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Fostering rural electrification through high time definition load demand calibration: the case-study of Matembwe

TESI DI LAUREA MAGISTRALE IN
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Alla nonna Maria Angela,

che mi ha insegnato a leggere, scrivere e contare.

Abstract

Ensuring access to affordable, reliable, sustainable and modern energy for all is, not only a United Nations Sustainable Development Goal, but a prerequisite for poverty elimination, economic development, improve public health, widespread education, and gender equality.

The NGO CEFA Onlus has been collaborating with Politecnico di Milano for several years in international cooperation on the topic of rural electrification. In particular, the subject of the studies is the village of Matembwe, in Tanzania, where CEFA has built two hydroelectric power plants and a mini-grid, which gives to eight villages access to electricity.

The objective of this research is threefold. The first objective is to provide a map of current and possible users divided by type (households, public services, business activities), with associated the characteristics of their buildings and energy sources. The second is to map the transformers used by the Ikondo-Matembwe mini-grid to distribute electricity to the eight villages, useful for future medium- or low-voltage line expansions. The third is to provide a Matembwe user-specific load demand with high temporal definition. The load curves provided are divided by user categories based on their average annual energy consumption. The load demand calculation is implemented by an open-source software developed by Politecnico di Milano, RAMP. In order to validate the curve processed by the modelling tool, it is necessary to compare it with that coming from consumption data recorded by the power company. The creation of the maps and curves was only possible following a data collection that took place on field.

The tools provided make it possible with hourly accuracy and divided by user classes to design future connections. In this way, CEFA, as other NGOs, can exploit the results to expand the mini-grid in a more effective way in future projects.

Key-words: rural electrification, Tanzania, energy for development, modelling software, load demand.

Abstract in italiano

Assicurare a tutti l'accesso a un'energia economica, affidabile, sostenibile e moderna è, non solo un Obiettivo di Sviluppo Sostenibile delle Nazioni Unite, ma un presupposto imprescindibile per l'eliminazione della povertà, lo sviluppo economico, il miglioramento della salute pubblica, la diffusione dell'educazione, e la parità di genere.

L'ONG CEFA Onlus collabora da diversi con il Politecnico di Milano nell'ambito della cooperazione internazionale sul tema dell'elettrificazione rurale. In particolare, oggetto degli studi è il villaggio di Matembwe, in Tanzania, dove CEFA ha costruito due centrali idroelettriche e una mini-grid, che dà accesso all'elettricità a otto villaggi.

L'obiettivo di questa ricerca è triplice. Il primo è una mappa di attuali e possibili utenti divisi per tipologia (abitazione, servizio pubblico, attività commerciale), con associate le caratteristiche delle loro costruzioni e fonti di energia. Il secondo è una cartina dei trasformatori che utilizza la Ikondo-Matembwe mini-grid per distribuire l'elettricità agli otto villaggi, utile per future espansioni della linea di media o bassa tensione. Il terzo è una curva della domanda degli utenti di Matembwe ad alta definizione temporale. Le curve di carico fornite sono divise per categorie di utenti in base al loro consumo energetico medio annuale. Il calcolo delle domande di carico è stato implementato da un software open-source sviluppato dal Politecnico di Milano, RAMP. Per validare la curva elaborata dallo strumento di modellazione, è stato necessario confrontarla con quella proveniente dai dati di consumo registrati dalla compagnia elettrica. La realizzazione delle mappe e delle curve è stata possibile solo in seguito ad una raccolta dati avvenuta sul campo.

Gli strumenti forniti rendono possibile con una precisione oraria e divisa per classi di utenza la progettazione di future connessioni. In questo modo, saranno utili a CEFA e a tutte le ONG per semplificare e rendere più efficace l'espansione della rete in progetti futuri.

Parole chiave: elettrificazione rurale, Tanzania, energia per lo sviluppo, software di modellazione, domanda di carico.

Contents

1 Introduction

1.1. Overview

This thesis is divided in four chapters, with the aim of presenting the work carried out to achieve the results obtained.

The first chapter includes a brief introduction to the problem of the access to energy with a focus on Tanzania, host country of the case study. A description of Matembwe, the village where the Ikondo-Matembwe mini-grid is placed and object of the analysis, is reported. Then, an outline of the history and of the actors that manage the mini-grid.

The second chapter is dedicated to present materials and methods employed for the analyses performed. Firstly, a description of the on-field work, including the data collection with surveys and instruments adopted. Secondly, the categorization of the mini-grid users is introduced. Thirdly, the defining process of the load demand calculated by the modelling tool and with actual values is explained. Furthermore, the method for the comparison between the two previous demands is presented.

In the third chapter all the results obtained are related retracing the points of the previous section. Maps, tables, and graphs are shown to illustrate the outcomes of the analysis. The comparison between the yearly average energy consumptions provided by the actual data and by the modelling tool is assessed to validate the high time definition calibration of the load demand.

In the fourth chapter, conclusions and discussions about the results achieved by the thesis work are reported.

1.2. Public-private relationships for rural electrification in Tanzania

The access to affordable, reliable, sustainable, and modern energy is one of the seventeen Sustainable Development Goals established by the UN as primary objectives to be reached before the 2030 [1].

Electricity is necessary to boost the economic development and to provide modern energy services, but in Sub-Saharan Africa less than the 50% of the population has access to electricity [1]. Few and unreliable infrastructures limit access to energy in African countries, where the development is slowed down by a reduced possibility to invest in the power sector, by the absence of financial policies that allow the growth and typically an instable government [2]. Thus, energy is generally not affordable neither reliable, so households have limited access to the services provided by electricity, considered humans basic needs, as lighting, cooking, communications, and thermal comfort [3]. In addition, in the absence of electricity, people tend to rely on traditional biomass for cooking, causing health and environmental issues for the users.

Particularly, in rural villages of sub-Saharan Africa the problem is even more unsolved, where the population that has access to electricity is the 28,5% [4]. These areas are usually far from big social centre and difficult to reach, so is challenging to connect them with distribution lines. Inhabitants of these villages mainly rely on agriculture, have access to electricity is a step necessary to improve the quality of life and foster the development of the activities.

Despite Africa has a very limited access to energy, in the global energy demand growth, has a very important role, since it is rich of reserves of fossil fuels and minerals, and a source solar power, crucial resources for fulfil the future demand [2]. This represents the most characteristic contradiction of the continent.

The figure below shows the percentage of the access to energy in the whole Africa continent.

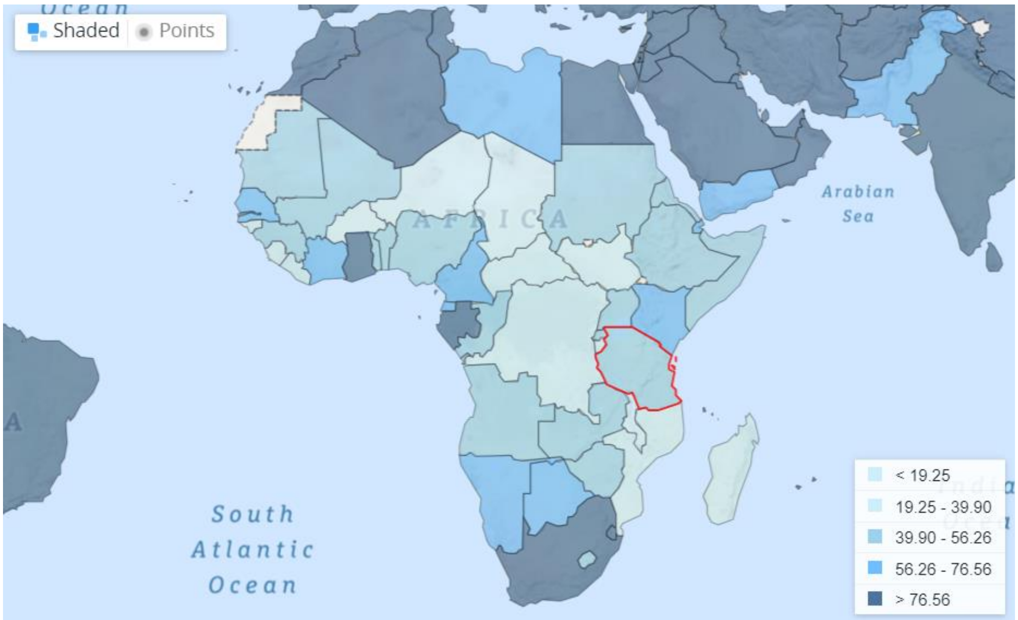


Figure 1.1: Access to energy in Africa (% of population) [4].

In Tanzania, around the 60% of the inhabitants do not have access to electricity [4], percentage of connected lower than the sub-Saharan average [1].

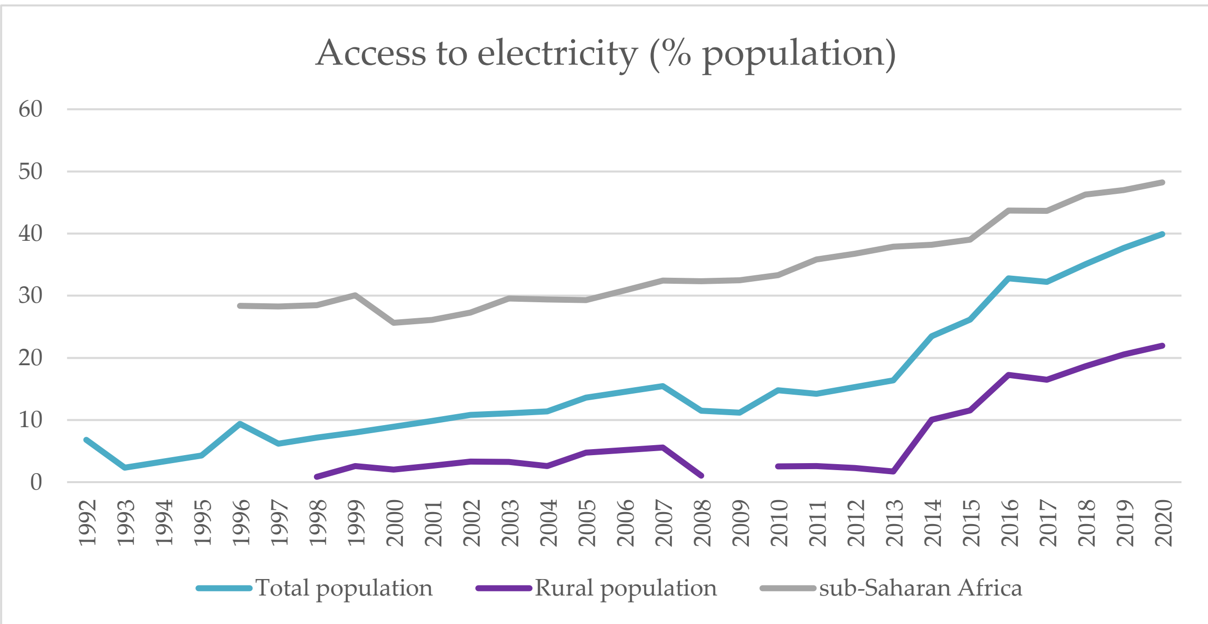


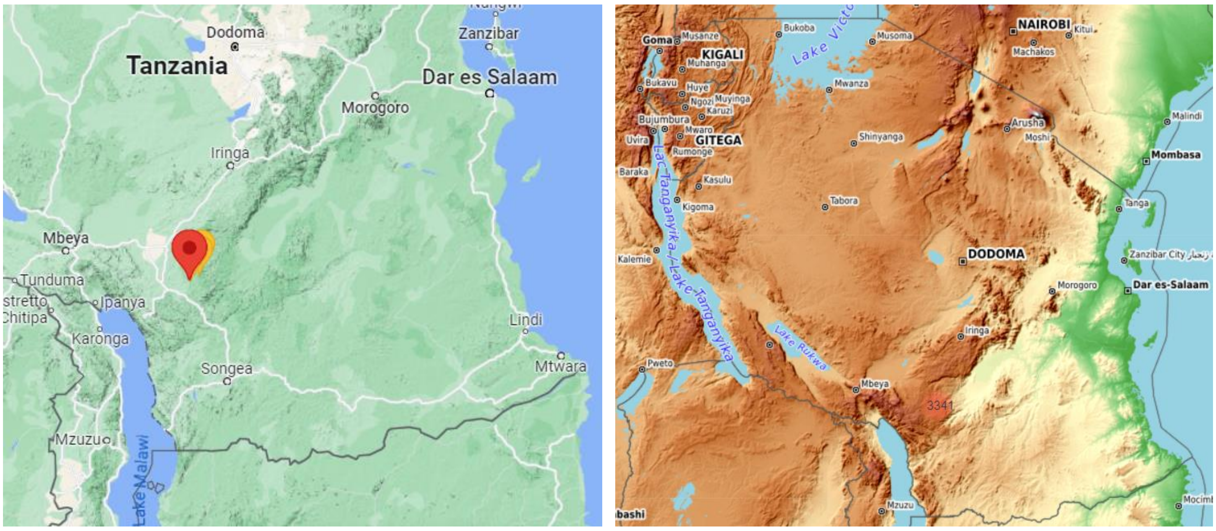
Figure 1.2: Trends of access to energy in Tanzania and sub-Saharan Africa [4].

The company that deals with the national supply of electricity in Tanzania is Tanesco, acronym of Tanzania Electric Supply Company, but the production of the electricity in the country is also sustained by mini-grid developed by NGOs. To address the problem of lack of electricity in areas that are geographically hampered, with an initial low demand of electricity, stand-alone systems based on renewable sources are a suitable alternative provided by projects of international cooperation [5]. The energy strategy of the government has changed during years, in according to the president that has been elected, moving from a strategy in collaboration with NGOs, to a reluctant approach, and then to a plan close to the NGOs for the production of energy rather than the distribution.

1.3. The electrification of the Matembwe village

1.3.1. The village of Matembwe

Matembwe is a rural village situated in the district of Njombe, in the south-west area of Tanzania. The village is 60 unpaved kilometres far from Njombe, center of the district, and around 750 km far from Dar Es Salaam, the most important center in the country. Since it is located on a plateau, the altitude of the village is about 1800 meters above sea level. The altitude of the village and the geomorphological shape of the location, brings the village to a usual condition of cold and rainfall. The typical weather of Matembwe allows to exploit the watercourse as source of energy in hydropower plants. For the same reason, in the region, photovoltaic power plants are not spread, instead, little panels are used as very small source of energy by few rural inhabitants. In addition, small-scale hydropower plant, can offer a higher energy service than domestic solar system. Thus, in rural villages, particularly in areas far from the national electricity grid, small hydropower resources can play an important role in fostering access to energy [5].



(a) Matembwe location. (b) Geography of Tanzania.

Figure 1.3: Maps of Matembwe and Tanzania.

1.3.2. CEFA, the Matembwe Village Company and the mini-grid

CEFA Onlus (Comitato Europeo per la Formazione e l'Agricoltura), called CEFA, is an Italian NGO located in Tanzania since 1976, that deals with rural electrification, water supply, agriculture, and agro processing.

From the beginning of its activity on the area, CEFA has realized an animal feed factory, a hatchery and three mini-grids fed by hydropower plants, two of these are situated in the district on Njombe and are protagonists of this thesis research.

The first hydropower plant was built in 1986 in the village of Matembwe, and since then is run by the Matembwe Village Company (MVC). MVC was founded by CEFA in 1989, then it has been gradually entrusted, and from 2014 CEFA is no longer a shareholder of the company. With no financial support from CEFA since 1989, MVC has demonstrated its capacity to successfully manage the social and economic activities inherited throughout the years, becoming a relevant actor within the local economy.

The first power plant, built in Matembwe, has a power of 120 kW, it's a reservoir micro hydropower plant, and is connected to two villages. The second power plant, built in 2005 is located in the village of Ikondo (Njombe district, north of Matembwe) where two Francis turbines are installed for a total power of 430 kW [6]. The first turbine has been installed in 2005, the second in 2015. It is a run-of-river micro hydropower plant and is connected to five villages. Both of them are connected also to the national grid since 2015. The construction of the power plants has been financed by different donors, including the European Union, that in 2015 allowed to expand the first mini-grid, permitting to extend the Ikondo plant, to connect both the plants to the national grid and to increase the number of users to connect. The connection to the national grid allowed also the MVC to sell the excess of electricity that peeks out from the inhabitants' consumption. Thus, nowadays the mini-grid is composed by three turbines, one in the plant of Matembwe and two in the Ikondo's plant, provides electricity to eight villages and to the national grid and is totally managed by the MVC. The inhabitants can choose if connect their utility to Tanesco, to MVC, or both. Indeed, some inhabitants choose to connect to Tanesco in addition to MVC to have a backup when in dry season rivers are not able to start the hydropower plant and ensure continuity of supply of electricity.

In the following, a map of the lines that nowadays connect the inhabitants of the Ikondo-Matembwe mini-grid.

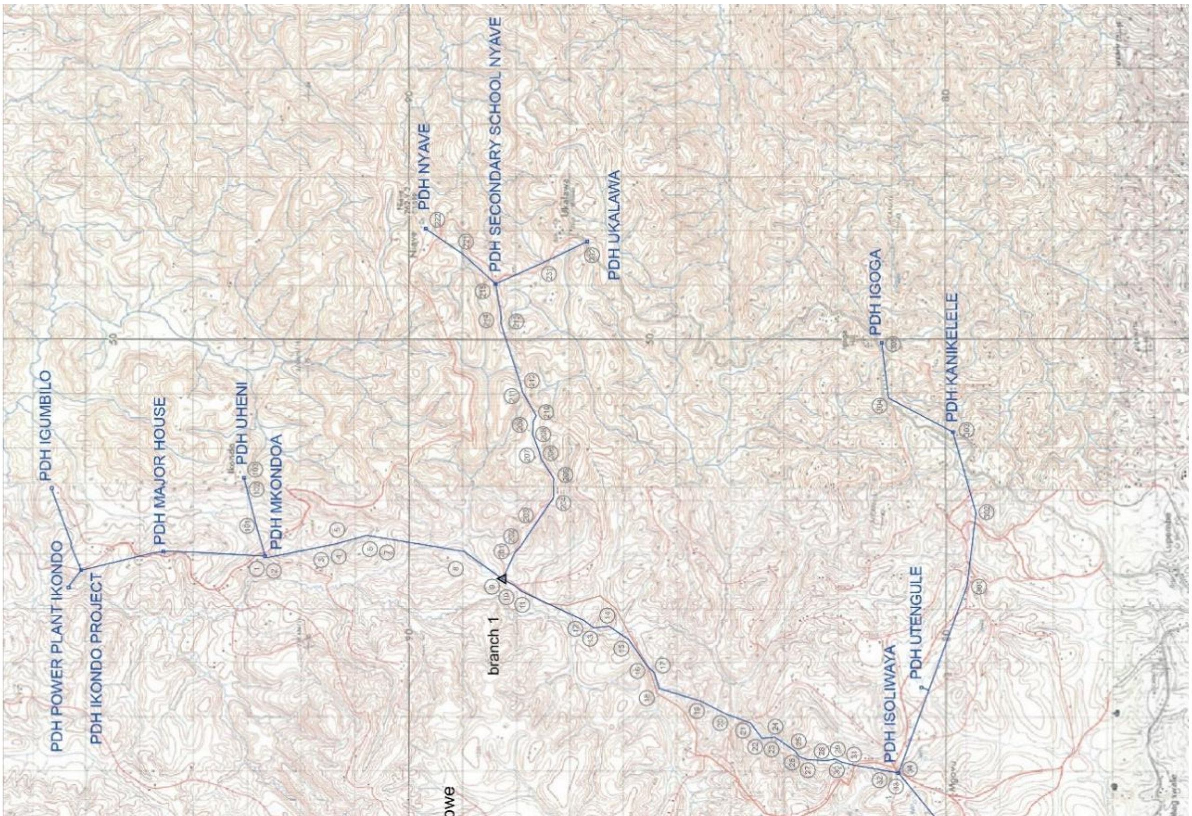


Figure 1.4: Ikondo-Matembwe mini-grid lines.

Matembwe is a case of success of sustainable development since its electrification is fully managed by a local company and lasts since 1986. Different factors allowed the described success, such that Matembwe has been object of a consequent case study in a project funded by Mott Foundation, aimed at gathering all the lectures learnt and best practices from its case. From the analysis performed, came to light that some implementation strategies adopted by CEFA in collaboration with the MVC, different from the method to operate of the national grid, were winning. MVC's mini-grid uses underground cables for the low voltage distribution line instead of aerial connections, and this choice allows to provide a reliable and safe electricity supply. However, in comparison to the national utility that provide a cheaper and less reliable distribution line, costs are higher but still affordable. In addition, CEFA realized training session on rational and safe uses of electricity and on energy efficiency practices, that had arisen awareness among users.

Figure 1.5: Turbines in the Ikondo hydropower plant.

1.4. Objective of the thesis

The objectives of this thesis are three and described in the following.

Firstly, a map of the buildings of five villages (including houses, public services, and business activities) will assess, for each user, the location, the gender of the connection owner, the number of people that are supplied, the type of business or public service, the structure of the building (roof, wall, and floor), and if present, the source of energy of the user. The information collected from this survey will provide a scheme of the users already connected to the mini-grid, connected to Tanesco and not connected (and so, potential users). Data gathered can support evaluations referred to a possible future extension of the connections to the mini-grid. Specific data on type of household can be used to evaluate the type of user that is going to connect in terms of consumption. The information collected on the characteristic of the building can assess the level of safety, the share of compliant users with law that are connected, or establish who to prioritize in case of connection request.

Secondly, a further map of the transformers connected to the mini-grid will be realized, and, added to the map of the users, will support the calculation of the length of the cables of the medium and low voltage distribution lines in case of new connections.

Then, a focus on the village of Matembwe, where CEFA and the MVC headquarters are settled, is performed with the aim to represent the habits of users in terms of electricity consumption to define a typical load demand for each category of user. In this case, the goal is to go from an actual very low temporal resolution of the load demand to a very high temporal resolution. The calibration is performed through RAMP, a modelling tool that allow to provide a curve with a minute-resolution, instead of monthly-resolution results. The final objective is to obtain, starting from data of appliances use collected for this case study, a load demand categorized for class of user. Have a load demand different for class of user, can give a more accurate prevision of the energy consumption of a possible user and support the design of a new expansion of the line.

Third objective is to validate the data collection performed on site and the accuracy of the load demand provided by RAMP. Those data will be compared with the actual yearly energy consumption of an average user of household, business activity and public service, during the years 2014 and 2015. The closer are values of the comparison, the more accurate are the results. After this operation, the objective of the thesis is reached, and it will be possible to exploit the results for support the expansion of the Ikondo-Matembwe mini-grid.

In this way, it is possible to provide a toolkit to support the development of the Ikondo-Matembwe mini-grid and others NGO that can rely con same set of instruments.

2 Materials and methods

2.1. On field data collection

To provide to the MVC the instruments for design the future expansion of the mini-grid, it is necessary to collect data on-field. Two surveys and two maps are realized with the aim of assess the energy needs, the characteristics and the location of already connected and potential users.

2.1.1. Map and survey of users and potential users

A first survey among 5 of the 8 villages connected to the MVC is performed. For each neighbourhood of Matembwe, Kanikelele, Isoliwaya, Nyave and Iyembela, the aim is to establish the following information:

- Location (GPS coordinates)
- Type of user (household, business activity, public service)

Accordingly to the type of user, different questions have been asked.

If the user is a household:

- gender of the owner;
- number of people living in the house.

If the user is a business activity or a public service:

- type of business activity or public service.

To all the interviewed it has been assessed:

- presence of metal sheet roof;
- presence of plaster on the inside wall;
- presence of concrete floor;
- connection to a grid (Tanesco, MVC, both);
- if not connected, alternative sources of electricity.

The inhabitants interviewed in this survey, can be connected to MVC, Tanesco, or both. For the assessment of the load demand of Matembwe will be considered only the ones that are connected to the MVC or to both the MVC and Tanesco.

Figure 2.1: On-field survey with local guide.

2.1.2. Map of transformers

In addition to the previous survey, that provides the localization of the user of the villages, a map of the transformers has been realized. For each transformer the GPS position has been registered, in this way the design of future connections will be facilitated.

2.1.3. Survey for electric consumption assessment

To define the consumptions of the users, a second survey among the inhabitants of Matembwe has been performed, and a sample of 90 consumers have been interviewed. The survey has been carried out in the center of the village, where are present different business activities and public services, with the help of a local guide.

The questionnaire has been proposed to 50 households, 40 business activities and 10 public services. To each interviewed, the questions asked were:

- type of user (household, business or public service);
- type of appliance;
- number of appliances;
- time of using;
- times a week.

2.1.4. On site surveys instrument description

The on-field survey has been performed with the support of KoboToolbox. KoboToolbox is an open-source tool for collecting, managing, and analyzing data of on-field surveys. It is used by researchers, NGOs, and governmental organizations working in remote and resource-limited areas, since it provides a set of tools to design forms and to collect, manage and visualize data online or offline. KoboToolbox offers the possibility to download Kobo Collect. Kobo Collect is a mobile application that has been installed on smartphone and tablets in order to easily collect data offline during on-field interviews. To carry on the interviews, firstly, the form has to be created online on the web site of KoboToolbox, in the section “Projects”, where a new scratch can be selected and compiled with the questions needed. Then, with Kobo Collect, it is possible to download the survey form on the appliances, answer to the survey, collect GPS coordinates, and then upload the collected data to the KoboToolbox server. KoboToolbox, then, has a component “Data”, that is a platform on the website that allows users to manage and analyze the collected data. It offers the possibility to visualize data in graphs and maps, and to export data in Excel, CSV, and KML.

2.2. Categorization of classes of user from data collected

Data collected during the survey are elaborated, dividing users in the following macro-categories:

- Households
- Business activities
- Public services

In turn, macro-categories have been furthermore divided.

Households and business activities, in the following categories:

- Very low
- Low
- Medium
- High
- Very high

Public services, in these others:

- School
- Dispensary
- Office
- Church

All the appliances used by the inhabitants interviewed have been considered, with standard peak power measured during the survey.

The division in categories of households and business activities has been performed following the scheme shown in the tables below.

Table 1: Typical household electric appliances by power load [7].

	Very low-power appliances	Low-power appliances	Medium-power appliances	High-power appliances	Very high-power appliances
Lighting	Task lighting	Multipoint general lighting			
Entertainment & communication	Phone charging, radio	TV, computer, printer			
Space cooling & heating		Fan	Air cooler		Air conditioner, space heater
Refrigeration			Refrigerator, freezer		
Mechanical loads			Food processor, water pump	Washing machine	Vacuum cleaner
Product heating				Iron, hair dryer	Water heater
Cooking			Rice cooker	Toaster, microwave	Electric cooker

Table 2: Appliances power capacity for category [7].

	Very low-power appliances	**Low-power appliances**	**Medium-power appliances**	**High-power appliances**	**Very high-power appliances**
Power capacity ratings	3 W	50 W	200 W	800 W	2000 W

Users are classified on the base of the electricity services they access and of the appliances they own. Appliances are classified in according to the amount of power requested to the electricity system to function. Some appliances function in a continuous way (e.g., fridges), others are needed at a specific time of the day. In any case, categories of users follow the classification of the most powerful appliance belonging to the consumer.

Power capacities and categories have been coupling following the categorization provided by Energy Sector Management Assistance Program (ESMAP) [7].

Matching the previous tables, users can be divided in categories as follow:

- users who own an appliance with a peak power around 3W, or lighting/phone chargers/radio: very low;
- users who own an appliance with a peak power less or about 50W, or multi point lighting: low;
- users who own an appliance with a peak power around 200W: medium;
- users who own an appliance with a peak power around 800W: high;
- users who own an appliance with a peak power around 2000W: very high.

Households and business activities just follow the described categorization, while public services are divided by types.

Each type of typical business activities present in the villages has been assigned to a category, as shown in the following table.

Table 3: Categories of business activities.

Business activity	Category
Tailor	high
Hair	low
Garage	very high
Carpentry	very high
Shop	very low
Milling machine	very high
Restaurant	low
Butcher	very low
Bar/pub	medium/low
Financial	low

Bars and pubs are split in this way: a half belongs to the low category, a half to the medium, since there are two types of bars or pubs, one with more powerful appliances than the other one.
Public services have been divided in 4 categories: church, dispensary, office, school.

Figure 2.2: School in Matembwe.

Figure 2.3: Class in Matembwe.

Figure 2.4: House with plaster on wall and floor.

From data extrapolated by the previous analysis, assigning the numbers of users interviewed in the second survey, it is possible to calculate the percentage of users of each category and extend the calculation to the whole population of Matembwe, considering data provided by the first survey.

2.3. Load demand estimation

Have data collected divided in categories make possible to obtain load demand specific and for macro-categories. In the following paragraphs is described how to calculate the load demands with the data collected on-field, through a modelling tool, and with the actual data provided by the MVC. Then, the process to compare the two load demands is reported.

2.3.1. Load demand simulation

The tool used to realize the high time definition curve of the load demand is RAMP [8].

Figure 2.5: Logo of RAMP.

RAMP is the acronym of Remote-Areas Multi-energy systems load Profiles, it's a bottom-up model implemented in Python and developed by Politecnico di Milano in 2019. It's an open-source software for the generation of multi-energy load profiles. With a stochastic simulation it provides load profiles for electricity demand, describing the probability distribution of energy consumption over time. For this thesis an Excel file has been used to input data in RAMP. The program has been run for each category of users selected: households with very low, low, medium, high, and very high power capacity, businesses with very low, low, medium, high, and very high power capacity and public services (church, school, office, dispensary).

Data to provide to the model are:

- the appliances used;
- the name of the interview;
- the number and the nominal power of the appliances;
- the hour at which users turn on and turn off the appliance considered;
- the times a week the appliance is turned on;
- if usually is turned on during the weekend or the weekday.

Below is reported an example of the data provided by one user of the "low" household's category in input to RAMP.

Time is expressed in minutes, where the value "0" means 00:00, "1" means 00:01, and so on. So, if a window is compiled with the values "0,360", means that the appliance is on from 00:00 to 06:00. It is also possible to set a total functioning time lower than the window of working, to represent the behaviour of an appliance that is not always functioning in a time lapse. In this case, the occasional use of the TV is 0,428, which means that the interviewed has answered that the appliance is turned on 3 days per week.

The output gave by the model for this research is an Excel reporting on the row the time, in minute, and on the column the power in Watt (per minute). The software gives the possibility to choose the number of days to consider for the calculation. For this analysis, it has been chosen 365 days, to have a yearly curve.

Table 4: Example of input data in RAMP.

Appliance	User name	Nominal power	Number	N. of windows	Tot functioning time	Min functioning time	Occasional use	Weekend/ weekday	Window 1	Window 2
Indoor_lights	Interview1	10	2	2	660	660	1	2	0,360	1140,1440
Charger	Interview1	3	2	1	60	60	1	2	1140,1200	
TV	Interview1	50	1	1	180	180	0,428	2	1140,1320	

2.3.2. Actual MVC data elaboration

It is necessary to assess the reliability of the exploitation of RAMP to design future expansion of the mini-grid.

To evaluate the accuracy of the data provided by RAMP, and so to validate the future utilization of the software to calculate the consumption needs of the possible users, a comparison with the data collected by the MVC is needed. The values considered are the amount of energy consumed by a user of a macro-category in one month. The information available consist of an Excel described in the following. On the rows are placed the users, to whom it has been measured the meter, and the macro-category to which they belong, on the column are present four values that correspond to the monthly energy consumption of the consumer of a representative month in a quarter.

In this way, to have an estimate of the consumed energy in one year per user, each provided monthly value has to be multiplied by 3, and after that summed to calculate the total yearly energy consumption. Data are available from 1992 to 2015, and for this analysis the consumptions of 2014 and 2015 have been elaborated. Years 2014 and 2015 have been chosen since are the closer in terms of time to the data collected and so are more representative of the actual situation. Then, once obtained a value of the yearly energy consumption for both the years, an average value of the two years has been calculated to compare to the RAMP result.

2.4. Comparison between actual and estimated load demands

To assess the accuracy of the load demand calculated, a comparison between actual values of consumption and data calculated is needed. Data collected by MVC are aggregated, the information available for the comparison is the energy consumed in one month by each user of the three macro-categories (households, business activities, public services) connected to the mini grid. For this reason, the value usable for the comparison is the number of kWh consumed in one year by a single user of a macro-category. For this research, data of the years 2014 and 2015 are considered, the closest years to 2022 with data available.

To make data comparable, values coming from RAMP are elaborated for each category of user. The 365-days load demand is transformed from W to kWh and multiplied by the number of users given by the survey, then values are summed, in order to obtain the amount of kWh consumed by a category. The same procedure has been followed for all the three macro-categories (households, business activities and public services). To have the number of kWh consumed by a user of each macro-category, all the value of each category within the macro-category are summed and then divided for the number of total users of the macro-category.

Data provided by the company have to be handle in order to have values that represent the yearly consumption of a user of the macro-category. For each month, values are summed, and the yearly consumption of the macro-category is calculated.

The value is divided for the number of users of the macro-category, and the consumption of a user is provided. Then, the average of the results of the years 2014 and 2015 is calculated.

The comparison of one user consumption is needed since data gathered by the company included data of all the villages connected to the mini-grid, while data collected during the survey are only from Matembwe, this unable to compare the total load demands. Villages connected to the mini-grid have behaviours very similar to the inhabitants of Matembwe, so it is possible to consider that appliances and times of consuming are extendible to alle the users that have the same habits.

To give an illustrated evidence of the comparison, results are plotted and reported in graphs. The results considered are the load demand for each category and macro-category of the typical day and week.

3 Results

3.1. Data collected and elaborations

3.1.1. Map and data of users and potential users

Numbers gathered with the survey include all the households, business activities and public services of the villages, but it is possible that some errors occur and data distance from actual values, since it has been a work performed in a rural context, moving on foot from building to building.

The users interviewed and mapped in the first survey in the villages of Matembwe, Kanikelele, Isoliwaya, Iyembela and Nyave are 3343.

In the following, the statistics calculated from data collected.

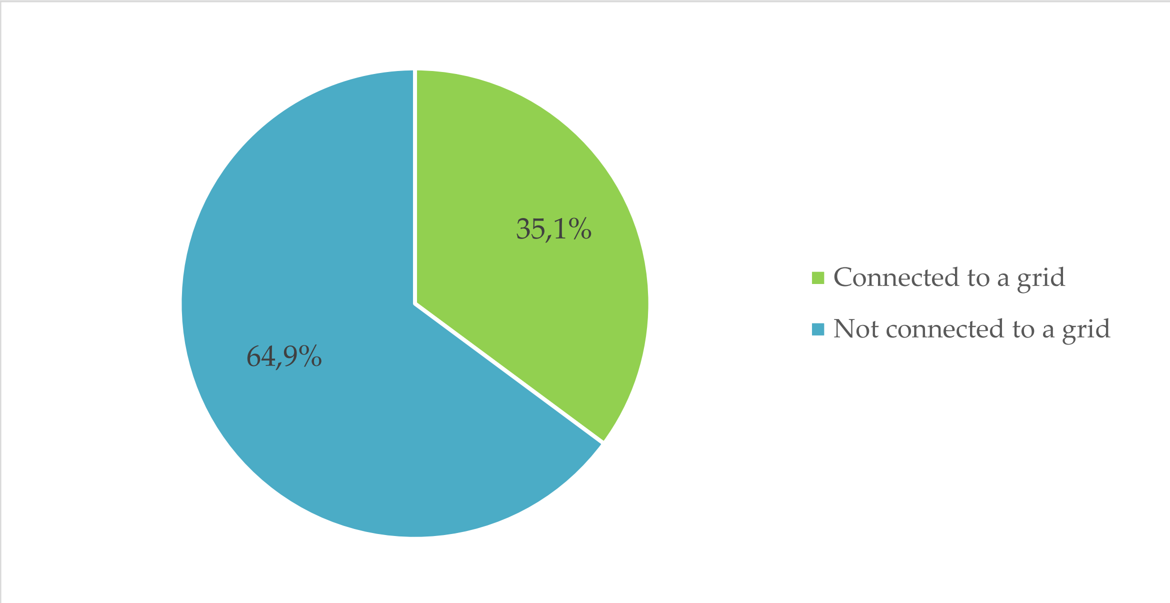


Figure 3.1: Respondents connected and not connected to a power grid (Tanesco or MVC).

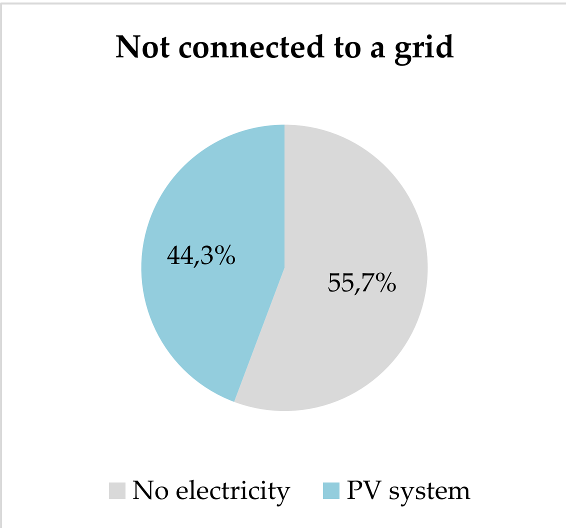


Figure 3.2: Detail of "Not connected to a grid".

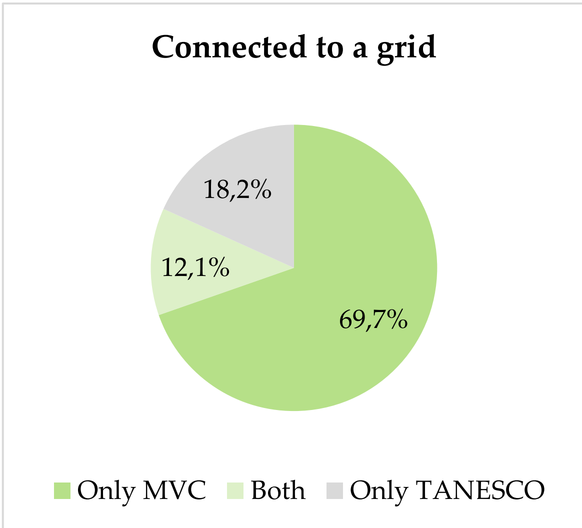


Figure 3.3: Detail of "Connected to a grid".

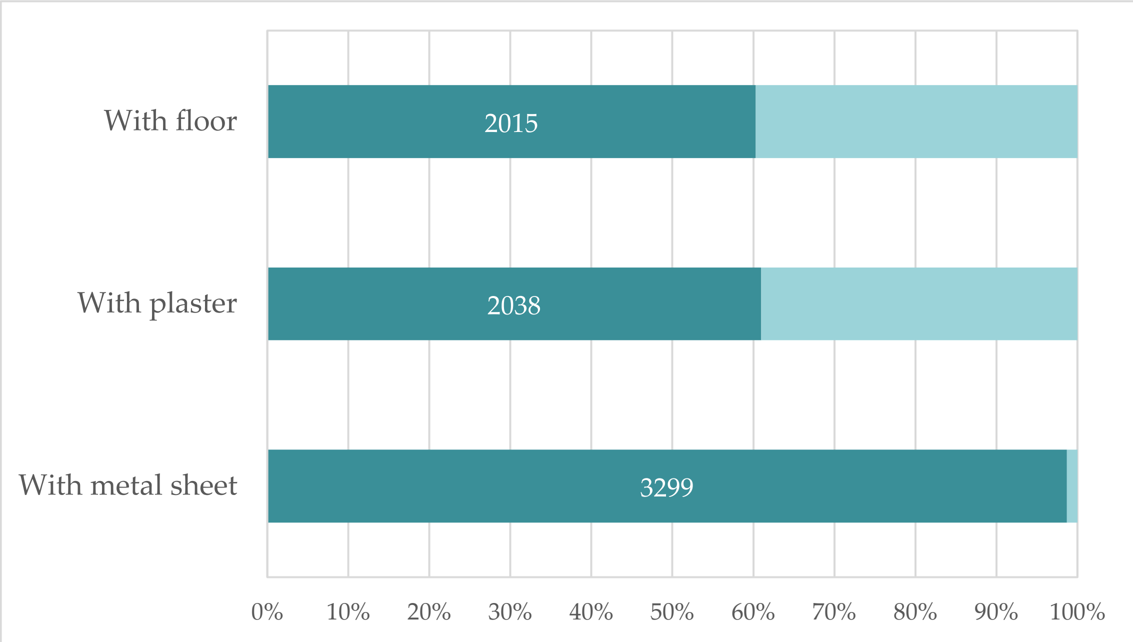


Figure 3.4: Results of interviews about envelope assessment.

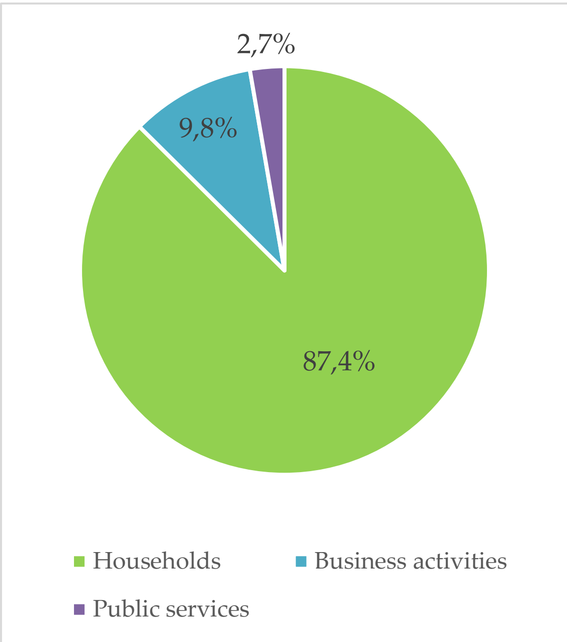


Figure 3.5: Respondents divided by user type.

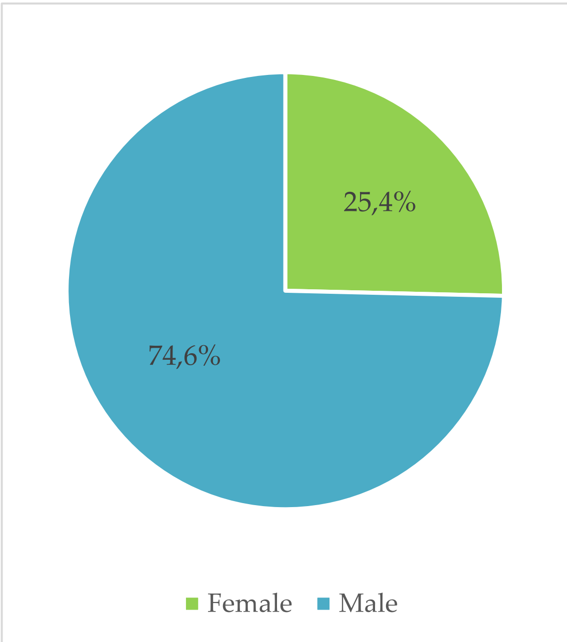


Figure 3.6: Owners divided by gender.

From the survey, users are divided among the villages as follows.

Table 5: Interviews per village.

Village	Number of users
Matembwe	1300
Kanikelele	781
Isoliwaya	627
Iyembela	384
Nyave	251

For the calculation of the load demand, it has been focused on Matembwe.

Users are divided in the three macro-categories, in the table below is shown the number of total users, the ones connected to electricity and the ones connected to the MVC, for each macro-category.

Table 6: Connected users per macro-category.

Macro-category	Number of interviewed	Connected	Connected to MVC
Household	1125	566	467
Business activity	142	127	99
Public service	33	22	19

From the survey, the connections to the MVC are 585, that is the 45% of the interviewed and the 82% of the connected ones.

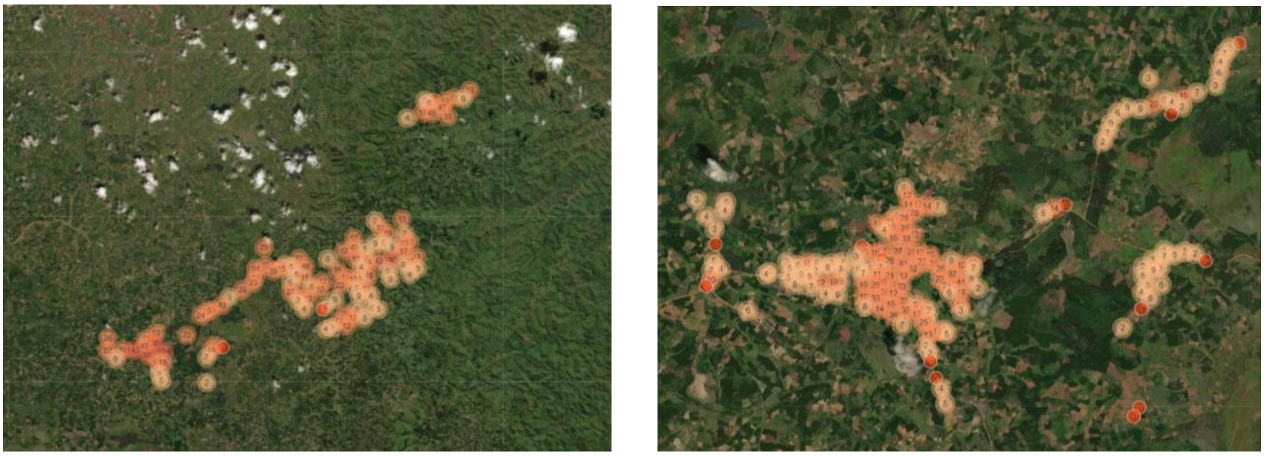
Then, business activities and public services are furthermore divided as follows.

Table 7: Connected users per category of business activity.

Business activity	Number of users	Connected	Connected to MVC
Bar/Pub	28	25	20
Butcher	4	4	2
Carpentry workshop/ Garage	12	12	10
Financial service	3	3	2
Guest house	7	7	6
Haircutting salon	4	4	4
Milling machine	10	10	6
Restaurant	10	9	7
Shop	59	51	39
Tailor shop	3	3	3

Table 8: Connected users per type of public service.

Public service	Number of users	Connected	Connected to MVC
Church	15	6	6
Dispensary/Health center	3	3	1
School/Boarding school	4	4	4
Public office	11	9	8



(a) Map of five villages. (b) Map of Matembwe.

Figure 3.7: Map of users.

3.1.2. Map of transformers

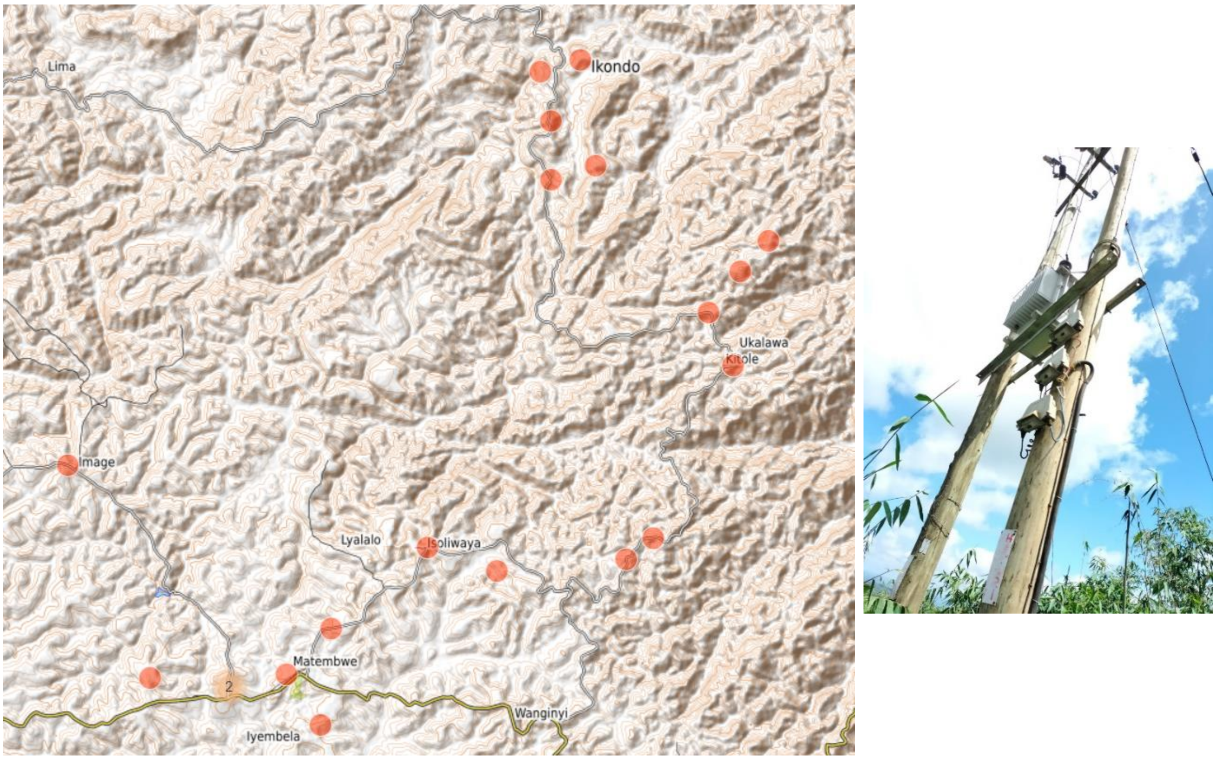


Figure 3.8: Transformers map and transformer on the distribution line.

Table 9: Transformers coordinates.

Village	Latitude	Longitude	Altitude	Identification
Matembwe	-9,2524691	35,1220028	1635,1	Manyunyu secondary school
Matembwe	-9,2561348	35,1453435	1596,9	MVC
Matembwe	-9,2546798	35,1452237	1610,0	MVC - Tanesco
Matembwe	-9,2515431	35,1616622	1584,1	Mission
Matembwe	-9,266152	35,1716521	1593,8	Mtakuja (new)
Matembwe	-9,2384433	35,1746241	1584,0	Lung'angali
Isoliwaya	-9,2151133	35,2028379	1612,5	Isoliwaya old
Isoliwaya	-9,221827	35,2233563	1545,9	Isoliwaya new
Kanikelele	-9,2182354	35,2609836	1550,5	Kanikelele 1
Kanikelele	-9,212403	35,2687072	1573,1	Kanikelele 2
Image	-9,1912791	35,0979387	1609,7	Image
Ukalawa	-9,1624279	35,2921606	1518,2	Ukalawa 1
Ukalawa	-9,1471005	35,2849777	1542,9	Ukalawa 2 secondary school
Nyave	-9,13523	35,2942013	1587,0	Nyave 1
Nyave	-9,126463	35,3025952	1578,4	Nyave 2
Ikondo	-9,1049214	35,2519109	1345,9	Ikondo Ihemi
Ikondo	-9,1088566	35,2388296	1311,8	Ikondo Mkondoa
Ikondo	-9,0920653	35,2389398	1340,8	Ikondo ofisini
Ikondo	-9,074228	35,2476553	1244,0	Ikondo Igumbilo
Ikondo	-9,0775288	35,2359536	1251,1	Ikondo Cefa office

3.1.3. Data elaboration for electric consumption estimation

During the on-field activities the power of the appliances owned by the inhabitants has been defined. In the following, the standard peak powers considered.

Table 10: Appliance powers.

Appliance	Peak power [W]
Indoor lights	10
Outdoor lights	10
Charger	3
TV	50
Radio	5
PC	50
Pop-corn machine	1500
Printer	150
Machine for financial services	25
Water pump	200
Electric iron	800
Mixer	500
Haematology analizer	150
Stereo	250
Power mixer	50
Piano	30
Welding machine	3000
HB machine	10
Rice cooker	350

Appliance	Peak power [W]
Sander polisher	1100
Oven	2500
Electric razor	4
Sewing machine	100
Fridge	150
Hair dryer	1750
Car washing machine	1500
Milling machine	2000
Washing machine	400
Sterilizer	1500
Electric kettle	1200
Microscopy	3
Photocopy machine	400
Electric drill	1200
Grinder	1000
Compressor	2000
Carpentry machineries	1800
Water heater	2000

With the information provided by the second survey it has been possible to divide the users interviewed in five categories (very low, low, medium, high, very high) for households and business activities, while public services have been divided in four types (school, dispensary, office, church).

In according to the method described in the chapter 2, the 50 households and the 40 business activities interviewed in the second survey are divided as follow.

Table 11: Number of households and businesses per category.

Category	Household	Business
Very low	4	8
Low	28	6
Medium	2	5
High	15	3
Very high	1	9

The users connected to the MVC's mini-grid are:

- 467 households;
- 99 business activities;
- 19 public services.

Guesthouses, that belong to the macro-category of the business activity, have been considered as part of the low category of the households, since their behaviour is more associable to that category.

From the previous data elaboration, the shares for each category of households and its number of users are the following.

Table 12: Households per category.

Category	Share	Households
Very low	7,8%	37
Low	56,7%	268
Medium	4%	19
High	29,6%	140
Very high	1,9%	9

Regarding the business activities, division has been performed differently, linking the types of business activities to a category, and then counting the number of users for each type of business (and category).

Table 13: Business activities per category.

Business activity	Number of users
Very low	39
Low	25
Medium	10
High	3
Very high	16

Table 14: Public services per category.

Public service	Number of users
Church	6
Dispensary	1
Office	8
School	4

3.2. High-resolution load curve estimate and calibration

The energy consumptions estimated with RAMP for each household and business category and are represented in the tables below.

Table 15: Households energy consumptions.

Households' category	Total yearly consumption [kWh]	Users	Yearly consumption per user [kWh]
very low	2297	37	62
low	39206	268	146
medium	3758	19	198
high	51659	140	369
very high	3990	9	443

Table 16: Business activities energy consumptions.

Business activities' category	Total yearly consumption [kWh]	Users	Yearly consumption per user [kWh]
very low	2534	39	65
low	6427	25	257
medium	7158	10	716
high	1513	3	504
very high	21679	16	1355

Table 17: Public services energy consumptions.

Public services	Total yearly consumption [kWh]	Users	Yearly consumption per user [kWh]
church	1663	6	277
dispensary	2284	1	2284
office	553	8	69
school	5979	4	1495

Table 18: Macro-category energy consumptions.

Macro-category	Total yearly consumption [kWh]	Users	Yearly consumption per user [kWh]
Household	100911	473	**213**
Business	39311	93	**423**
Public service	937	19	**551**

Values elaborated from data collected and provided by the company in 2014 and in 2015 are shown below.

Table 19: MVC energy consumptions of 2014.

Macro-category	Total yearly consumption [kWh]	Users	Yearly consumption per user [kWh]
Household	41352	178	**217**
Business	3908	5	**668**
Public service	18338	63	**511**

Table 20: MVC energy consumptions of 2015.

Macro-category	Total yearly consumption [kWh]	Users	Yearly consumption per user [kWh]
Household	41352	178	**232**
Business	3908	5	**291**
Public service	18338	63	**781**

A comparison among yearly consumptions calculated with data collected by the MVC in 2014, in 2015 and obtained by RAMP are reported below.

Table 21: Energy consumption comparison with years detail.

Macro-category	2014 MVC consumption [kWh]	2015 MVC consumption [kWh]	RAMP consumption [kWh]
Household	217	232	213
Business activity	668	291	423
Public service	511	781	552

In the following table a comparison between the average value of (2014 and 2015) MVC and RAMP consumptions is shown.

Table 22: Energy consumption comparison with average value.

Macro-category	MVC average consumption [kWh]	RAMP consumption [kWh]	Error [%]
Household	224	213	5
Business activity	480	422	12
Public service	646	552	14,6

The average value found for the household macro-category from the company data is different from the value calculated by RAMP of 11 kWh, inducing an error of the 5% on the actual average. Thus, it is possible to affirm that the electric consumption calculated for this macro-category respect the actual load demand, and, since household macro-category is the largest, accounting for 473 users, RAMP profile developed it is a reliable profile for future connections.

Concerning business activities and public services, it is necessary to note that the 2014 curve and 2015 curve, have different values, and data are not constant. This is due to the fact that data provided by MVC are not accurate, since values are not available for all the months of the year. There is also to consider the fact that RAMP is fed by input data of Matembwe, while MVC data includes also values of other villages, that have very similar habits, but this introduces an error in the comparison.

For public services and productive uses of energy, since the consumption fluctuation is higher and the error is in the range of 12-15%, it is possible to consider the RAMP load demand, with an approximation of ±15%.

For future connections, the MVC can rely on RAMP to assess the needs and the kWh necessary to increase the users of the mini-grid. In addition, the actual map of transformers and users gives a complete picture of the already existing connections. The overlapping of this information will pave the way for further future connections.

In the following pages, the graphs representing data collected and the comparisons performed are represented.

3.2.1.1. Households

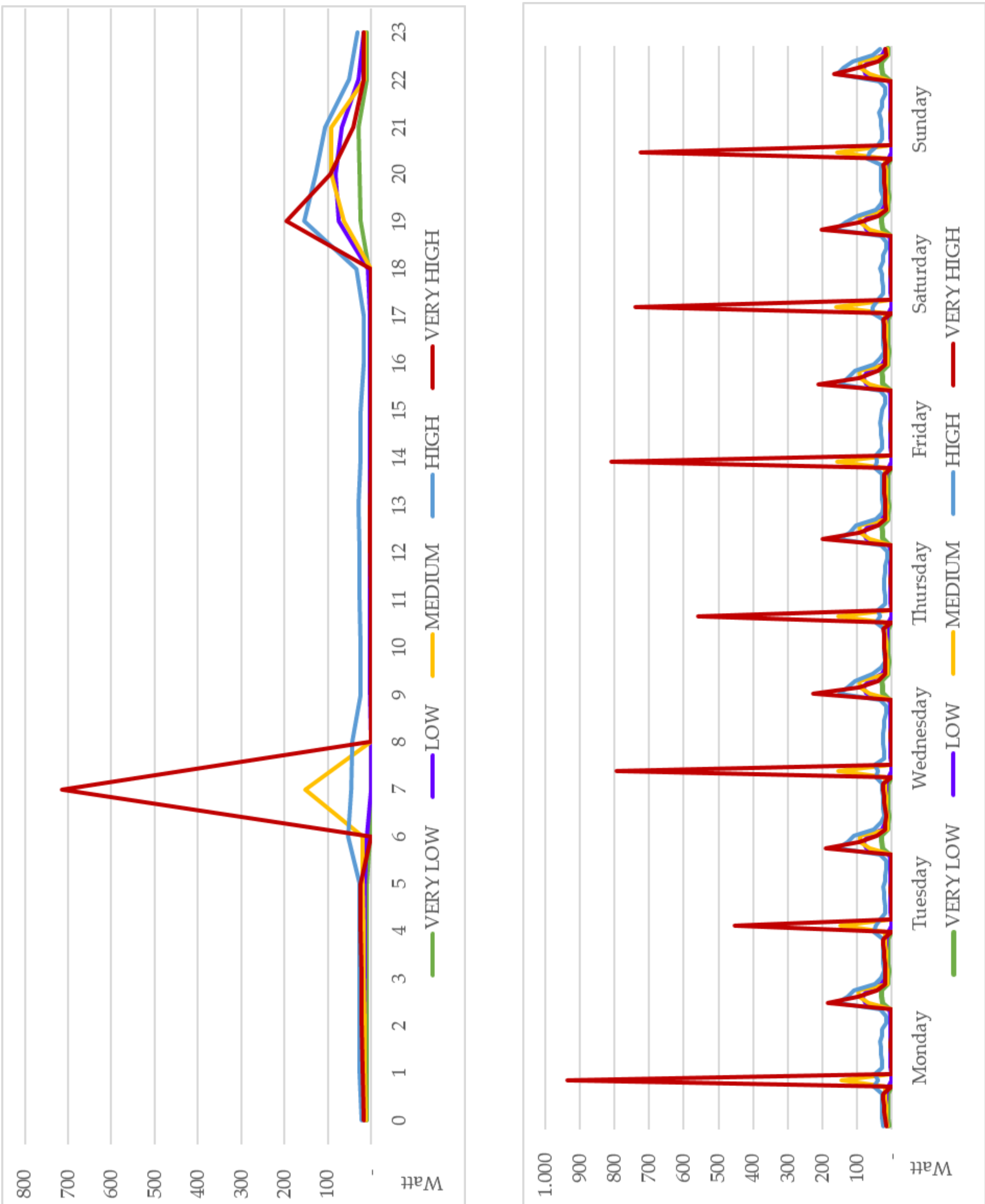


Figure 3.9: Daily and weekly user-specific load demand of the household macro-category.

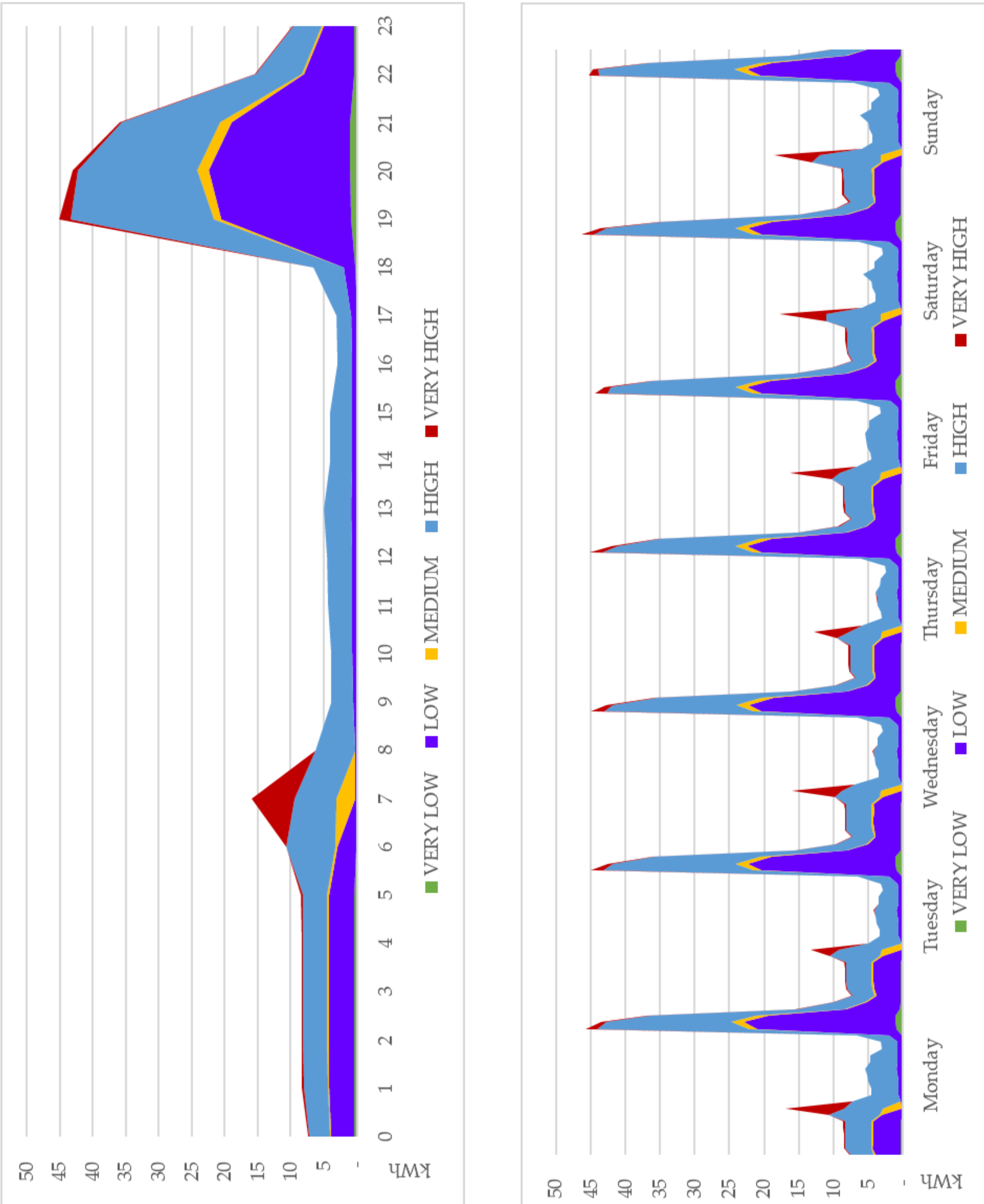


Figure 3.10: Daily and weekly cumulative consumption of Matembwe connected users of the household macro-category.

The user-specific curves show two peaks, one in the morning and one in the evening. All the categories follow the same shape, since the first peak represents the households when in the morning wake up and turn on lights and appliances for pump water, listen the radio, or charge the phone, while the evening peak describes the situation when households come home from work and turn on lights for cooking, watch TV and charge the phones. The highest peak, coming from the very high category, is provoked by the use of the water heater, energy-intensive appliance not widespread among the Matembwe inhabitants. No differences between weekdays and weekend are highlighted.

The cumulative curves show that households of the very low category consume a negligible amount of energy in comparison with the others. While low and medium categories differ for a very small amount, since the appliance that distinguish the medium category is mainly the usage of the water pump. High and very high curves are quite similar, the distance from the other curves is mainly due to the use of the iron, common among the high category inhabitants.

3.2.1.2. Business activities

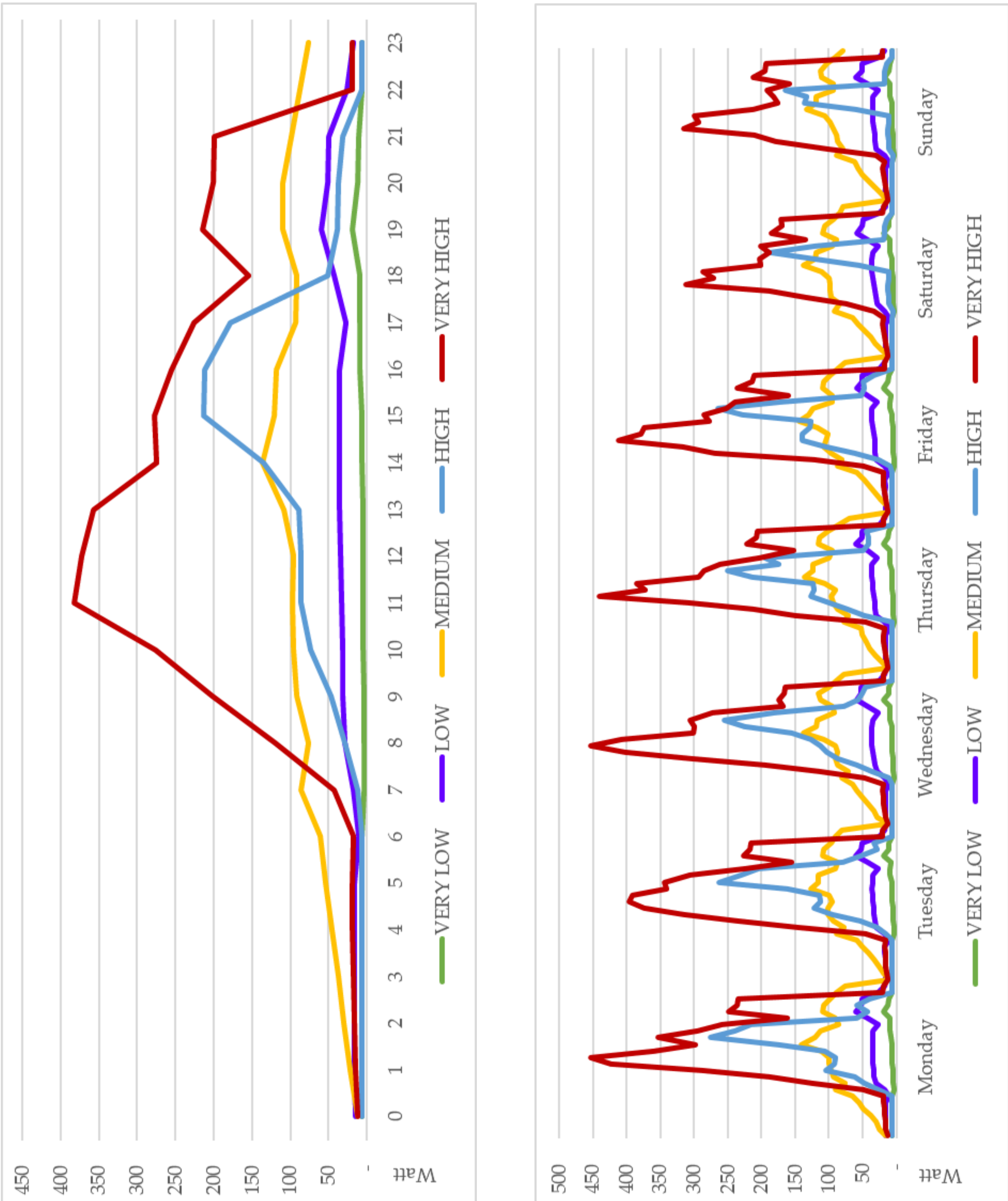


Figure 3.11: Daily and weekly user-specific load demand of the business activity macro-category.

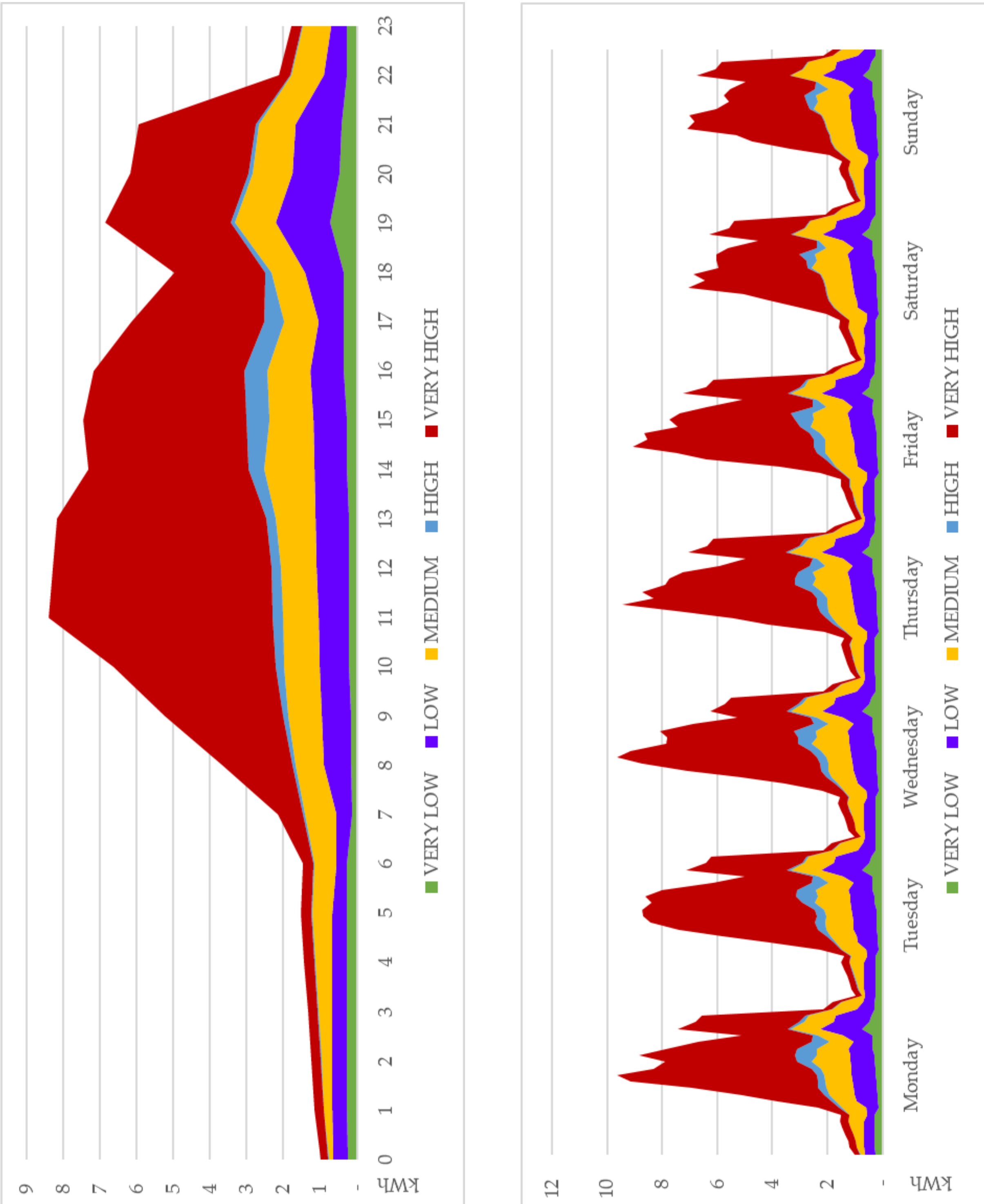


Figure 3.12: Daily and weekly cumulative consumption of Matembwe connected users of the business activity macro-category.

The user-specific curves show that, as expected since we are considering business activities, the load is concentrated in the working hours, starting from 8 in the morning. Very low and low categories have a constant behaviour, since are mainly represented by small shop or bar with reduced need of electricity. Also medium category has a quite constant shape, but higher than the lower categories, due to the fact that the majority of business activity considered in this category owns a fridge. Thus, categories until the medium one, present a light peak in the evening, since categories are mainly populated by bar or pub that are active in night hours. High category is principally represented by tailor shops, and shows a peak in the afternoon, due to the use of the iron of the sewing machines, and when it starts to get dark they need to turn on lights to work. Generally, the small growth in the evening is due to the lighting and to TVs. Very high category shows two peaks, the peak in the evening is due to the business activities related to evening entertainment. The biggest amount of energy is consumed by garage, carpentry machineries and milling machines. Since the curves describe the operation of business activities, it is explained a decrease of the consumptions in the weekend.

The cumulative curves reflect the behaviour above-mentioned, highlighting the difference between the consumptions of the very high category against the others.

3.2.1.3. Public services

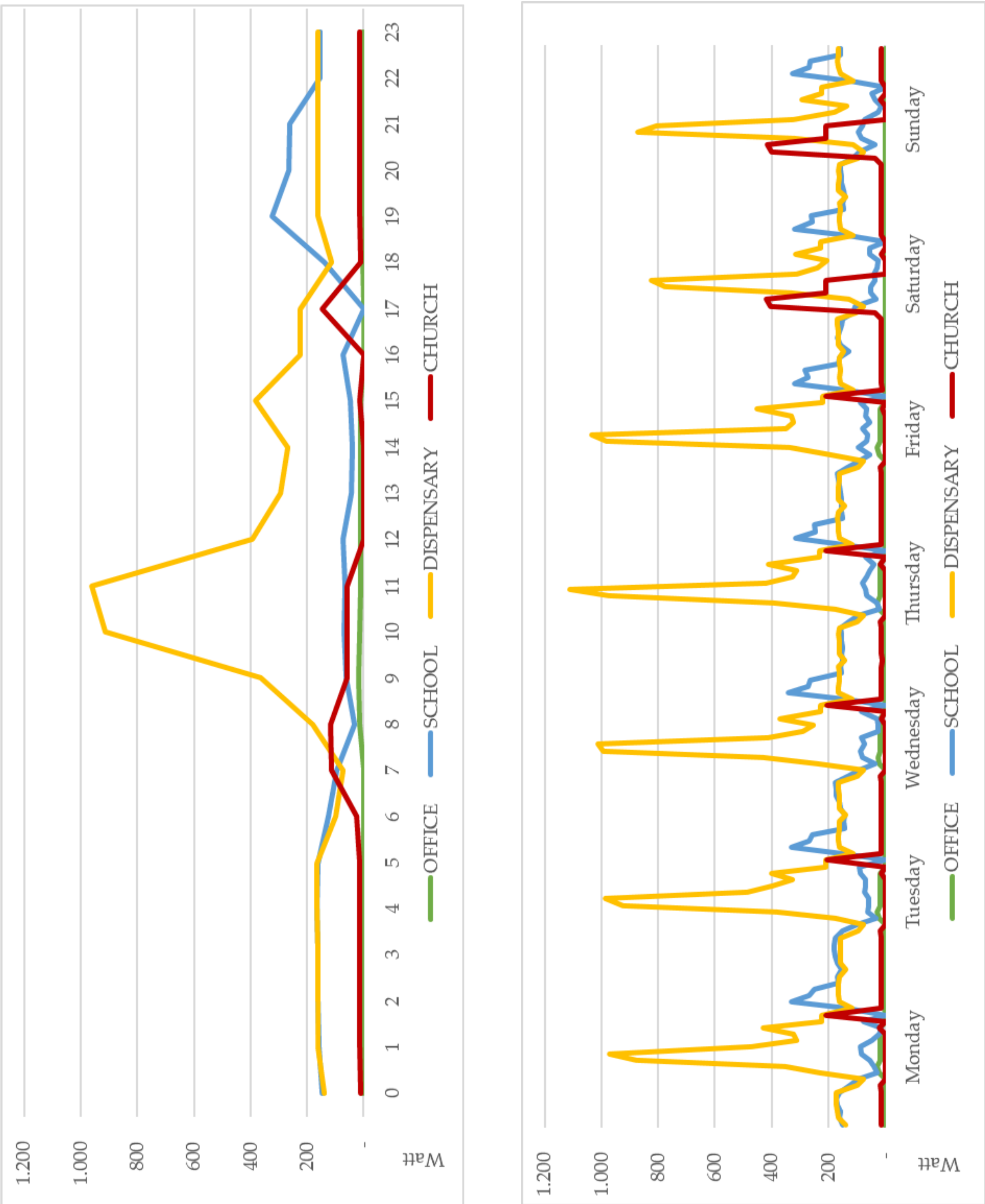
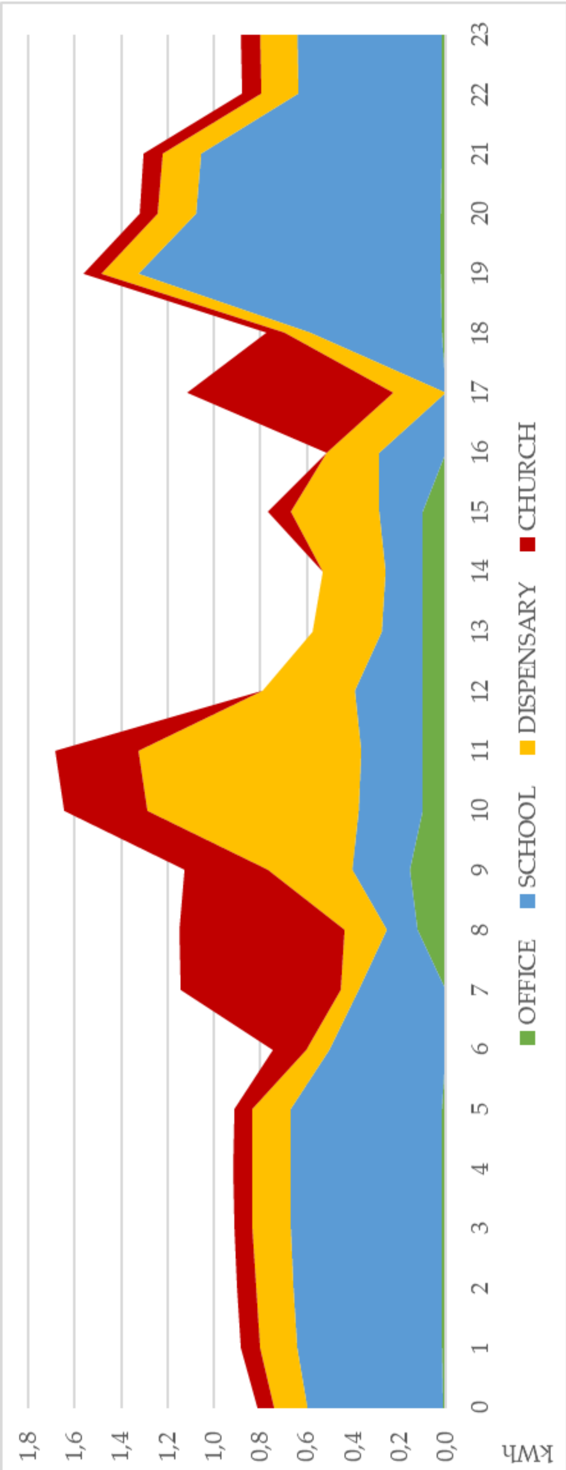


Figure 3.13: Daily and weekly user-specific load demand of the public service macro-category.



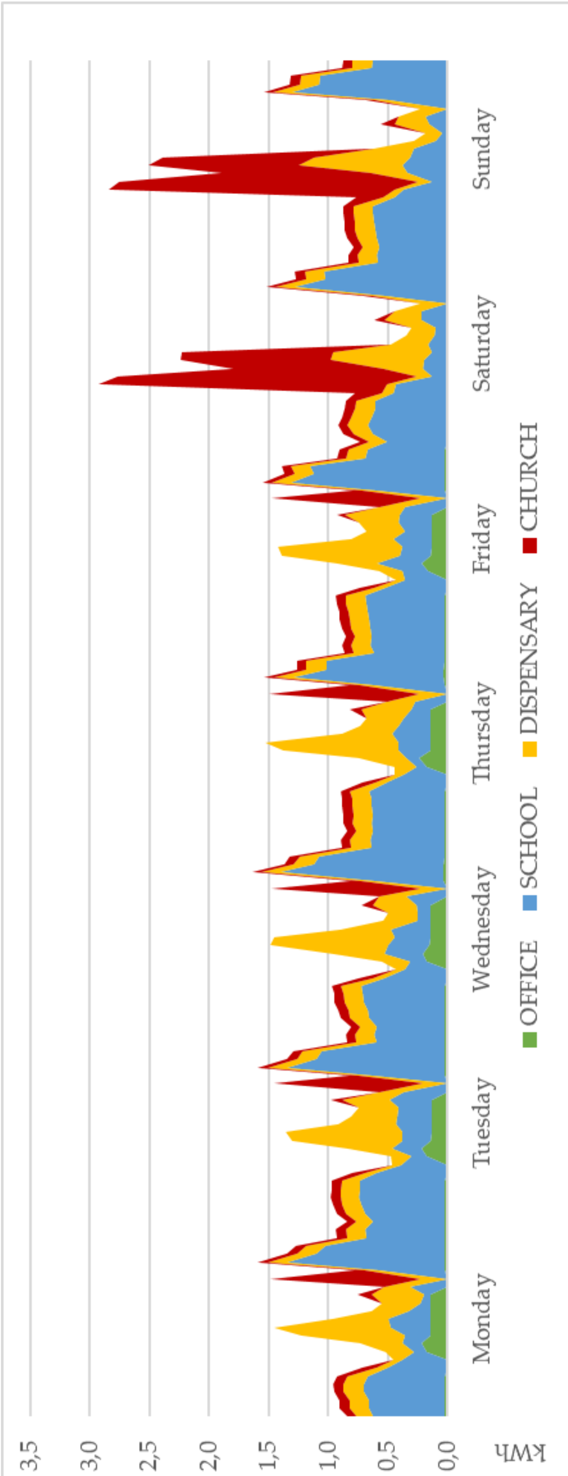


Figure 3.14: Daily and weekly cumulative consumption of Matembwe connected users of the public service macro-category.

From the above graphs emerge that public services follow different paths on the base of the type they are, and confirm that it has been a good choice to perform the load demand estimation divided per school, dispensary, office and church. Offices are a category very low demanding in terms of electricity, since the appliances that are mainly turned on are lights, with some exceptions for PCs or rare photocopy machines. School curve includes consumptions of boarding and not schools. The peak in the evening represents the lighting of places where students live in the board, while other consumptions are owed to PCs, milling machines, water pumps, photocopy machines and lighting, but the presence of these appliances vary with the type of school. Church has low consumptions, concentrated in the weekend, when observant go to Mass and pray or prepare for the Sunday. Dispensaries are the more energy-intensive, considered appliances as washing machines, sterilizer, PCs, water heater. Also in this case it depends on the quality of the service that the dispensary is able to provide, and the curve displayed is more representative of high-level dispensary.

In addition, it is easy to note that office consume only during the weekdays, while church behave oppositely, as expected. Schools, instead, decrease during the weekend, but including boarding schools there are consumptions also during the weekend. Dispensaries, since there is the necessity to be open every day, do not have substantial changes between weekend and weekdays.

3.2.1.4. Macro-categories

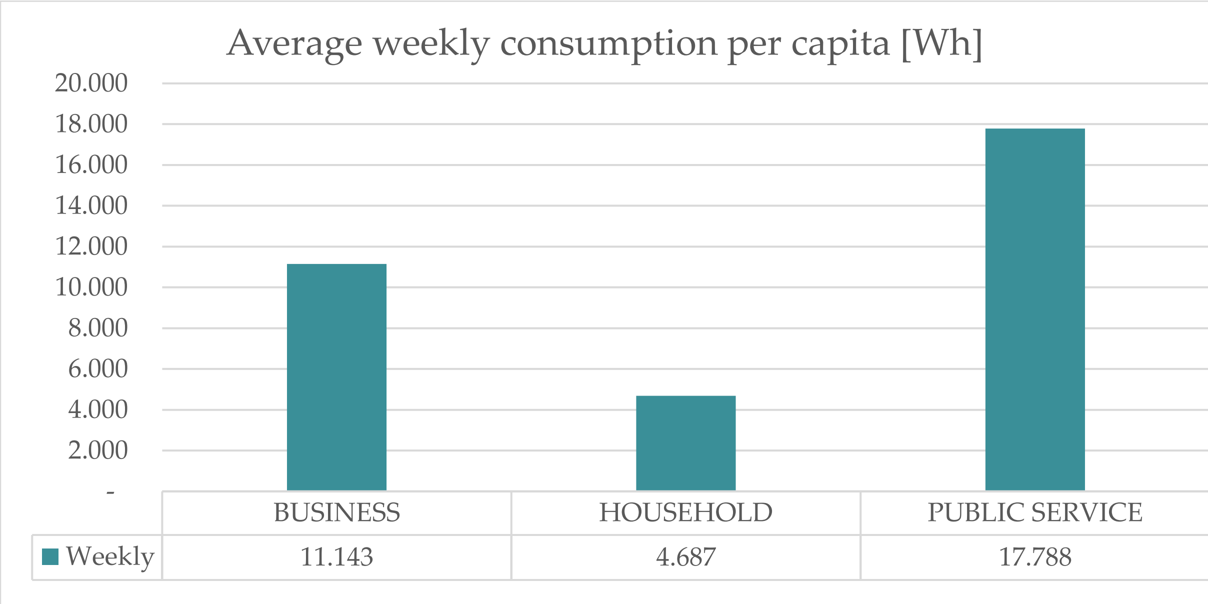


Figure 3.15: Average weekly consumption per macro-category.

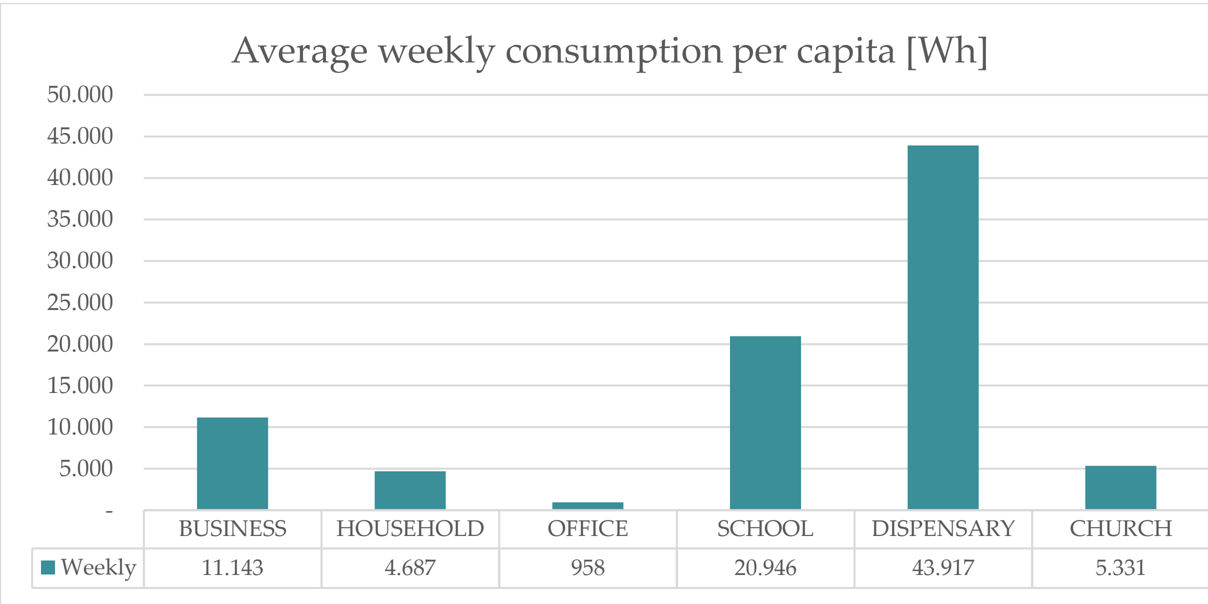


Figure 3.16: Average weekly consumption with public services detailed.

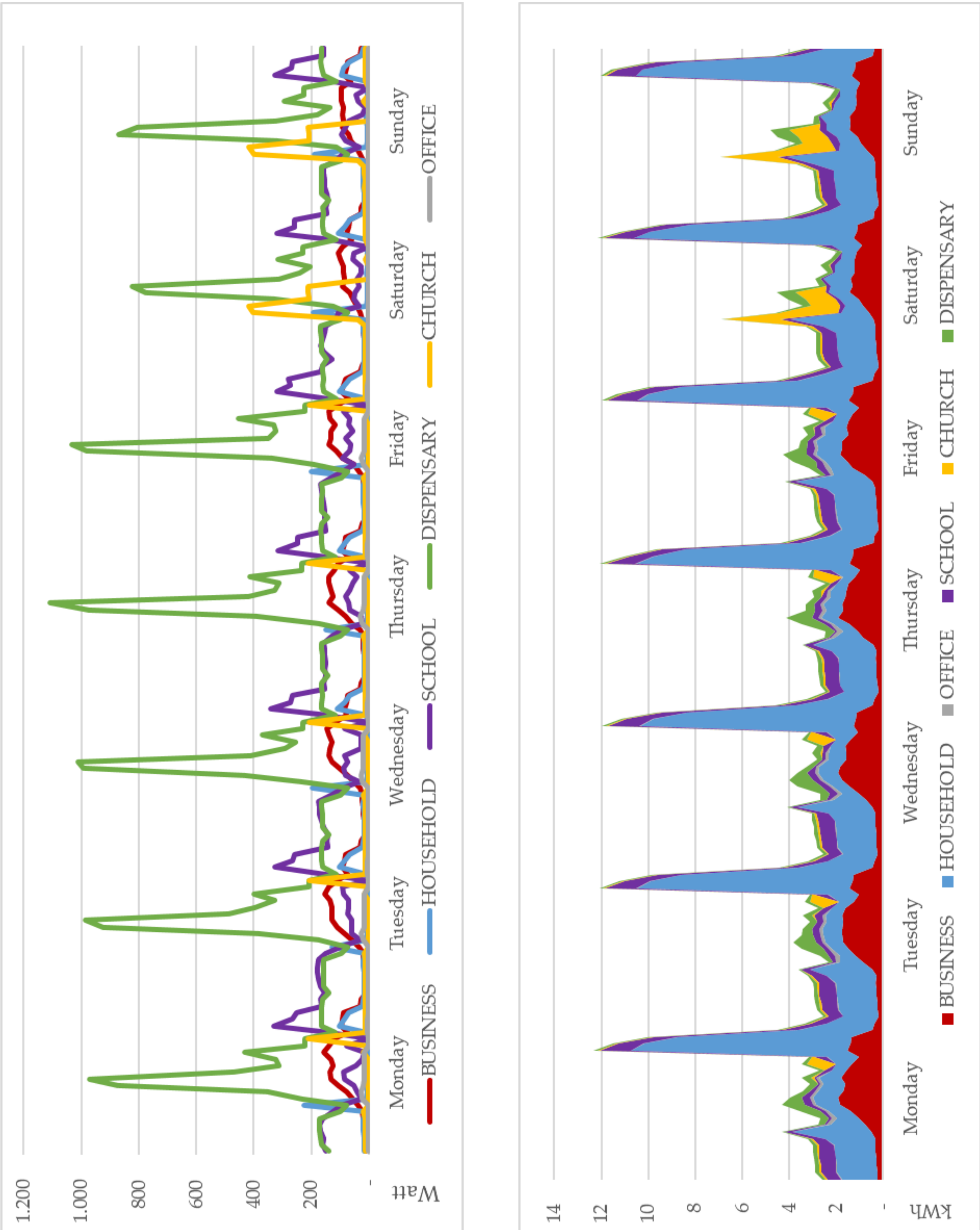


Figure 3.17:Weekly load demand user-specific (left) and weekly consumption cumulative (right) of Matembwe connected users.

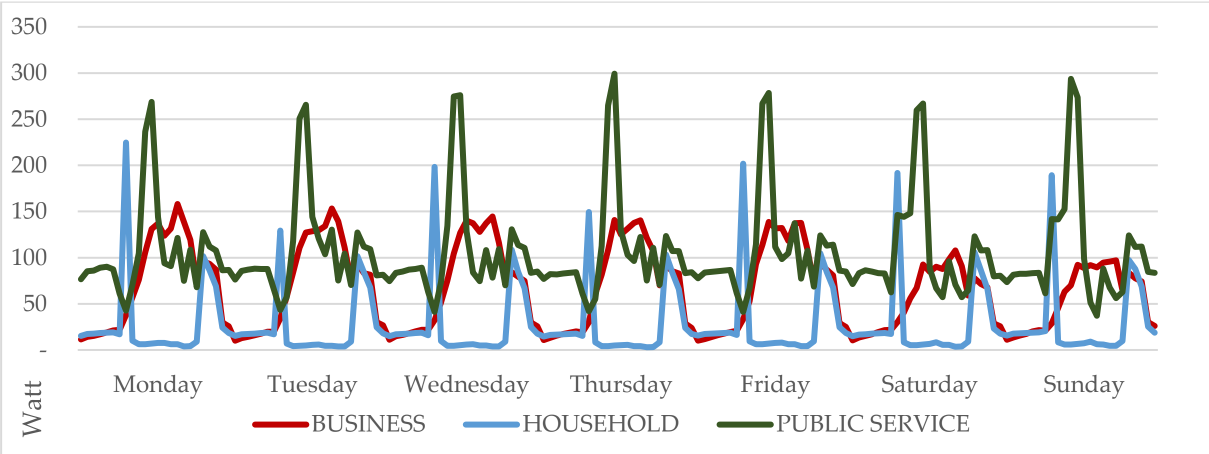


Figure 3.18: Weekly load demand user-specific of Matembwe per macro-category.

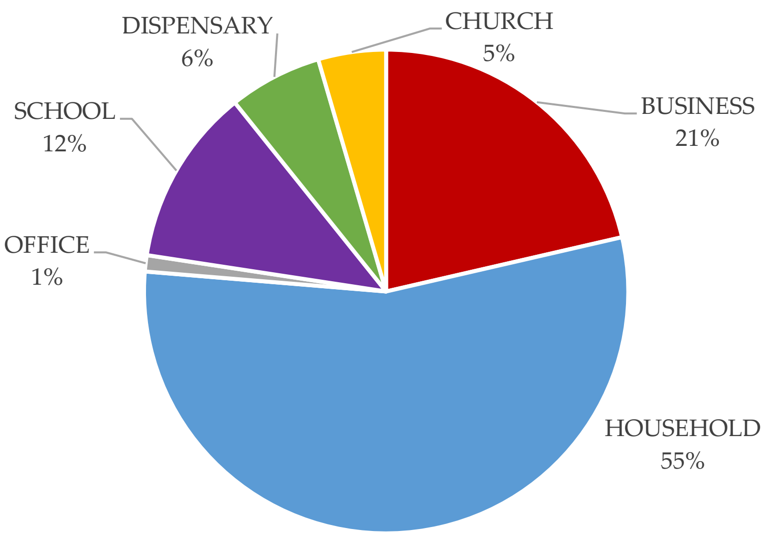


Figure 3.19: Breakdown of consumptions by macro-category.

In the end, results extrapolated from this thesis research for the case-study of Matembwe can be extended for supporting NGOs fostering rural electrification. In fact, the enhanced time accuracy of the calibrated curve with the division in categories, can be exported and taken as a guide for future mini-grid design. The design of the mini-grid and the sizing of the expansion is supported by the prevision of consumption performed with the modelling tool, that is able to implement different per hour curves for different user.

4 Conclusion

Rural electrification in Matembwe, during years, brought to the economic development of its inhabitants, that mainly rely on agriculture and small business activities as shops, garages, and bars. The hydropower plants built in the area captured the attention of the national utility, that has been interested in extending its lines to the villages powered by the mini-grid. This means that the work made by the NGOs is fundamental in connecting rural areas, encouraging their economic growth. The aim of this thesis was to give instruments for foster the expansion of the grid among inhabitants of the villages.

The results show that the curves provided by the modelling tool and the actual ones are comparable. In particular, the household category, that represent the 87% of the users, is the most accurate one. With the load demand provided by RAMP, it is possible to have a high time definition calibration of the consumption of the users, that represent the consumptions per hour instead of per month. In addition, the analysis performed with the data collected provided a load demand divided specific per category of user, instead of a division per macro-category. The characteristics of the users, their localization, and the maps of the transformer are part of the toolkit to give to the MVC as instruments to drive future connections.

In the end, all the tools provided by this thesis work can be exploited by NGOs interested in expanding the mini-grid, as the MVC and CEFA for future projects.

The last comment to leave as just a conjecture for future projects, is on the need of the adoption of end-of-life strategy to avoid environmental and health impact of the power appliances, when they need to be disposed. This problem is much bigger than strictly the case of Matembwe, indeed involves the whole African continent, and the African and not-African government programmes.

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A Appendix A

A.1. First survey

Date

yyyy-mm-dd

Village

- ◯ Matembwe
- ◯ Image
- ◯ Iyembela
- ◯ Isoliwaya
- ◯ Kanikelele
- ◯ Ukalawa
- ◯ Nyave
- ◯ Ikondo

Neighborhood Matembwe

- ◯ Majengo
- ◯ Ukinga
- ◯ Itundu
- ◯ Mtakuja
- ◯ Lung'angali

Neighborhood Image

- ◯ Usakanyo
- ◯ Mtowo
- ◯ Mlangali
- ◯ Ulinganyi
- ◯ Muone
- ◯ Igunguli

Neighborhood Iyembela

- ◯ Iyembela A
- ◯ Iyembela B

Neighborhood Isoliwaya

- Ihembo
- Utengule
- Mgude
- Ikalila
- Mnemele
- Mpeto
- Usakila

Neighborhood Kanikelele

- Ndago
- Igoga
- Ituli
- Luganga
- Kimbo
- Mtonga
- Ibanawanu

Neighborhood Ukalawa

- Ukalawa
- Mgongolo
- Kinguchilo
- Mlangali
- Kilanzi
- Mkobi
- Ituli
- Mngate

Neighborhood Nyave

- Igombola
- Ilala
- Iduli
- Uchange A
- Uchange B

Neighborhood Ikondo

- ◯ Idyadya
- ◯ Igumbilo
- ◯ Manyamle
- ◯ Uheni
- ◯ Mtanga
- ◯ Itova
- ◯ Mkondoa

Record your current location

latitude (x.y °)

longitude (x.y °)

altitude (m)

accuracy (m)

Type of building

- ◯ Household
- ◯ Business
- ◯ Public service

Owner

Gender

- ◯ Male
- ◯ Female

Number of people

Type of business

- ○ Shop
- ○ Carpentry workshop
- ○ Haircutting salon
- ○ Bar/pub
- ○ Butcher
- ○ Garage
- ○ Financial services
- ○ Guest house
- ○ Restaurant
- ○ Tailor shop
- ○ Milling machine
- ○ Other

Other type of business

____

Type of public service

- ○ School
- ○ Dispensary
- ○ Public office
- ○ Church
- ○ Other

Other type of public service

____

Metal sheet roof

- ○ Yes
- ○ No
- ○ I don't know

Plaster inside wall

- ○ Yes
- ○ No
- ○ I don't know

Concrete floor

- ○ Yes
- ○ No
- ○ I don't know

Connected to the grid

- ○ Yes
- ○ No

Connected to

- ☐ Tanesco
- ☐ MVC

Alternative sources

- ☐ PV panel
- ☐ Generator
- ☐ Other
- ☐ No

Other alternative sources

____

The business can work without electricity

- ○ Yes
- ○ No

Other informations

- ○ Now
- ○ Later

Date of the connection

____

Financing program

- ○ TEDAP
- ○ RBF I
- ○ RBF II
- ○ REIF
- ○ Other

Other program

____

A.2. Transformers map

Village

- ◯ Matembwe
- ◯ Iyembela
- ◯ Isoliwaya
- ◯ Kanikelele
- ◯ Ikondo
- ◯ Nyave
- ◯ Image
- ◯ Ukalawa

Record your current location

latitude (x.y °)

longitude (x.y °)

altitude (m)

accuracy (m)

Name

A.3. Second survey

Type of user

- ◯ Business
- ◯ Household

Type of business

- ☐ Shop
- ☐ Carpentry workshop
- ☐ Haircutting salon
- ☐ Bar/pub
- ☐ Butcher
- ☐ Garage
- ☐ Financial service
- ☐ Guest house
- ☐ Restaurant
- ☐ Tailor shop
- ☐ Milling machine
- ☐ Other

Other

Type of household

- ◯ Only roof
- ◯ With floor

Appliances

- ◯ Indoor lights
- ◯ Outdoor lights
- ◯ Charger
- ◯ Radio
- ◯ TV
- ◯ Electric iron
- ◯ PC
- ◯ Fridge
- ◯ Rice cooker
- ◯ Mixer
- ◯ Hair dryer
- ◯ Electric razor
- ◯ Fan
- ◯ Printer
- ◯ Photocopy machine
- ◯ Sewing machine
- ◯ Washing machine
- ◯ Grinder
- ◯ Water pump
- ◯ Compressor
- ◯ Welding machine
- ◯ Milling machine
- ◯ Carpentry machineries
- ◯ Other

Other

___

Number of appliances

___

Time of using

- ☐ 5 - 6 (TZ 11 usiku - 12 asubuhi)
- ☐ 6 - 7 (TZ 12 asubuhi - 1 asubuhi)
- ☐ 7 - 8 (TZ 1 asubuhi - 2 asubuhi)
- ☐ 8 - 9 (TZ 2 asubuhi - 3 asubuhi)
- ☐ 9 - 10 (TZ 3 asubuhi - 4 asubuhi)
- ☐ 10 - 11 (TZ 4 asubuhi - 5 asubuhi)
- ☐ 11 - 12 (TZ 5 asubuhi - 6 mchana)
- ☐ 12 - 13 (TZ 6 mchana - 7 mchana)
- ☐ 13 - 14 (TZ 7 mchana - 8 mchana)
- ☐ 14 - 15 (TZ 8 mchana - 9 jioni)
- ☐ 15 - 16 (TZ 9 jioni - 10 jioni)
- ☐ 16 - 17 (TZ 10 jioni - 11 jioni)
- ☐ 17 - 18 (TZ 11 jioni - 12 jioni)
- ☐ 18 - 19 (TZ 12 jioni - 1 usiku)
- ☐ 19 - 20 (TZ 1 usiku - 2 usiku)
- ☐ 20 - 21 (TZ 2 usiku - 3 usiku)
- ☐ 21 - 22 (TZ 3 usiku - 4 usiku)
- ☐ 22 - 23 (TZ 4 usiku - 5 usiku)
- ☐ 23 - 24 (TZ 5 usiku - 6 usiku)
- ☐ 24 - 5 (TZ 6 usiku - 11 usiku)

Times a week

____

Comments

____

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