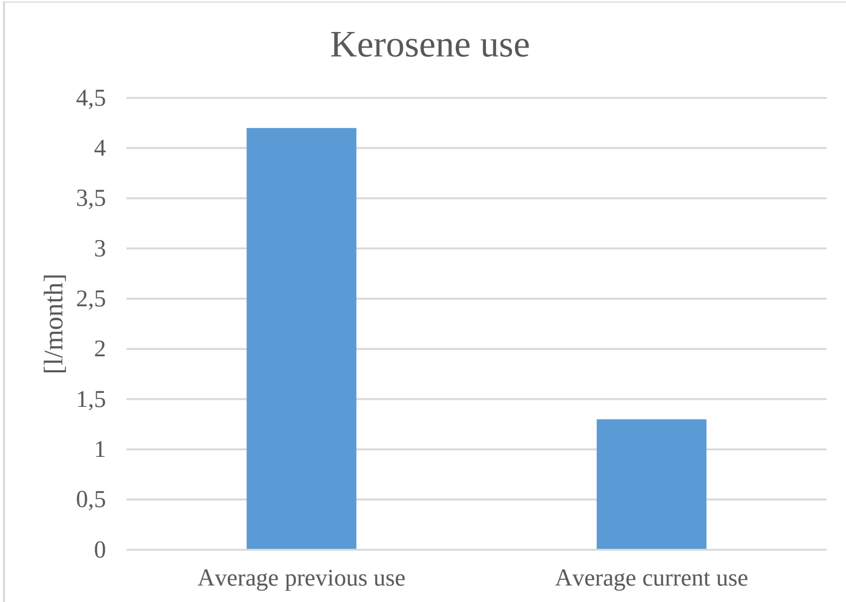

Figure 20. Previous and current use of kerosene for microgrid solar installations-customers.

For the microgrid approximately 30 litres of gasoline per month were used to power the generator. This alone results in 6.5 kg of $CO_{2\text{-eq}}$-emissions per household each month.

5.9 Land use

Interview questions:
How do you cook your food? Do you use coal or wood when you cook? Where do you get it from? How many people live in your household?

Observations:
Deforestation
Agricultural land

5.9.1 Solar Home Systems

Deforestation
When asked about their cooking fuels, all of the eight interview-participants used firewood, all of which stated that they pick up dry branches from the ground which would not have any influence on the deforestation in Bungoma/Kitale. When asked about their cooking habits pre-electricity there was almost no change in their habits that had been influenced by gaining access to electricity.

Population growth
No record was found in Bungoma/Kitale of the actual growth in population. However, there were in average 6 people in each household of the interviewed.

5.9.2 Microgrid solar installations

Deforestation
When asked about their cooking fuels, eleven out of twelve used firewood, all eleven of which stated that they pick up dry branches from the ground which would not have any influence of the

deforestation in Sidonge A'. When asked about their cooking habits pre-electricity there was no change in their habits that had been influenced by gaining access to electricity.

Population growth
No record was found in Sidonge A' of the actual growth in population. However, there were in average 5.3 people per household of the interviewed.

5.10 Air quality

Interview questions:
How do you feel about your indoor air quality? How was it before?

Observations:
Inside air quality
Outside air quality

5.10.1 Solar Home Systems

Inside air quality
All interview-participants answered that they had improved their indoor air quality, six of eight people that they had experienced less coughing than before. Five of eight has stopped using kerosene at all.

Outside air quality
To help determine the impact of the outside or overall contribution to the air quality in the local area, the Photochemical Ozone Creation Potential (POCP) was used. This was done using the same input as for *Contribution to climate change* in 5.11.1, i.e. the kerosene use in Bungoma/Kitale.

5.10.2 Microgrid solar installations

Inside air quality
All of the interview-participants stated that their indoor air quality had improved. Six out of twelve had experienced less or no coughing at all and three had less problems with their eyes. Out of twelve, four people had stopped using kerosene.

Outside air quality
To help determine the impact of the outside or overall contribution to the air quality in the local area, the Photochemical Ozone Creation Potential (POCP) was used. This was done using the same input as for *Contribution to climate change* in 5.11.2, i.e. the kerosene use and in Sidonge A's case, also the gasoline generator.

5.11 Indicators with no information

Since there was in total 29 indicators chosen, the possibility that some of them would not be quantifiable or possible to obtain results for was seen as large. Below the indicators where no information was able to be obtained is listed.

Soil and water
No observations were made of the quality of soil and water in general in either Bungoma/Kitale or Sidonge A'.

Amount of agricultural land
The amount of agricultural land was not observed in either villages.

5.12 Weighting results

When weighting was chosen as a method to be able to quantify the importance of the different indicators, the necessity for this was that different stakeholders would contribute with input. This would ensure that the different perspectives of the stakeholders could be more thoroughly understood and indicators of more or less importance compared from these perspectives. However, it was realized that the willingness to participate in such a study was quite low and which resulted in only getting results from the consumer perspective. The results of the weighting from the consumers are presented below in Table 5.

Table 5. Results from the consumers' point of view how important each indicator is i.e. weighting of indicators.

INDICATOR	AVERAGE WEIGHTING	
	SHS-consumer	Microgrid-consumer
SOCIAL	**4,63**	**4,79**
Health	5	5
Water access and water quality	5	5
Vaccines	4,75	5
Deadly diseases	5	5
Mortality	4,33	4,92
Education	5	4,67
Time to study	5	4,92
Primary school enrolment	5	5
Primary school completion	5	5
Housing	4,5	5
Mobile usage	4,25	4,75
Internet usage	3	1,67
Improved sanitation access	4,75	5
Population	2,75	4,17
Cooking possibilities	4	4,83
Gender equality	4	4,5
Women in agriculture	4,33	4,92
Women in business	5	4,92
Primary school gender ratio	4	5
ECONOMICAL	**3,17**	**4,55**
Labour force	3,14	4,67
Participation rate	3	4,67
Employment	3,57	4,75
Productivity	2,86	4,58
Work contribution	2,5	4,64
Investment	3,71	4,75
Private: appliances, basic consumption	3	4,18
Sectoral share	2,57	4
ENVIRONMENTAL	**4,58**	**4,77**
Climate change	4,29	4,08
Land use	5	5
Amount of agricultural land	4	5
Deforestation	4	5
Population growth	4,5	4,5
Surrounding environment	4,71	5
Soil and water	5	5
Air quality	4,33	5
Inside air quality	5	5

6 Analysis

The analysis will primarily focus on two things: direct impacts of gaining access to electricity observed in the results, and the main differences observed between the different technologies. Also, indicators that was not influenced by gaining access to electricity and weighting will be presented at the end of the chapter.

6.1 Health

There was for the microgrids a decrease in the number of malaria cases, in addition to that in Sidonge A' there was also a decrease in typhoid fever- and cholera cases. Regarding the mosquitos, when the microgrid users previously had used kerosene lamps, they experienced a problem with smoke accumulating in the living room and bedroom which led to a need of opening windows to let some of the smoke out. Kerosene lamps was mostly used during the evening when the sun had set or early in the morning. At that time there are a lot of mosquitos carrying malaria outside. Thus opening the windows at that time will most often lead to an increased number of mosquitos being able to enter the house. More mosquitos inside the house would also lead to more mosquito bites. As the kerosene use had dropped, there was no longer a need to open windows. This would with the same logic result in fewer mosquitos entering the house and fewer cases of malaria. However, in the way houses were built there were several gaps where mosquitos still could enter. This and the fact that the interview-participants also occasionally would venture outside their houses in the evening and the dawn, could help explain why the cases had not yet dropped to 0. During the interviews, this information was not obtained when doing the first case study in Bungoma/Kitale, which is why there is no information regarding the malaria cases. There are though several reasons as for why the same effect also should be observed in Bungoma/Kitale, if asked about, depending on a few similarities. The lighting works in the same way, the kerosene use had dropped to zero in five of eight households and the houses are built in the same way. All of these factors implicates that the same effect also would have taken place in Bungoma/Kitale, though not asked about. The need for open windows would logically decrease in the same was as in Sidonge A' when the kerosene use decreases or ceases.

What also was mentioned during the interviews, as well as observed, was that kerosene lamps was a fire hazard. The tables and floors were often not entirely straight which increased the risks when handling a kerosene lamp. Parents were worried of letting their children study next to a kerosene lamp as they both had to sit close to it to see, and that there could be terrible consequences if such a lamp should fall, both to people and property. In Sidonge in 2015 there was a case when a kerosene lamp fell which caused damages both to the house as well as a person inside that got severely hurt. The households were much more positive to use electricity lighting also because of this.

As the typhoid fever- and cholera cases had dropped in Sidonge A' but not in Bungoma/Kitale, the main explanation was thought to be the drinking water since in Sidonge A' the water is obtained from the Kudura container where there is a water purification system and the water is sold at the same price as chlorinated water from the river. In Bungoma/Kitale the water access is good due to the nearby river, however the water is not cleaned using a purification system, but is instead chlorinated. It should however be remembered that the water purification system in Sidonge A' is applicable only in this case and not in general when comparing SHS and microgrid solar installations. Had there not been a water purification system as a complement to the microgrid solar installations, the water would have been purchased in the same way and would have the same quality in Sidonge A' as in Bungoma/Kitale.

When interviewing the households about their indoor air quality, it was also clear that it had improved which had positive implications to their health due to less coughs and less eye problems. When comparing the overall effects on air quality between SHS and microgrid solar installations, the POCP of SHS has decreased far more than the POCP of microgrid solar installations, 66% compared to only 14%. This difference occurs mainly due to the gasoline generator used in Sidonge A' to help generate enough power. However, there is a plan in the village that the gasoline generator will be removed at the installation of more solar panels which was an ongoing procedure observed during the time spent in the village. Therefore an extra scenario was generated, seen in Figure 21 below, which did not include the emissions from the gasoline generator, rendering instead in a future possible decrease with 69%.

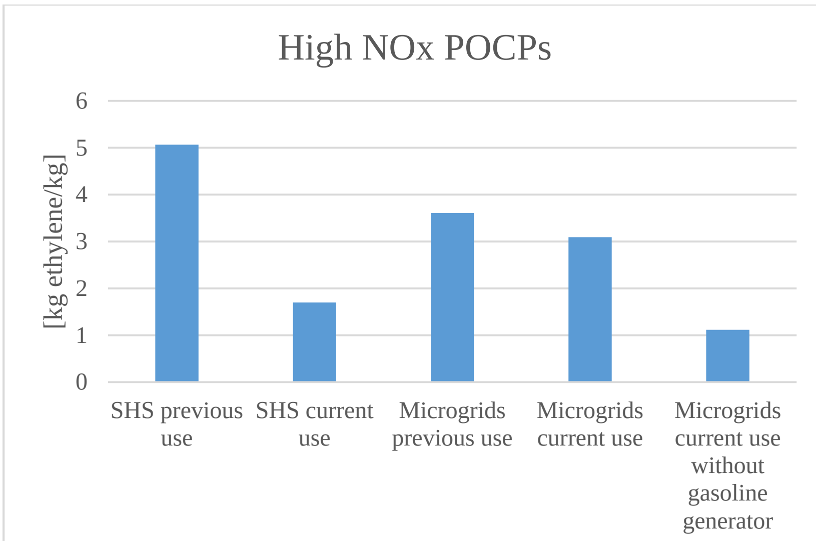

Figure 21. Photochemical Ozone Creation Potential of SHS vs Microgrid solar installations including a case where the gasoline generator would not be used.

6.2 Education

As Figure 22 shows, the increase in amount of hours studied was consistent throughout the two technologies. This was most probably due to that the lighting was used in the same way with similar lamps, which results in that for the consumer the difference was negligible.

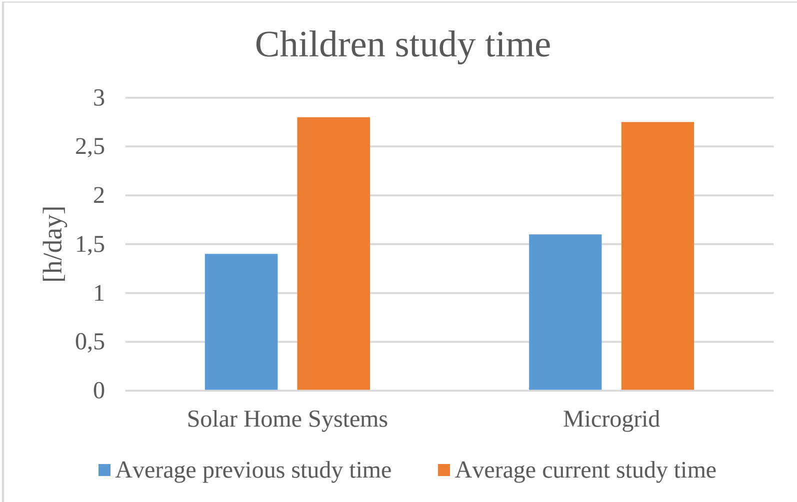

Figure 22. Amount of hours children studied before and after using solar power.

As children could increase their study time as a similar effect of both technologies, and as the teachers also verified, children with access to electricity were better at studying and keeping up at school and as an effect of this they had performed better at tests. With that type of positive influence, an effect of more and more people gaining access to electricity and switching from kerosene lamps to electricity lamps, could be that an increasingly large group of electricity users will prove to be more educated and as a result this will give a positive influence in society, whether it is by gaining higher degrees by studying for more years or using their increased knowledge in businesses or farming. The indication is nonetheless that if children perform better in school, they are more able to complete primary school and also to obtain higher educations. However other factors must be considered, especially in rural areas where the households often depend on farming and labour force is directly related to the number of individuals working at the farm, there is also a tradition that the entire family help as much as they can with the labour. Factors such as diseases within a farmer family could lead to a less attendance rate since income would be the main priority.

6.3 Mobile phone and internet usage

There was no big difference in mobile phone usage as can be seen in Figure 23. There was only one interview-participant that was not using a mobile phone, the person in question was an 81 year old retired teacher which could explain that the non-use would be more related to the generation of the interview-participant than something else. All of the interview-participants with mobile phones concluded that they could use them more after gaining electricity because of both that the charging was free, but also the convenience of being able to charge it at home instead of bringing it somewhere else. To charge the phone away from home would also mean leaving it there overnight to collect it the day after.

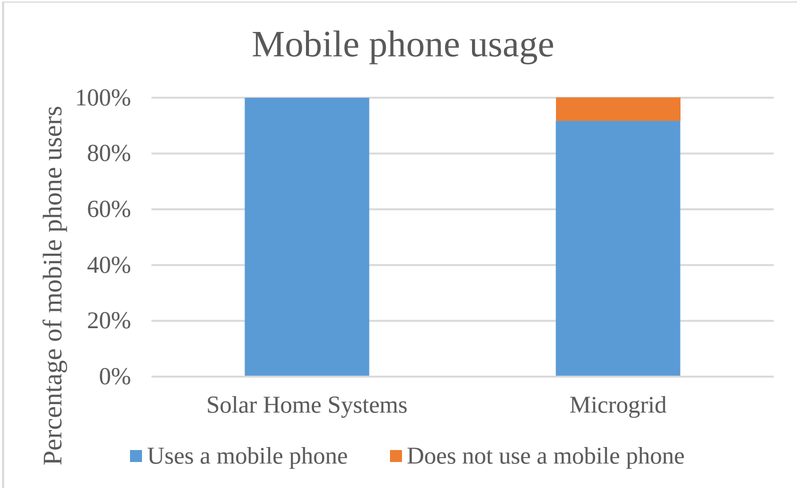

Figure 23. Graph showing how big percentage of the interviewies using mobile phones.

As Figure 24 below shows there was a larger amount of internet users among SHS-users than those who used the microgrid. One reason for this could be that the people in Sidonge A' did not have a 3G-station to be accessed nearby until 2013, which could indicate that there was no reason before 2013 to purchase an internet-package from their mobile phone operators, thus meaning that it is too early to see the effects of the 3G-station installed. In and around Bungoma/Kitale the information was not obtained regarding how long the 3G-stations had been accessible.

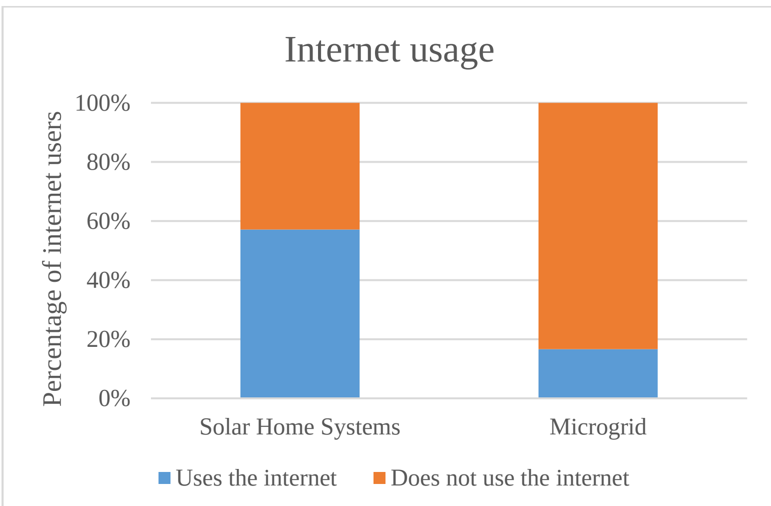

Figure 24. Internet users and non-internet users in the two different cases.

6.4 Gender equality

Unfortunately the SHS did not seem to have any effect on the households in the area of gender equality. Therefore only the effects of the microgrid on equality are analysed below.

Women in agriculture

The women's situation does not seem to have changed since they started using electricity most were farmers before they gained access to electricity and they still are. Although two women stated that since they started using electricity they had been able to save money and because of this they were able to start small businesses. One started a small business by buying and reselling kale around the village giving the household and herself an extra income and empowering her. She was very proud of this accomplishment. The other women did the same thing but with grains. This could indicate that solar PV can help women empower themselves and start earning their own money even if it is still within the agricultural sector.

Women in business

The businesses dedicated to women in Sidonge A' is a good start to try to empower women and if it had not been for the solar PV this chance would not have arisen. But there still is problems around this, first of all it has not been implemented yet so if there only will be women running these businesses is yet to see. And this is only because the committee running Kudura seeing the potential of empowering women, in other villages with similar systems the committees running the system may not see the benefits of this. Therefor it may be a stretch to say that it is because of the solar PV there are effects on empowering women.

6.5 Economy

In terms of money saved there are some differences between the systems that can be viewed in Figure 25, also see Appendix A.13 for more details. SHS-users are offered to pay 1000 KES every two weeks until their entire debt of 7500 KES is payed off. In Sidonge the microgrid-users pay 380 KES every month which is less per month. However, several of the SHS-users that participated in the interviews had paid their entire debt, which rendered a monthly cost of 0 KES for these services. This means that SHS-users logically have the same ability to employ people for instance in their farms, which is why the results obtained should be reflected upon with caution. The main result of interest in both villages is that people save money and that they have the ability to use them on income-producing activities, such as employment. If SHS-users also would stop using kerosene there will be a large amount of money saved, since they will after their SHS-system is payed for have a monthly cost of 0 KES for lightning, mobile phone charging and the ability to listen to the radio. For the microgrid users, the lowest monthly cost would still be 380 KES without any purchase of kerosene. This means that over a five year period, a microgrid-user would pay 22800 KES while a SHS-user pays 7500 KES.

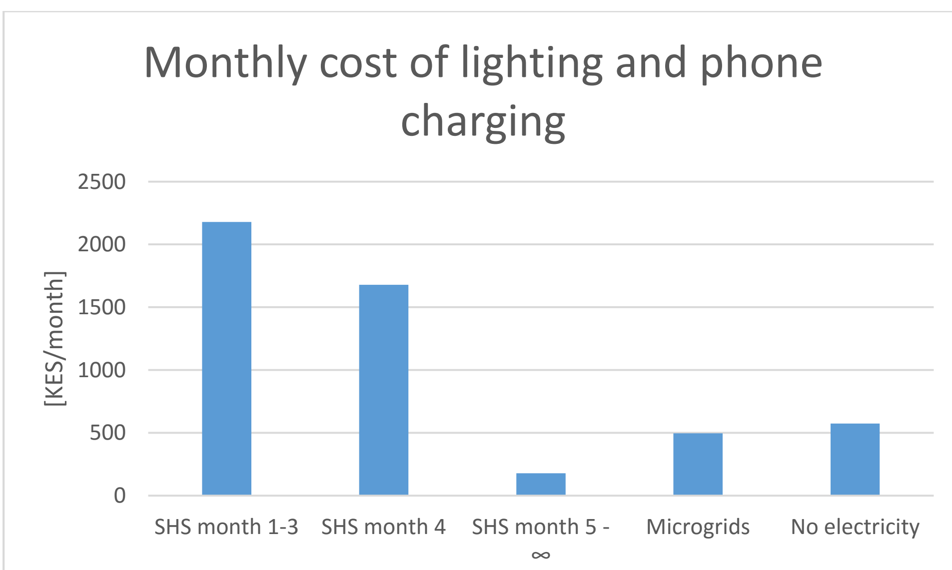

Figure 25. The monthly cost of lighting and phone charging for SHS-users, microgrid-users and people without electricity.

Labour force
In Bungoma/Kitale and Sidonge A’ it was found that the interviewed people using SHS were more able to participate in labour since gaining access to electricity. This was explained by the reduced use of kerosene. In both Sidonge A’ and Bungoma/Kitale there were kerosene which could be bought in the areas, however in the areas it was very expensive so most people walked at least 10 km to buy it to a cheaper price which often would mean that the whole day would be spent walking back and forth to purchase this. When this no longer is required in the same amount, nine out of twenty had stopped using kerosene at all, that time could instead be spent on farming, thus increasing the labour force.

Employment
People with SHS did not give an indication that they had been more employed or employed people, and in Sidonge A’ two out of twelve had employed people to work in their farms with money they had saved from reducing the kerosene use by using microgrid solar installations.

Productivity
In both Bungoma/Kitale and Sidonge A’ the productivity had increased based on the answers the participants of the interviews gave. This was for the interview-participants linked to the same reasons that had increased *Labour force,* which was less time-consuming activities that led to people being more able to focus on generating income. In both Bungoma/Kitale and Sidonge A’ the water access was good but of different qualities, however the kerosene will often be purchased at least 10 km away from the villages which results in entire days spent not contributing to any type of productivity.

Private and business investments
As the results showed, all the interview-participants claimed to have saved money, but gave many different examples of what they had used it for. In Bungoma/Kitale the overall focus was on their children’s different basic needs such as school and food. In Sidonge A’ the answers were more related to home appliances and home improvement. These could possibly be seen as larger investments than schooling, as all of the households in Sidonge A’ that had children claimed that they go to school. A TV could be seen as a larger investment and more worth mentioning when thinking of what type of private investments that has been made when answering the question in an interview. The microgrid solar installations have a higher capacity where there is room for larger investments and more appliances than for the SHS.

No business investments were observed at all in Bungoma/Kitale as shown in the results. However, there were several business investments made in Sidonge A’ as an effect of gaining access to electricity. Two buildings, a video hall and a barber shop, were up and running. The video hall often showed big football matches every week, movies and basic TV series every week, collecting an entrance fee of 40 KES from each person with attendances of up to 200 people. The pricing at the barber shop was also set lower than in Funyula, the nearby town. People would also come from nearby villages to enjoy these services, especially the video hall as there are many people interested in football throughout Kenya. As was observed in the village, there were also several more public investments being built. A milk cooling facility, a small shop, a saloon and water bottle storage where the actual buildings were already raised. The remaining part was to provide access for the buildings to electricity, to install more solar panels that would ensure a higher capacity and to purchase all the equipment needed internally for the shop.

In Table 6 the economic effects of SHS and microgrids are summarized.

Table 6. The economic effects of SHS and microgrids.

SUBTHEME	INDICATOR	SHS	MICROGRIDS
LABOUR FORCE	Participation rate	↑	↑
EMPLOYMENT	Basic employment	-	↑
PRODUCTIVITY	Work contribution	↑	↑
INVESTMENTS	Private	↑	↑
	Business	-	↑

Sectoral share

The sectoral share had been slightly influenced in Bungoma/Kitale as people would have the ability to hire others to help with farming etc. Some of these could possibly already have been farmers, but others might be unemployed. There were also no observations made regarding entrepreneurship or starting businesses for the SHS-users, however they could invest more in improving their current business to for instance buy cattle and other animals. For the microgrid-users, there were several businesses opening up. Not only the video hall and barber shop where employment was needed and also for the other shops under construction, but also the before mentioned women's fund and two women that had, since gotten electricity, started to purchase and sell grains and kale.

6.6 Global Warming Potential

In this section the global warming potential (GWP) is compared between the different technologies. As seen in Figure 26, there are three different alternatives for the microgrid solar installations. First the use pre-electricity followed by the current use and finally the scenario where the gasoline generator is no longer used. The GWP table used in the calculations can be seen in Appendix. The GWP was calculated from the kerosene and gasoline use previously versus the current use.

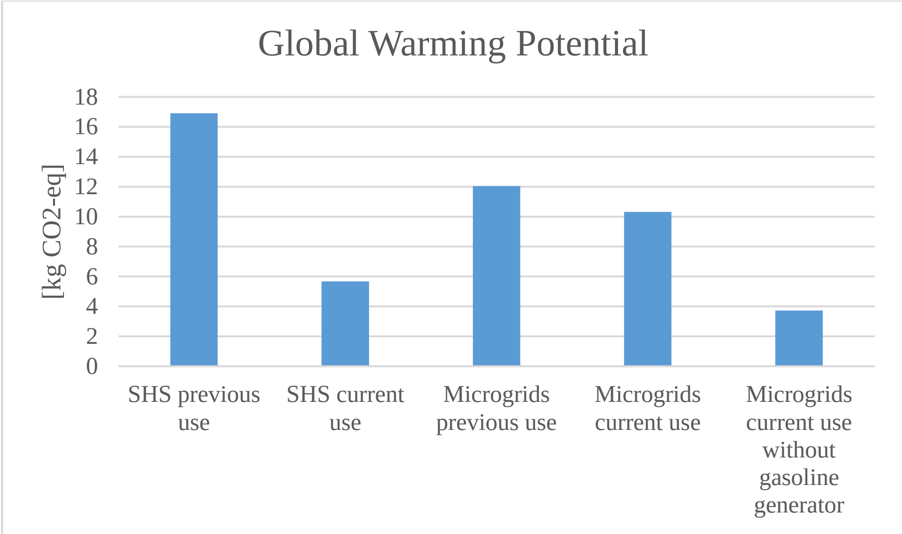

Figure 26. GWP per household per month before and after using solar power for the two different technologies, including a case with no gasoline generator.

As can be seen from Figure 26 both the SHS and the microgrid resulted in a decrease in GWP. The reason the microgrid decrease is not bigger is because the system in the current state requires rather a lot of gasoline to function without power cuts. There is still a decrease but if the system could maximize its potential and decrease the usage of gasoline or even stop using gasoline all together the benefits could be even greater. Therefore the case where the effects from the gasoline are excluded was added to the graph. It is only a potential scenario but there are plans of making it happen which is why this case was included.

6.7 Deforestation

Since many used firewood there is a reason to believe that their cooking habits would have a major influence on deforestation and if that is the case, major impacts could also have arisen from changes in cooking habits as a result. However, all of the interview-participants that used firewood also claimed not to cut down trees but instead going into nearby forests and picking up branches from the ground. When discussing deforestation with some of the interview-participants, the general opinion as well as the observations made was that the issue of cutting down too many trees was well understood. This would on the other hand not ensure that people would act accordingly as they have more primary needs to fulfil.

6.8 No difference from gaining electricity

As important as some indicators may be, some had taken no effect at all from gaining access to electricity. This can depend on a number of reasons, either it is as for vaccinations where the vaccine programs were handled by the government, or as for improved sanitation access where there probably are more measures needed. There is also the possibility that it was yet too soon to examine such effects. The indicators where no effects could be observed when gaining access to electricity are presented below:

Amount of agricultural land
Primary school gender ratio
Soil and water

Vaccines
Improved sanitation access
Population

6.9 Weighting

As could be seen in Table 5 the results were almost the same for between the systems and also the same between the indicators. This makes it hard to analyse and therefore these results was not taken into account in this study. It was also because there were only results from one of the stakeholder groups which made the comparison between these groups impossible.

7 Discussion

The average amount of years that the SHS-users had had the system was 3.3 years and for the microgrid solar installations it was 4.2 years. This is perhaps too little time to fully estimate the effects given by gaining access to electricity. After a few more years there could possibly be even greater and more easily quantifiable effects as people would have saved more money, increased their amount of businesses, employed more people, reduced the use of kerosene even more, have experienced more obvious health effects etc.

One of the findings from this report is that solar PV solutions for rural electrification has a significant impact on children's education. They are able to study longer at home and therefore they get better results in school. There are other studies with similar results but according to (Jacobson, 2006) these results are often exaggerated. But since it was confirmed not only by the parents themselves but also by their teachers it could be argued that these results are not exaggerated at all. And since education can play a role in poverty alleviation it is a big positive for solar PV solutions if they can help children in their education. However (Jacobson, 2006) also states that solar PV solutions in rural areas is only for the richest part of the community since the poor cannot afford it. This is in some ways confirmed by this report. The SHS providers do not even target the poorest people in the rural areas but only them with a stable income. In Sidonge A' the households need to be able to pay 380 KES per month to be considered to be connected to the grid. This may exclude a lot of people from the chance to get electricity to their household and can limit the effects the solar PV solutions has on poverty alleviation. Another thing that (Jacobson, 2006) mentions is that when people in rural areas get access to electricity they are able to communicate more freely. This is one of the effects the interview-participants in this study talked a lot about. They were very happy that that they no longer needed to walk for hours just to pay to charge their mobile phone and that they now could use their phone every day.

(Okello, et al., 2013) has seen a similar decrease in kerosene use for households as was found in this study which confirms that the results are not exaggerated. The project in Sidonge A' has had a lot of community involvement which is probably one of the reasons this project has been working well. This is supported by (Palit & Ranjan Bandyopadhyay, 2016) who claims that community involvement is a key factor for the success in off-grid, rural, solar PV solutions. In Sidonge A' the community started doing businesses around the Kudura which created income and increased the social behaviour of the village which lead to them being more eager to make this system.

There were many different limitations regarding the amount of total interview-participants. In Bungoma/Kitale, the main limiting factor was budget constraints. The implication of this was that the focus primarily was to conduct as many interviews in as less time as possible. This should however not have any large implication on the results since the effects this had was that the households participating in the interviews was located within a fixed area to avoid time-consuming travelling between households. It was decided after eight interviews that the answers and observations were similar enough to represent the SHS-users in Bungoma/Kitale. Had more people been interviewed the possibility was therefore seen as small of obtaining any new information. In Sidonge A' the limiting factor was the amount of interview-participants as only twelve households had gained access to electricity, therefore only twelve interviews with microgrid solar installation-users could be made. However, the twelve interviews in Sidonge A' were very similar as shown in Appendix A.5.

In Kenya both Swahili and English are the official languages. However, in rural areas not many speak English, which is why interpreters in both Bungoma/Kitale and Sidonge A' needed to be used. There is of course an uncertainty when doing this as different phrases translated word by word from Swahili to English and vice versa can have different meanings. A challenge was therefore to ensure that the interpreter that was used would be able to minimize such mistakes. As some of the interview-participants spoke English, the results from the English-speaking people were compared to the results obtained via the interpreter, to ensure that the interpreter was not trying to influence the results of the interview questions in any direction. However in the weighting part there were large uncertainties as to how much both the interpreters influenced the interview-participants and to how much it was understood as to what they were grading. This led to that almost all of the indicators had too high grades to be able to compare them. This is a quite common problem when using a weighting system, and it could also have been prevented by using some sort of ranking system, where the interview-participant would not have been able to rate each indicator as extremely important but instead would have to choose between them, only being able to give a fixed number of higher grades. As also explained in the analysis and results, weighting from only one stakeholder makes the comparison between different groups impossible. Given the results, the comparison could not be done in a way that would give just results.

Weighting was chosen as a method that would help understand the importance of different indicators to different stakeholders. Comparing these with each other was in the beginning of the project seen as an interesting view to obtain. It was however not directly related to the research questions, which is why the results in this project, to be able to answer the research questions, has not been affected. For future similar weighting processes it is recommended that a ranking system is to be used to obtain more comparable results. As for the willingness to participate in a study such as this by other stakeholders there are no guarantees, which is why the stakeholder should be given a request before one would put time into constructing such a questionnaire.

As the method of interviewing people was new for us, a more experienced interviewer would probably had gotten more detailed results already from the beginning. The fact that windows could be closed at night leading to less mosquitos finding their way into the house and therefore less malaria could be seen as an example of something that a more experienced interviewer would find out sooner when conducting the interviews in both villages. A semi-structured interview was therefore a suitable choice in this project, because it both gave results to the indicators that was determined before the interviews while also being able to provide results in areas where it was hard to estimate on beforehand.

One can question the method of using a case study since the results may not be applicable on other projects if the conditions are not the same. However when comparing the results to previous studies on rural electrification with solar PV solutions the results are similar which may imply that the results of these studies could be generalized for all projects on rural electrification by solar PV.

When comparing the costs of the different systems, it is quite clear that in the long run, SHS-users are able to save more money as the cost for lighting and mobile phone charging is in fact zero after the entire payment is made after a few months. For a microgrid-user, that is not a possibility. As calculated in the report, the microgrid-users that participated had saved a small amount of money.

Some might not even have saved money even if the average households have, which ultimately raises the question if it is worth for the consumer to pay the extra money for microgrids. If the goal is to save money and only use electricity for lighting and phone charging while having a very small impact on the environment, a SHS would be seen as a better alternative. For rural households that live in poverty, it could seem very easy to choose the cheaper technology to fulfill the basic needs, since over a five year period roughly 15000 KES would be saved that could be used for many important things. However, if the ability to purchase and use more appliances, business growth, women empowerment and an increased number of social interactions is more prioritized than saving money and having less environmental impact, there would be more arrows pointing towards microgrids. For an increased HDI, a SHS is to be regarded as a very small first step while microgrids must to be seen as a larger step. This means that in the long run, for rural areas in developing countries to reach western standards and similar HDIs, microgrids would be better to invest in since it has more socioeconomical impact. In a future scenario there is a possibility to connect microgrids to the national grid, which is something that cannot happen with a SHS.

7.1 Reflections

If there would have been more time to do this study there are a number of different things which could have been done to give more results or confirm the result even more. Below is a list of the things which would have been done with more time and which also can be seen as recommendation for future studies based on the results from this study.

- Interview more people in the villages
- Visit other villages with similar solar PV solutions in other countries
- Include solar lanterns in the study as third option for rural electrification
- Develop a better ranking system for the weighting process
- Test the systems personally and observing more closely the households throughout an entire day

8 Conclusion

What is the socioeconomic and environmental impact of gaining access to off grid electricity via solar PV in rural areas?

The socioeconomic and environmental impact of gaining access to off grid electricity via solar PV in rural areas are listed below.

- Improvement in health
- Increased feeling of safety
- Improved household economy
- Increase in time able to study at home
- Better school results for children
- Increased mobile phone and internet usage

The improvement in health was related mainly to the decrease in kerosene use and safer lighting equipment. The health issues which were improved were coughing, runny noses and malaria. The improvement in household economy was due to saving money and time from using the solar PV solutions instead of kerosene. The children were able to study longer in the evenings since the solar PV provided better lighting than the kerosene lamps which also led to them performing better in school. Easier access to charging also enabled more mobile phone and internet usage.

What main differences regarding socioeconomic and environmental impact can be observed between the different solar PV off grid electricity solutions for rural areas?

The main differences between the different solar PV off grid electricity solutions for rural areas have been found in contribution to climate change, outside air quality, business investments, gender equality and women in businesses. Regarding climate change and air quality SHS-users had less impact than the microgrid solution. In business investments, SHS had no observed impact, but microgrid solar installations had benefited from several business investments which had improved social life and strengthened the entire community. This is due to that they were able to gather and enjoy social activities at the newly installed businesses which all had access to electricity. For the microgrid solution there were impacts regarding women empowerment related to them creating their own businesses with the money they had saved each month from not having to buy kerosene and not paying for mobile phone charging. No impacts regarding women starting businesses was observed from the SHS users.

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Appendix

A.1 Sustainability goals

1. End poverty in all its forms everywhere
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3. Ensure healthy lives and promote well-being for all at all ages
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
5. Achieve gender equality and empower all women and girls
6. Ensure availability and sustainable management of water and sanitation for all
7. Ensure access to affordable, reliable, sustainable and modern energy for all
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10. Reduce inequality within and among countries
11. Make cities and human settlements inclusive, safe, resilient and sustainable
12. Ensure sustainable consumption and production patterns
13. Take urgent action to combat climate change and its impacts (Acknowledging that the United Nations Framework Convention on Climate Change (UNFCCC) is the primary international, intergovernmental forum for negotiating the global response to climate change)
14. Conserve and sustainably use the ocean seas and marine resources for sustainable development
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation and halt biodiversity loss
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

A.2 Interview form

Questions marked with “*” were only asked to people that had either SHS or microgrid solar installations not those who had not yet gained access to electricity.

Villagers

What’s your name? What do you do for a living? How old are you? *How long have you had this technology? Introductions, small talk etc.

How much kerosene do you use per day/week/month?
When do you use kerosene and what do you use it for? *How much did you use before you started using electricity?
How do you cook your food? Do you use coal or wood when you cook? Where do you get it from?
How do you feel about your indoor air quality? *How was it before?
Have you or anyone in your family had any health problems during the latest years?
What kind of diseases have you had during the latest years? *Have you noticed any improvement in your health since you started using electricity?
*Do you feel that you have saved money from switching to solar power? If so, have you been able to purchase anything you’ve wanted with the money you have saved?
What kind of vaccines have you gotten?
Are you/your children going to school? How many hours of studying do you/your children do per day from home? *Can your children study longer at home since you’ve gained access to electricity? How many minutes/hours?
Do you have a mobile phone? What do you use it for? *Have you been able to use it more than before?
Do you have access to the internet? What do you use the internet for? *Have you been able to use it more than before?
How many people live in your household?
*Are there any other improvements or changes that you have noticed since you’ve gained access to electricity?
*Have your amount of social interactions increased or decreased?

Teacher
Have you noticed any changes since parts of the village gained access to electricity?
How big part of the children in the community goes to school?
How many years in average do people go to school?
What are the main reasons for not completing school?
What is the ratio between boys and girls in classes?

A.3 Observations

Checklist of things needed to be observed.

- Health
  - Water access
  - Water quality
- Housing
  - Improved sanitation access
  - Appliances
- Equality
  - Gender ratios in general in different areas of the community (agriculture, school, business, household chores etc.).
- Labour
  - Unemployment and contribution
  - Sectoral shares
- Land use
  - Deforestation
  - Agricultural land
- Surrounding environment
  - Soil and water
- Air quality
  - Inside
  - Outside

A.4 Interview questions – results in Bungoma/Kitale

Question	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Conclusions
How much kerosene do you use per month?	0	2	1,875	0	10 (only for cooking, no indoor use)	0	0	0	1,98 litres average now, only 0,55 average indoor use
What do you use it for? How much did you use before?	No use, 5	3	No use, 7,5	No use, not so much before)	Cooking (no indoor use), 7,5	No use, 7	No use, 7,5	No use, 4	5,9 litres average before
How do you cook your food? Where do you get it from?	Firewood and charcoal	Firewood and charcoal, uses kerosene to light the fire.	Firewood	Firewood, pick up dry branches	Charcoal, firewood, paraffin, no use of kerosene before	Firewood and charcoal	Firewood and charcoal	Charcoal and firewood	No real changes observed, only one person changed their cooking habits (to the worse unfortunately).
How do you feel about your indoor air quality? How was it before?	Better than before	Better than before	Better than before	Better than before	Better than before	Better than before	Better than before	Better than before	8 of 8 says it is better than before
Have you or your family had any health problems in the latest years?	Yes, no coughs or sneezing and less running nose	Only coughs once in a while now vs a lot before. Same with runny nose.	No	Yes, no coughing and throat problems any more	Yes, better eyesight	Yes, no more problems with nose and coughing	Yes, no more problems with coughing and nose	Yes, no more coughing and better eyesight	6 of 8 people cough less or not at all. Also 4 of 8 people experience less runny nose or not at all anymore.
Do you feel that you have saved money from switching to solar power? What have you been able to do with the money?	Yes, better school for her kids	Yes, books for children, healthier food and minor things they don't really need but likes.	Yes, bought ordinary things	Yes, built a better house	Yes, no examples	Yes, bought sheep, products, presents and money for grandchildren and husband	Yes, bought more animals (chicken and cattle)	Yes, better breakfast for the children, books, clothes	8 of 8 people have had more money over, mostly used to help their kids in different ways.
How long do your children study? How much before?	2, 1	3, 1	4, 2	Too small before, 2 hours now	2,5, 1	2,5, 1	2, 1	3,5, 2,5	1,4 hours per day before, 2,8 now. Increase with 100%.
Do you have a mobile phone? If so, what do you use it for? Been able to use it more?	Yes, call relatives and friends, yes	Yes, call relatives and friends, yes	Yes, keeping in touch with people, yes	Yes, call relatives and friends, yes	Yes, call friends, yes	Yes	Yes, for communication and MPESA, yes	Yes, communication and MPESA, yes	8 of 8 use their mobile phones more

Do you have access to the internet? What do you use it for? Have you been able to use it more?	Yes, social media, yes	No	Yes, social media and job searching, yes	Yes, social media, yes (didn't use it before)	No		No	Yes, work and social media, yes	4 of 7 has increased their internet usage
How many people live in your household?	4, husband and two kids	8, 4 children to him, 2 others	6, parents and 3 siblings	5, husband and three kids	7, husband and 5 kids	5, husband and children	7, husband and 5 children	6, husband and 4 kids	Average of 6 people
Other improvements?	Safer for the kids, kids perform better in school	Saves time, money and got better health, also studying longer per day		The kids are able to study more	Less health problems, children perform better in school	Safer for the kids than to use kerosene lamps		Unsafe because of kerosene lamps (fire hazard), children were complaining about the smoke, hurting their eyes, more stable economy now	The most common thing that they mentioned is that is safer.
Age	30	70	20	28	35	45	36	42	
Gender	Female	Male	Female	Female	Female	Female	Female	Female	
Occupation	Farmer	Retired teacher	Unemployed	Housewife	Farmer	Farmer	Farmer	Teacher	
How long have you had the system?	4 years	1 years	4 years	4 years	3,5 years	4 years	2 years	4 years	Average of 3,3 years
Other comments		Wife was with us as moral support during interview, very talkative,	Forgot to record, very shy and a bit reluctant to answer			She ran out before we finished the interview since she had to give first aid to a neighbour who just got attacked by a bull			

A.5 Interview questions – results in Sidonge A'

Question	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9	Person 10	Person 11	Person 12	Conclusions
How much kerosene do you use per month?	0	1,2 for lighting in kitchen	0,25	2	3,125	2	0	0	1	2,4	3,6	0	in average 1,3l/month now
What do you use it for? How much did you use before?	No use, 37,5	4	2	4	Only uses it for cooking, 11,67	2,8	No use, 3	1	2	5	8	2,8	in average 4,2l/month
How do you cook your food? Where do you get it from?	Firewood	Firewood	Firewood	firewood	Firewood and kerosene	firewood	Firewood	firewood	firewood and kerosene	firewood	firewood	charcoal	no changes in ways of cooking
How do you feel about your indoor air quality? How was it before?	Better	Better	Better	better	Better	better	Better	better	better	better	better	better	12/12 says its better
Have you or your family had any health problems in the latest years?	Kids have reduced their amount of coughing, less common colds and reduced amount of sickness in general.	Yes, no more coughing, though now she feels stress when she has now power and did not experience that stress before.	Yes, bad smell, less mosquito bites-less malaria, no more chest pains	no more chest pain, children complained about the light	No more coughing	yes, irritated eyes,	No more coughing and children used to complain about their eyesight	yes, better eyesight all day, not only when using kerosene light, less mosquito bites,	yes, no bad smell now, no more cough, feels generally more healthy	before it was hard to see but not anymore	yes, not as often malaria, no bad smell now		
Do you feel that you have saved money from switching to solar power? What have you been able to do	Yes, bought two cows and paid for the kids at school.	yes, bought a mobile phone, radio and help with farming	yes, made a business of buying and selling kale, bought mobile and tv	yes, wants to buy tv for the money and build new house	Yes, ordinary things, owns a television and a radio	yes, formed a women's fund	Yes, able to save, bought kitchen appliances and a television	yes, bought chairs for visitors	yes, can now pay labourers to help his work, bought radio	yes, buys soap, buys better and different food so not to eat same everyday	yes, buys food	yes, doesn't buy anything special that she can recall. Saves about 20 KES/month	12/12 saves money now

with the money?													
How long do your children study? How much before?	3, 1	no children in household	2 now 1 before	2, 0,75	2 (with kerosene lamp), 2	has no children	3, 1	no children	kids not in school yet	3,1	4,2	3,4	2,75 now, 1,6 before
Do you have a mobile phone? If so, what do you use it for? Been able to use it more?	Yes, communicate with relatives and older kids, yes	yes, for communication	communication	has phone and uses it more now	Yes, communicate with relatives, yes	uses here phone more now	Yes, communication, yes	has phone for communication	uses his phone more now	no	yes, uses it more now	uses phone more now for M-pesa, communication in both personal and business relations.	11/12 has phone, everyone can either use it more now or has bought one
Do you have access to the internet? What do you use it for? Been able to use it more?	Has it but doesn't use it	no	no	no	Yes, social media and whatsapp, yes	no	No	yes, for studying, business, social media	no	no	no	no	2/12 uses the internet
How many people live in your household?	10, husband, children and grandchildren	1	7	8, 7 children	5, husband and three kids	2	6, husband and 4 adopted kids	2	4	5, 4 grandchildren	8, 6 children	?	5,3 in average
Other improvements?	Got bored when there was no light		More social life since people come and watch tv with her	feels proud and as a city folk and more equal, more social now goes to the video hall	Brighter indoors, uses drinking water from Kudura, saves time, son uses the video hall and the shaving shop which is cheaper than in Funyula	timesaving	Feeling better, uses television and electricity, talks to some people in the evening	safer, no fire risk now, more social now with the video hall and with having a tv	more social now	more social now, kids get better grades	lights whole house now not only small area, kids are more social now, uses radio more	Kids don't complain about the soot anymore and their eyes anymore, light is brighter so can do things inside instead of outside	It is timesaving and safer, children doesn't complain of their eyes when doing homework and being more social now are common thing mentioned
Age	56	57	38	45	37	20	58	30	48	81	38	36	
Gender	Female	Female	Female	female	Female	female	Female	male	male	male	male	female	

Occupation	Farmer	farmer	Farmer and business owner	farmer	Unemployed, takes care of her children. used to work in Funyula	farmer, business owner	Farmer, bread cattle	business owner, student	farmer	retired farmer	farmer	shop owner and farmer	
How long have you had the system?	5 years	5 years	5 years	5 years	3 years	3 years	5 years	3 years	1 years	5 years	5 years	5 years	Average of 4,16 years
Other comments	Husband came in during the interview				The studying is done with kerosene lamp because of it being done early in the morning when the system is not active		Didn't use a mobile phone before,	Our translator during interviews in Sidonge A'					

A.6 Interview questions – results from people without electricity

Question	Person 1	Person 2
How much kerosene do you use per month?	5,2	5
How do you cook your food? Where do you get it from?	Charcoal	Kerosene, firewood, coal
How do you feel about your indoor air quality? How was it before?	Not so fresh, problems with the smoke such as sneezing	Does not like his air quality, they get eye problems, lung problems, coughing and black flem
How long do your children study? How much before?	3,5 (kerosene light)	1
Do you have a mobile phone? If so, what do you use it for? Been able to use it more?	Yes, charges it at Sidonge biogas	Yes, charges it at friends' houses close to home
Do you have access to the internet? What do you use it for? Been able to use it more?	No	Yes, watches sports and news
Other	Kids complain about their eyes when using the kerosene lamp	They often get malaria because of open windows to let out the smoke
Age	40-50	40
Gender	Female	Male
Occupation	Teacher	Teacher

A.7 Interview questions – results from interviewing teachers

Question	Teacher 1	Teacher 2
1.Have you noticed any changes since parts of the village gained access to electricity?	Kids with access to electricity at home perform better at tests than the ones without electricity. The kids with electricity are more advanced, have a lot of different views, can compare Kenya to other countries, better storytelling, more time to read. The ones without electricity will remain the way they are.	The kids with access to electricity perform better. The children who uses kerosene lamps study less at home. They get more done in an hour with electricity, better light, more efficient. They can study in groups with electricity, with kerosene only 1-2 people at the time. Most of the improvement from children with electricity is in math and science.
2. How big part of the children in the community goes to school?	Most children complete eighth grade, however more girls than boys in the community goes to school. But there are more boys than girls in the village.	
3. How many years in average do people go to school?	Most complete eight grade.	
4. What are the main reasons for not completing school?	Mainly boys but also girls, helping their families at home with farming etc.	
5. What is the ratio between men and women in classes?	About equal amount. However more boys than girls in the community.	
Other		It is not safe with the kerosene lamp, if it falls down the house can get burnt. He teaches 4-8th grade, Kiswahili, social studies and science.

A.8 Emissions related to POCP [kg/household/month]

kg emissions per household per month	**SHS previous**	**SHS current**	**Microgrids previous**	**Microgrids current**	**Microgrids current without gasoline generator**
SO_2	0,0844786	0,0283504	0,0601373	0,0515409	0,0186139
NO_x	0,0333468	0,011191	0,0237384	0,0203451	0,0073476
CO	0,0028901	0,0009699	0,0020573	0,0017632	0,0006368

A.9 Photochemical Ozone Creation Potential – emission factors for High NO_x POCPs

Substance	High NO_x POCPs (kg ethylene/kg)
CO	0.027
NO_2	0.028
NO	-0.427
SO_2	0.048
Methane	0.006
Ethane	0.123
Propane	0.176
n-butane	0.352
n-pentane	0.395
Ethylene	1
Propylene	1.12
Benzene	0.218
Toluene	0.637
Methanol	0.14
Ethanol	0.399
Acetone	0.094
Formaldehyde	0.519

A.10 Global Warming Potential – actual emissions

Kerosene use per household per month		**Before**				**Now**			
		SHS	**unit**	**Microgrids**	**unit**	**SHS**	**unit**	**Microgrids**	**unit**
		5,9	l/household	4,2	l/household	1,98	l/household	1,3	l/household
37,68	MJ/l	222,312	MJ	158,256	MJ	74,6064	MJ	48,984	MJ
CO2									
0,0758	kgCO2/MJ	16,8512496	kg CO2	11,9958048	kg CO2	5,6551651	kg CO2	3,7129872	kg CO2
GWP(CO2)	1	16,8512496		11,9958048		5,6551651		3,7129872	
CH4									
2,8436E-06	kg CH4/MJ	0,000632167	kg CH4	0,000450017	kg CH4	0,0002122	kg CH4	0,0001393	kg CH4
GWP(CH4)	21	0,013275503		0,009450358		0,0044552		0,0029251	
N2O									
5,6872E-07	kg N2O/MJ	0,000126433	kg N2O	9,00034E-05	kg N2O	4,243E-05	kg N2O	2,786E-05	kg N2O
GWP(N2O)	310	0,039194343		0,027901058		0,0131534		0,008636	

A.11 GWP for gasoline use from microgrid solar installations

Gasoline use				
Current use [l/month] for 12 households				30
34,66	MJ/litre	86,65	MJ	
CO2				
		0,0758	kg CO2/MJ	
		6,56807	kg CO2	1 household
	GWP(CO2)	6,56807		
HC				
		0,00001	kg HC/MJ	
		0,0008665	kg HC	
	GWP(HC)	0,0181965		
	GWP(Total)	6,5862665		

A.12 Global Warming Potential

Substance	GWP 100 years (kg $CO_{2\,eqv}$/kg)
CO_2	1
CH_4	21
1,1,1-trichloroethylene	110
CCl_4	1400
N_2O	310
SF_6	23900
CF_4	6500
CFC-11	4000
CFC-12	8500
CFC-13	11700
CFC-113	5000
CFC-114	9300
HCFC-22	1700
HCFC-123	93
HCFC-124	480

A.13 Economical calculations

Monthly cost of lighting and phone charging [KES/month]					
Activity	**SHS month 1-3**	**SHS month 4**	**SHS month 5 - ∞**	**Microgrids**	**No electricity**
Lighting[13]	2178,2	1678,2	178,2	497	454,5
Phone charging	0	0	0	0	120[14]
Total	**2178,2**	**1678,2**	**178,2**	**497**	**574,5**

[13] The lighting also includes costs of kerosene which is based on the current average use per month and the current average price per month for kerosene which is 90 KES/litre.
[14] The phone charging was based on a cost of 20 KES per charge six times per month.