POLITECNICO DI MILANO

Scuola di Ingegneria Industriale e dell'Informazione

Corso di Laurea Magistrale in Ingegneria Energetica

ACCESS TO ENERGY IN RURAL TANZANIA: ELECTRICAL LOAD CURVES EVALUATION AND ENERGY DEMAND ASSESSMENT OF 13 VILLAGES IN NJOMBE REGION

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Anno Accademico 2015/2016

Acknowledgements

Il primo pensiero va ai miei genitori che mi hanno appoggiato nella scelta di frequentare gli ultimi anni di studio a Milano.

Ringrazio poi Emanuela per avermi avvicinato al mondo della cooperazione e dato la possibilità di vivere un’esperienza unica in Tanzania.

Grazie Fabio per il prezioso tempo che mi hai dedicato con grande pazienza e impegno durante tutto il lavoro.

Grazie Fabrizio per il fondamentale aiuto nel lavoro e per la compagnia durante l'esperienza vissuta assieme in Africa.

Un ringraziamento a tutto il gruppo CEFA e in particolare a Jacopo per la collaborazione e la sua disponibilità e per averci accolto con grande ospitalità.

Grazie Stefano e Matteo per avermi aiutato ad ambientarmi in una realtà completamente diversa e per avermi fatto conoscere e scoprire molto della cultura Tanzaniana.

Grazie Flavian e Evanton per il vostro importante aiuto durante le interviste nei villaggi, senza di voi sarebbe stato impossibile.

Infine un grazie a Stela e Prisca per avermi fatto scoprire ed apprezzare la cucina tipica Tanzaniana. Asante sana!

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Abbreviation Index

DIT	Dar Es Salaam Institute of Technology
HH	Households
PB	Public Services
ADC	Average Daily Consumption
DIT	Dar Es Salaam Institute of Technology
HH	Households
PB	Public Services
US	Productive Usages
EE	Electrified
NonEE	Non Electrified
NGO	Non-Government Organization
LPG	Liquefied Petroleum Gas
LHV	Lower Heating Value
ODK	Open Data Kit
TSH	Tanzanian Shillings

Nomenclature

$\boldsymbol{\delta}$	Density
$\boldsymbol{W}$	Watt
$\boldsymbol{P}$	Power
$\boldsymbol{Ec}$	Electricity

Abstract

This study arises from a request for collaboration with CEFA to the Department of Energy of Politecnico di Milano. CEFA is a Non-Government Organization who is working on its latest rural electrification project for the installation of a small hydro power plant in order to bring access to electricity to 13 rural villages in Njombe region, in Tanzania.
The purpose of this work, which included a mission of one month and half, consisted in carrying out an assessment of energy needs and consumptions of the 13 non electrified villages.

The first goal of this thesis was to estimate the future electrical energy demand of the villages when CEFA electrification project will be completed. The goal was achieved by using a novel methodology implemented in a software for estimating electrical load curve in rural contexts developed by the Department of Energy at Politecnico di Milano. The second goal consisted in evaluating primary energy consumptions of the villages. After collecting data about energy consumption for each source used, data collected was reorganized and processed and final energy consumptions for each source were calculated.

Results of the future load curve estimations show that a study based on collecting data on site and using a software for the load profiles generation in rural contexts may lead to considerably different results than an estimation based on hypothesis and information from literature studies of similar rural contexts.
Results of the energy demand assessment demonstrate that the energy balance of the villages is characterized by a strong dependence on biomass source, typical of rural areas in developing countries. Indeed, results show that more than 80% of primary energy demand of the villages is met by firewood and charcoal. The overuse of biomass inevitably leads to the problems of smoke inhalation and deforestation.

In conclusion, results of this thesis may be useful for CEFA to achieve an optimal technical-economical design and implementation of its electrification project and for possible future interventions aimed at reducing the dependence on traditional and fossil primary fuels within the study area.

keywords: access to energy; rural electrification; load curve estimation; primary energy consumption; CEFA

Sommario

Questo studio nasce dalla collaborazione tra il dipartimento di energia del politecnico di Milano e CEFA, Organizzazione Non-Governativa che sta lavorando ad un progetto di elettrificazione rurale (chiamato progetto Ninga-SHPP) per la realizzazione di un impianto mini idroelettrico con lo scopo di portare accesso all'energia elettrica in 13 villaggi rurali nella regione di Njombe in Tanzania.

Lo scopo di questo lavoro, che ha previsto una missione nella regione di Njombe della durata di un mese e mezzo, è stato quello di effettuare uno studio su consumi e bisogni energetici dei 13 villaggi non elettrificati

Il primo obiettivo è stato quello di stimare la domanda futura di energia elettrica dei villaggi nel momento in cui il progetto di elettrificazione di CEFA sarà completato ed è stato raggiunto utilizzando una metodologia implementata in un software per la stima di curve di carico in contesti rurali sviluppato dal Dipartimento di Energia del Politecnico di Milano. Il secondo obiettivo è stato la valutazione dei consumi energetici attuali nei suddetti villaggi. Dopo una raccolta dati sui consumi di ciascuna fonte di energia primaria utilizzata, i dati raccolti sono stati organizzati e elaborati e i consumi finali per ciascuna fonte primaria di energia sono stati calcolati.

I risultati della stima della domanda elettrica futura dei villaggi mostrano come uno studio basato su una raccolta dati in loco e l'utilizzo di un software apposito per la stima di curve di carico in contesti rurali possa portare a risultati molto differenti rispetto ad una stima effettuata sulla base di ipotesi e informazioni dalla letteratura corrente di contesti simili. I risultati della valutazione della domanda di energia primaria dei villaggi confermano la condizione di forte dipendenza da biomassa tipica dei villaggi rurali dei paesi in via di sviluppo. I risultati mostrano infatti che più dell'80% della domanda di energia primaria dei villaggi viene soddisfatta dal legname e da carbonella. Il sovra consumo di biomassa in queste aree porta inevitabilmente a problemi di intossicazione da fumi colpendo soprattutto donne e bambini e al problema della deforestazione.

In conclusione i risultati di questa tesi saranno utilizzati da CEFA per una realizzazione ottimale del suo progetto e per futuri interventi volti a ridurre la dipendenza da combustibili fossili e tradizionali nell’area di studio.

parole chiave: accesso all’energia; elettrificazione rurale; stima curva di carico; consumo di energia primaria; CEFA

Introduction

In recent years the problem of access to energy and in particular access to electricity has become more and more relevant in the eyes of the international community. The nexus between access to energy and sustainable development is now obvious, but the problem is still far to be solved. Due to the importance and urgency of the problem, in the last few years the number of local and international agencies operating to bring access to modern energy in developing countries is quickly increasing. One of these agencies is CEFA, an Italian Non-Government Organization operating for sustainable development in poor countries. In recent years it has successfully carried out important projects in the rural electrification sector by the realization of small hydropower plants in Tanzania.
In particular CEFA has recently carried out a feasibility study for a possible small hydro power plant situated in the region of Njombe, Tanzania. This new important project is called "Ninga-SHPP" and consists of a 6 MW small hydro power plant that will provide access to electricity to 13 rural villages and will produce an excess of electricity that can be sold to the national electric grid operator TANESCO. The need for a detailed in-depth study on the energy situation of the villages has led CEFA to request a collaboration with the Energy Department of Politecnico di Milano. The final goal of the Mission in Tanzania is carried out a study about energy usages and consumptions in the 13 villages of the Ninga project so that the results obtained will be useful for CEFA in order to carried out an optimum technical-economic system design of the power plant and to understand the possible future interventions in the energetic field in the area.

The first goal of this thesis consists of estimating the future load curve profile of the 13 non electrified villages that will be electrified by the connection to a mini grid powered by the NINGA hydro power plant. In other words, the purpose is to evaluate how much electricity the 13 villages are going to demand on a daily basis when they will have access to affordable and reliable electricity. The second goal of this thesis consists of assessing the primary energy demand of the villages in order to provide a snapshot of the current primary energy consumptions.

In order to achieve the first goal, surveys about use and usage habits of electric appliances are administered in selected villages and a novel methodology for load curve estimation implemented in a software called LoadProGen is used. In order to achieve the second goal, surveys about primary energy consumptions of the 13 villages are administered, data collected are organized, arranged and results briefly analyzed.

In Chapter 1, an overview of access to energy is carried out, with a particular attention to the theme of access to electricity in rural areas. Then the energy situation in Tanzania is described and the possible solution to bring electricity in rural contexts are briefly shown. Finally, the hydro power source and potential in Tanzania is described. In Chapter 2, the NGO CEFA is described and its successfully completed electrification projects in Tanzania are shown. Then the technical analysis of the SHPP project of Ninga is described in detail. In Chapter 3, the two goals of the mission are introduced. Firstly, a brief summary of the activities carried out during the entire period spent in Tanzania are listed and the study area is described. Then questionnaires administered during the period spent in the villages are described and the tool used to administer them and to collected data is briefly presented. Finally, the novel methodology and the software used to evaluate the future load curve and the methodology used to carry out the primary energy demand assessment of the village are explained in detail. In Chapter 4, results are shown and a brief analysis of them is carried out.

1 Access to energy

1.1 Overview of access to modern energy in the world

Access to modern energy is a fundamental prerequisite to trigger and ensure a sustainable development and to fight poverty in developing country. Modern forms of energy are essential for the provision of clean water, sanitation and healthcare and provide great benefits to development through the supply of reliable and efficient lighting, heating, cooking, mechanical power, transport and telecommunication services [1]. Indeed, sustainable energy is a basic condition to allow access to services, resources and public goods and it is indispensable for human and social progress, along with environment conservation.

At the United Nations Sustainable Development Summit on 25 September 2015, world leaders adopted the 2030 Agenda for Sustainable Development, which includes a set of 17 Sustainable Development Goals (SDGs) to end poverty, fight inequality and injustice, tackle climate change and ensure a sustainable development and global prosperity by 2030 [2].The 7th Development Goal set, "Affordable and clean energy for all", underlines the importance of energy access as pre-requisite for meeting the challenges posed by the other SDGs and demonstrates a three-dimensional power of sustainable energy in enabling economic, social and environmental sectors. From the economic point of view an adequate energy provision has become essential for economic development since the time of industrial revolution. Indeed, reliable energy services are essential to allow and attract investments in the industry, transport, services and all economy sectors. The second dimension concerns the environment: the production, distribution and consumption of energy have severe environmental implications. Therefore, a wide spread use of modern and renewable energy sources can open a path towards the reduction of pollutant emission, land degradation and massive deforestation. Finally, the social dimension: energy is vital for alleviating poverty, improving human welfare and raising living standards. Modern services allow major enhancements in education and health otherwise impossible, ensuring social inclusion and supporting gender equity.

1.2 The problem of access to modern energy

There are two main problems concerning energy access in the world today: access to electric energy along with energy affordability and reliability and inefficient use of traditional biomass for cooking and space heating.

The increasing attention given by the international community during the last years, has led to a number of activities and projects for fighting against these problems but despite of this as indicated in the World Energy Outlook 2015 by the International Energy Agency (IEA) [3], problem in access to energy in the world has still a very big size.

Table 1-1 Access to electricity in the world

Region	Population without electricity [millions]	Electrification rate [%]
Developing countries	**1,200**	**78%**
Africa	**635**	43%
North Africa	*1*	*99%*
Sub-Saharan Africa	*634*	*32%*
Developing Asia	**526**	86%
China	*1*	*100%*
India	*237*	*81%*
Latin America	**22**	95%
Middle East	**17**	92%
Transition economies & OECD	**1**	**100%**
WORLD	**1,201**	**83%**

(SOURCE: IEA, World Energy Outlook 2015)

As shown in Table 1-1 about 1.2 billion people - 17% of the global population – did not have access to electricity in 2013, 84 million fewer than in the previous year. Still, 1.0 billion people are connected with unreliable electric grid and suffer from poor quality electricity supply. More than 95% of those living without electricity live in sub-Saharan Africa and developing Asia, predominantly in rural areas (around 80% of the world total). While still far from complete, progress in providing electrification in urban areas has outpaced that in rural areas two to one since 2000. [3]

Table 1-2 Population relying on traditional use of biomass

Region	**Population relying on traditional use of biomass [millions]**	**Percentage of population relying on traditional use of biomass [%]**
Developing countries	**2,722**	50%
Africa	**754**	**68%**
North Africa	*1*	*0%*
Sub-Saharan Africa	*753*	*80%*
Developing Asia	**1,895**	**51%**
China	*450*	*33%*
India	*841*	*67%*
Latin America	**65**	**14%**
Brazil	*8*	*4%*
Middle East	**8**	**4%**
WORLD	**2,722**	**38%**

(SOURCE: IEA, World Energy Outlook 2015)

Regarding access to modern energy for cooking and space heating as shown in Table 1-2 in 2015, more than 2.7 billion people – 38% of the world's population – are estimated to have relied on the traditional use of solid biomass for cooking, typically using inefficient stoves in poorly ventilated spaces. It increases indoor air pollution and growth of premature deaths. Developing Asia and sub-Saharan Africa once again dominate the global totals. While the number of people relying on biomass is larger in developing Asia than in sub-Saharan Africa, their share of the population is lower: 50% in developing Asia, compared with 80% in sub-Saharan Africa. Overall, nearly three-quarters of the global population living without clean cooking facilities (around 2 billion people) live in just ten countries.

1.3 Access to modern energy in Sub Saharan Africa

Africa's energy sector is fundamental for the future development of the continent and yet remains one of the most poorly understood regions within the global energy system. Despite the fact the continent has energy resources more than sufficient to meet domestic needs, more than two-thirds of its population does not have access to modern energy [4].

Regarding access to electricity Africa accounts for about 915 million people and has more people living without access to electricity than any other world region – more than 620 million people, and nearly half of the global total -.

Thanks to efforts to promote electrification in the last years many people got access to electricity in Africa: about 145 million people gained access to electricity since 2000, led by Nigeria, Ethiopia, South Africa, Ghana, Cameroon and Mozambique.

Overall, the electricity access rate in Sub-Saharan Africa has improved from 23% in 1990 to 32% in 2015 [3]. But as African population is growing really fast, the energy sector of Sub-Saharan Africa is not yet able to meet the needs and aspirations of its citizens so that the total number without access is growing up. In addition those who do have access to modern energy face very high prices for a supply that is both insufficient and unreliable because of an under-developed system that is not able to meet their needs [4].

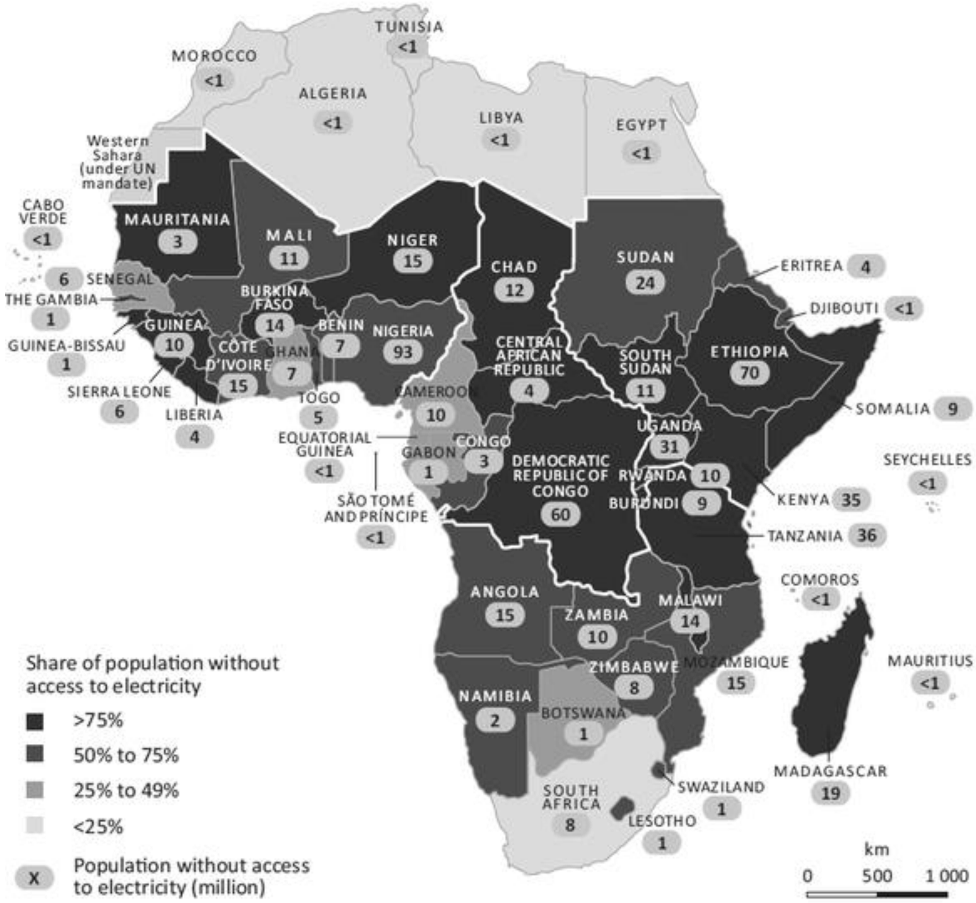

Figure 1-1 Population and share of population without access to electricity by country [5]

Insufficient and unreliable power supply has a large impact on the productivity of African businesses. On average, around 5% of annual sales are estimated to be lost due to electrical outages [6]. Poor quality grid-based supply reduces utility revenues (non-payment) and makes it more difficult to increase tariffs, thereby constraining the availability of finance for investment. In addition, the use of back-up power generation to mitigate poor grid-based supply increases strongly costs for businesses.

Regarding the second problem concerning access to modern energy in Africa, nearly 730 million people rely on the traditional use of solid biomass for cooking typically with inefficient stoves (Figure 1-2) in poorly ventilated spaces. This reliance affects women and children severely: 4.3 million children in the world die prematurely each year, of which nearly 600000 live in Africa. It can be attributed to household air pollution resulting from the traditional use of solid fuels, such as firewood and charcoal and traditional cooking stoves.

Figure 1-2 Three stone stoves in Ninga village

Around 80% of residential energy demand in sub-Saharan Africa is for cooking compared with around 5% in Organization for Economic Co-operation and Development countries (OECD). This is due, mainly, to households prioritizing energy for cooking and lighting and the low efficient of the cook-stoves used (typically 10-15% efficiency for a three-stone fire, compared to 55% for an LPG cook-stove).

Five countries – Nigeria, Ethiopia, DR Congo, Tanzania and Kenya – account for around half of the Sub-Saharan population using solid biomass for cooking.

Although this seem to suggest that this situation is concentrated in just a few countries, the reality is very different. In 42 countries, more than half of the population relies on solid biomass for cooking needs and in 23 of these the share is above 90%. Nearly three-quarters of those dependent on solid biomass for cooking live in rural areas and often devote hours of each day to collect firewood [1]. While this issue is often given les attention that that of electricity access, several countries have implemented programs to promote clean cooking fuels and stoves. Unfortunately, a transition to cleaner cooking fuels and appliances is not straightforward, as people who have access to modern fuels, such as LPG, natural gas, biogas or electricity, may also continue to use solid biomass for cultural or affordability reasons, a phenomenon also known as “fuel stacking”.

1.4 Access to energy in rural areas in Tanzania

1.4.1 General description

The United Republic of Tanzania was created as the union between Tanganyika and Zanzibar on 26 April 1964. It has 30 administrative regions, of which 25 are on mainland (Tanganyika) and 5 on the Island (Zanzibar). Tanzania is one of the most peaceful and politically stable countries in Africa. Indeed, the country has never experienced a civil war since independence in 1961. The Tanzanian population continues to live in peace with a sense of a common national identity.

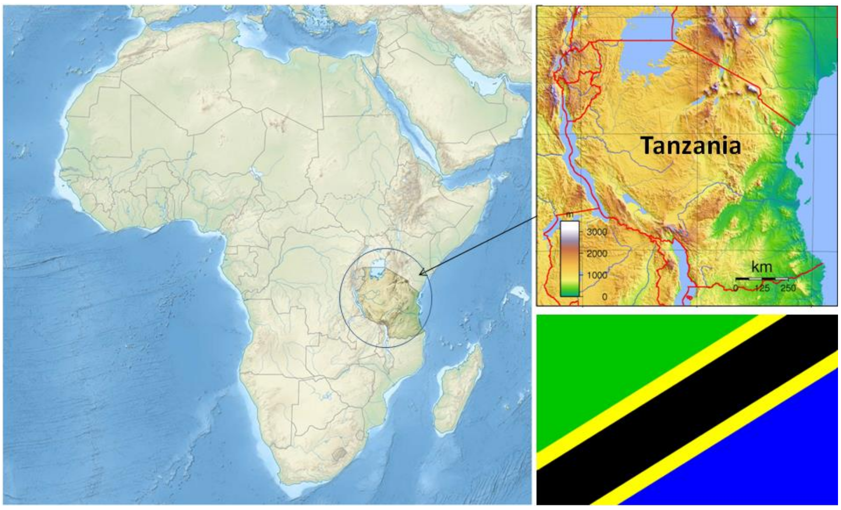

Figure 1-3 Tanzania flag and location

Tanzania is located in East Africa and borders Kenya and Uganda in the north; the Democratic Republic of Congo, Burundi and Rwanda in the west; Zambia, Malawi and Mozambique in the south and the Indian Ocean in the east. It has a total area of 945,749 Km2 with a population of 44.9 million people, and a population growth rate of 3,2% per annum [6]. The literacy rate is about 74% and 84% for female and male, respectively, while life expectancy is 63.5 years for males and 66.4 years for females. Since 1996, the official capital of Tanzania has been Dodoma but the biggest and most important city of the country is Dar-Es-Salaam, and the official languages are Swahili and English. The economy of the country heavily depends on agriculture, which accounts for 42.5% of GDP, provides 70% of exports, and employs about 75% of the workforce. Industry accounts for 18.9% of GDP and is mainly limited to processing agricultural products and light consumer goods [6]. The services sector (tourism, transport, energy and mining) accounts for 38.6%. The real GDP growth rate is about 7% (2015), current GDP is about US $44.895 billion and annual GDP per capita is 865 USD.

1.4.2 Energy situation of Tanzania

At the present, the energy balance in Tanzania is dominated by traditional use of biomass – about 86% of total energy consumption is Biomass in the form of firewood and charcoal for cooking. Commercial energy sources such as Oil, Gas, Electricity, and Coal, as well as Non-Biomass Renewable energy, account for the remaining 14%. Petroleum (Oil) and Electricity account for about 11% and 2%, respectively, for primary energy use. Coal, Gas, Wind and Solar account for about 1% of the energy used as shown in Figure 1-4 below [7].

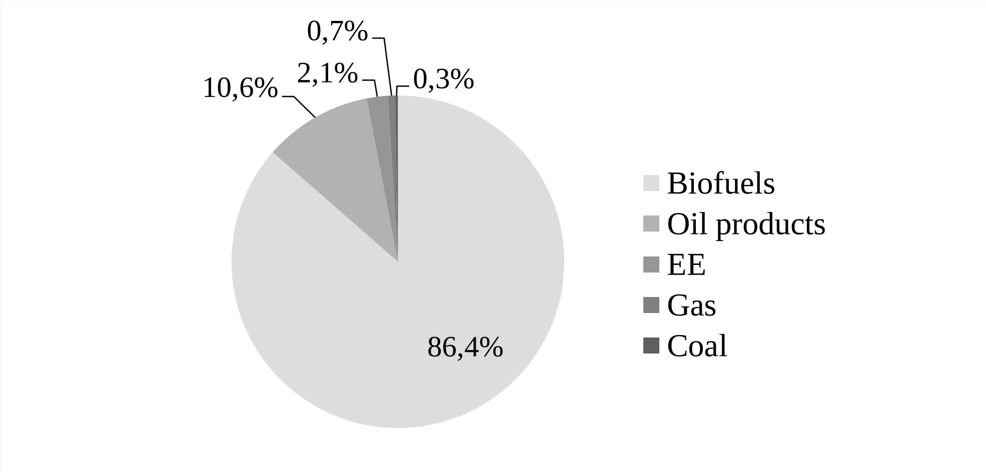

Figure 1-4 - Share of total final energy Consumption in Tanzania

Tanzania's power supply consists of the national interconnected system and several mini-grids serving areas located far from the national grid. The total installed electricity generation capacity is 1,564 MW. It is composed of Hydro 553 MW (or 35%), Small Hydro 13 MW (or 1%), Natural Gas 501 MW (or 32% percent), Liquid Fuels 456 MW (or 29%), Biomass 27 MW. Independent and Emergency Power Producers (IPPs and EPPs) own and operate power plants with a total installed capacity of about 417 MW. Tanzania also imports electricity from Uganda 8 MW, Zambia 5 MW, and Kenya 0.85MW. [8] The country suffers from low coverage of the electric grid and an increasing shortage of electric power production capacity in relation to demand, which roughly grows with the economic growth. In addition, as everywhere in Sub Saharan Africa, the reliability of the electric grid power is low, with frequent brownouts and blackouts.

Table 1-3 Power generation capacity in Tanzania in 2015 (Source[9])

	Power generation capacity [MW]
Hydro	553
Small Hydro	13
Oil	456
Biofuel	27
Gas	501
import	14
TOT	1564

(USAID, power for Africa)

1.4.3 Problem of overuse of biomass in Tanzania

More than 80% of Tanzanians depend on biomass as a source of energy by burning firewood, dung, and other traditional fuels. [10]

As shown in Figure 1-4 biomass use in Tanzania accounts for around 86% of total energy consumption and its use is growing in absolute terms due to the increase in population. The major biomass energy consumers include charcoal and firewood for domestic use, tobacco production, brick making, and tea drying.

The first important consequence of increasing use of firewood and charcoal in Tanzania concerns health. The indoor use of open fires or inefficient stoves in households (Figure 1-5) releases large amounts of smoke from incomplete combustion of solid fuels (carbon monoxide and small particles and many other health damaging chemicals). Breathing this smoke affect the health of all members of the family, especially children and women who suffer every day with difficulty in breathing, chronic respiratory diseases and stinging eyes.

Figure 1-5 Women and children sitting around an open fire in a wooden kitchen

Second consequence of increasing use of biomass in Tanzania concerns impact on the environment. Recently biomass energy consumption (mainly firewood and charcoal) has increased dramatically and the rapid population growth of both urban and rural areas has placed severe strain on the biomass resources, which has led to deforestation and desertification of some areas. Indeed, need for traditional biomass energy causes over exploitation of forests leading to deforestation and consequently severe soil and land degradation through firewood extraction and cutting down of trees for charcoal production.

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1.4.4 Problem of access to electricity in Tanzania

Access to electricity is one of the most important problems in Tanzania. Tanzania is growing up in number of people and in GDP so energy demand since 2000 has strongly increased and in order to sustain country's development growth, access to electric energy is a fundamental prerequisite.

Access to electricity measures the share of population which has a domestic electricity connection. This connection could vary in quantity (availability of electrical energy during the day) or quality (stability in voltage and frequency of electrical power during the day). Overall Electricity access rate in Tanzania was 15,3% , and today is 24% [6].

Access to electricity in urban areas accounts for 71%. It significantly decreases when considering rural areas to 4% (on average only 2% is connected to the national grid). As only less than 30% of population live in urban centres the overall electricity access rate in Tanzania is 24% [3].

Table 1-4 Access to electricity in Africa and Tanzania in 2015

Region	Population without electricity millions	National electrification rate %	Urban electrification rate %	Rural electrification rate %
Africa	**635**	**43%**	**68%**	**26%**
Sub-Saharan Africa	**634**	**32%**	**59%**	**17%**
Tanzania	***37***	***24%***	***71%***	***4%***
North Africa	**1**	**99%**	**100%**	**99%**

(SOURCE: IEA, World Energy Outlook 2015(

The annual per capita electricity consumption is about 90 kWh (225 kWh is the average annual per capita electricity consumption in Sub Saharan Africa excluding South Africa), which is very low compared with the world average of around 3000 kWh. Consumption per capita is significantly lower in rural areas, typically in the range of 50 to 100 kWh per year [11]. For a five person's household, annual consumption of 50 kWh per person could, for instance, allow the use of a mobile phone, two compact fluorescent light bulbs and a fan or radio for few hours a day. In urban areas, households generally own more appliances, such as televisions, refrigerators or an electric water heater.

Figure 1-6 Access to electricity to national grid by region (Source [12])

Despite of the fact that the recent phenomenon of urbanisation has often facilitated increasing access to modern energy, as more than 70% of those lacking access to electricity in Tanzania live in rural areas, rural electrification will be fundamental in order to reach universal access to electricity in the country.

1.4.5 Rural areas in Tanzania

As already underlined around 70% of total population in Tanzania live in remote areas. The main sources of income for rural households are agriculture, pastoralism, livestock, cattle raising and forestry. Rural areas in developing countries are characterised by scattered population and are generally difficult to reach due to their geographical isolation and very bad road conditions. The road conditions and long distances from urban settlements make these places accessibility limited, and hence service suppliers cannot guarantee regular visits, thus preventing local populations from participating in national or regional markets. Moreover, high educated people (i.e. teachers, doctors, technicians, etc.) are despondent to work in such areas. Rural areas are also affected by high illiteracy rate, gender inequality, lack of access to health care, infrastructure and clean water supply.

Therefore, bringing access to electricity in rural area is a fundamental prerequisite to trigger and ensure a sustainable development. However, as a result of several factors, the progress of rural electrification in Tanzania are meagre: scattered population, bad road conditions, rural-urban demographic shifts, poor conditions for investment credits, absence of financial institute, presence of fairly few actors dealing with rural electrification, are all factors that make slow and complex the progress in rural electrification.

Figure 1-7 Photo of Ikondo village in Njombe region

1.4.6 Providing access to electricity in rural area in Tanzania

There are to possible approaches to bring electricity to non-electrified region: the centralized electrification and the decentralized/distributed electrification. The first one consists in the extension of the national grid and is undertaken by national governmental entities such as the state-owned national utility (TANESCO), the Rural Electrification Agency (REA), or the ministry of energy, acting alone or together. Connection to the national centralized grid is generally limited to those towns and villages along main roads and to nearby areas. When it is available, often only the high income households, few enterprises and community services can afford connections since electricity may cost as much as 10 times more than in urban areas.

When cost for extending national grid to rural areas is unsustainable, Off-grid power systems are the only solution to bring Electricity in remote areas. Depending on number of energy sources used, the off-grid systems can be divided into Decentralised and Distributed systems as shown briefly in Table 1-5 [13]

Table 1-5 Off Grid Systems Matrix for rural electrification systems in DCs (Source[13])

OFF-GRID SYSTEMS MATRIX	**DECENTRALIZED**		**DISTRIBUTED**
Rural Energy Uses	**Stand-alone Systems**	**Micro-Grid Systems**	**Hybrid Micro-Grid Systems**
Households	Home-based Systems	Systems including a distribution grid	Systems including a distribution grid
Community services	Community-based Systems		
Productive uses	Productive-based Systems		
Consumer number	Single	Multiple	Single or Multiple
Energy Sources	Single		Multiple

The decentralized/distributed electrification is generally carried out through nongovernmental entities such as cooperatives, community user groups, or private entrepreneurs. These entities usually construct and operate isolated mini-grid, small-scale distribution networks typically operating below 11 kilovolts (kV) that provide power to one or more local communities and produce electricity from small generators using fossil fuels, renewable sources, or a combination of the two.

Therefore, in order to achieve universal access to electricity Off-grid small-scale electricity generation represents the most appropriate option to spread access to electricity in remote areas in Tanzania. It can be seen both as a first step in the electrification process and as building-block for a possible future national grid connection development. The forecasts drawn by the International Energy Agency reports that about 60% of the additional electricity generation requested to provide universal access to energy, is expected to be generated through off-grid systems and about 90% of them are supposed to rely on renewable-based sources systems and mini grid.

The best source to be used in rural context in Tanzania to produce electricity is Micro and Mini Hydropower source because the country has a huge hydropower potential still untapped.

1.4.7 Hydropower source for rural electrification

Thanks to his numerous basins draining towards the three oceans in the east, west and north of the African continent Tanzania has the largest hydropower potential of East Africa (Kenya, Tanzania, Uganda, Rwanda and Burundi), estimated to be up to 4700 MW. Only about 10% of hydropower potential is tapped. The country's installed electricity generation capacity is 1564 MW [9]: about 61% of grid generation capacity is from thermal (32% from natural gas and 29% from oil), whilst 35% is from large hydropower and 1% is from small hydropower. The rest 3% comes from biofuel energy power and imports (Figure 1-8).

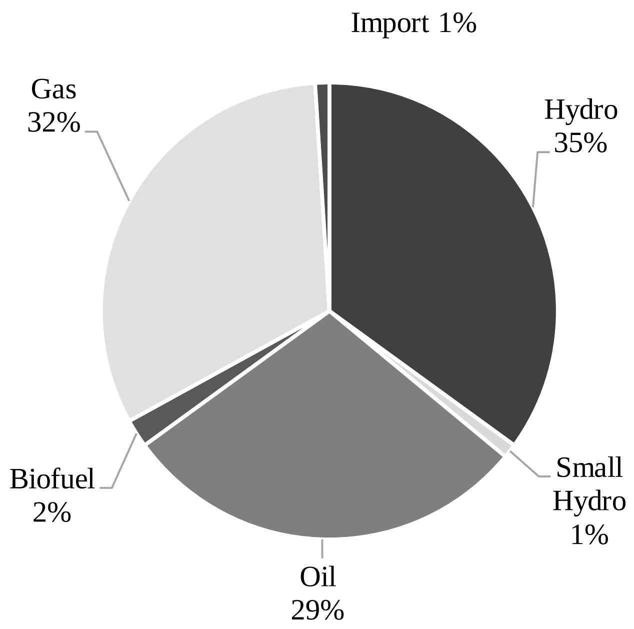

Figure 1-8 Share of power generation by fuel in Tanzania (Source [9])

Small Hydropower typical capacity range from few kW (micro-hydro) to few MW (mini-hydro), depending on various factors as hydrology, load demand and geographical constraints. The assessed potential of Small Hydropower resources up to 10 MW (micro and mini Hydropower power sources) in Tanzania is 480 MW. The installed grid-connected, small-hydro projects contribute for only 13 MW. Most of the developed small-hydro projects are owned by private entities and are not connected to the national electricity grid.

Hydropower is the most popular and the oldest renewable energy source used to produce electricity for rural mini-grids and SHPP (Small Hydro Power

Plant) are the most attractive solutions to bring electricity in remote areas due to several factors: Tanzania rural areas have big potential assessed that is still untapped; the powerhouse is pretty standard hosting one or more turbines, alternators and control system; the technology is quite simple and well mature, allowing local repairing; there are several examples of local manufacturing or assembling companies in Africa dealing with Cross-flow or Pelton turbines for rural applications; investment costs for micro-mini hydropower plant (SHPP) are generally claimed to be low and average costs of electricity generated is lower than any other technology, renewable or otherwise. On the other hand, the infrastructure and civil works can be rather complex and costly depending on the water collection system (pond, weir, channel, fore bay, and penstock, the long preparation (studies, permits) and lead times are other hurdles)[14].

In order to bring electricity in rural areas Tanzanian government policy on small hydropower is to develop small sites in areas which are not supplied with power from the national grid or to replace diesel generation in isolated areas. Based on this policy, several small scale hydropower development activities have been initiated by the government in cooperation with local and foreign agencies.

One of these agencies operating in rural electrification in Tanzania is CEFA Onlus, an Italian Non-Government Organization. CEFA in recent years has successfully carried out important projects in the rural electrification sector by the realization of small hydropower plants in the regions of Ninga e Iringa.

2 Background

2.1 CEFA Onlus

2.1.1 CEFA NGO general description

CEFA (European Committee for Training and Agriculture) is an Italian NGO, founded in 1972 by a group of agricultural cooperatives based in Bologna that promotes initiatives of development, cooperation and international volunteer service. CEFA supports projects in rural regions of the Mediterranean, East Africa and Latin America to promote integrated self-development which means to support and accompany local communities in establishing a sustainable and durable development process. [15]

Since 1976 in Tanzania CEFA promotes interventions in the fields of water supply, agriculture, agro-processing and rural electrification. CEFA's aim is to support community and local institution in the poorest countries of the world through family and community, economy improvement, valorization of human resources and training and recognition of fundamental human rights. CEFA works in cooperation in the field of humanitarian aid, through projects that combine productive activities with a commitment to achieving social growth and development of democratic and ethical organizations. CEFA's international cooperation actions are related to the following sector of intervention:

- Rural economy with production, transformation and commercialization of agricultural products

- Crafting products;
- Basic infrastructures to guarantee water access, requalification and environment protection of the territory and the use of renewable energies;
- Technical and Management training;
- Promotion of local communities;
- Re-integration in the community of underprivileged people;
- Help to local school institutions and promotion of a real education right for everybody
- Electrification or rural areas with no access to electricity

Figure 2-1 Photo with CEFA's electrification projects team

2.1.2 CEFA's rural electrification projects in Tanzania

CEFA's commitment to rural electrification in Tanzania lasts for 25 years and in this period the NGO has realised three mini hydro-electric power plants in the rural areas of Iringa and Njombe regions, which currently serve 5 villages (about 1070 households, public services and private enterprises) connected to the mini-grids.

Matembwe

The first power plant was realised in the village of Matembwe, in the District of Njombe, in 1984. The hydropower plant has a nominal power of 120 kW and supply electricity to 2 villages serving about 700 connections. At present, the power plant and the distribution network are owned and managed by the Matembwe Village Company (MVC Ltd), a local entity established by CEFA together with the other partners of the original project (Catholic Dioceses of Njombe, District of Njombe and Village of Matembwe).

Figure 2-2 Reservoir micro hydropower plant of Matembwe

Table 2-1 Characteristics of Small Hydro plant in Matembwe (Source [16],[17])

MATEMBWE	
Type of facility	Reservoir micro hydropower plant
Commissioning year	1984
Funded by	Italian Ministry of Foreign Affairs, Belgian Ministry of Foreign Affairs, European Union, CEFA
Ownership	Matembwe Village Company **-** MVC Ltd (CEFA, Chatolic Diocess of Njombe, District of Njombe)
Output power	120kW
Villages served	Matmbwe and Image
Distribution network	19km of MV
Households connected	556
PS and US connected	64
Acqueducts powered	4
Connection with TANESCO	Yes (in 2015)

Bomalang'ombe

The second power plant was realized in the village of Bomalang'omb**e**, in the District of Kilolo. The hydropower plant has a nominal power of 250 kW and supply electricity to 3 villages serving about 400 connections. The availability of electric power determined a rapid development of the village of Bomalang'ombe, that in these years has seen its population grow from 5.000 to more than 12.500 inhabitants. At present the power plant and the distribution network are owned and managed by the Bomalang'ombe Village Company – BVC Ltd, a local entity established by CEFA together with the other partners of the original project (Catholic Dioceses of Iringa, District of Kilolo and Village of Bomalang'ombe).

Figure 2-3 Reservoir micro hydro plant of Bomalang'ombe

Table 2-2 Characteristics of the small hydro power plant in Bomalang'ombe [16], [17]

BOMALANG'OMBE	
Type of facility	Reservoir micro hydro plant
Commissioning year	2001
Funded by	Italian Ministry of Foerign Affairs, Belgian Ministry of Foreign Affairs, European Union, CEFA
Ownership	Bomalang'ombe Village Company - BVC Ltd (CEFA, Chatolic Diocess of Iringa, District of Kilolo and Village of Bomalang'ombe)
Output power	120kW
Villages served	Bomalang'ombe and Lyamko
Distribution network	17,3km of MV
Households connected	252
PS and US connected	76
Acqueducts powered	3
Connection with TANESCO	No

Ikondo

The third power plant was realized in the village of Ikondo, in the District of Njombe. The hydropower plant has a nominal power of 80 kW and supply electricity to the village of Ikondo. Unlike the previous two sites, Ikondo is a run-of-river plant, which uses the water provided by the river Kyepa. The project intended to help start-off the development to the village of Ikondo, a very isolated settlement in the District of Njombe. At present the power plant and the distribution network are still owned and managed by CEFA.

Figure 2-4 Run-of-the-river micro hydro plant of Ikondo

Table 2-3 Characteristics of Small Hydro plant in Ikondo [16]

IKONDO	
Type of facility	Run-of-the-river micro hydro plant
Commissioning year	2004
Funded by	Italian Ministry of Foreign Affairs, Belgian Ministry of Foreign Affairs, European Union, CEFA
Ownership	CEFA (to be handed over to MVC Ltd)
Output power	83kW
Villages served	Ikondo
Distribution network	8km of MV
Households connected	130
PS and	46
Acqueducts powered	1
Connection with TANESCO	Yes (in 2015)

Ikondo II

CEFA is going to finalize soon its more recent electrification project consisting in an upgrade of the previous project in Ikondo. The project, called "Ikondo2" co-funded by the European Union, started in September 2011 and has been concluded at the end of the 2015 with an upgrade of the output of the power plant up to 480 kW. The final step is to increase the actual distribution grid in order to reach new villages and connect the mini-grid to the Matembwe micro-grid and to TANESCO's national grid in order to sell the excess of production. At the end of the project the power plant and the distribution network will be owned and managed by the Matembwe Village Company – MVC Ltd. [17]

Figure 2-5 Run-of-the-river micro hydro plant upgraded in Ikondo

Table 2-4 Characteristics of the upgraded Small Hydro plant in Ikondo [16]

IKONDO II	
Type of facility	Run-of-the-river micro hydro plant
Commissioning year	2015
Funded by	European Union, CEFA
Ownership	CEFA (to be handed over to MVC Ltd)
Output power	430kW
Villages served	Ikondo, Nyave, Ukalawa, Isoliwaya, Kanikele
Distribution network	47km of MV (in 2016)
Households connected	280
PS and US connected	75
Acqueducts powered	1
Connection with TANESCO	Yes (in 2015)

2.2 Ninga SHPP: CEFA's last electrification project

Moreover, CEFA has recently been awarded by Rural Electrification Agency a matching grant for the realization of a feasibility study for a possible 6 MW SHPP situated in Ninga – Njombe. This feasibility study was finalized in March 2015 by ENSCO, an Italian engineer consulting company located in Belluno and CEFA is currently looking for the financial closure. [17] The goal of the proposed Hydro Power Plant is to give electricity to 13 non electrified villages through mini-grid connected to the main grid, and the excess of energy will be sold to TANESCO.

2.2.1 Location of the plant

The territory of Tanzania is divided into 9 drainage basins, 5 draining into the internal lakes and 4 draining into the Indian Ocean. The proposed 6 MW capacity SSHP lies in the Rufiji Basin, a big river in the South East of Tanzania, flowing into the Indian Indian Ocean. [18]

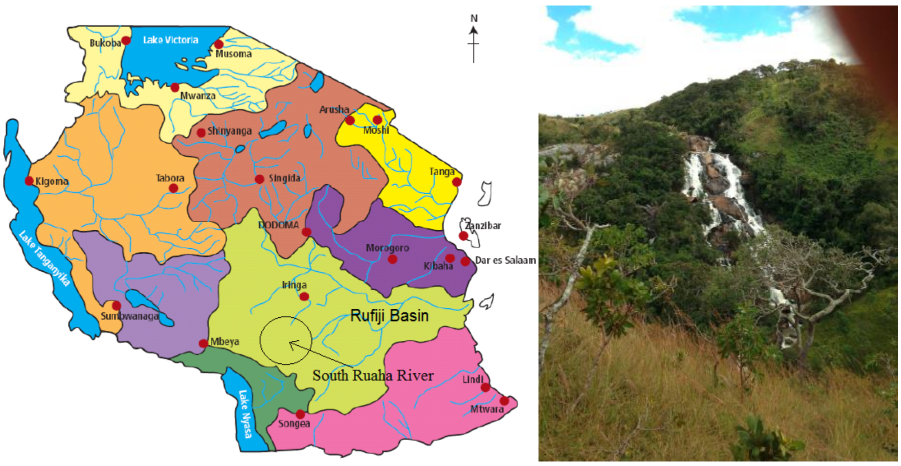

Figure 2-6 River basins of Tanzania (left); project site (right)

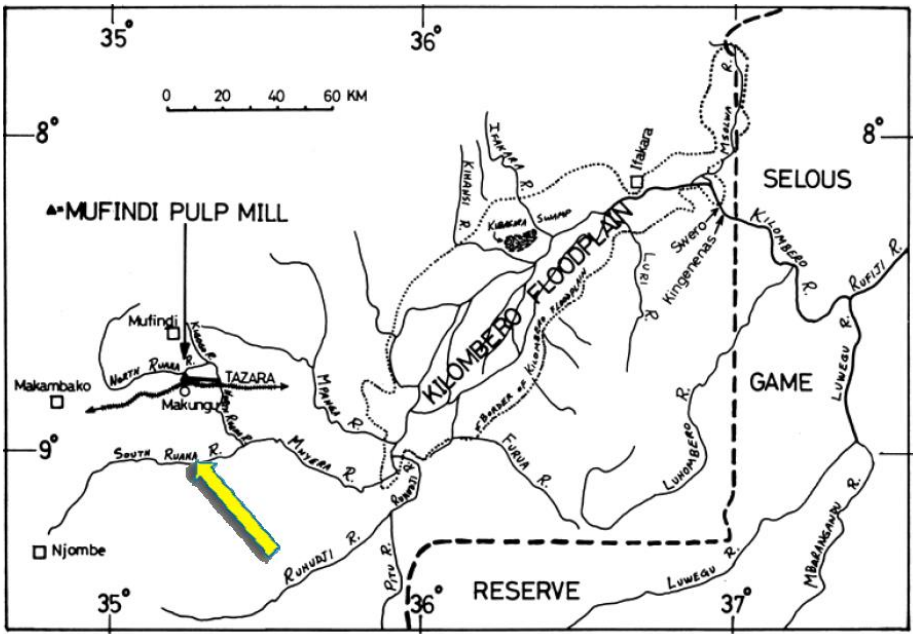

Figure 2-7 Kilombero River tributary basin and South Ruaha River

The project makes use of the water of South Ruaha River, affluent of the Mnyera and part of Kilombero River tributary basin. South Ruaha River is located in Njombe Region, not far from Matembwe, in the ward of Ninga.

The area, situated approximately 55 km north-east from Njombe township, has an average altitude of 1800 meter above-sea-level and is characterised by undulating hills and plateaus. The soils are volcanic and mostly covered with planted and natural forest trees, scattered shrubs and grasslands. Crop framing includes maize widely cultivated, bananas, green peas, tea, coffee, wheat, pyrethrum, temperate fruits. Livestock keeping includes dairy cattle, pigs and sheep. The possible site of the intake on the river can be reached partly by an unpaved road, about 12 km from Ninga. A substantial repair of the road is needed and the construction of about 3 km new road have to be executed in order to reach the intake area.

2.2.2 Climate and rainfall trend in Njombe Region

In order to best evaluate the hydropower potential of the propose power plant a good knowledge of climate and rainfall trend of the study area is required. Tanzania's climate conditions are characterised by enormous variability in terms of rainfall, temperature and stream flow or levels. Furthermore, the climate is closely associated with the topography and ranges from tropical to subtropical, and the annual rainfall ranges between 500 mm and 2000 mm. Most of the rain is derived from the South-eastern Monsoon winds originating from the Indian Ocean. In the study area of Njombe Region the climate is humid and the average temperature lies below 15° C. The amount of rainfall in the area lies around 1100 mm per annum or more, falling mostly in a single season from November through May. The dry and cold season occurs after the rain season, from June to October. The climate trends in the relevant zone were investigated with reference to rainfall data. Figure 2-8 [18] shows the rainfall records of the last 20 years at the Itambo met station, Kibena tea Limited positioned about 23 km from the project.

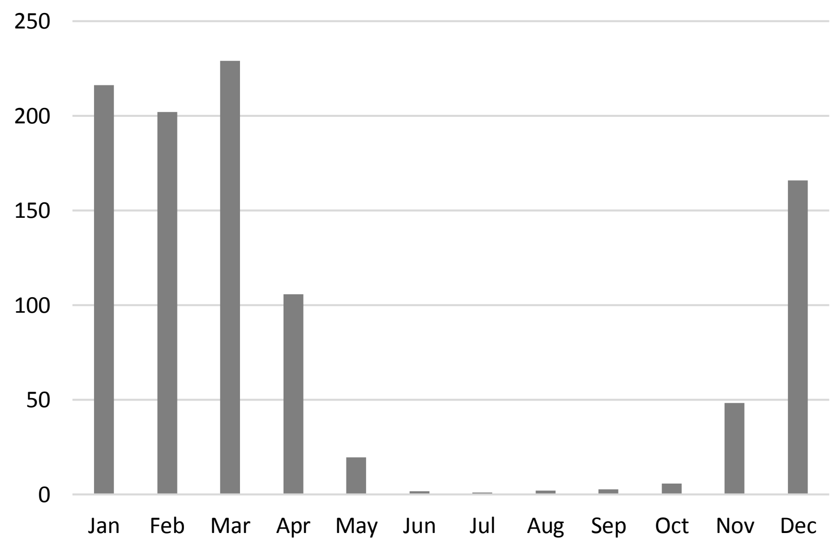

Figure 2-8 Mean monthly rainfall in the study area [mm]

2.2.3 Technical features and energy production evaluation

The Small Scale Hydropower Plant will be a "Run of River" plant, a type of hydroelectric generation plant whereby little or no water storage is provided. Run-of-the-river power plants may have no water storage at all or a limited amount of storage, in which case the storage reservoir is referred to as poundage. The plant to be built has no water storage and is, therefore, subject to seasonal river flows. Indeed, turbines generate electricity as and when the water is available and provided by the river. When the river dries up and the flow falls below some predetermined amount or the minimum technical flow for the turbine, generation ceases. More in details, the project consists of a diversion dam on the river South Ruaha, a relevant water course with a huge flow rate. The intake will be positioned upstream a waterfall so that an optimal hydropower potential can be developed. It works with a gravel sluice and two sand traps on the left bank of the river. There is a weir to divert water to the intake. A diversion channel and a penstock leads the diverted flow to the powerhouse where two Francis turbines produce electricity, and there is a tailrace to return the flow to the river [18]. The main technical features of the proposed power plant are shown in (Table 2-5).

Table 2-5 Technical features of the proposed power plant

SHPP Technical features	
Intake location	UTM 725.465 E; 9.001.143 N 1397.50 m asl
Powerhouse location	UTM 725.167 E; 9.001.159 N 1322.24 m asl
Penstock lenght	177.5 m
Gross head	76 m
Mechanical capacity	6.3 MW
Electrical power	6.0 MW
Annual energy output	26,410,00 kWh

As few data of South Ruaha river flow are available, data on the near Ruhudji river have been utilised for a preliminary evaluation. On the basis of the hydrological studies and the available head, two vertical-shaft Francis turbines with a straight conical diffuser, will be installed. The two Francis turbines characteristics are shown in Table 2-6.

Table 2-6 Technical characteristics of Francis turbines [18]

	Unit of measure	T1	T2
Flow rate	m^3/s	2.9	6.73
Net head	m	75.67	75.29
Efficiency of the turbine	-	89%	89%
Frequency of the network	Hz	50	50
Mechanical power	kW	1916	4424
Electical power	kW	1820	4203

The electric line (33kV) is 82 km long and will connect 13 villages. It also will connect to the national grid nearby the villages of Ikuna and Lole, some kilometers north of Nyombo. The villages served by electricity within the project are shown in Figure 2-9.

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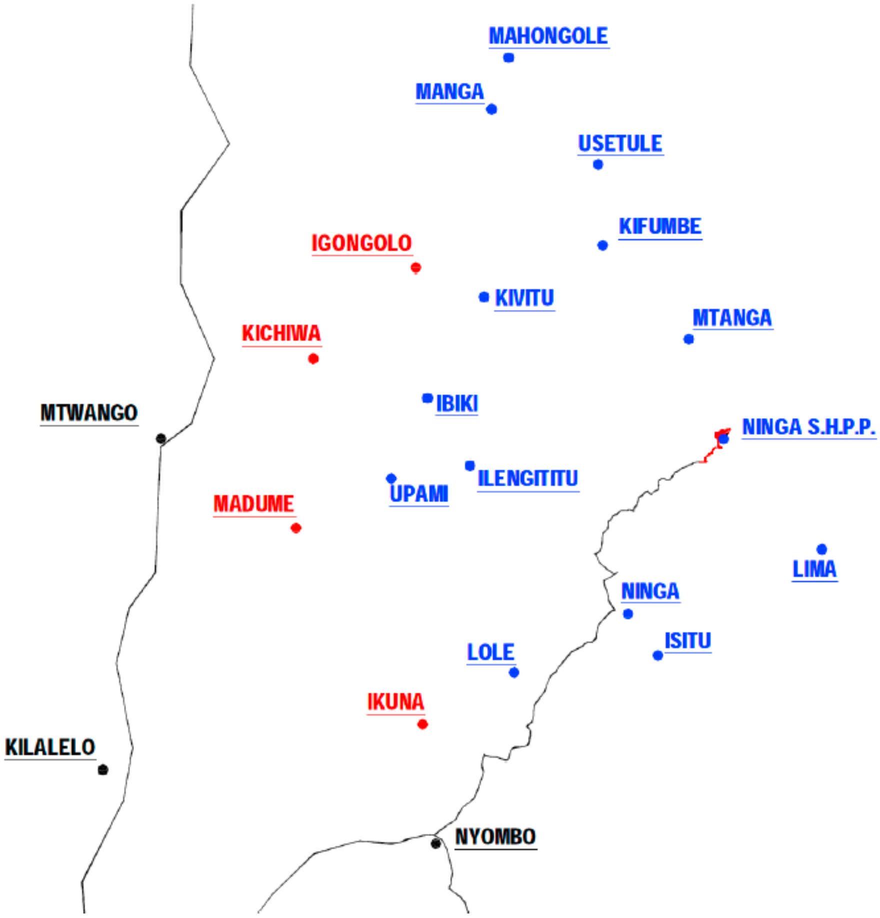

Figure 2-9   Location of the 13 villages (colour blue) and Ninga S.H.P.P. [19]

On the base of annual data, the flow evaluation and the net of electricity production can be evaluated. The Table 2-7 shows the monthly energy produced by the power plant.

Table 2-7 SHPP monthly energy production [18]

	mean river flow [m3/s]	utilised flow [m3/s]	Electric Capacity [kW]	Energy Produced [kWh]
Jan	6.49	5.88	3679	2737163
Feb	10.23	9.63	5975	4015167
Mar	12.78	9.63	5975	4445363
Apr	12.59	9.63	5975	4301964
May	7.51	6.91	4316	3210428
June	5.13	4.53	2836	2042083
July	4.1	3.5	2194	1632647
Aug	3.48	2.88	1807	1345090
Sept	2.42	1.82	1142	822592
Oct	2.01	1.4	882	656034
Nov	1.87	1,26	793	571421
Dec	3.71	3.1	1948	1449574
Mean annual	6.03	5.02	*losses = 3%*	27229526
			Net Energy	**26,412,640**

In order to realize this project, CEFA has decided to adopt the Non-Profit/For-Profit Partnerships approach: the NP/FPP is one of the best mechanisms to supplement and overcome budgetary constraints for widening access to energy services, especially to the local communities, as they can allocate project-risks between the public/non-profit and private sector. This innovative approach, both financially and operationally, based on a partnership with a private actor is an opportunity for increasing the action's impact on the beneficiaries granting the future sustainability of the project.[17]

In this context, as the energy produced by the SHPP will exceed the local energy demand if the mini grid will be connected to the national grid the output could be sold to the TANESCO making the project commercially attractive.

So in order to calculate the excess of energy produced by the plant an accurate load demand evaluation of the 13 villages is required.

3 Load Curve Estimation and Primary Energy Assessment

The purpose of the internship at CEFA Onlus in Njombe region is to carry out a deep study about energy needs and usages in the thirteen villages of the Ninga's SHPP project.

In the first paragraph the two goals of the thesis are explained. The next paragraphs show the activities carried out during the mission, the surveys administered in the villages and the tool used to collect data. Subsequently the procedure and the software used in order to obtain the first goal and the method used to achieve the second goal are explained. Finally, in the last chapter results are shown and a brief analysis is carried out.

3.1 Purposes of the thesis

The objectives of the internship at CEFA Rural Energy Program in Njombe region in Tanzania are the followings:

1. Future load curve estimation of 13 non electrified rural villages
2. Energy demand assessment of 13 non electrified rural villages

Goal number 1 consists of estimating the future load curve profile of 13 non electrified villages that are going to be electrified soon by the connection to a mini grid powered by a Small Hydro Power Plant (SHPP). In other words, the purpose is to evaluate how much electricity the 13 villages are going to on daily basis when they will have access to affordable and reliable electricity (with a short term perspective - 1 year) through mini-grid connected to the main grid. In order to achieve goal number 1 surveys have been administered in the villages and data collected have been used as input in LoadProGen, a software for the estimation of load curve in rural remote areas. Results will be useful for CEFA and may allow an optimum technical-economic system design of the Power Plant. Indeed, the evaluation of future daily electricity consumption of the 13 villages allow to calculate the excess of energy that the Power Plant is going to produce and so the excess of energy that can be sold to TANESCO when the scheduled connection to the National grid will be completed.

The goal number two consists of assessing the primary energy demand of the 13 non-electrified villages of Ninga project in order to provide a snapshot of the current primary energy consumption.

3.2 Summary of activities

In the following paragraph, a brief overview of the activities carried out during the entire period is described.

The first period (around one month) consisted in literature research, particularly load curve estimation methods in rural context and energy demand estimation methods. The second period (around two months) was spent in the study area of Njombe in Tanzania and it represented the core of the entire work. It can be further divided into 4 shorter periods of time:

- during the first week, a first draft of questionnaires was prepared
- during the following two weeks, some of the villages in the study area were visited and information about CEFA' s projects and local villages was collected. Based on the information gathered, the questionnaires were reviewed;
- during the following two weeks, all the surveys were administered in the selected villages and all necessary data was collected;
- during the last two weeks, the collected data was reorganized and a first analysis carried out.

The last period spent in Milan consisted of processing and analysing data and writing of the thesis.

3.3 Study area

In the following paragraph, the geographical area where the activities were carried out during the period of the mission is described.

The 13 villages are located within a 10000 km2 area. The area (Figure 3-1), situated approximately 55 km north-east from Njombe township, has an average altitude of 1800 meter above sea level and is characterised by undulating hills and plateaus. The soil is volcanic and mostly covered with planted and natural forest trees, scattered shrubs and grasslands. Crop farming includes maize widely cultivated maize, bananas, green peas, tea, coffee, wheat, and temperate fruits. Livestock includes dairy cattle, pigs and sheep. The main sources of income for rural households are agriculture, pastoralism, cattle raising and forestry. Rural areas in developing countries are characterised by scattered population and are generally difficult to reach due to their geographical isolation and limited infrastructure.

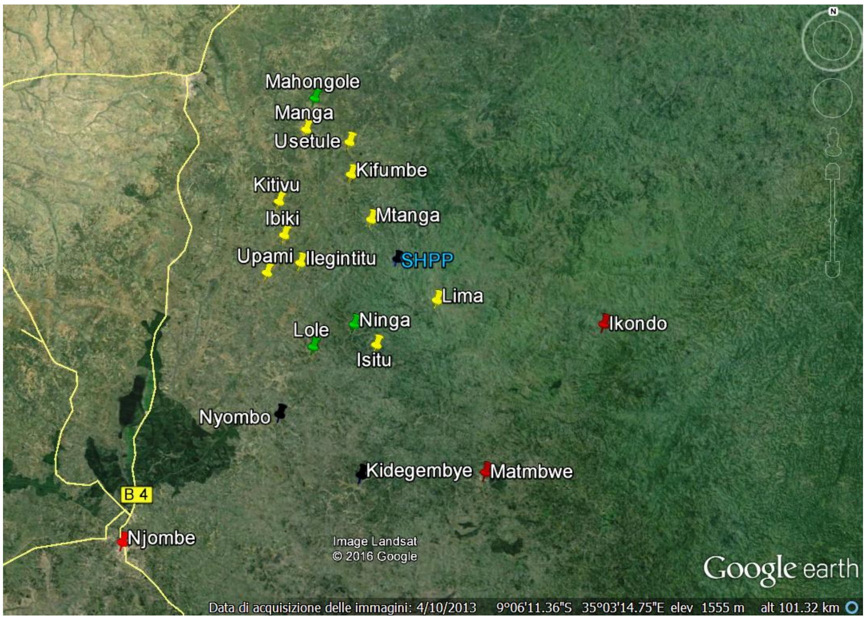

Figure 3-1 View from satellite of the study area where the villages are located [20]

3.4 Surveys

The first activity carried out during the time spent in Tanzania was the creation of questionnaires to be administered to local villages in the study area. The goals of the surveys were the following:

- to collect input data required by Load Profile Generator [21] in order to evaluate the future load curve of the thirteen villages
- to collect data about energy sources used in the villages in order to assess the primary energy demand and have a snapshot of the current primary energy consumption of the 13 villages

In order to achieve the previous targets, two different surveys have been prepared: a questionnaire for Electrified Villages and a Questionnaire for Non Electrified Villages.

3.4.1 Questionnaires addressed to Electrified Villages

Two different Surveys addressed to Electrified Villages have been created in relation to the interviewees: a survey addressed to the Households of the villages and a survey addressed to Public Services and Productive Usages.

The Questionnaire addressed to Households (see Q_EE_HH in Appendix A) is composed of three sections: the first section concerns questions about general information those interviewed, composition of the family, employment, income and expenditure of households; the second section concerns questions about electric devices use and usage habits of electric appliances. Number and type of electric devices used in the house, the average daily use, the minimum functioning time and the functioning windows for each appliance have been asked to households (data required by LoadProGen for load curve estimation). Finally, the last section concerns questions about electricity consumption and electricity bill.

The Questionnaire addressed to the PB&US (see Q_EE__PB&US in Appendix A) is the same of the previous but in the first section, questions about family composition and employment of households was not asked. The entire Survey is in Appendix A

3.4.2 Questionnaires addressed to Not Electrified Villages

Two different Surveys addressed to Non Electrified Villages were created: a survey addressed to the Households of the villages and a survey addressed to Public Services and Productive Usages.

The Questionnaire addressed to the Households (see Q_notEE_HH in Appendix B) is composed of three different sections: the first section concerns questions about general information of those interviewed, composition of the family, employment, income and expenditure of households; the second section concerns questions about electric devices use and usage habits of electric appliances to those User Classes have a minimum access to electricity through connection to home-based solar panel system or a small gen-set. Number and type of electric devices used in the house, average daily use, minimum functioning time and functioning windows for each appliance were asked only to households connected to a stand-alone power system (Solar Panel or GenSet); the third section concerns questions about primary energy consumption. For each source used in the villages (Firewood, Charcoal, Kerosene, Gasoline, Diesel) questions about daily energy source consumption, purpose of using the source and ways of supplying source were asked to Households of the villages.

The Questionnaire for Not Electrified Villages addressed to the PB&US (see Q_notEE_PB&US in Appendix B) is the same as the previous one but questions about family composition and employment have not been asked.

3.4.3 Open Data Kit

ODK software, a free suite of tools for data collecting services was used in order to create the Form of the surveys, administer them during field work and gather data collected on the computer.

Open Data Kit (ODK) is a free and open-source set of tools that allows data collection using Android mobile devices and data submission to an online server, even without an Internet connection or mobile carrier service at the time of data collection. This suite of tools streamlines the data collection process by replacing traditional paper forms with electronic forms that allow text, numeric data, GPS, photo, video, barcodes and audio uploads to an online server. ODK is formed by 3 main tools, which allow the user to create a questionnaire form, to administer the survey and to collect data on the computer in a simple and fast way. [22]

ODK-Build

The first tool, called ODK-Build is a form designer with a drag-and-drop user interface for HTML5 web application that allows the user to "Build" a data collection form or survey. Once the form has been created it can been sent on the server "ODK Aggregate".

Figure 3-2 ODK-Build online form screen view

ODK-Collect

The second tool, called ODK-Collect allows the user to administer the surveys by collecting data obtained from the interviews on a mobile device and send them to the server (ODK-Aggregate).

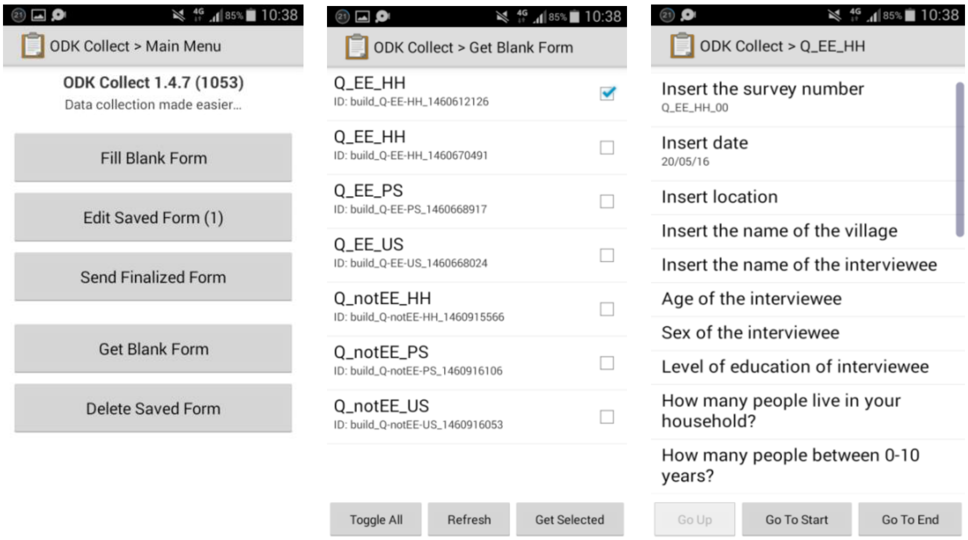

fig.1.1. ODK-Collected screen view for mobile devices

The following few steps summarize the main features of this simple tool:

- to get the Blank Form (created by using ODK-Build) from the server
- to fill the Blank Form during the interviews time
- to edit the Saved Form (when necessary)
- to send the Finalized Form to the server ODK-Aggregate (when internet connection is available)

ODK-Aggregate

The last tool, called ODK-Aggregate, provides a ready-to-deploy server and data repository. Its main features are following listed:

- to provide blank forms to ODK Collect.
- to accept finalized forms (submissions) from ODK Collect and manage collected data.
- to visualize the collected data using maps and simple graphs.
- to export data (e.g., as CSV files for spreadsheets, or as KML files for Google Earth), and also publish data to external systems (e.g., Google Spreadsheets).

ODK Aggregate can be deployed on *Google's App Engine*, enabling users to quickly get running without facing the complexities of setting up their own scalable web service. [23]

Figure 3-3 ODK-Aggregate online desktop screen view

3.4.4 Fieldwork 1: interviews in Electrified Villages

Once the surveys were reviewed and ODK set for the collection of data, the questionnaires were administered in the selected villages.

The interviewed electrified villages - Nyombo e Kidegembye - were selected based on the following criteria:

1. The interviewed villages must be placed nearby the study area where the 13 villages of Ninga SSHP project are situated
2. The interviewed villages must be recently (less than 2-3 years) connected to the National grid by TANESCO

The two selected villages - Nyombo and Kidegembye - are placed around 15 km north of Ninga, the main village of the project. All villages are characterized by 2-3 main roads and 2-3 main centers where there are the few typical activities of these rural areas: milling machines, carpentries, garages, shops, guest houses, hair cutters and pubs. Despite of the presence of these activities, the main source of income of households is agriculture. The two villages were electrified 1 year and half ago by TANESCO thanks to the National Grid Extension.

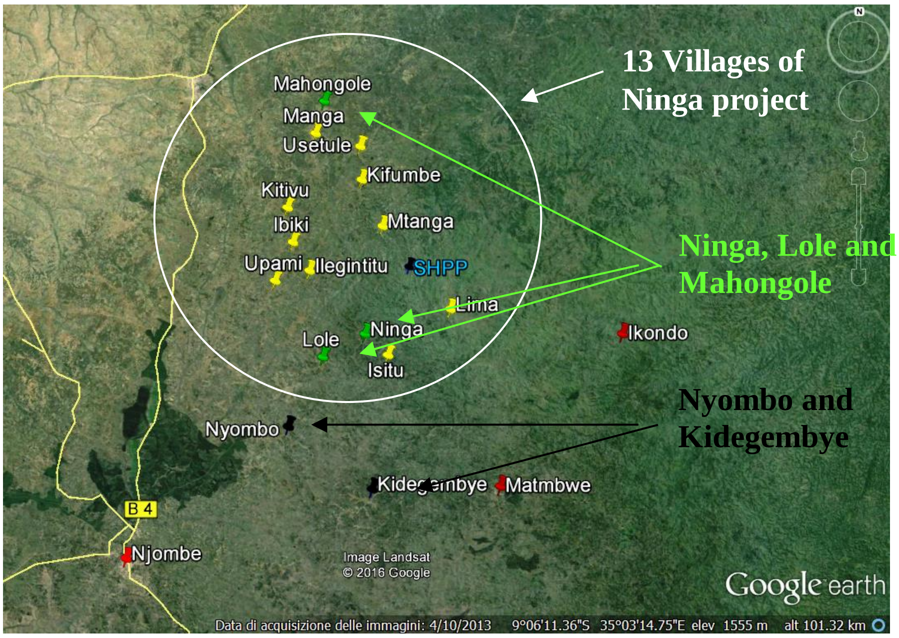

Figure 3-4 Google Earth view of the 13 villages of the study area

The following table shows the number of Users interviewed for each User Class in the villages of Nyombo and Kidegembye.

NYOMBO and KIDEGEMBYE		
	User Class	**N° of interviewed**
HH	Household	33
PB	School	3
	Office	2
	Dispensary	1
	Church	1
US	Millings	4
	Carpentries	3
	Shops	4
	Hair Cutters	3
	Guest Houses	2
	Garage	3
	Pub	3

Table 3-1 Number of interviewed in Electrified Villages

The interviewed EE villages are characterized by very similar features to 13 nonEE villages:

- similar number in member per household (on average 4/5 members within the family)
- similar collocation of households and structure of the villages (2-3 main roads where most of productive activities are located),
- same type of productive usages
- similar economic conditions (the income of HH and US is similar in EE and NonEE villages)
- similar size of the villages. (on average there are around 400 Households per village and 2000 inhabitants)

Due to the previous considerations it can be assumed that the appliances used and usage habits of electrical devices of HH, PB and US in the two villages will be the same (or at least very similar) to those of the 13 villages when access to electricity will be provided to them by the mini grid project.

Previous assumption it was confirmed by CEFA's team. CEFA's previous experience in electrification project in Njombe region (Ikondo project) confirms the hypothesis that when social, economic and environmental conditions between nonEE and recently-EE rural villages are similar, energy use habits and consumptions are strongly similar on a short-medium term perspective (1-5 years).

So the data collected in the 2 villages about electric appliances used and habits may be used in LoadProGen to estimate the load curve profile of the 13 non electrified villages.

3.4.5 Fieldwork 2: interviews in Not Electrified Villages

After visiting some of the villages of the project together with CEFA's rural electrification project team the following observations were made**:** the villages have an average population of 2000 people and each village has on average around 400 Households and 5 members per family. All villages are characterized by 2-3 main roads and 2-3 main centers where there are the few typical productive activities of these rural areas: milling machines, carpentries, garages, shops, guest houses, hair cutters and pubs. On average there is a School in each village and more than one Church. Few villages have a Dispensary. The main source of income of households in all the villages is Agriculture.

Due to a strong correlation between the 13 villages it was decided to interview 3 out of 13 villages. On the base of the previous observations it can be assumed that data collected by interviewing the sample of 3 villages can be considered significant of the whole population of the 13 villages. The following table shows number of Users interviewed for each User Class in the villages of Ninga, Lole and Mahongole.

NINGA, LOLE and MAHONGOLE		
	User Class	**Number of interviewed**
HH	Household	50
PB	School	4
	Office	1
	Dispensary	1
	Church	1
US	Millings	3
	Carpentries	3
	Shops	3
	Hair Cutters	2
	Guest Houses	2
	Garage	2
	Pub	4

Table 3-2 Number of interviewed in Not Electrified Villages

Some information about the villages was already collected by CEFA project manager during previous fieldwork in the area, other information was directly collected by surveying head office of each ward or village. The information about the villages already available and collected during the fieldwork is the following: population, number of Households, number of Users within each User Class of Public Services, number of Users within each User Class of Productive Usages.

			HOUSEHOLDES
WARD	**VILLAGE**	**POP**	**HH**
Ninga	Ninga	2,865	611
	Lima	1,602	285
	Isitu	1,736	374
Ikuna	Lole	2,126	514
Kichiwa	Upami	2,800	420
	Ilengintitu	1,700	397
Igongolo	Ibiki	1,972	363
	Kivitu	1,350	350
Mahongole	Kifumbe	3,500	600
	Mtanga	1,728	423
	Manga	3,000	400
	Usetule	1,450	308
	Mahongole	2,250	562
	TOT	**28,079**	**5,607**

Table 3-3 Population and number of Household in the villages

	PUBLIC SERVICES			
VILLAGE	**Schools**	**Offices**	**Dispensaries**	**Churches**
Ninga	3	2	1	4
Lima	1	1	1	4
Isitu	2	1	0	5
Lole	2	1	0	6
Upami	1	1	1	3
Ilengintitu	1	1	0	3
Ibiki	1	1	0	5
Kivitu	1	1	0	4
Kifumbe	1	1	1	0
Mtanga	1	1	1	4
Manga	2	1	1	5
Usetule	1	1	0	4
Mahongole	3	1	0	9
TOT	**20**	**14**	**6**	**56**

Table 3-4 Number of Users within each User Class for Public Services

	PRODUCTIVE USAGES						
VILLAGE	**Millings**	**Carpentries**	**Shops**	**Haircutters**	**Guest Houses**	**Garages**	**Pubs**
Ninga	12	10	30	7	3	1	6
Lima	4	3	10	1	0	1	1
Isitu	11	4	10	1	0	1	1
Lole	3	3	20	1	0	2	4
Upami	1	2	10	1	0	0	3
Ilengintitu	2	6	10	1	0	0	1
Ibiki	2	6	10	1	0	0	2
Kivitu	2	2	10	1	0	0	1
Kifumbe	4	2	10	1	0	0	3
Mtanga	5	0	10	1	0	0	1
Manga	5	5	10	4	0	0	3
Usetule	5	4	10	1	0	1	1
Mahongole	5	3	30	1	0	0	2
TOT	**61**	**50**	**180**	**22**	**3**	**6**	**29**

Table 3-5 Number of Users within each User Class for Productive Usages

3.5 Future Load Demand Estimation

3.5.1 Novel methodology for Load Demand Estimation

In order to estimate the future load curve of the thirteen villages a Novel methodology implemented in a software called LoadProGen was used.
This novel procedure, developed by the group of the UNESCO Chair in Energy for Sustainable Development of Politecnico di Milano consists of a new algorithm for estimating the load profiles of non-electrified areas.
The procedure is based on a set of data that can be surveyed and/or assumed in rural areas, and it relies on a stochastic bottom-up approach with correlations between the different load profile parameters (i.e. load factor, coincidence factor and number of consumers) in order to build up the coincidence behavior of the electrical appliances. [21]
The main features of this model are the following:

- It is based on a rigorous mathematical formulation which allows developing the load profile shape, i.e. apart input data, the designer judgments should not affect the profile shape;
- it is based on a bottom-up approach, i.e. the load profile computation has to rely on microscopic input data referring to each appliances features within a specific type of user class;
- it builds up the coincidence behavior of the appliances and the power peak value with regards to the existing correlation between number of users, load factor and coincidence factor;
- it is stochastic in order to embrace uncertainty, i.e. given the input data, the procedure output has not to be unique, but it should embrace the uncertainty given by the fact that a single correct load profile does not

exist in rural areas. Furthermore, it has the possibility of considering un uncertainty of the input data by introducing randomization parameters.

3.5.2 LoadProGen input data

The software LoadProGen requires little input data that is commonly considered in the simplest approaches for energy need estimations in rural areas, coherently with the data that may be available in the subject under consideration. [21]

The first requisite required by the software is the identification of different User Classes within the population to study. The population was divided into three “categories” which are Households (HH), Public Services (PB) and Productive Usages (US).

The Households were divided in 33 User Classes that correspond to the number of HH interviewed in the electrified villages of Nyombo and Kydegembye. It was decided to implement the largest possible number of User Classes in order to maximize usefulness of data collected. Therefore, each User Class (HH_1, HH_2, HH_3, HH_4…etc.) represents 1/33 of the total population of the 13 villages. The Public Services were divided into 4 User Classes: Schools, Offices, Dispensaries, Churches. The Productive Usages were divided in 7 User Classes: Milling machines, Carpentries, Shops, Haircutters, Guest Houses, Garages, Pubs. When more than one interview was made within the single User Class (e.g. 3 Schools were interviewed as shown in Table 3-1) average values of data collected have been calculated.

For each User Class the data required by the tool are listed below. j refers to the specific User Class (e.g. Houshold_2, Household_7, School, Carpentry, Milling machine etc.), and *i* refers to the type of electrical appliances (e.g. indoor light, television, radio, razor etc.):

- $\boldsymbol{N_j}$ refers to the *number of Users* within UserClass *j* (e.g. number of schools, number of households, etc.).
- $\boldsymbol{n_{ij}}$ refers to the *number of Appliances of type i* present in each User which belongs to UserClass *j* (e.g. number of televisions in each school).
- $\boldsymbol{P_{ij}}$ refers to *nominal power rate* [W] of the appliance *ij* (e.g. nominal power of TV).
- $\boldsymbol{D_{jk}}$ refers to the *functioning cycle* [min], i.e. minimum continuous functioning time once appliance *jk* turns on.
- $\boldsymbol{h_{ij}}$ refers to the *daily functioning time* [min], i.e. the duration of the period the appliances *ij* are on, in a day. *hij* is set for each type of appliance *i*, not for each single device: this means that, for example, all TVs (type of appliance: "TV") present in all the schools (user class: "School") will have the same daily functioning time.
- $\boldsymbol{Wf_{ij}}$ refers to the *functioning window(s)*, i.e. period(s) during the day when the appliances *ij* can be on. Defined by a starting window time and an ending window time, which are set for each type of appliance, similarly to the h*ij*. Each type of appliance can have up to three functioning windows in a day.
- $\boldsymbol{Rh_{jk}}$ refers to the *percentage random variation of the functioning time* of the appliance jk.
- $\boldsymbol{RWf_{jk}}$ refers to the *percentage random variation of functioning window(s)* of the appliance jk.

In Table 3-6 is showed an example of Input Data for the User Class: "Carpentry". The file input required by LoadProGen is an Excel file with several sheets.

Appliance	User_Class	Nj	Pij [W]	nij	Dij [min]	h,ij [min]	R_h [%]	R_Fw [%]	N_Win	Wfs_1 [min]	Wfe_1 [min]	Wfs_2 [min]	Wfe_2 [min]
Ind_ligths	Carpentry	60	18	3	30	450	15	15	2	1	360	1140	1440
Out_lights	Carpentry	60	18	1	30	600	15	15	2	1	360	1140	1440
Charger	Carpentry	60	5	3	30	300	15	15	1	780	1140	0	0
Radio	Carpentry	60	10	1	20	660	15	15	1	420	1140	0	0
Lathe	Carpentry	60	2200	1	30	90	15	15	1	420	1260	0	0
Drill	Carpentry	60	1500	1	10	90	15	15	1	420	1260	0	0
Wood_Route	Carpentry	60	1600	1	30	90	15	15	1	420	1260	0	0
Circular_saw	Carpentry	60	3700	1	30	420	15	15	1	420	1260	0	0

Table 3-6 Example of Input Data for the User Class “Carpentry”

All the types of appliances used in the villages are list in Appendix C.

When subjects were unable to describe the minimum continuous functioning time of appliance once it turns on, values were hypothesized based on literature research [24].

In order to introduce an uncertainty of the input data, the following randomization parameters has been set: the percentage random variation of the functioning time of the single appliance has been set equal to 15%; the percentage random variation of functioning windows of the appliance has been set equal to 15%.

Only two functioning windows were defined. Wfs_1 refers to the starting time of the first functioning window, Wfe_1 refers to the ending time of the first functioning window.

3.6 Energy Demand Assessment

The second goal of the thesis consists of assessing the Energy Demand of the 13 non-electrified villages in order to provide a snapshot of the current primary energy consumption.

3.6.1 Questionnaire for energy sources assessment in Non-Electrified Villages

As shown in previous paragraphs, questionnaires addressed to 13 non-electrified villages are composed of 3 different sections (see Appendix B).

The first section consists of questions about general information of those interviewed. The second section provides necessary data for electricity consumption evaluation and consists of questions about use and usage habits of electric appliances to those User Classes have a minimum access to electricity through connection to home-based solar panel system or a small gen-set. (The electricity produced by the home-based power systems installed was considered as Primary Energy). The surveys have been carried out in 3 out of 13 non-electrified villages (Ninga, Lole, Mahongole). 50 Households were interviewed and 60% of them hold a home-based solar panel system. It was then assumed that around 60% of households in non-electrified villages have a minimum access to electricity through connection to home-based solar panel system. The third section of the survey consists in questions about primary energy consumptions in the villages. All the energy sources used in the villages were considered:

firewood, charcoal, kerosene, petrol, diesel. For each previous energy source three main questions/information were asked to interviewed: purpose of using the energy source, the collecting/delivery systems of the energy source, the daily/weekly energy source consumption.

When more users were interviewed within each User Class, an average value for each energy source consumption was calculated in order to obtain a unique value for each User Class. The table shows the main values calculated for the User Class "Hair Cutters". In the example, three Users were interviewed and the they use only "Electricity" as primary energy source.

Table 3-7 Example of calculation of mean values within the User Class "Hair Cutter"

Hair Cutters interviewed	Electricity [kWh]	Wood [kg]	Charcoal [kg]	Kerosene [l]	Petrol [l]	Oil [l]
1	0.81	-	-	-	-	-
2	0.91	-	-	-	-	-
3	0.92	-	-	-	-	-
Mean value	**0.88**	-	-	-	-	-

3.6.2 Electricity consumption

As already seen in previous paragraph, in order to valuate Electricity consumption of nonEE villages questions about use and usage habits of electric appliances were asked to households, public services and productive uses those have a minimum access to electricity through connection to home-based solar panel systems. The table below shows the data collected which was necessary for calculating the electricity consumption of each User Class.

Table 3-8   Data collected for the Electricity consumption calculation for the User Class “Hair Cutter”

Appliance	User_Class	N_j	P_{ij} [W]	N_{ij}	h_{ij} [h]
Ind. lights	Haircutter	22	7	1	8
Out. lights	Haircutter	22	7	2	11
Radio	Haircutter	22	10	1	4
Razor	Haircutter	22	5	1	3
TV	Haircutter	22	80	1	3

Figure 3-5   Hair Cutter connected to Solar Home-based system

In order to calculate the daily electricity consumption of each User within each User_Class (12 User_Class was defined) the following formulation has been used:

$$\boldsymbol{Ec} = \sum_{i}^{Appliance} \boldsymbol{N_{ij} \cdot P_{ij} \cdot h_{ij}} \ \ [\boldsymbol{Wh/day}]$$

The amount of Electricity consumed by the whole User Class can be calculated simply by multiplying the Electricity consumed by each User (Hair Cutter) by number of Users (Hair Cutters) within the User Class itself (i.e. by number of Hair Cutters in the Villages)

$$\boldsymbol{Ec} = \boldsymbol{N_J} \cdot \sum_{i}^{Appliance} \boldsymbol{N_{ij} \cdot P_{ij} \cdot h_{ij}} \ \ [\boldsymbol{Wh/day}]$$

Finally, the amount of energy consumed by each “category” (HH, PB, US) can be calculated by adding all the values of the User Class within the “Category”. The following formula to calculate Energy Consumed by the Category “PB” (Public Service).

$$\boldsymbol{Ec_{PB}} = \sum_{j}^{User\_Class} \boldsymbol{N_J} \cdot \sum_{i}^{Appliance} \boldsymbol{N_{ij} \cdot P_{ij} \cdot h_{ij}} \ \ [\boldsymbol{Wh/day}]$$

The table 3.4 shows Electricity consumption for each User_Class calculated by using the previous formulas.

Table 3-9 Electricity consumption

Electricity consumption			
	User_Class	**Number of interviewed**	**Average Daily Electricity consumption [kWh/user]**
HH	Household	33/50*	0.94
PB	Schools	4	0.18
	Offices	2	0.89
	Dispensaries	-	-
	Churches	-	-
US	Millings	-	-
	Carpentries	-	-
	Shops	3	0.65
	Hair Cutters	3	0.88
	Guest Houses	-	-
	Garage	-	-
	Pub	4	0.90

*Number of interviewed using the energy source

3.6.3 Wood consumption

In order to assess wood consumption in interviewed villages, questions concerning Wood use, supply and consumption were asked to Households, Public Services and Productive Usages (see Appendix A).

Firewood is the most used energy source in rural villages. Data collected from the survey administered in Ninga, Lole and Mahongole shows that cooking and water heating are the main purposes of using firewood as energy source. Almost all the interviewed said to use three stone stoves as cooking device, only few of them make use of mud stoves. The average number of daily meals for households is 3. Regarding Wood supply and transportation it is possible to state that those who purchase firewood, do so every 15-30 days and are used to carry wooden logs to home by using a car or truck; those who collect firewood for free in the woods do so every 1-3 days and are used to carry wooden logs home by walking or by using cycle or motorbike.

In order to obtain daily Wood consumption from data collected from local surveys the following method was used. During the surveys, people were asked to give information about daily, weekly or monthly wood consumption and photos of the amount they claimed to use within a certain period of time were taken. Afterwards during data analysis in order to evaluate wood consumption of each interviewed (express in Kg/day) it was first assessed by eye the number and sizing of wooden logs consumed by each interviewed by looking at photos took during fieldwork and then, considering 4 different wooden log sections size, the total volume of wood stock was calculated.

Figure 3-6 The amount of wood-stock consumed per week in a house in Lole village (left); a typical mud stove used by some households in Ninga (right)

Table 3-10 The four size of Wooden Logs chosen for Wood consumption estimation method

	Diameter of Wooden logs [cm]
Small	3
Medium-small	7
Medium-large	10
Large	14

Table 3-11 Example of Wood consumption assessment of Household

Number* of logs	Section size* [cm^2]	Lenght* [cm]	Period [days]	daily Volume [m^3]	daily Mass* [Kg]
20	7	200	2	0.014	10.78

* in order to calculate the daily Mass of firewood consumed it was used the Eucalyptus density value (770Kg/m^3).

Finally, an average value was calculated within each User Class.

Wood consumption				
	User_Class	**Number of interviewed**	**ADC* of Wood [kg/user]**	**Purpose use**
HH	Households	50/50*	6.6	cooking
PB	Schools	4	325	cooking
	Offices	-	-	-
	Dispensaries	-	-	-
	Churches	1	6.5	cooking
US	Millings	-	-	-
	Carpentries	-	-	-
	Shops	-	-	-
	Hair Cutters	-	-	-
	Guest Houses	2	20	cooking
	Garage	-	-	-
	Pub	4	15	cooking

*ADC = Average Daily Consumption

*Number of interviewed using the energy source

3.6.4 Charcoal consumption

In order to assess Charcoal consumption in interviewed villages, questions concerning Charcoal use, supply and consumption has been asked to Household, Public Services and Productive Usages (see APPENDIX A). All the interviewed who make use of charcoal use to buy 1-2 Charcoal bags (each bag weight around 30 Kg) every 15-30 days. So to calculate the daily consumption is simply sufficient to divide by number of days**.** Data collected from surveys shows that Charcoal is used mainly in Pubs and Guest Houses for cooking purposes and by some Households for space heating purposes.

Figure 3-7 Typical charcoal stove for cooking or water heating purposes

Table 3-12 Charcoal use and consumption

Charcoal consumption				
	User_Class	**Number of interviewed**	**ADC of Charcoal [kg/user]**	**Purpose use**
HH	Households	22/50*	0.8	Space Heating
PB	Schools	-	-	-
	Offices	2	1	Cooking/SH
	Dispensaries	1	2	Sterilization
	Churches	-	-	-
US	Millings	-	-	-
	Carpentries	-	-	-
	Shops	-	-	-
	Hair Cutters	-	-	-
	Guest Houses	2	0.5	cooking
	Garages	-	-	-
	Pubs	4	2	cooking

3.6.5 Kerosene consumption

In order to evaluate liquid fuels consumption questions about Kerosene use, supply and consumption were asked to HH, PB and US (see Appendix B).

Figure 3-8 Typical Kerosene lamp for lighting purpose

Table 3-13 Kerosene use and consumption

Kerosene consumption				
	User_Class	**Number of interviewed**	**ADC of Kerosene [liter/user]**	**Purpose use**
HH	Households	2/50*	0.8	Space Heating
PB	Schools	-	-	-
	Offices	-	-	-
	Dispensaries	-	-	-
	Churches	-	-	-
US	Millings	-	-	-
	Carpentries	-	-	-
	Shops	-	-	-
	Hair Cutters	-	-	-
	Guest Houses	-	-	-
	Garages	-	-	-
	Pubs	-	-	-

3.6.6 Diesel consumption

In order to evaluate liquid fuels consumption questions about Diesel use, supply and consumption were asked to Household, Public Services and Productive Usages (see Appendix A). Data collected from surveys shows that Diesel is mainly used by Households for transportation purpose (fuel for Truck) and by some Productive Usages as Millings, Carpentries, Garages as fuel for machines' engines or by Guest Houses as fuel for power generators (GenSet).

Figure 3-9 Cutting Wood machine fueled by Diesel engine (left); Diesel Engine technical features (right)

Table 3-14 Diesel use and consumption

Diesel consumption				
	User_Class	**Number of interviewed**	**ADC of Diesel [liter/user]**	**Purpose use**
HH	Households	3/50*	3.3	Truck fuel
PB	Schools	-	-	-
	Offices	-	-	-
	Dispensaries	-	-	-
	Churches	-	-	-
US	Millings	3	2.86	Millings
	Carpentries	3	1.43	Engine
	Shops	-	-	-
	Hair Cutters	-	-	-
	Guest Houses	2	0.43	GenSet
	Garages	2	1.43	Engine
	Pubs	-	-	-

3.6.7 Petrol consumption

In order to evaluate liquid fuels consumption questions about Petrol use, supply and consumption has been asked to Households, Public Services and Productive Usages (see Appendix A).

Data collected from surveys show that Petrol is only used by Households for transportation purpose (as fuel for Motorbike or Car Truck) and by Garages as fuel for Air Compressed machine.

Figure 3-10 Motorbike seldom own by HH (left); Air compressor used by garage (right)

Table 3-15 Petrol use and consumption

Petrol consumption				
	User_Class	**Number of interviewed using Petrol**	**ADC of Petrol [liter/user]**	**Purpose use**
HH	Households	18/50*	1.2	Car/Motorbike
PB	Schools	-	-	-
	Offices	-	-	-
	Dispensaries	-	-	-
	Churches	-	-	-
US	Millings	-	-	-
	Carpentries	-	-	-
	Shops	-	-	-
	Hair Cutters	-	-	-
	Guest Houses	-	-	-
	Garages	2	0.1	Compressor
	Pubs	-	-	-

4 Results

In the following paragraphs, results about Future Load Demand Estimation and Energy Demand Assessment are shown and analysis carried out.

4.1 Future Load Demand Estimation results

Due to very high number of data analyzed by LoadProGen in order to avoid extensive processing time of the software, two input data Excel files were created and two separated load curves were obtained. The first file was formed by 33 User Classes of Households and the second was formed by 11 User Classes of Public Services and Productive Usages. Processing time required by the software to obtain the load curve for the 33 User Class of HH was around 6 hours. Processing time required by the software in order to obtain load curve for the 11 User Classes of PB&US was around 36 hours. The two load curves for HH and PB&US were then added in order to obtain the total aggregate curve.

The output file of LoadProGen is a matrix, 1440 lines (representing the energy demand per minutes in a day) for “n” columns, where “n” is the number of simulations run by the software, set equal to 300. In other words, LoadProGen starting from the same input data simulates 300 possible load curves.

The total number of Households in the village was estimated to be equal to 5607. Due to the uncertainty about the number of Households who will be connected to electricity, different scenarios for the load curve estimation were depicted.

4.1.1 Scenario 50%

In order to obtain the Scenario_50% it was hypothesized that 50% of Households in the villages will have access to electricity when SHPP project is completed. So the total number of Households connected to the mini grid is hypothesized to be 2803. Number of total Users considered within each User Class for PB and US in the villages is shown in Table 3-4 and Table 3-5.

The line graph below (Figure 4-1) illustrates the estimated future load curve of the thirteen villages in the Scenario_50% and the uncertainty bands.

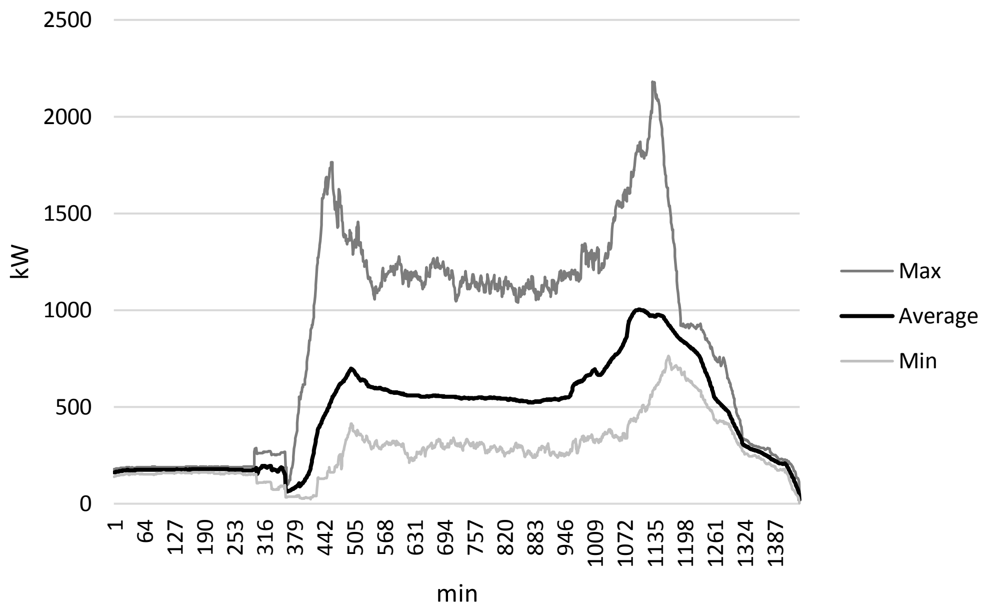

Figure 4-1 Load curve of the thirteen villages: Scenario_50%

The “black” Load curve in Figure 4-1 is the average values of 300 possible load curves resulted from LoadProGen simulations starting from the same input data. The number of simulations “n” to run it was set based on the following conditions:

$$\frac{\bar{y}(k)_n - \bar{y}(k)_{n+1}}{\bar{y}(k)_n} \leq 0.25\% \quad and\ k \geq 95\%\ of\ time\ steps$$

Where k refers to the profile time-steps and $y(k)_n$ refers to the average load profile values of n generated profiles at the time-step k.

The uncertainty bands do not represent possible limit curves but they represent respectively the maximum and minimum load values which can occur in 1440 min (duration of a day in minutes). As shown in the graph, uncertainty bands are very broad. This is due to the fact that this study is the first application of LoadProGen in contexts with a very high number of users: 2803 Households, 96 Public Services and 351 Productive Usages. A further development of the software would be interesting and useful for future studies in similar large rural contexts.

In addition, it can be observed that peak value of the load curve is at sunset between 19:00 and 20:00. Indeed, in rural villages when sun sets, people come back home from work and they turn on lights, radios and televisions. Besides it can be seen that during the night the demand electricity fall to a lower value. Indeed, productive usages are closed and households keep turned on only one or two outdoor lights at nighttime.

In the Scenario_50% the daily energy demand of the villages is equal to 11.1 MWh, while the load peak value is equal to 1.0 MW.

4.1.2 Scenario30% and Scenario70%

In order to obtain Scenario_30% and Scenario_70% it was supposed that 30% and 70% of Households respectively will have access to electricity when SHPP project is completed. So the total number of Households connected to the mini grid is hypothesized to be 1526 for Scenario_30% and 4065 for Scenario_70%.

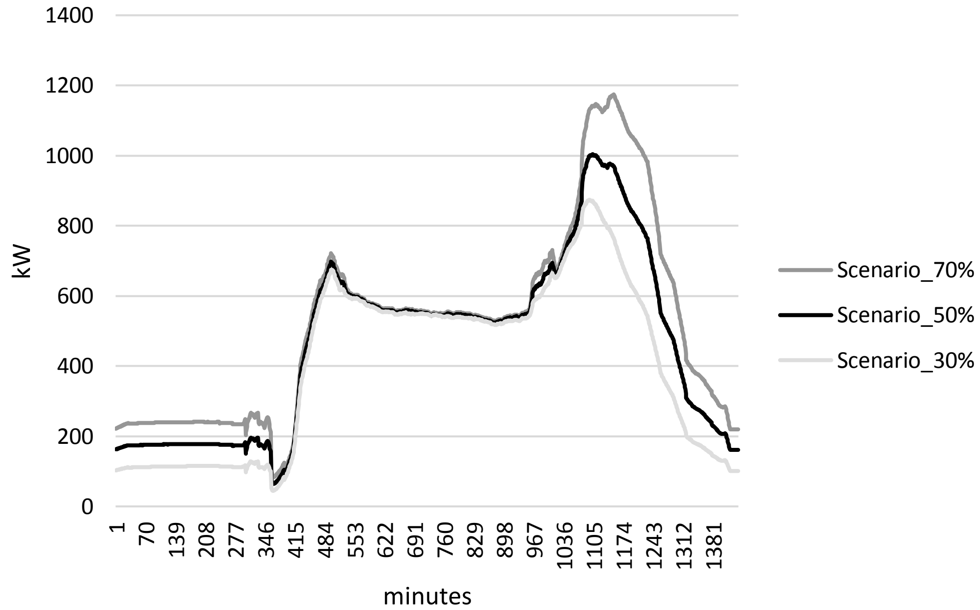

Figure 4-2 Load curves for the three different Scenarios

In the Scenario_30% the daily energy demand of the villages is equal to 9.7 MWh, while the load peak value is equal to 0.87 MW. In the Scenario_70% the daily energy demand is equal to 12.5 MWh and load peak value is equal to 1.17 MW. In the middle of the day, the load curve of the different scenarios roughly overlaps because energy contribution to the load curve in daytime is mainly due to Productive Usages.

4.1.3 Comparison between ENCO and LoadProGen load curve estimation

As already mentioned, the feasibility study for the SHPP of CEFA's Ninga-project was finalized in March 2015 by ENCO, an Italian engineer consulting company. In order to evaluate the excess of electricity that can be sold to the public utility company of Tanzania (TANESCO), ENCO carried out a quick load curve evaluation based on hypothesis and information from studies in similar contexts. In the following paragraph the comparison between ENCO load curve estimation and that one carried out by surveying data and using LoadProGen software is described.

The estimated number of Households in the villages, according to the ENCO feasibility study was 6511. The number of connections promptly realizable was estimated around 50% of the existing premises and other load centers. So the possible connections would be: 50% x 6,511 = 3,256. This number corresponds to 58% of 5706 which is the estimated number of Households according to this study. Thus, in order to compare the two studies, a fourth load curve was implemented in LoadProGen software. It was called scenario_58%.

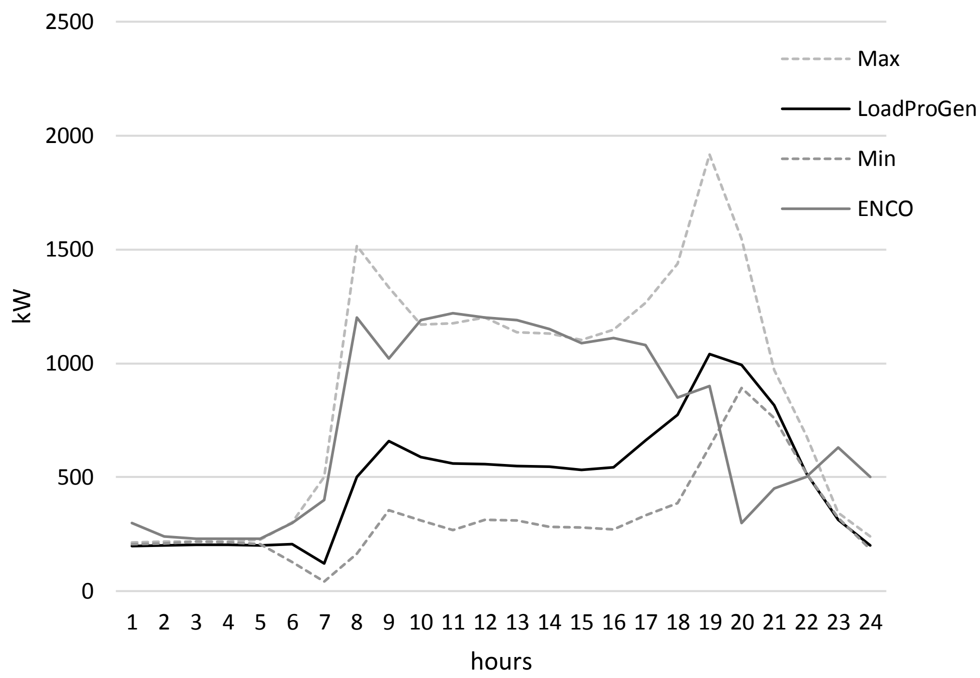

Figure 4-3 Comparison between ENCO and LoadProGen load curve

The graph in **Errore. L'origine riferimento non è stata trovata.** represents the two load curves for the different studies.

By looking at the graph it can be firstly observed that the daily energy demand (area under the load curve) in ENCO estimation is 17.5 MWh, higher than in LoadProGen estimation that is equal to 12 MWh. Table 4-1 shows the monthly and yearly excess of energy that can be sold to TANESCO in the two cases.

Table 4-1 Monthly and yearly energy produced and excess of energy [MWh] for the two conducted studies.

	Ninga SHPP		ENCO		LoadProGen	
	Electric capacity [kW]	Energy Production	Energy demand	Energy surplus	Energy demand	Energy surplus
Jaunary	3679	2737	373	2365	543	2194
February	5974	4015	337	3679	490	3525
March	5974	4445	373	4073	543	3903
April	5974	4302	361	3941	525	3777
May	4315	3210	373	2838	543	2668
June	2836	2042	361	1681	525	1517
July	2194	1633	373	1260	543	1090
August	1807	1345	373	972	543	802
September	1142	823	361	462	525	297
October	881	656	373	283	543	113
November	793	571	361	211	525	46
December	1948	1450	373	1077	543	907
Annual		27230	**4387**	22842	**6391**	20838

The annual energy demand estimated by the consulting company is equal to 6391 MWh while that estimated by LoadProGen is equal to 4387 MWh (around 30% lower). Excess of energy calculated by LoadProGen is around 10% higher than that estimated by ENCO.

Furthermore, it can be noted that the "shape" of the two load curves is significantly different: the peak load value of ENCO's load curve is during central hours of the day (between 10:00 and 13:00) by contrast that of LoadProGen is at sunset (between 18:00 and 19:00).

connections / users	Nr	Installed Capacity Unit W	Installed Capacity Total KW	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	KWh/d
HH connectable	**3256**	200	651.20	35%	30%	30%	30%	40%	55%	80%	50%	40%	35%	30%	25%	25%	20%	20%	25%	25%	30%	35%	60%	70%	88%	70%	40%	6431
Water Pumps	**65**	500	32.50								40%	60%	80%	100%	100%	80%	80%	80%	60%									221
Street lighting	**65**	100	6.50	100%	100%	100%	100%	100%	80%	60%										20%	90%	100%	100%	100%	100%	100%	100%	88
Barber/saloon, bicycle repair, tailors, video	**21**	250	5.25							40%	60%	80%	90%	90%	90%	80%	60%	100%	90%	80%	40%							47
Carpenter, welding, battery charging	**17**	2000	34.00	10%	10%	10%	10%	10%	10%	40%	40%	40%	60%	80%	80%	10%	10%	80%	90%	80%	40%	10%	10%	10%	10%	10%	10%	262
Mills	**66**	15000	990.00							60%	60%	80%	88%	88%	88%	88%	88%	88%	80%	60%	60%							9158
Dispensaries	**8**	3000	24.00	50%	50%	50%	50%	50%	60%	60%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	80%	60%	50%	437
Churches, mosques	**40**	250	10.00							20%	20%	40%	60%	60%	60%	60%					40%	40%	40%	40%	20%			50
Primary schools	**17**	250	4.25						40%	60%	80%	80%	80%	60%	60%	60%	60%	60%	90%	90%	60%	40%						39
Secondary schools	**3**	250	0.75						40%	60%	80%	80%	80%	60%	60%	60%	60%	60%	90%	90%	60%	40%						7
Kindergarten	**0**	250	0.00						20%	40%	60%	60%	60%	90%	90%	50%	40%	90%	90%	90%	80%	20%						0
Hostel	**1**	3000	3.00	40%	10%	10%	10%	20%	40%	90%	60%	20%	10%	10%				10%	10%	40%	90%	90%	90%	80%	70%	60%	40%	27
	3559		**1761**	251	218	218	218	283	384	1157	979	1120	1177	1157	1124	1093	1054	1080	1036	817	842	268	429	494	603	482	284	**16,766**
Total with losses	5%		**1850**	264	228	228	228	297	404	1214	1028	1176	1236	1215	1180	1148	1106	1134	1088	858	884	282	450	518	633	506	298	**17,604**

Figure 4-4 ENCO load curve estimation method (source[19])

By looking at Figure 4.4 it can be sustained that ENCO Load curve estimation may overestimate energy contribution due to electricity consumption of machinery used by Productive Usages of the villages. Indeed, in parallel with the company estimation, functioning hours and functioning windows of Milling machines (power peak 15000W) and Wood cutting machines (3700W) positively correlate. In reality, after visiting and surveying the villages it can be affirmed that during day time the effective functioning time of working machines is much lower than respective functioning windows (e.g. functioning time of Millings is equal to 180 min while the width of functioning windows is equal to 10h – from 08:00 until 18:00 -). Consequently, the energy contribution of Productive Usages to the load curve estimated by ENCO is much higher than that come from this study.

The peak value evaluated by ENCO is equal to 1,22 MW while that estimated by using LoadProGen is equal to 1,04 MW.

The following figure shows the monthly electric capacity of the SHPP. It can be observed that according to ENCO's load curve estimation, the load demand of villages cannot be satisfied during September, October and November because electric capacity in these months is lower than the peak value of the load curve demand of the villages. On the contrary, according to LoadProGen results, load demand cannot only be satisfied during the months of October and November.

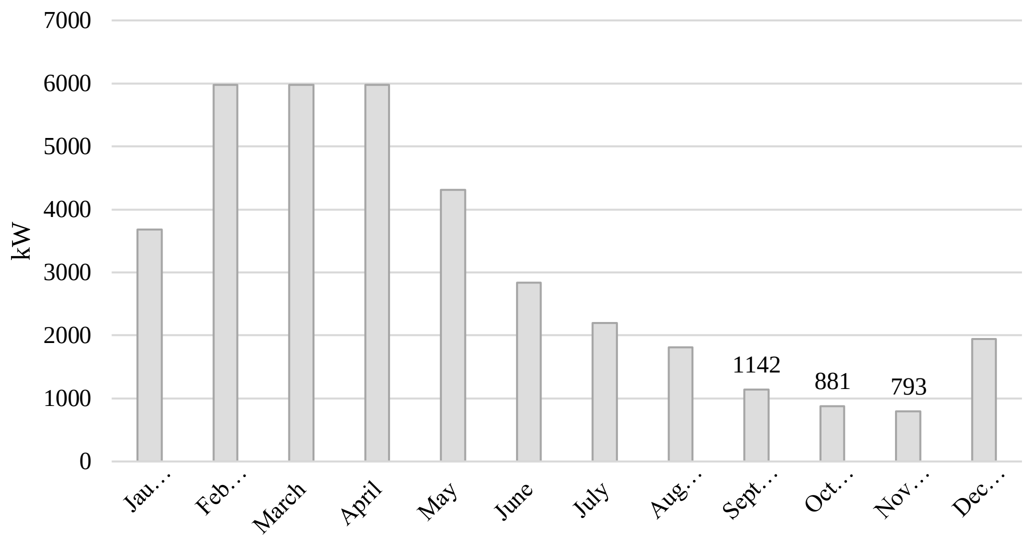

Figure 4-5 Monthly electric capacity of SHPP [kW]

4.2 Energy demand assessment results

The following paragraphs show the results of the primary energy demand assessment illustrated in Chapter 3. As seen before, in order to assess the primary energy demand of the non-electrified villages 3 out of 13 villages were interviewed (see Questionnaire in Appendix B).

Table 4-2 Number of Users interviewed in selected villages

NINGA, LOLE and MAHONGOLE		
	User Class	**Number of interviewed**
HH	Household	50
PB	School	4
	Office	2
	Dispensary	1
	Church	1
US	Millings	3
	Carpentries	3
	Shops	3
	Hair Cutters	2
	Guest Houses	2
	Garage	2
	Pub	4

During interviews it was observed that energy consumption values of Users within each User Class of PB and US were very similar. Base on this observation and on available time, it was decided to spend more time on administering surveys to Households than Public Services or Productive Usages. A total of 50 Households, 8 Public Services and 19 Productive Usages were interviewed in the selected villages (Table 4-2).

In the Chapter 3 the daily primary energy consumption expressed in kg/day or liter/day was estimated. In the next paragraphs in order to convert the daily primary energy consumption expressed in kg or liter to energy consumption expresses in "kJ" the conversion factors of Table 4-3 have been used. The Lower Heating Value for Wood and Charcoal is expressed in kJ/kg. The Lower Heating Value for Kerosene, Petrol and Diesel is expressed in kJ/liter.

Table 4-3 Lower heating value and density of primary energy sources [25]

	Wood	**Charcoal**	**Kerosene**	**Petrol**	**Diesel**
LHV [kJ/Kg]	**14400***	**29600**	43000	48000	44800
density [Kg/lt]	-	-	0,79	0,905	0,894
LHV [kJ/lt]	-	-	**33970**	**43440**	**40051**

*LHV of unseasoned firewood (fresh/wet), humidity value equal to around 20%

4.2.1 Households primary energy consumption

In order to assess the Energy consumption of the 5607 households of the villages it was assumed that the sample of 50 Households interviewed is representative of the total population of the villages. Implementing this assumption, it is concluded for example that 44% of interviewed households use Charcoal as energy source, so 44% of the entire population of the 13 villages makes use of charcoal (i.e. 0.44*5607 = 2467 households make use of Charcoal).

Figure 4-6 Typical house in rural villages

As shown in Table 4-4, Wood is the most used energy source by HH in the villages. Cooking and water heating are the main purposes of using firewood as energy source. 44% of HH use Charcoal with an average daily consumption of 0.79 kg per day mainly for heating and boiling water uses. Only 4% make use of Kerosene for lighting purpose. Those who own a motorbike or a car (36%) have an average daily consumption of Petrol equal to 1.2 liter per day, while those own a truck (6%) have an average daily consumption of Diesel equal to 0.94 liter/day.

Table 4-4 Households primary energy consumption

HOUSEHOLD	% of population using the source	Consumption per HH [kg/day]	Energy per 5067 HH [kJ/day]
Wood	100	6.59	532093534
Charcoal	44	0.79	57377232
Kerosene	4	0.21*	1632598
Diesel	6	3.33*	48713616
Petrol	36	1.18*	95128640
Electricity	60	0.94*	12514824

* [liter/day]

Around 60% of HH have a home-based solar panel system that allow the use of few bulbs for lighting and charging. The total primary energy demand of Households in the thirteen villages is equal to 747460 MJ/day.

The pie chart of Figure 4-7 shows the share of daily primary energy consumption by fuel for Households in the 13 villages.

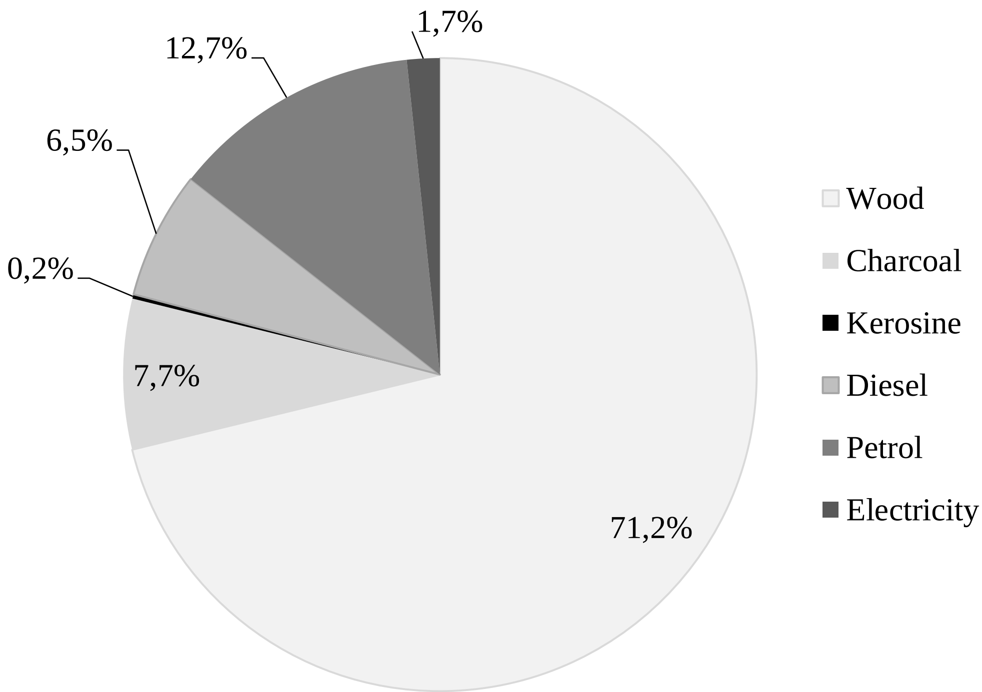

Figure 4-7 Share of daily energy consumption for Households

The pie chart in Figure 4-7 shows that around 80% of the energy demand of Households in the villages is met by using biomass in the form of Wood and Charcoal.

4.2.2 Public Services energy consumption

A total number of 8 Public Services were interviewed in order to assess primary energy demand: 4 Schools, 2 Public Offices, 1 Dispensary and 1 Church were interviewed in the selected non-electrified villages. In order to calculate the total energy demand of each User Class within the category "Public Services" the daily energy consumption of each User was multiplied by the number of Users in the villages (Table 3-4). Results are shown in the following tables.

Schools

2 secondary and 2 primary schools have been interviewed. 3 out of 4 Schools have a small solar panel system that provides the building with a minimum of electricity. It allows to use few light bulbs in 5/6 rooms for few hours per day. The average number of students within the interviewed school is set on 500. The only energy source used by the Schools is firewood. It has been estimated that each School consumes around 325Kg of firewood per day. The firewood is generally collected by hand by students once every 15-30 days. Firewood is used mainly for cooking and water heating and the kitchen is usually located outside of the schools inside a walled or wooden building.

Table 4-5 Secondary School in Ikondo village

SCHOOLS	
	Energy for 20 Schools [MJ/day]
Wood	93600
Charcoal	0
Kerosine	0
Diesel	0
Petrol	0
Electricity	13
Total	93613

Offices

Two offices in the selected villages were interviewed. The first primary energy source used in the Office is Charcoal. It is used mainly for boiling water and heating. Every Office have a small solar panel system that provides the building with a minimum of Electricity that allows to use few light bulbs and a charger for few hours per day. No printer and computer are used in the villages.

Table 4-6 Public office in the village Mahongole

	OFFICE
	Energy per 14 Offices [kJ/day]
Wood	0
Charcoal	414400
Kerosene	0
Diesel	0
Petrol	0
Electricity	44604
Total	459004

Dispensaries

In the thirteen villages there are a total of 6 Dispensaries**.** Only one dispensary was interviewed but information pertaining nearby dispensaries was asked to local people. Dispensaries do not have access to electricity through connection to a stand-alone power system (solar panel or Gen-set). The only primary energy source used in the villages is Charcoal, used for sterilization purpose.

Table 4-7 Dispensary in the village of Ninga

DISPENSARY	
	Energy per 6 Dispensaries [kJ/day]
Wood	0
Charcoal	355200
Kerosene	0
Diesel	0
Petrol	0
Electricity	0
Total	355200

Churches

In the thirteen villages there are a total of 53 Churches. Only one church was interviewed in the selected villages. The only primary energy source used in the Churches is Charcoal, mainly for heating or cooking purposes.

Table 4-8 Church in Matembwe village

CHURCHES	
	Energy per 53 Churches [kJ/day]
Wood	5241600
Charcoal	0
Kerosene	0
Diesel	0
Petrol	0
Electricity	0
Total	5241600

The following pie charts shows the Share of total energy consumption by fuel for the category “Public Services”. More than 99% of energy needs of Public Services are met by using wood.

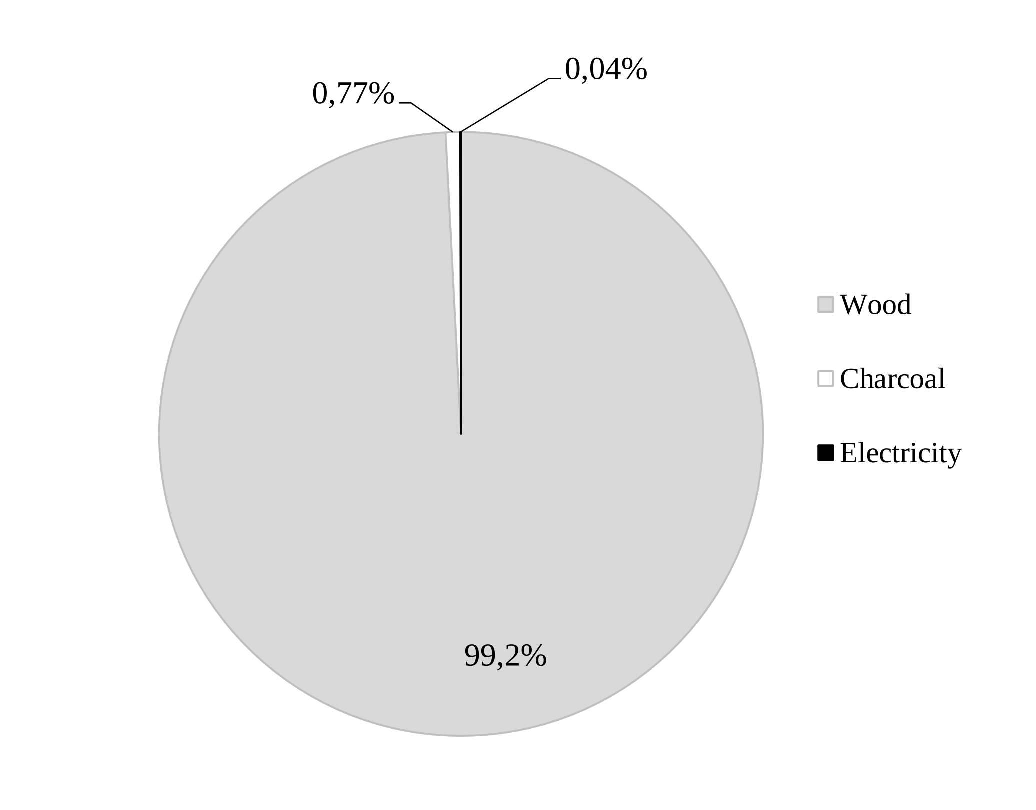

Figure 4-8   Share of Total energy consumption for “PB” of the villages

4.2.3 Productive Uses energy consumptions

A total Number of 16 Productive Usages were interviewed in order to assess primary energy demand: 3 Millings, 3 Carpentries, 3 Shops, 2 Hair Cutters, 2 Guest Houses, 2 Garages and 4 Pubs. In order to calculate the total energy demand of each User Class within the category "Productive Usages" the daily energy consumption of each User was multiplied by the number of Users in the villages (Table 3-5). Results are shown in the following tables.

Millings

In the thirteen villages there are a total of 61 Millings. They allow the production of maize flour which is the base ingredient of Ugali, the most important and common source of nourishment in rural areas in Tanzania. The only energy source used in the Millings is Diesel, used for milling machines engine with an average daily consumption of 2.86 liter per User per day. Due to the high price for purchasing this fuel (price is higher in rural areas) grinding maize becomes a business activity difficult to sustain in rural contexts.

Table 4-9 Milling machine and its owner in Mahongole

MILLINGS	
	Energy per 61 Millings [kJ/day]
Wood	0
Charcoal	0
Kerosene	0
Diesel	7570971
Petrol	0
Electricity	0
Total	7570971

Carpentries

Carpentries use only Diesel as a primary energy source. It is used mainly as fuel for Wood Cutting machines, but also as fuel for Generator in order to produce electricity to power Drills and Wood routers. In the villages there are 50 Carpentries and their total primary energy consumption is equal to 3102 MJ per day.

Table 4-10 Circular saw powered by a diesel engine

CARPENTRIES	
	Energy per 50 Carpentries [kJ/day]
Wood	0
Charcoal	0
Kerosene	0
Diesel	3102857
Petrol	0
Electricity	0
Total	3102857

Shops

In the thirteen villages there are a total of 180 Shops. Three shops in the selected villages were interviewed. The energy source used in the Shops is Electricity. Every Shop has a small solar panel system that provides the building with a minimum of electricity that allows to use 1/2 light bulbs, a charger and sometimes a radio for few hours per day.

Table 4-11 Shop in the village of Lole

SHOPS	
	Energy per 180 Shops [kJ/day]
Wood	0
Charcoal	0
Kerosene	0
Diesel	0
Petrol	0
Electricity	423144
Total	423144

Hair Cutters

The energy source used by Hair cutters is Electricity. Hair Cutters have a small solar panel system with battery storage. It provides the building with a minimum of electricity that allows the use of a razor for cutting hair, 1/2 light bulbs, a charger and sometimes a radio or a TV for few hours per day. The availability of energy from the sun is variable during the year.

Table 4-12 Hair cutter with home-based solar panel system

HAIR CUTTERS	
	Energy per 22 Hair Cutters [kJ/day]
Wood	0
Charcoal	0
Kerosene	0
Diesel	0
Petrol	0
Electricity	69775
Total	69775

Guest Houses

There are only three Guest Houses in the thirteen villages of the Ninga project. All the interviewed Guest Houses use wood and charcoal for cooking and heating purposes. They also have a Diesel generator that produces electricity to power light bulbs in the building and TV and radio in the dining room.

Table 4-13 Guest House in the village of Mahongole

GUEST HOUSES	
	Energy per 3 Guest Houses [kJ/day]
Wood	864000
Charcoal	44400
Kerosene	0
Diesel	55851
Petrol	0
Electricity	0
Total	964251

Garages

Garages are small bikes and motorbikes repairers using electric devices.

They have a Diesel Generator that produce electricity to power Welding Machines, Drills and they use Air compressors fueled by a Petrol engine.

Table 4-14 Air compressor fuelled by Petrol

GARAGES	
	Energy per 6 Garages [kJ/day]
Wood	0
Charcoal	0
Kerosene	0
Diesel	372343
Petrol	24031
Electricity	0
Total	396374

Pubs

Pubs are small places where people can get food and beverages and meet for a drink. The energy sources used are mainly firewood and charcoal for cooking purpose and they usually have a small solar panel that gives electricity to power a few light bulbs and a TV or radio.

Table 4-15 Inside of a pub in the village of Mahongole

	PUBS
	Energy per 29 Pubs [kJ/day]
Wood	6264000
Charcoal	1716800
Kerosene	0
Diesel	0
Petrol	0
Electricity	94169
Total	8074969

The following pie chart shows the share of total energy consumption for the category “Productive Usages”.

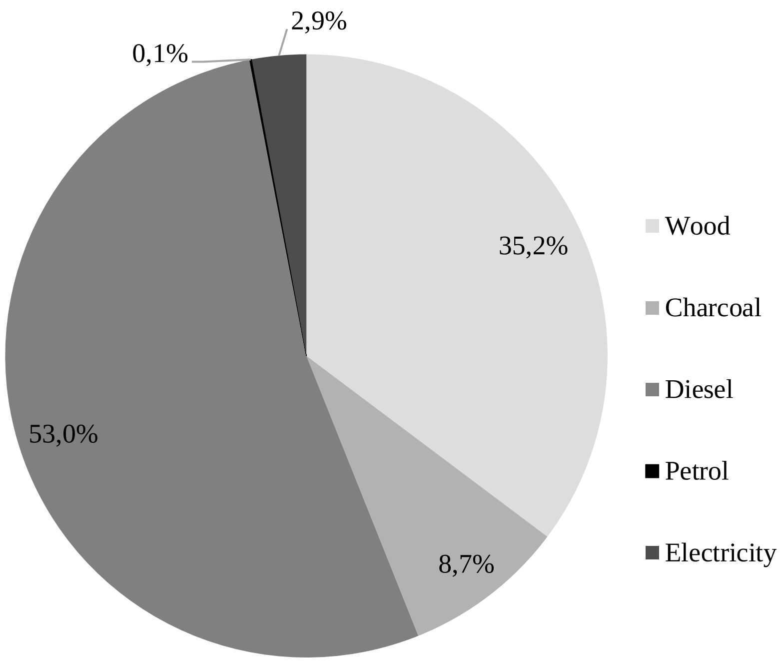

Figure 4-9 Share of total energy consumption for “Productive Usages”

It can be stated that Diesel fuel is the most heavily used energy source for Productive Usages accounting for over half of the total energy demand of the villages.

4.2.4 Total energy consumption in the 13 Villages

The following pie chart shows the Share of total energy consumption of the 13 villages.

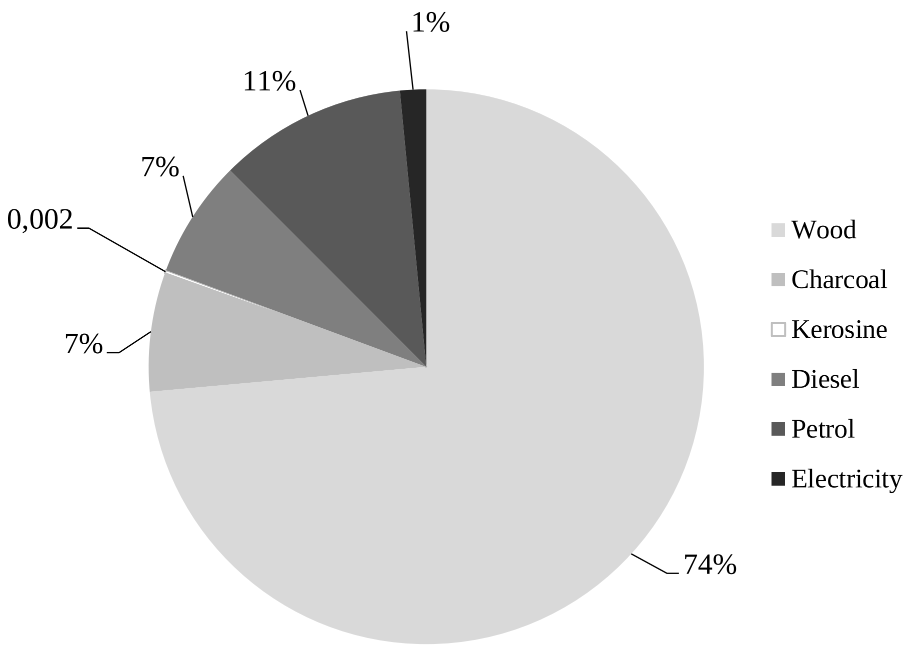

Figure 4-10 Share of Total Energy consumption by fuel in the 13 villages

The chart shows that more than 80% of total primary energy demand in the villages is met by biomass in the form of Wood and Charcoal.

Conclusions

The final intent of the Mission in Tanzania was carried out a study about energy usages and consumptions in the 13 villages of the Ninga project.

The first goal of this thesis was to evaluate the future electrical load curve of 13 non electrified villages when they will have access to electricity through connection to the mini grid powered by the Small Hydro Power Plant of the Ninga project. In order to achieve the goal, questionnaires were created and data collected by surveying local villages during the time spent in Tanzania were used as input in a software called LoadProGen for the load curve estimation in rural contexts.

Four different electrical load curves of the villages were obtained in order to represent the possible scenarios that may arise in relation to the future number of Households connectable to the mini grid. By comparing a previous load demand estimation (it was conducted based on assumptions and literature research) carried out in March 2015 by the engineering company ENCO with the novel methodology implemented in the software LoadProGen used in this study, the following observations were made.

The ENCO's electrical load estimation overrates the functioning time of electric devices used by the Productive Usages in the daytime. Indeed, the load curve shows a peak load in the middle of the day. Contrary, the results of this study, which arise from surveyed data in local villages, show that effective functioning time (functioning hours) of electric devices of Productive Usages are much lower than respective functioning windows. So accordingly with this study, the energy contribution of Productive Usages to the load curve during the day is much lower as represented by the load curve estimated by Load Pro Gen.

Moreover, it can be also observed that daily electrical energy demand estimated in this study is around 30% lower than that evaluated by the engineering company. Consequently, the results show that the annual excess of energy that can be sold to TANESCO is around 10% higher compare to the ENCO study. This makes the Ninga project economically and financially more attractive for the future private investors.

The second goal of this thesis was the assessment of the primary energy consumption in the 13 villages of the Ninga project. In order to achieve the goal, questionnaires were created and data collected by surveying the villages were organized and analyzed.

Regarding to energy consumptions of Households, the results of the primary energy assessment confirm what is found in the literatures relating to energy consumption in rural Tanzania: more than 80% of primary energy demand is met by using Firewood and Charcoal used for cooking and heating purposes. This consequently leads to the problems of premature deaths for inhaling smoke produced by the daily use of traditional stoves and to the problem of deforestation, which are common in developing countries where there is an overuse of biomass.

On one hand, a possible future energy intervention for CEFA in the villages may be to promote the use of alternative sources to Wood and Charcoal as LPG or electric devices. LPG and electrical cook stoves are more efficient and less polluting and their spread could lead to a reduction to premature deaths. On the other hands, other intervention may be to promote the use of improved wood stoves which have a higher efficiency compare to the traditional ones in order to reduce the wood and charcoal consumptions and mitigate the problem of deforestation.

Finally, regarding to energy consumptions of Productive Usages, it can be observed that more than 50% of the primary energy demand is met by using Diesel. As the price of purchasing Diesel in rural contexts is very high due to the transportation fees, often local businesses are economically unsustainable. The electrification of the villages will lead to the replacement of old and inefficient machinery fueled by Diesel engines with electric machines which are more efficient and less polluting making local businesses economically more sustainable. A more detailed study regarding the replacement of machinery powered by Diesel with electric ones would be interesting in order to understand the effect on the new electric profile of the village and the economic impact on local businesses.

Appendix A

This section reports the two surveys administered to Electrified Villages:

- questionnaire to Households of the villages **Q_EE_HH**
- questionnaire to Public Services and Productive Usages **Q_EE_PB_US**

Questionnaire addressed to Electrified Household (Q_EE_HH)

1. General information

Date: .../.… /….…
Location:
Number of user:
Name of the village

Interviewed information:

Name: ...
Age: ….
Role: ….
Education: ....

1.1. How many people live are in your house?

1.2. How many people between 0 - 10 years old?

1.3. How many people between 10 - 20 years old?

1.4. How many people more than 20 years old?

1.5. How many rooms are there in your household?

1.6. Which is the size of your house? …. (can I measure your room size)

1.7. Which is the main source of income of the household?

- □ Agriculture
- □ Cuttle breeding
- □ Salaried employment
- □ Self employment
- □ Other

1.8. Which is the monthly average income of your household (TSH)?

1.9. How much money does your household spend per month (TSH)?

1.10. How often do you have difficulty in getting enough food?

- ◻ Always
- ◻ Often
- ◻ Seldom
- ◻ Never

2. Electricity use and supply

2.1. Which are the devices using electricity in the house?

Appliance	Power	Num.	Average time of daily use	Minimum time	Functioning window
i	P_{ij} [W]	N_{ij}	h_{ij} [h]	D_{ij} [min]	$Wf,_{ij}$
Indoor lights					
Outdoor lights					
Radio					
Charger					
….					
Other					

2.2. How often do you pay your electricity bill?

- ◻ Daily
- ◻ Weekly
- ◻ Monthly
- ◻ Bimonthly
- ◻ Trimonthly
- ◻ Other

2.3. How much do you pay for the bill every time (TSH)?

2.4. Which is the monthly average electricity consumption of your household?

2.5. Do you have any comment about the electricity supply?

Questionnaire to Electrified Public Services and Productive Usages (Q_EE_PB_US)

1. **Type of User Class:**

- School
- Dispensary
- Publi Office
- Curch

- Milling Machine
- Carpentry
- Shop
- Hair Cutter
- Guest House
- Garage
- Lighted Pub

2. **General information**

Date: ... /… /…

Location:

Number of user:

Name of the village

Interviewed information:

Name: ...
Age: ….
Role: ….
Sex: …
Education: ....

3. Electricity use and supply

3.1. Which are the devices using electricity in the house?

Appliance	Power	Num.	Average time of daily use	Minimum time	Functioning window
i	P_{ij} [W]	N_{ij}	h_{ij} [h]	D_{ij} [min]	Wf_{ij}
Indoor lights					
Outdoor lights					
Radio					
Charger					
TV					
DVD					
….					
Other					

3.2. How often do you pay your electricity bill?

- ◻ Daily
- ◻ Weekly
- ◻ Monthly
- ◻ Bimonthly
- ◻ Trimonthly
- ◻ Other

3.3. How much do you pay for the bill every time (TSH)?

3.4. Which is the monthly average electricity consumption of your household?

3.5. Do you have any comment about the electricity supply?

Appendix B

This section reports the two surveys administered to Non-Electrified Villages:

- questionnaire to Households **Q_nonEE_HH**
- questionnaire to Public Services and Productive Usages **Q_nonEE_PB_US**

Questionnaire to Non Electrified Households (Q_notEE_HH)

1. General information

Date: …./…. /….…
Location:
Number of user:
Name of the village

Interviewed information:

Name: ...
Age: ….
Role: ….
Sex: …
Education:..

1.1. How many people live in your house?

1.2. How many people between 0 - 10 years old?

1.3. How many people between 10 - 20 years old?

1.4. How many people more than 20 years old?

1.5. How many rooms are there in your house?

1.6. Which is the size of your house? …. (can I measure your room size)

1.7. Which is the main source of income of the household?

- □ Agriculture
- □ Cuttle breeding

- ◻ Salaried employment
- ◻ Self employment
- ◻ Other

1.8. Which is the monthly average income of your household (TSH) ?

1.9. How much money does your household spend per month (TSH) ?

1.10. Is your house connected to a stand-alone power system?

- ◻ Diesel Generator
- ◻ Solar panel
- ◻ Rechargable battery
- ◻ Not connected

2. Electricity use and supply

2.1. Which are the devices using electricity in the house?

Appliance	Power	Num.	Average time of daily use	Minimum time	Functioning window
i	P_{ij} [W]	N_{ij}	h_{ij} [h]	D_{ij} [min]	$Wf_{,ij}$
Indoor lights					
Outdoor lights					
Radio					
Charger					
TV					
DVD					
Razor					
Other					

3. Firewood use and supply

3.1 Do you use firewood in your house?

3.2 Which are the main purposes of using firewood?

- Cooking
- Space heating
- Water heating
- Other

3.3 Which are the cooking systems used?

- Three stone fire
- Saw dust stove
- Mud stove
- Improved stove
- Wood stove
- Other

3.4 Where do you usually cook?

- Inside the house
- Outside wooden kitchen
- Outside walled kitchen
- Open air

3.5 On a daily basis, how many meals do you cook using firewood?

3.6 Where do you take the firewood from?

- In the wood for free
- by purchasing it
- other (specify...)

3.7 How is the firewood transported to your house?

- By hands
- By bike
- By motorbike
- By car
- By Truck

3.8 How often do you provide firewood to your house?

- By hands
- By bike
- By motorbike
- By car
- By Truck

3.9 How much firewood do you use per day?

3.10 Are you aware of the issue of deforestation linked to the use of wood as fuel?

- ☐ Yes
- ☐ No

4. Charcoal use and supply

4.1. Do you use charcoal in your house?

4.2. Which is the main purpose of using charcoal?

- ☐ Cooking
- ☐ Space heating
- ☐ Water heating
- ☐ Other (please specify ….)

4.3. How much charcoal do you use per day?

5. Kerosene use and supply

5.1. Do you use kerosene in your house?

5.2. Which is the main purpose of using kerosene?

- ☐ Cooking
- ☐ Water heating
- ☐ Others (please specify ...)

5.3. How much do you purchase per week?

6. Diesel use and supply

6.1. Do you use diesel in your house (i.e, for a GenSet or transportation)?

6.2. Which is the main purpose of using kerosene?

- ☐ GenSet
- ☐ Transportation (car, tractor, truck, ...)
- ☐ Others (please specify)

6.3. How much Diesel do you use/purchase per week?

7. Oil/Gasoline use and supply

7.1. Do you use gasoline in your house (i.e, for transportation)?

7.2. Which is the main purpose of using gasoline?

- □ Transportation (car, tractor, truck, …)
- □ Others (please specify …)

7.3. How much gasoline do you purchase per week?

Appendix C

The following table shows the appliances used in the villages and their electric power.

Appliance	**P [W]**
Charger	5
DVD	20
Ind_ligths	7
Out_lights	7
PC	100
Radio	10
Razor	5
TV	80
Circular_saw	3700
Cutting _metal_machine	2200
Decoder	20
Drill	1500
Kettle	1500
Lathe	2200
Milling machine	15000
Organ	300
Photocopy	1200
Printer	150
Pump	300
Welding machine	2500
Wood_Route	1600
Refrigerator	250
Sterilizer	2300

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