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Implementation and validation of a Multidimensional Needs-to-Strategy Energy Planning tool for developing country

TESI DI LAUREA MAGISTRALE IN
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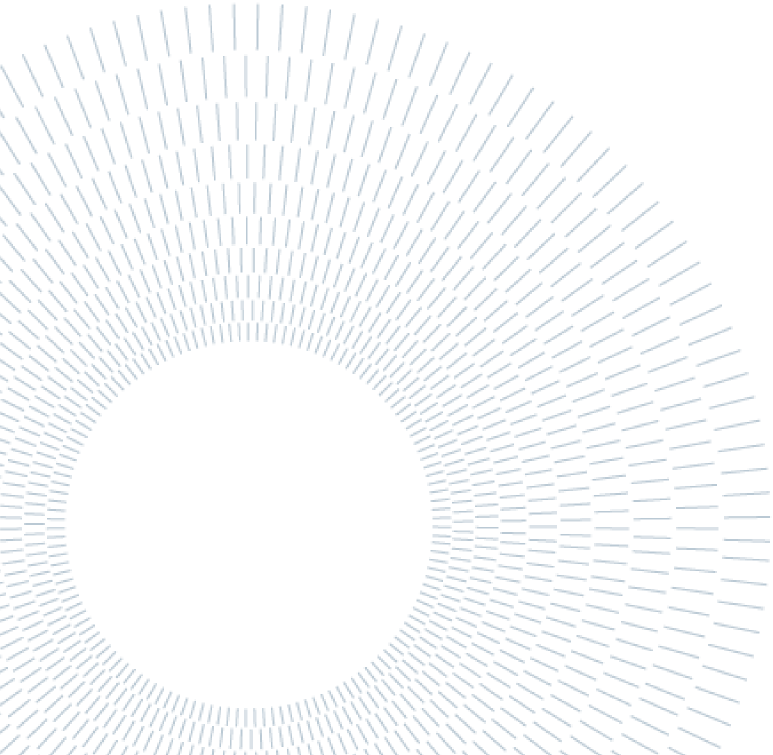

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Gian Giacomo & Tommaso

The first thanks certainly go to my family for the support they have given me over the years and for being a reference point I could count on.

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Khanimambo

Gian Giacomo Sommariva

Abstract

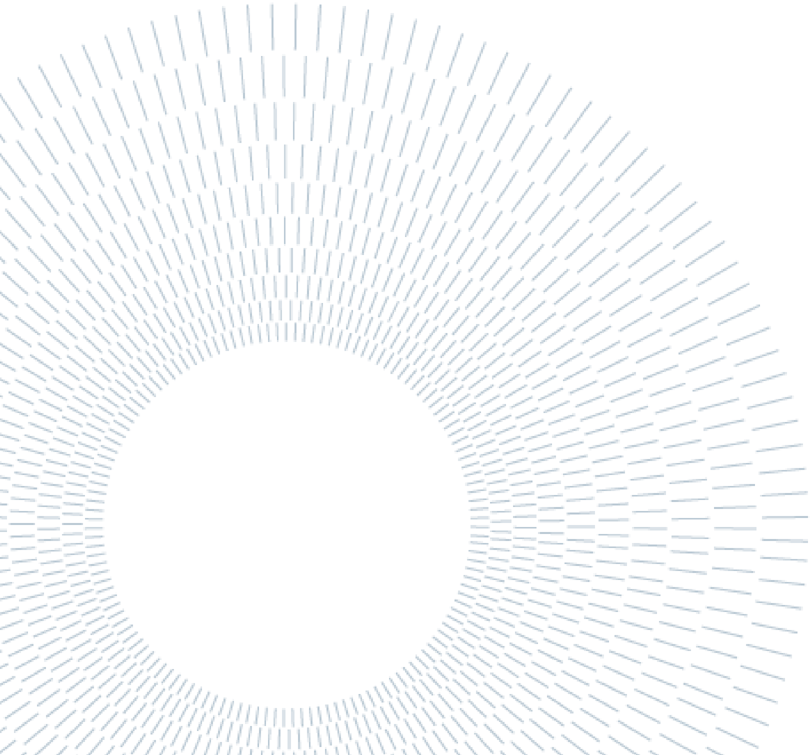
One of the main goals of the Agenda 2030, expressed in SDG 7, is to ensure universal access to a modern, sustainable, affordable and reliable energy system. The main challenge in achieving this goal is to provide energy access to rural communities in developing countries. This requires the implementation of electrification projects that can best reflect the needs of the community in question. This study began with an analysis of the literature on the definition of energy access, which is no longer seen as a simple connection to the grid, but as a means of enabling essential functions in daily life. In line with these new definitions, ESMAP has developed the Multi-Tier Framework (MTF) methodology, which proposes a definition of energy access that is multidimensional, overcoming the binary approach of this concept, with a fragmentation of energy into different attributes, each classified on a scale of values from 0 to 5. In the context of this thesis, a tool has been developed, implemented on the Excel platform, inspired by the MTF as a framework for data collection and classification of energy access of a generic community. This first part was followed by a discussion on how to process the data in order to offer a new decision support system. The tool not only provides a series of results related to the MTF but has also been designed to guide the user towards a design choice by incorporating parameters, indices and graphs proposed by the authors. In particular, an index based on the well-known concept of willingness to pay has been introduced but re-proposed in energy terms. The aim is to make the user aware of how much energy the project beneficiaries can afford in relation to their salary. Overall, the proposed tool aims to identify the needs and priorities of the community and to choose the best strategy in terms of economic sustainability. The validation of the tool was carried out using data from the ILUMINA project, implemented by the NGOs AVSI and COSV, in order to verify its correct functioning and to illustrate the logical processes to be followed when using it. In conclusion, it can be said that the tool is an innovative instrument in the sector, providing new insights for the actors involved, but leaving space for possible improvements by extending the treatment to production and public activities.

Keywords: energy access; multi-tier framework; decision support system; energy needs identification.

Abstract in italiano

Uno dei principali obiettivi dell'AGENDA 2030, espresso dall'SDG-7, è garantire un accesso universale ad un sistema di energia moderno, sostenibile, economicamente accessibile e affidabile. La sfida più significativa per raggiungere tale obiettivo risiede nel fornire accesso all'energia alle comunità rurali dei paesi in via di sviluppo. A tal fine, è necessaria l'implementazione di progetti di elettrificazione che possano rispecchiare al meglio le esigenze della comunità in esame. Questo studio è partito da un'analisi della letteratura scientifica sul tema della definizione di accesso all'energia, pensato non come semplice connessione alla rete ma come mezzo per sbloccare funzionalità importanti nella vita di tutti i giorni. Sulla scia di queste nuove definizioni, ESMAP ha proposto la metodologia Multi-Tier Framework (MTF), la quale propone una definizione dell'accesso all'energia che sia multidimensionale, superando l'approccio binario di tale concetto, con una frammentazione dell'energia in diversi attributi, ciascuno classificato su una scala di valori da 0 a 5. Nel contesto di questa tesi è stato sviluppato un tool, implementato sulla piattaforma Excel, che si ispira all'MTF come strumento per il raccoglimento dati e la classificazione di accesso all'energia di una generica comunità. A questa prima parte è stata annessa tutta una successiva trattazione che permetta di elaborare i dati al fine di offrire un nuovo strumento di supporto decisionale. Il tool offre una gamma di risultati non unicamente riferiti all'MTF ma è stato pensato anche per poter indirizzare l'utente verso una scelta progettuale includendo parametri, indici e grafici proposti dagli autori. In particolare, è stato introdotto un indice basato sul concetto, già noto, di disponibilità a pagare ma riproposto in termini energetici. L'obiettivo è far capire all'utente la quantità di energia che i beneficiari del progetto possono permettersi relativamente al loro stipendio. Pertanto, nel suo complesso il tool proposto ha come scopo quello di identificare i bisogni e le priorità della comunità e scegliere la strategia migliore dal punto di vista della sostenibilità economica. È stata compiuta la validazione del tool sfruttando i dati del progetto ILUMINA, condotto dalle ONG AVSI e COSV, al fine di verificarne il suo corretto funzionamento e illustrare i processi logici da seguire durante l'utilizzo. In conclusione, è possibile affermare che il tool si pone come uno strumento innovativo nel settore fornendo nuovi spunti per gli attori in gioco ma lasciando spazio a possibili miglioramenti estendendo la trattazione anche alle attività produttive e pubbliche.

Parole chiave: accesso all'energia; multi-tier framework; sistema di supporto decisionale; identificazione dei bisogni energetici.



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Abbreviations Index

AfCFTA – Africa Continental Free Trade Area

BCs – Basic Capabilities

CA – Capability Approach

CO_2 – Carbon Dioxide

CWR – Consumption-Willingness Ratio

DSS – Decision Support System

ESMAP – Energy Sector Management Assistance Program

GDP – Gross Domestic Product

GHI – Global hunger Index

HDI – Human Development Index

H&C – Heating & Cooling ()

IEA – International Energy Agency

IWA – International Water Association

MDGs – Millennium Development Goals

MPI – Multidimensional Poverty Index

MTF – Multi-Tier Framework

OECD – Organization for Economic Cooperation and Development

OPHI – Oxford Poverty and Human Development Initiative

PAC – Practical Action Consulting

SCs – Secondary Capabilities

SDGs – Sustainable Development Goals

SESAM - Sustainable Energy System Analysis and Modelling

SE4ALL – Sustainable Energy for All

SREP – Scaling Up Renewable Energy Program

SSA – Sub-Saharan Africa

TEA – Total Energy Access

TES – Total Energy Supply

TFC – Total Final Consumption

UN – United Nations
UNDP – United Nations Development Programme
US – United States
WB – World Bank
WHO – World Health Organization
WTC – Willingness to Consume
WTP – Willingness to Pay

1 Introduction

The research gap addressed in this paper revolves around the absence of a readily available tool that integrates design choices and adapts the Multi-Tier Framework (MTF) approach to assess energy access in a multidimensional manner. This gap leads to challenges in accurately quantifying energy needs, which can result in underestimating or misinterpreting the problem with a knock-on effect on all the other phases and activities of the project as the various steps are interrelated. For example, misinterpreting community needs may lead to incorrect electricity demand forecasts, affecting the sizing of the energy production system. Flawed strategy selection can also hinder the achievement of intervention objectives, potentially proposing unaffordable technological solutions or providing no benefits to the village.

The objectives of this dissertation are outlined to address these gaps. The aim is to develop a comprehensive tool that integrates the MTF into electrification projects in rural villages. The motivation behind proposing the innovative tool stems from the recognition of the need to go beyond a purely techno-centric perspective and incorporate social and environmental factors. In this regard, Süsser et al. have rightfully criticized models that overlook social and environmental factors in favour of a narrow technical focus [1]. These factors are of extreme importance. This refers to all the parameters that define the socio-economic conditions of the population under consideration. Merely planning and implementing an electrification project are insufficient for achieving success. It is vital to fully comprehend the underlying problems and their root causes.

The first objective is to integrate the MTF into a comprehensive tool that can be applied to projects aimed at electrifying rural villages. In this way it will be possible to shift away from the perception of the MTF solely as a tool for data collection and evaluation of general access at the country level as demonstrated in the case of Ethiopia and Rwanda ([2], [3]).

By doing so, the aim is to provide a quantitative assessment of energy access by employing a simple questionnaire administered to the local population. Thus, the MTF makes it possible to identify which attributes of electricity limit its consumption and which energy services are most required. In this way, it is possible to determine which individuals or class of individuals it will be most appropriate to include in the project among the beneficiaries and for each of them to determine the most appropriate direction of intervention. This approach will establish a direct connection between the "Needs and Priorities Identification" phase and the "Diagnosis and Load Demand Assessment" phase.

Another objective of equal importance, once the basic needs are understood, is to predict the direction of intervention and anticipate the benefits it will bring to the community. To achieve this, a decision support system (DSS) is necessary, which demonstrates the direct impact of the intervention on individual households and the broader community. This integration of the "Strategy Selection" and "Design and Implementation" phases creates a complete picture for the user. It is worth noting that the strategy selection phase has generally always focused primarily on selecting the most suitable and cost-effective technology according to specific objectives, such as the extension of the national grid or the implementation of decentralized or distributed off-grid solutions. In this tool, on the other hand, this phase is not conceived as a techno-economic decision, but more as a social aspect, in terms of its impact on the community – using specific indices such as the Gini Index – and echoing, in a way, the founding concept of Multi-Criteria Analysis as expressed by Cherni et al. [4]. The work presented here aims to translate the direction of intervention into an a priori selection of which classes or family groups to favour for the project and the level of intensity of action required.

Finally, the tool has been implemented in Excel with the aim of making it available to the majority of actors operating in the sector since it is a very versatile and globally recognized program. In this way, the proposed tool would not require highly specialized knowledge, but would gain further value by extending its use to a much wider portion of users.

Chapter 1 provides an overview of the issue to access to energy in developing countries, with a specific focus on the sub-Saharan Africa region. It includes a brief energy outlook for the region and discusses the evolution of the concept of energy poverty from binary perspective to a multidimensional way.

Chapter 2 focuses on the methodology employed in developing the "Multidimensional Needs-to-Strategy Energy Planning" tool in all its modules.

Chapter 3 provides an in-depth description of the tool itself, including its modules, input data, decision support tools, interpretation of results, and the recommended approach for utilizing the tool.

Chapter 4 presents the results obtained from the validation of the tool, using data collected by the NGOs AVSI and COSV during the ILUMINA project. This chapter therefore compares the load demand curve estimation results obtained from the tool with those obtained without this methodological approach.

Chapter 5 is devoted to a more detailed analysis of the results presented in the previous chapter and discusses possible improvements with regard to both the methodology and the implementation of the tool.

2 Energy Context

2.1. Background

2.1.1. Global Poverty: evolution of definitions and state-of-the-art

Poverty is one of the most important issues facing the world today. However, there is still no universally accepted definition of poverty. The United Nations (UN) defines poverty as "*the lack of resources, means, opportunities, security and power necessary to enjoy an adequate standard of living and other civil, political, economic and social rights*" [5].

The concept of poverty has changed significantly over time, moving from a strictly economic definition to a more multidimensional perspective that includes social, cultural and political dimensions. After the Second World War, poverty was perceived mainly as a lack of income and material resources. The dominant economic paradigm of the time focused on economic growth and industrialization, and poverty was seen as a reflection of inadequate economic development [6]. The historical approach to poverty reduction thus focused on increasing the incomes of the poor, mainly through economic growth and redistributive policies. However, this approach was increasingly challenged in the 1970s and 1980s as poverty persisted despite significant economic growth in many countries. Academics and policymakers began to recognise that poverty was a more complex and multidimensional phenomenon, with social, cultural and political factors playing a significant role in its persistence [7]. As a result, new approaches to poverty and development emerged, emphasising the multidimensional nature of poverty and the need to address a range of factors that contribute to poverty. Among these paradigms, Nobel Prize-winning economist Amartya Sen introduced the concept of "development as freedom" in the late 1990s [8]. This new concept of development derives from the capability approach (CA) and emphasises the importance of empowering people to lead valuable lives, rather than simply providing them with material resources ([8], [9]). Section 1.3.2 is devoted to explaining more in details this new approach.

The evolution of the concept of poverty from a purely economic to a multidimensional view has had a profound impact on development policy. This paradigm shift has been reflected in the development policies of many countries and international organisations, including the United Nations Development Programme (UNDP), which has begun to focus on human development and empowerment rather than on economic growth alone. In parallel, new indicators have been developed to measure and monitor poverty that go beyond the traditional income-based dimension. One of the most important of these indicators is the Multidimensional Poverty Index (MPI), launched in 2010 by the United Nations Development Programme (UNDP) in collaboration with OPHI [10].

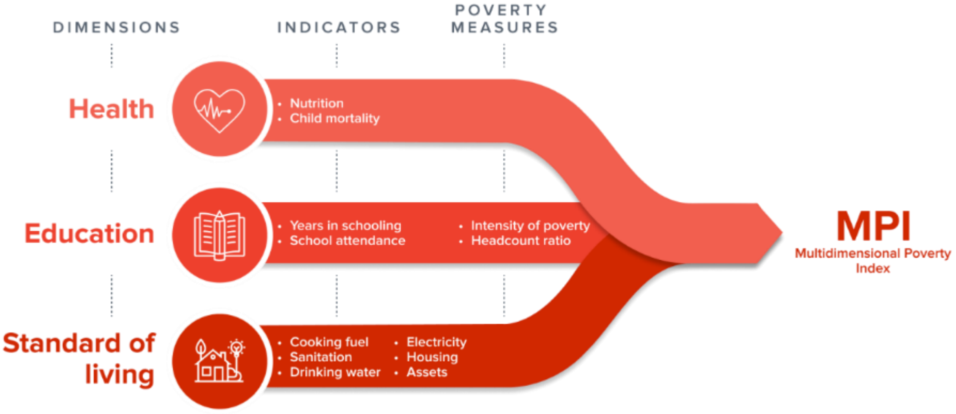


Figure 1. Scheme of MPI. Source: Human Development Reports

Unlike traditional measures of poverty that focus solely on income, the MPI considers a range of deprivations in health, education and living standards, providing a more comprehensive and nuanced picture of poverty. The application of the MPI has been documented through a case study of three countries – Ethiopia, Lao People's Democratic Republic and Nepal – to investigate the relationship between poverty reduction, multisectoral policy interventions and interrelated deprivation [10]. The report aims to point out the importance of frequent and up-to-date household survey to measure poverty and to put in place strategic tool to tackle extreme poverty and explores pathways out of poverty that have successfully addressed poverty.

According to the latest global MPI report [10], an estimated 1.3 billion people worldwide, or nearly double the number of people in monetary poverty, live in acute multidimensional poverty, with the highest concentration of poverty found in sub-Saharan Africa (nearly 579 million) and South Asia (nearly 385 million). The report also highlights the disproportionate impact of poverty on children, with nearly half of all children in sub-Saharan Africa and South Asia living in multidimensional poverty. The adoption of the MPI and other multidimensional measures of poverty represents an important step towards a more integrated and effective approach to poverty reduction. By identifying the specific dimensions of poverty that are most relevant in a given context, policymakers and development practitioners can design more targeted and effective interventions that address the root causes of poverty.

The MPI was mentioned, but in recent years various new indices have been proposed, such as human development index (HDI), global hunger index (GHI) and others, trying to capture different aspects of poverty and human and planetary development. They provide policymakers and researchers with valuable tools to assess progress, identify gaps, and design targeted interventions to address specific challenges in various dimensions of well-being and human development. By utilizing these multidimensional indexes, policymakers can develop more comprehensive and effective strategies to combat poverty and promote sustainable development.

2.1.2. Towards the End of Energy Poverty

Access to electricity and clean cooking fuels are among the many dimensions considered by the MPI. Not having adequate access to energy has a negative impact on various aspects of daily life. In general, there is no single definition of energy access as the definition of energy itself is already very broad. It depends, in fact, on who uses it – might be the individual household, a business or a public body – what it is used for – lighting, cooking, communication, transport, etc. – and in what form it is used – electricity, biomass, gas and others fossil fuel.

One definition that tries to encompass all these different dimensions is the one provided by the SE4ALL program which states: *"Energy poverty is a lack of access to modern energy services which include electricity, clean cooking facilities and appliances, modern transport, and heating and cooling services that are necessary for basic household needs, healthcare, education, and economic development"* [11]. This lack of access has significant impacts on the quality of life and well-being of individuals and communities, particularly in developing countries. The effects of not having energy access are wide-ranging and severe. Lack of access to electricity, for example, limits the ability to perform daily activities such as studying, cooking, and working [12]. Without electricity, lighting is scarce, and people are often forced to rely on kerosene lamps or candles, which can cause respiratory problems and fires. Lack of access to clean cooking facilities also has negative health consequences, as people often cook on open fires or traditional stoves, leading to indoor air pollution and respiratory diseases. In addition, energy poverty limits economic opportunities, hindering the ability to develop and sustain businesses and industries.

Globally, an estimated 747 million people lack access to electricity and 2.38 billion [13] people lack access to clean cooking facilities in 2020. Most of these people live in sub-Saharan Africa, where energy poverty rates are among the highest in the world. In sub-Saharan Africa, 52% of the population lacks access to electricity, and 82% of the population relies on traditional biomass for cooking [13]. Between 2000 and 2020, the absolute number of people without access to electricity increased from about 500 million to almost 600 million, but when considering the same data in percentage values, a clear improvement is measured over the past two decades from only one in four people (25.6%) with access to electricity to almost one in two (48.2%) [13]. This makes evident how Africa's population growth has also been matched by economic and social growth, thanks to the efforts of local governments and targeted policies to electrify the continent [14]. Even in terms of access to clean technology for cooking, there has been a percentage improvement with growth over the total population from 9% to 17.6% [13]. However, this pace is not enough to reach the targets set by the SDG of the 2030 Agenda, especially with regard to the sub-Saharan rural population, 71.5% of which is currently still without electricity and 94% of which is still dependent on traditional biomass [13].

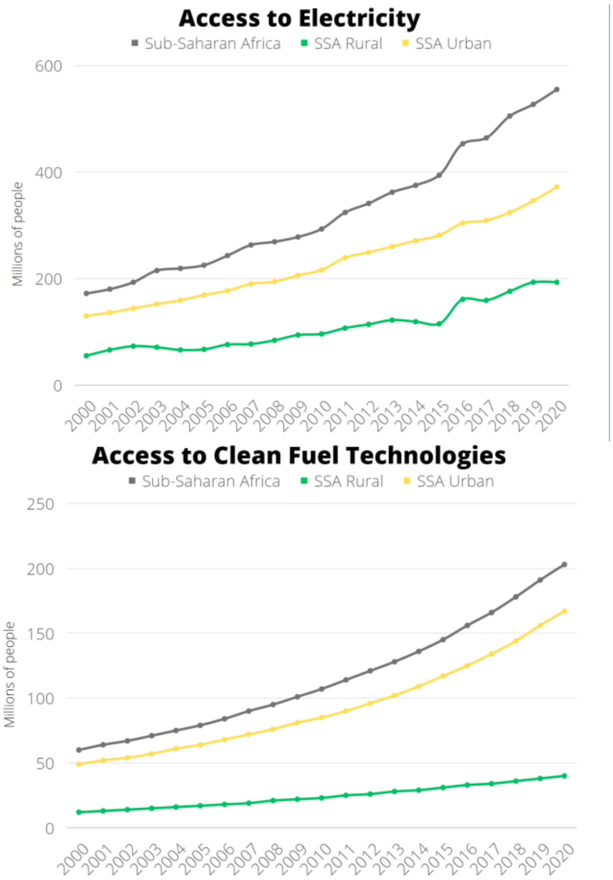


Figure 2. Trend of access to electricity and clean fuel in Sub-Saharan Africa. Source: World Bank data elaborated by the authors

To fight against energy poverty, several initiatives and interventions are being implemented. These include off-grid renewable energy solutions such as solar home systems and mini-grids, as well as government-led efforts to expand access to electricity and clean cooking facilities. Additionally, international organizations such as the United Nations and World Bank are working to increase funding and support for energy access projects in developing countries. The following sub-section will detail these initiatives.

2.1.3. Role of International Organizations in Fighting Energy Poverty

International organizations have played a crucial role in addressing global problems and promoting international cooperation in various fields. The role of these organizations is particularly important in tackling the complex and interconnected challenges facing the world today, from poverty and inequality to climate change and global health. International organizations such as the United Nations, the World Bank, and the International Monetary Fund have been instrumental in promoting sustainable development and addressing poverty in the world. These organizations have implemented numerous policies and programs aimed at reducing poverty and promoting economic growth in developing countries. While the role of governments is also important in addressing these challenges, international organizations bring a unique perspective and level of expertise to the table. They have the ability to pool resources and coordinate efforts across borders, leveraging their collective power to achieve common goals.

One area where international organizations have been particularly effective is in addressing energy poverty. To address this challenge, international organizations such as the World Bank, the United Nations Development Programme and the International Energy Agency (IEA) have implemented numerous policies and initiatives aimed at increasing access to energy in developing countries. As examples, the *"Lighting Global"*, World Bank Group's initiative [15], works to increase rapidly access to off-grid solar energy trying to unlock key market barriers and enable access and affordability to those that would otherwise be left behind. *"Power Africa"* [16], launched by the United States government, aims to increase access to electricity in Sub-Saharan Africa strengthening energy infrastructure and promoting policy reforms for sustainable energy development. These initiatives include the provision of financial support for renewable energy projects, the development of energy-efficient technologies, and the promotion of policies and regulations that support universal access to energy.

The Agenda 2030 is one of the most relevant initiatives in action nowadays in terms of the ambition of the goals set and the area of action. Launched in September 2015 by the United Nations General Assembly, it is a plan of action for people, the planet and prosperity. The agenda is a continuation of the Millennium Development Goals (MDGs) that were set in 2000 and expired in 2015. The MDGs focused on reducing poverty, hunger, and disease in developing countries, but the 2030 Agenda is more ambitious and aims to end poverty, protect the planet, and ensure peace and prosperity for all by 2030.

The 2030 Agenda consists of 17 Sustainable Development Goals (SDGs), developed through a process of consultations and negotiations involving all 193 UN Member States and other stakeholders. The SDGs cover a range of interconnected issues, based on the principle of leaving no one behind and recognizing the interdependence of social, economic and environmental factors and the need for integrated approaches to development.

Since the adoption of the 2030 Agenda, progress has been made towards achieving the SDGs, but much more needs to be done. According to the UN [17], the COVID-19 pandemic has set back progress towards the goals, particularly in areas such as poverty reduction, hunger, education and health. The pandemic has also highlighted the importance of achieving the SDGs as a means of building more resilient and sustainable societies.

Sustainable Energy for All (SE4ALL) [11], launched by the UN, aims to achieve universal access to modern energy services, improve energy efficiency and increase the share of RE in the global energy mix, promoting partnerships and mobilizing resources to address energy poverty and advance sustainable development.

To promote the realisation of the goals of the 2030 Agenda, the UN has entered into agreements with other existing initiatives. One example is Sustainable Energy for All (SE4ALL), which was launched by the UN in 2011 and has become an independent organisation with the aim of accelerating action to achieve Sustainable Development Goal 7 (SDG7).

According to SDG 7, SE4ALL is focused on ensuring access to affordable, reliable, sustainable and modern energy for all. This is critical for achieving sustainable and inclusive development, as energy is essential for economic growth, social development, and environmental sustainability.

The targets of SDG 7 are:

- By 2030, ensure universal access to affordable, reliable, and modern energy services.
- By 2030, increase substantially the share of renewable energy in the global energy mix.
- By 2030, double the global rate of improvement in energy efficiency.
- By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency, and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.
- By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular

> least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programs of support.

Achieving SDG-7 can improve health outcomes by reducing indoor air pollution from traditional cooking fuels, increase productivity and economic growth by providing reliable electricity to businesses, and promote environmental sustainability by reducing reliance on fossil fuels and reducing greenhouse gas emissions. It has brought many benefits since its adoption; according to the IEA, progress has been made towards achieving universal access to electricity, with the number of people without access falling down from 2015 to these recent years but not with the expected trend. In spite of everything, stronger collaboration and commitment from governments and institutions through policy are needed to achieve the targets imposed.

2.1.4. Energy Sector Management Assistance Program (ESMAP)

One organization that has played a critical role in addressing energy poverty is the Energy Sector Management Assistance Program (ESMAP), a global technical assistance program managed by the World Bank in partnership with 24 governmental and non-governmental organisations. ESMAP works to promote sustainable energy development and addresses energy poverty through a range of activities, including technical assistance, research, and knowledge sharing. One of its key contributions to the field is the development of the Multi-Tier Framework (MTF) [18], a tool for measuring energy access and tracking progress towards achieving universal access to modern energy services. In June 2015, ESMAP launched the MTF as an initiative proposing a new definition of energy access, going beyond the traditional binary measure of “connected or not connected” for electricity access, and “solid vs non-solid fuels” for cooking [18]. The MTF’s international initiative has been possible with the valued technical and financial support of ESMAP, sustained by additional funding from the Scaling Up Renewable Energy Program (SREP) and with the collaboration of the Sustainable Energy for All initiative (SE4ALL).

The program aims to propose a specific survey in order to collect data and so deliver an innovative narrative about the country’s energy status. The MTF defines the energy access as a ladder made of more steps representing energy services. These surveys provide detailed energy data at the household level for governments, development partners, the private sector, non-governmental organizations and investor.

Figure 3. Organization scheme of ESMAP. Source: elaborated by authors

The MTF is based on a multi-dimensional approach to measure energy access that considers attributes such as reliability, affordability, and quality of energy services. The framework includes five tiers, with Tier 0 representing no access to energy services and Tier 5 representing full access to modern energy services. By using the MTF, policymakers and stakeholders can better understand the nature of energy poverty in a particular context and design effective interventions to address it. ESMAP's work on the MTF has been instrumental in shaping the global discourse on energy poverty and has contributed to the development of policies and programs aimed at expanding access to modern energy services. Through its technical assistance and knowledge-sharing activities, ESMAP has also helped build the capacity of governments and other stakeholders to design and implement effective energy access programs. ESMAP’s MTF has rapidly become the most affirmed reference when it comes to measuring energy access in a non-binary fashion and planning interventions accordingly. This tool will be expanded in the literature review section with more detail about it.

2.2. Africa Energy Context

2.2.1. Africa’s growing relevance

Nowadays Africa counts 1.4 billion individuals [16], representing 17.5% of the global population and with an impressive number of young, only those who are below 15 years old represent 40% of the total. However, the WB predicts [13] that the African population will grow up to 2.19 billion people by 2050 and that half of the newborn will occur in the continent. Despite this, population growth is not the only driver that catches the interest of nations and private sector but together with good governance and willingness to close the gap in all the main and essential infrastructure, some countries and soon all Africa are attracting geopolitical interest and foreign direct investment.

With its *"Agenda 2063"*, the African Union has established an ambitious strategy for a prosperous Africa based on inclusive and sustainable development. Agenda 2063 is a strategic framework for the socio-economic transformation of the continent. It builds on and seeks to accelerate the implementation of previous and current continental policy initiatives with the intention to create: *"An integrated, prosperous and peaceful Africa, driven by its own citizens, representing a dynamic force in the international arena"* [19]. This includes the start of the African Continental Free Trade Area (AfCFTA) [20] in 2021 (a flagship project within Agenda 2063), a huge milestone towards accelerating intra-Africa trade and strengthening the continents position in the global economy creating a 1.2-billion-person market and the world's largest free trade zone.

Increasing global interest in the African economy signals the growing attention of several economies beyond a desire to get access to resources (critical raw materials), but to infrastructure (increasingly digital infrastructure), agribusiness, retail and services. Several global players' interests culminate in Africa: Europe, China, the US, India, Turkey, Saudi Arabia, Japan and others are all supporting the development of Africa [21]. This is a huge opportunity for Africa that needs to utilize the various investments and support initiatives to transform the investment and support into the sustainable development of their own economy.

Improvements in governance coupled with demographic gains from the large and growing young population in Africa, promise growth for the future. A diversification of the investment flow and using it for structural transformation will be central to Africa's future economic success.

To fully realize Africa's potential, it is essential to channel investments towards structural transformation, job creation, and inclusive growth. By maximizing the benefits from its resources, Africa can foster long-term development and ensure that its population collects the rewards of economic progress. With the right policies, governance, and strategic partnerships, Africa has the opportunity to shape its own future and become a significant player in the global economy.

2.2.2. Energy Outlook

The African continent is facing a historical period of fast evolution in which challenges don't miss for sure. SSA has begun to build from scratch the majority of its infrastructure, institution, regulations and so on. The one that will be analysed in this section it's the energy infrastructure since it lays the foundation for a modern society. The concept of energy is wide and can be classified in many ways, for example by source – fossil fuel, biomass, electricity, hydrogen – by consumption sector or activity – industrial, domestic, public – and by type of connection – on-grid or off-grid.

However, there is a fundamental point to be made about energy and electricity in particular, namely the fact that it is a key factor in many everyday human activities and the provision of energy services underpins the socio-economic development of nations and their increasing prosperity, as expressed by Fouquet et al. [22]. The activities referred by Fouquet et al. are manifold, from industrial to domestic, from commercial to public services. It is also an essential element that provides potable drinking water, sanitation, health care, lighting, communication, and so on.

Today, Africa's energy system and poor energy infrastructure are limiting factors, as they should be meeting basic daily needs at the household level and supporting productive uses in industry and agriculture. Graphs are shown below to give some quantitative indices and values to the problem. The Total Energy Supply (TES) and electricity consumption per capita reveal more or less the same result, i.e., that in both cases Africa is far below both the OECD countries and the world average. As far as the other two indices of energy intensive and CO_2 emissions are concerned, it can be said that these values are closer to the world average with a trend that has steadily improved in recent years. Energy intensive is a measure of how well a country is able to convert energy into GDP. The concept of CO_2 intensity is also similar in that it measures how much CO_2 is emitted to produce $1 of GDP.

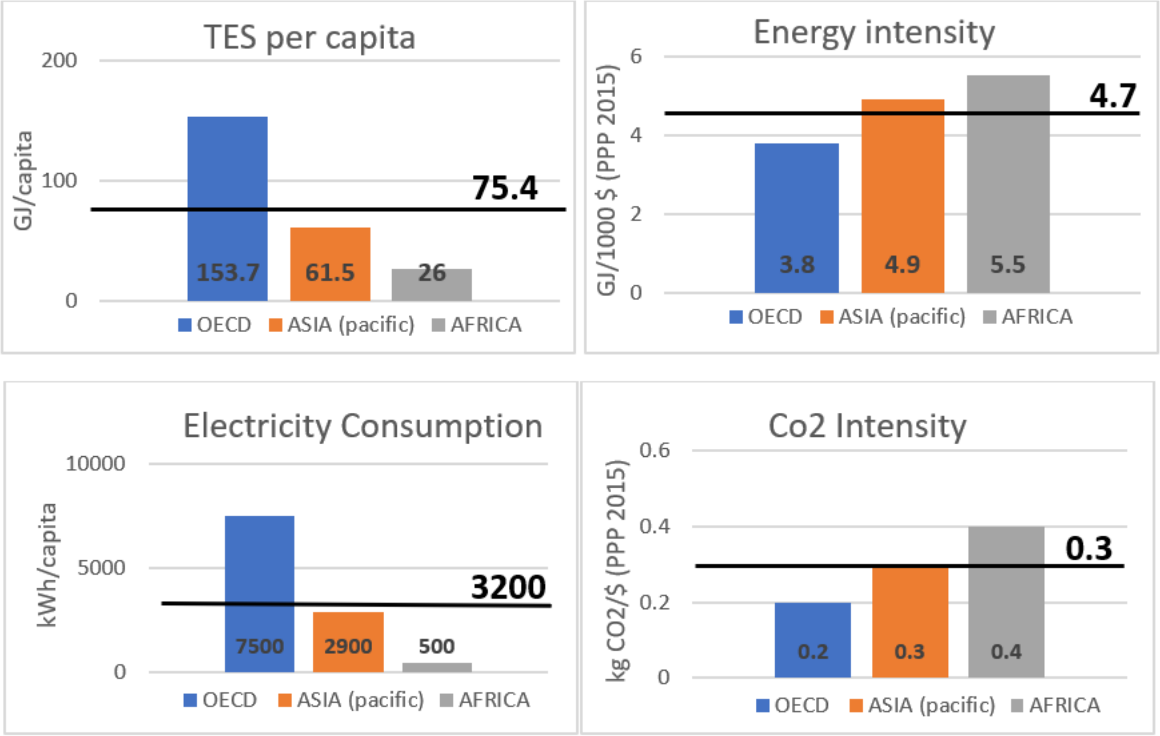


Figure 4. Indices to compare Africa situation with OECD and Asia. Note that the black line represents the world's average. Source: IEA data

Within the global framework, the African energy market suffers from a paradox as African states are among the main extractors of primary resources and rare materials but the majority of them lack the main infrastructure to process and refine them and consequently to consume at an affordable price; this deficit is the effect of decades of exploitation by foreign countries that has prevented the growth of the secondary sector.

Currently, the largest oil producers are Nigeria, Angola, Egypt and Algeria, but the goal for 2030 is to gradually decrease production to make space for other renewable sources.

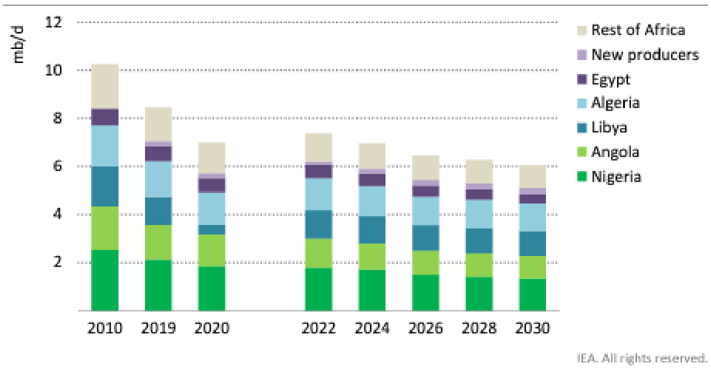


Figure 5. Oil production by region. Source: IEA Africa Outlook 2022

Natural gas, on the other hand, is a different matter. It's an optimal alternative to the traditional biomass and it is more efficient respect the other resources, contributing in positive to air pollution. So given the continuous growth of the population and consequently of energy demand, the goal is to maintain the current percentage of production constant over the years. The largest producers of natural gas are Egypt, Algeria and Nigeria, and soon also Mozambique, since gas extraction from the offshore Coral South field began this year and is expected to be one of the largest ever discovered.

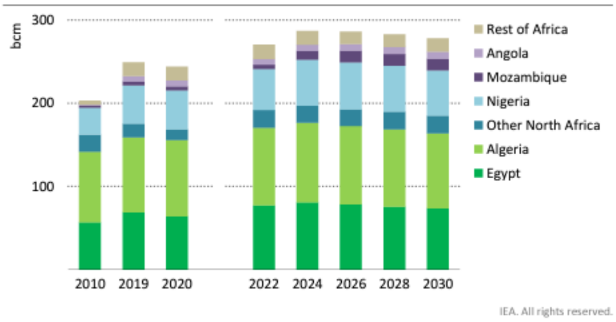


Figure 6. Gas production by region. Source: IEA Africa Outlook 2022

However, these two resources remain important for the so-called hard-to-abate industries – such as steel, cement, fertilizer, etc. – the sector where a major leap forward can and should be made is the residential sector. Looking at Total Final Consumption (TFC), one can immediately see that the residential sector is the most energy consumer and is becoming more and more valuable; over the last three decades it has doubled its consumption from 7 EJ to 14 EJ.

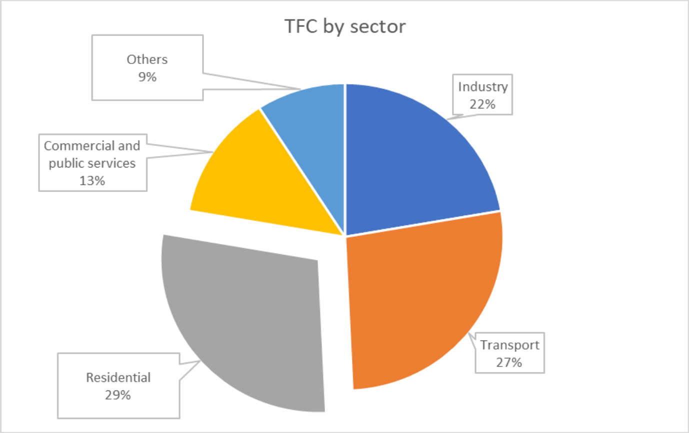


Figure 7. Total Final Consumption (TFC) by sector. Source: elaborated IEA data from the authors

Looking at the TFC by source, the most used resource is biomass, which at the residential level is used both for cooking and heating. This dependence is felt even more at the rural level where the population relies on traditional biomass with percentages close to 100%. This leads to a slowdown in social and economic development, since the collection of biomasses is mainly done by women and children who therefore cannot use their time to work and study.

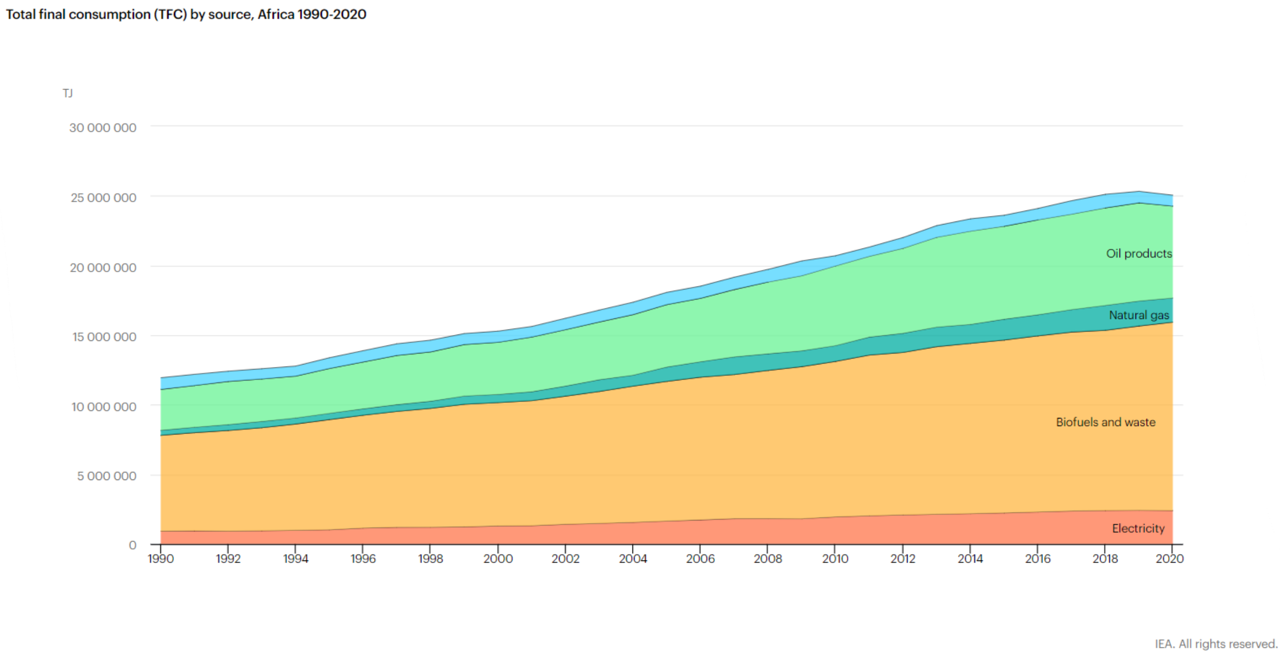


Figure 8. Total Final Consumption (TFC) by source. Source: IEA data

To achieve the goals proposed in Agenda 2030, African states must have the capacity to capture technology spillovers and attract foreign investment, targeting rapid but sustainable growth and leaving no one behind.

The first priority must be to provide affordable access to energy. From an electricity point of view, to achieve this goal by 2030, it is necessary to bring the connection to 90 million people per year, a rate three times higher than in recent years.
As far as access to clean cooking fuel and technologies is concerned, the situation is even worse as by 2030 it will require shifting 130 million people away from dirty and polluting fuel each year. There are currently 970 million people without access to clean cooking. Here the solution is to try to provide as many people as possible with the new technologies and above all to make them understand the health damage caused by traditional use of biomass. These are the graphs representing the trend of these two important challenges that must be the priority in the coming years.

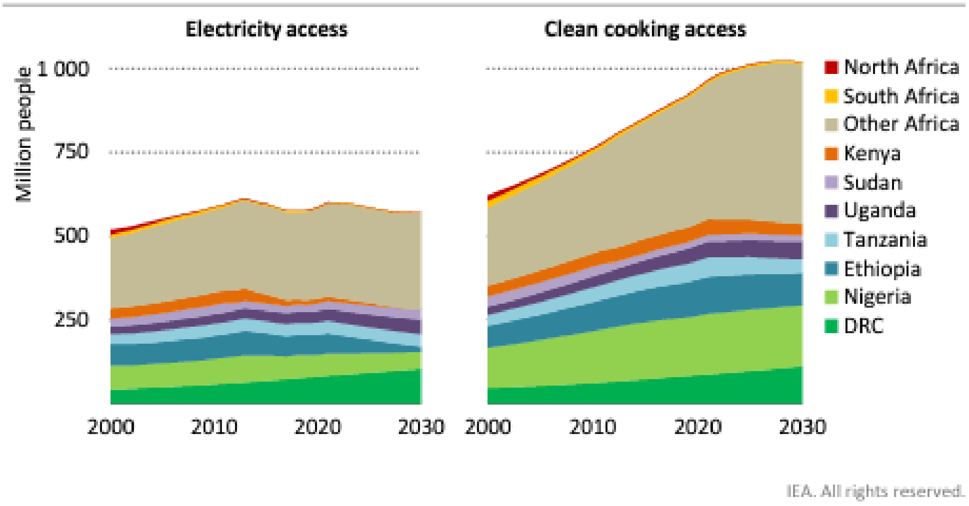


Figure 9. Energy and clean fuels access. Source: IEA Africa Energy Outlook 2022

In general, several factors such as large investments, willingness on the part of local governments, and technological solutions will be crucial in order to achieve the goals imposed by Agenda 2030. It is relevant to provide some additional information regarding possible technological solutions to ensure energy access. With regard to clean fuels, countless cooking stoves have been proposed that allow either using the same fuel but improving its efficiency with the aim of reducing biomass consumption or another category involving the use of other cleaner fuels with higher energy density. Let's take a look at the options for a new electricity connection. They can basically be summarized in two macro categories: the extension of the national grid and the installation of an off-grid system. In order to assess which is the best option usually a cost analysis is done; in Africa extending the national grid often turns out to be very expensive - $3000/km transmission and $30000/km distribution. On the other hand, off-grid energy system has been gaining attention as a possible solution to fill the gap on the electricity access in Africa. Recent evidence (IEA, 2019) has shown that these could account for nearly one third of new electrification in sub-Saharan Africa until 2030. These systems are small-scale energy system that can operate independently of the national grid and create a more resilient energy system by reducing reliance on large, centralized power plants. Such off-grid systems can be categorized according to how many customers are served: if it is only one then it is called Stand-Alone system while if it is more than one then it is called Mini-Grid. The latter can be further subdivided according to how many energy sources are present in the system: if only one then it is defined as decentralized otherwise distributed.

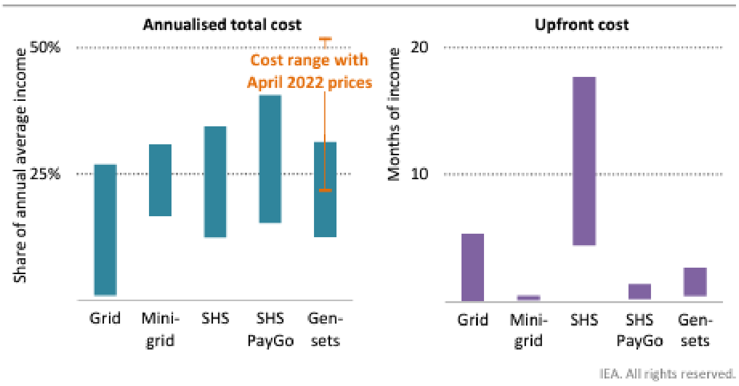


Figure 10. Annualized cost of gaining access to electricity as a share of the annual income of extremely poor people in sub-Saharan Africa, 2020. Source: IEA Africa Energy Outlook 2022.

Decentralized systems also have the potential to exploit the local renewable resources, such as solar, wind, and biomass, which are abundant in many parts of Africa. By utilizing these resources, decentralized systems can help to reduce greenhouse gas emissions and improve the sustainability of energy systems. However, the development of decentralized systems in Africa faces several challenges, such as access to finance, regulatory barriers, and limited technical capacity. Despite these challenges, decentralized systems offer an alternative approach to expanding access to electricity in Africa and have the potential to promote sustainable and inclusive development in the continent.

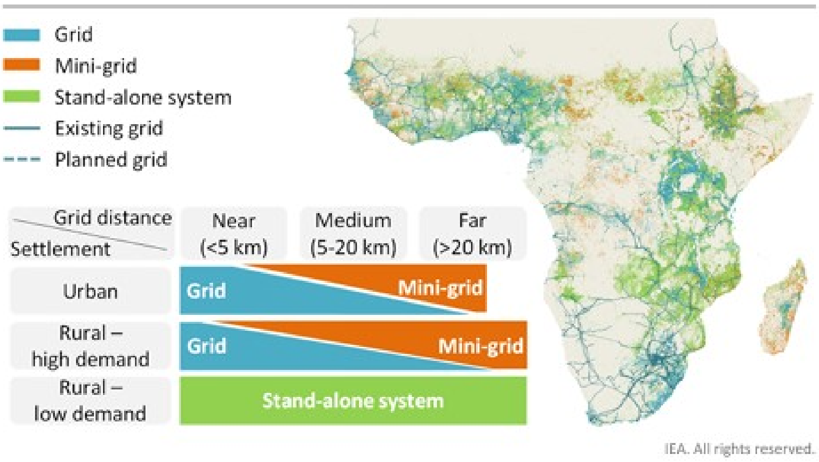


Figure 11. People gaining access to electricity by technology by 2030 in Africa in the SAS. Source: IEA Africa Energy Outlook 2022

Sub-Saharan Africa is playing a major role in the global efforts to keep global warming "well below 2°C". The energy-related greenhouse gas emissions of the continent have reached the peak of 1.2 Gt CO_2 in 2019 (IEA, 2019). These emissions can be attributed to electricity and heat generation, combustion of other fuels and fugitive emissions such as gas flaring. The electricity and heat production represents the most CO_2-emitting's sector among all with 40% of the total.

Africa is endowed with vast untapped renewable energy sources, which can be harnessed to provide electricity to millions of people currently without access to reliable power. The continent's untapped renewable energy potential includes solar, wind, geothermal, hydro, and biomass resources. Solar power is particularly abundant in Africa, with high levels of solar radiation throughout the continent, making it an ideal source of energy. Wind power is also a promising renewable energy source, with the potential to generate significant amounts of electricity, especially along the coastlines and in mountainous regions. Additionally, hydroelectric power has already been utilized in many African countries, and there is potential for further development. Biomass energy, which includes agricultural waste and forestry residues, is also abundant in Africa, especially in rural areas.

Complemented with off-grid solutions, these untapped renewable energy sources can be used to power decentralized electricity systems, bringing reliable and affordable electricity to remote and underserved communities.

2.3. Measuring energy access – brief review

2.3.1. Background and state-of-the-art

In the Energy Outlook section, an attempt was made to give a quantitative idea of how much access to energy is a problem in sub-Saharan Africa, but there is no single view to measure this data, and over the years the definition of energy access has gone through different facets; because, as already mentioned, access to reliable and affordable energy is a crucial factor for human development, poverty reduction, and economic growth.

For decades, the concept of energy access has been defined in a binary way: either a household or a community has access to electricity or not. However, this binary definition fails to capture the nuances of energy poverty, which is a complex issue that goes beyond the mere availability of electricity.

In response, Bathia and Angelou in their studies ([18], [23]) argue that the traditional definition of energy access, based on a binary measure of presence/absence of electricity, is insufficient to reflect the complexity of communities' energy needs and their effects on human well-being and sustainable development. To overcome this limitation, the authors propose a multidimensional framework of energy access that considers the following seven dimensions: capacity, availability, reliability, quality, affordability, legality, health & safety. Each of these dimensions is further broken down into specific indicators, allowing for more detailed data collection and a better understanding of the needs of communities.

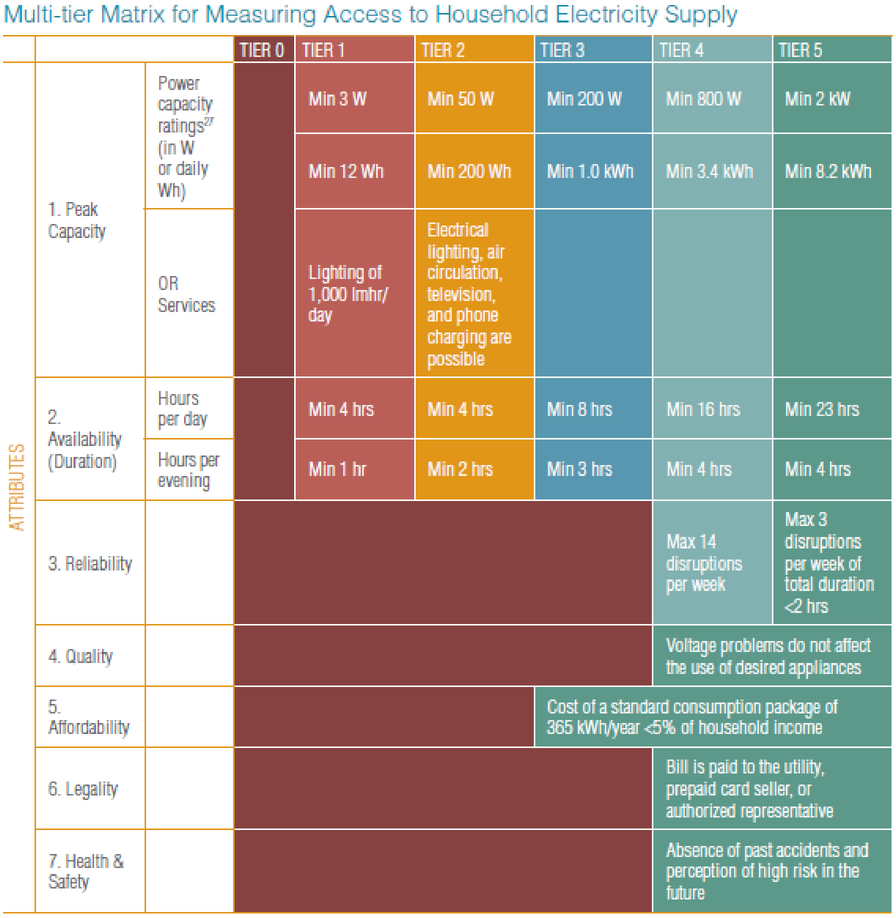
The MTF was thus born in the footstep of other indicators that over time have gone from a binary assessment such as the ones presented by a study conducted by the UNDP and WHO, in which the imposed objective is to individually assess the access to electricity and cooking fuels [24] or the Energy Poverty Line, in which a minimum threshold of consumed energy necessary for human survival is defined, taking up the concept of the economic poverty line, to an increasingly multidimensional concept with a more complex and articulated assessment. Examples of these are the one developed by PAC (Practical Action Consulting) ([24], [25]), the Total Energy Access (TEA) model, which comprises nine parameters that define minimum standards for energy access. This delineates what level of energy services a household should be receiving in order to avoid energy poverty. The Energy Supply Index complements the TEA by providing a multi-tier framework of energy access across three dimensions: household fuels, electricity and mechanical power.

Multi-tier methodologies have become increasingly popular, since there is a growing recognition that energy access should be measured not as a binary metric, but as a continuum of progress. The implementation of the MTF fits into this historical background. Its purpose is to assess energy access inside households, where energy is needed in the form of electricity for lighting, air circulation, communication and many mechanical and thermal uses, as well as for cooking and heating. However, energy is also needed outside the home, in productive activities and community infrastructure, hence the MTF also considers these, to give a comprehensive view of the entire village.

It is divided into several sections that seek to specifically analyse access to energy and the modern technologies:

- Household
- Productive activities
- Community infrastructure

Each of these is divided into several subsections to go into even more detail and assess the different facets of energy access. Starting with the first, the MTF examines separately (i) access to electricity, (ii) access to energy for cooking and (iii) access to energy for heating households. These are analysed according to different indices and with different thresholds designed specifically for the index under consideration. Access to electricity is analysed individually because of its importance in everyday life, without electricity people use less energy or rely on forms of energy that are much more polluting, more expensive and time consuming. Furthermore, electricity extends the length of the day, frees up time for additional activities or repose and leads to better education. The framework is constructed upon seven attributes of energy, which determinate the usefulness of the electricity supply and affect the extent to which electricity services are used, thus, determining the customer's experience. Some attributes, such as quality of supply, legality of connection, and affordability, are indispensable for using almost any energy service. Others, such as quantity, duration of supply, and evening supply, vary with the type of energy service. Minimum requirements for guaranteeing the adequacy of the attributes may be established.



Multi-tier Matrix for Measuring Access to Household Electricity Supply

			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Peak Capacity	Power capacity ratings[27] (in W or daily Wh)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
				Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
		OR Services		Lighting of 1,000 lmhr/ day	Electrical lighting, air circulation, television, and phone charging are possible			
	2. Availability (Duration)	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
		Hours per evening		Min 1 hr	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
	3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration <2 hrs
	4. Quality						Voltage problems do not affect the use of desired appliances	
	5. Affordability					Cost of a standard consumption package of 365 kWh/year <5% of household income		
	6. Legality						Bill is paid to the utility, prepaid card seller, or authorized representative	
	7. Health & Safety						Absence of past accidents and perception of high risk in the future	

Figure 12. Matrix for measuring access to household electricity supply.

The lack of access to clean, modern, affordable and safe cooking and heating solutions imposes considerable costs in terms of time, effort and money spent, but also has serious health consequences due to household indoor air pollution. The levels of access to energy for cooking reflect simultaneous rises in attributes linked to indoor air quality, safety, convenience, quality, efficiency affordability and availability. This approach is also in line with the parameters dictated by WHO and International Water Association (IWA) to measure cookstove performance. However, measuring air quality would require a lot of instrumentation that cannot be installed in every home, therefore, mathematical models with simplifications must be used.

Productive use of energy is a significant driver of socioeconomic growth because it is one of the key inputs of the production process for most enterprises. It increases productivity, income and employment, reduces workloads and frees up time for other activities and facilitates the availability of higher-quality or lower-priced products. In agreement with this view, there are many studies that highlight the positive effects of electrification on gross domestic product ([27], [28]) as well as with employment, especially of women ([29], [30]). Also on a technical level, the electrification of productive activities helps to increase the load factor by distributing demand evenly throughout the day. Nevertheless, it is not possible to set norms of energy needs for different types of enterprises and applications, and above all, lack of access to energy is not always the only (or primary) constraint with which productive activities interface; there may be problems due to raw materials, capital, land, skilled force, markets, transportation, government licenses and so forth.

For this reason, a multi-step process is applied in the MTF in which the most relevant production activities are identified first, followed by the energy sources used for each application. The behaviour of the energy supply is evaluated for each configuration across eight attributes of energy, and, finally, a multi-tier measurement of access to energy for various applications is compiled to obtain the multi-tier energy access rating for the productive activity as a whole.

Energy for community services is extremely important as it positively promotes social development and income generation in an indirect manner, as opposed to the use of energy for productive purposes, which has a direct impact. This aspect is confirmed by the study conducted by Cabraal et al. [31] which highlights how healthy and better educated individuals with access to basic common infrastructure have a better chance of escaping the poverty trap. In the MTF these infrastructures were classified into five key elements: (i) street lighting, (ii) health facilities, (iii) education facilities, (iv) government buildings, and (v) public buildings. However, the paper highlights some challenges in proposing a model that can consider a large number of energy services, multiplicity of energy sources and problems in electricity supply. Two different approaches are proposed: direct assessment through survey of community institutions and indirect assessment through survey of users. The former can provide more detailed information but might be carried out through international agencies in the relevant domain while the latter is certainly easier to administer but risks providing subjective and therefore unreliable information.

For community services, therefore, a single table in which to enclose all cases is not sufficient. In this case, a table is proposed for each energy attribute, subdividing it between street lighting and community institutions, with a further subdivision for the two approaches of survey of users and survey of institutions. The substantial difference is that in this case an attempt is made to offer a broader opportunity with which to classify institutions according to energy source and energy service.

The MTF by ESMAP provides a comprehensive and nuanced approach to measuring energy access, which allows for a better understanding of the specific challenges and needs of different populations. This multi-dimensional approach has significant policy implications. It allows policymakers to identify specific gaps and prioritize interventions accordingly. By understanding the specific dimensions in which energy access is lacking, policymakers can design targeted policies and interventions that address the unique challenges faced by different communities.

Overall, the MTF by ESMAP represents a significant improvement over the binary definition of energy access, allowing for a more nuanced and comprehensive understanding of the challenges and opportunities for energy poverty reduction. But in spite of this, it still presents critical issues, given the fact that each level has thresholds that are considered subjective by many scholars [32] and that it requires a very large data collection, which is very often not available. This is why in many subsequent studies there is an attempt to go beyond the MTF, focusing more on what energy access implies and what functionalities it can unlock.

2.3.2. Beyond MTF

The MTF has played an important role in understanding and measuring energy access, but there is space for further development. An integration of insights from different research strands, accounting for the critiques moved towards ESMAP's MTF, can allow to push the boundaries of energy access assessment beyond the MTF.

The new conceptions of multidimensional well-being are consistent with Amartya Sen's capabilities approach (CA) ([8], [33]), which emphasizes the importance of considering multiple dimensions of well-being and the ability to achieve positive outcomes in areas that are relevant to individuals' lives.

The two key concepts of CA are *"functionings"* and *"capabilities"*, the former representing a person's *"beings and doings"* where the term "beings" means being educated, being well nourished, being part of a society while the latter term means doing a specific action, such as travelling, eating, taking part in a debate. Capabilities, instead, are the freedoms and opportunities of people to be able to perform an action and achieve functionings, like the capability to maintain good health. The distinction between these two terms is the effective realisation, on one hand, and the freedom or opportunity to choose, on the other.

Sen's capabilities approach is a theory that does not seek to explain poverty, inequality or well-being but instead proposes concepts and methods that are intended to facilitate the conceptualisation and evaluation of these factors [9]. Although Sen's proposal was initially addressed in economic terms, it was later put into practice in a variety of forms, due to the broad scope of the approach.

Sen's capabilities approach focuses on evaluating an individual's actual opportunities to act and choose freely in a given social and economic context. According to Sen, freedom to choose one's life options and achieve one's goals depends on the availability of resources that can be exploited based on one's personal capabilities, the presence of institutional structures that promote the protection of rights and access to resources, and greater awareness of available opportunities.

Furthermore, Sen's capabilities approach highlights the importance of a pluralistic vision of well-being, which does not limit itself to considering a single dimension such as income or economic growth, but considers a wide range of dimensions, including education, health, safety, political participation, and the right to freedom of expression and choice.

The conceptualisation of energy poverty using the following approach leads to a multi-dimensional analysis that links the lack of energy services to reduced well-being and development and it reveals a wider set of impacts and outcomes than conventional approaches [34], as shown for instance in the studies of Velasco-Herrejon and Bauwens [35], which used it to assess local adoption of utility scale wind energy in Mexico.

The issue of energy poverty is a complex and multi-faceted problem that has received increasing attention in recent years. While traditionally, energy poverty has been viewed solely in terms of access to energy, the CA offers a more nuanced perspective that considers the multiple dimensions of poverty – economic, social, political and environmental – and how these relate to access to energy services. Through a capability’s lens, energy poverty can be examined as a restriction of human capabilities, where individuals are unable to fulfil their basic needs and live a life of dignity due to lack of access to energy services.

This is evident, for instance, in the work by Day et al. [36]: the capabilities framework provides a holistic understanding of energy poverty, identifying five dimensions of energy poverty: physical, material, health and well-being, social, and knowledge and skills. Bartiaux et al. [37] build on this framework by highlighting the importance of a systemic approach when addressing energy poverty. They argue that energy policies need to be designed and implemented in a way that considers the interrelatedness of different factors that contribute to energy poverty, such as income, housing conditions, household composition, and cultural practices. In line with the CA, Chipango [38] contends that the focus on energy efficiency and cost-effectiveness alone in energy policy debates falls short of recognizing the social and cultural dimensions of energy poverty. The author proposes that a capabilities approach can broaden the scope of energy policy, by not only promoting access to energy services but also acknowledging and addressing the social suffering associated with energy poverty.

Frigo et al. [39] emphasize the importance of viewing access to energy as a human right, grounded in the capability to exercise agency, participate in society, and live a life of dignity. This perspective shifts the focus from mere access to energy as a commodity to the broader set of capabilities that energy services enable, such as the ability to wash clothes, prepare meals and others. Day et al. [36] define these services as secondary capabilities (SCs), considered not as the final purpose of development but as fundamental to unlock opportunities of beings, called basic capabilities (BCs).

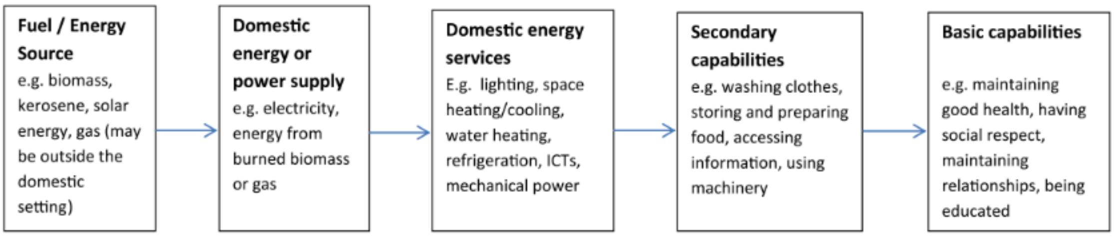


Figure 13. Conceptualizing the relationship between energy, services and outcomes. Source: Day et al. [36]

Looking at the diagram, it can be observed that secondary capabilities (or functioning) involve the consumption of energy services and consequently create demand for energy. While BCs are fundamental in all societies, secondary capabilities are much more specific to local culture and context.

A prominent example is the study proposed by Wang et al. [34], which applied this conceptual framework to understand how community members perceived their current energy situation as a limitation to their essential (basic) capacities, and how they thought improved energy services could expand their essential capacities. As a starting point for the study, the population was divided into groups according to age and gender, and discussions were held focusing on Nussbaum's so-called “Central Capabilities” [40], which the German philosopher identified in a list of ten capabilities that, if pursued, allow individuals to flourish. In this way, by working backwards, the researchers were able to identify which energy services were most insecure and where action was needed.

3 Methodology

This thesis proposes a new tool that can be used as a reference for projects whose aim is the electrification of rural communities. The objective of this tool is therefore to offer decision-making support in order to be able to better define the identification phase of the problems and needs of the community under consideration, while also attempting to extend the treatment to non-experts. It aligns with the MTF by ESMAP and pushes beyond, including a broader view on a set of complementary indicators to build a comprehensive decision-support system.

In essence, the tool proposed is designed to provide two results:

1) first, a dashboard of data and graphs that can highlight the problems and suggest the direction of intervention.
2) second, the inputs needed to construct a load demand curve consistent with the needs identified and the intervention strategy selected.

To be able to achieve these results, two elements are essential: a framework that establishes a methodology with which to classify the population under scrutiny into energy access levels so as to be able to establish the causes of limited electricity consumption; second, a modelling software for networks and production systems that has a section dedicated to setting the load demand curve. The scheme below represents how are achieved the two results, starting from the initial elements:

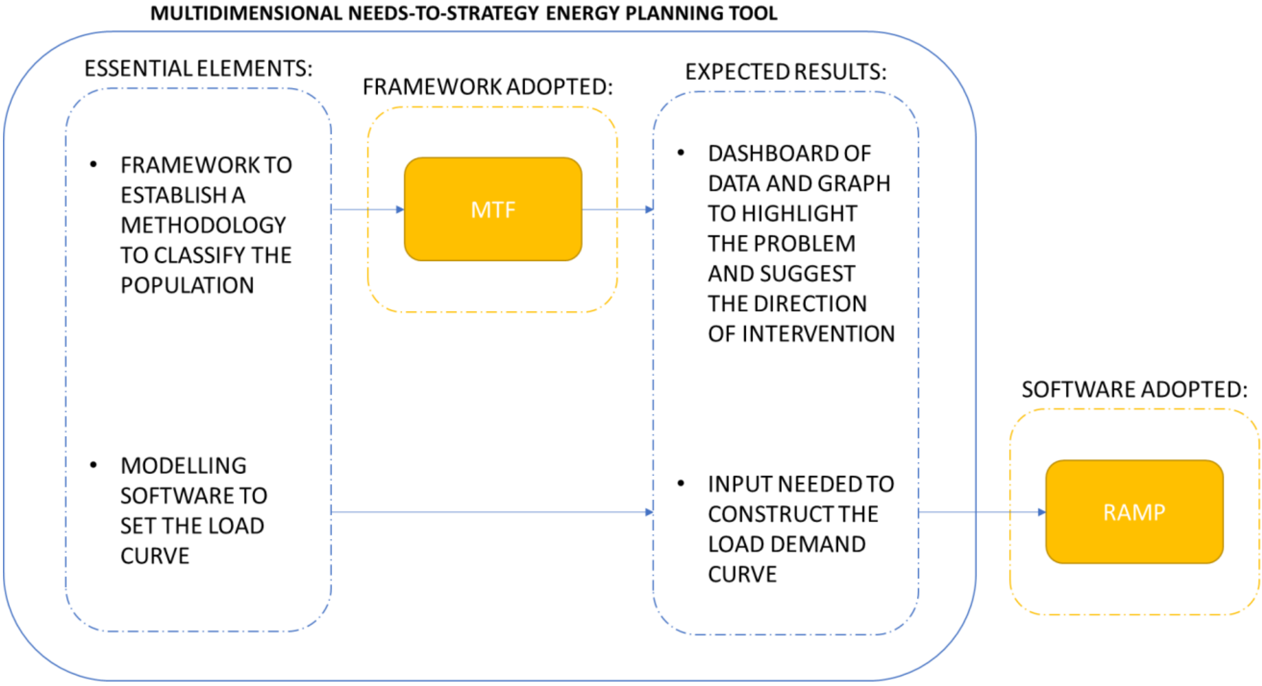


Figure 14. Scheme of the methodology proposed.

As far as methodology is concerned, it has been chosen to make use of the MTF proposed by ESMAP. The reasons that have led the author to choose the MTF over others, as already introduced, is that it is first and foremost a state-of-the-art document with international recognition. In addition, the MTF approach is very specific to the topic at hand and provides both a methodology with which to, not only classify energy access, but also to differentiate it by classes of energy use and services. The MTF itself provides a quantification of energy services, making it simpler to deal with and freeing it from subjective user interpretations. Another important factor is that the MTF proposed a very detailed questionnaire to be administered to the population in the field analysis phase. This was crucial as it allows to further integrate the MTF to the tool. To this regard, the work will propose a simplified and more compact version of this questionnaire with the aim of making it as understandable as possible and limited to strictly useful information. However, in order to maintain a high degree of accuracy and completeness, it was necessary to add some questions. In this way, it was possible to integrate the MTF methodology fully and without gaps. The purpose consists in processing the answers given to the survey to set the parameters as inputs for the tool itself.

It was chosen to include all these functionalities in Excel because of its adaptability and ease of programming. Moreover, through Excel, it is possible to convey the multi-step mode and the consequentiality of the module of the methodology. In fact, the tool has been designed in four different modules that should accompany the user from the very first module of data collection, through a selection of the questions proposed by the MTF, to the selection of an intervention choice and electrical demand curve.

The above-mentioned phases can be summarised as:

- Module 1 – Data collection & classification
- Module 2 – DSS, first results and decision analysis
- Module 3 – Intervention's selection
- Module 4 – Final results: expected outcome and load demand curve

Module 1 serves to initialise the data collected according to the MTF. A simplified questionnaire was proposed to calculate the level considering both technical and economic specificities. In addition, it is suggested to collect further information from the user to simplify the subsequent steps and provide more accuracy to the analysis. The second part of Module 1 focuses on assigning appliances to each previously defined class. The purpose of this module is to recreate the situation observed by the operators in the field during their mission, prior to any intervention.

Module 2 represents a step preceding the actual intervention choice. This module involves analysing the current situation from the perspective of the residents, based on the class identified through survey responses. To achieve this, the results of the MTF and other analysis tools are utilized, calibrated not on the absolute maximum – Tier 5 in the case of the MTF – but on a relative maximum based on economic availability – such as the willingness to pay (WTP). This approach enables the user to determine the most suitable direction of intervention for the success of the project.

Module 3 involves the actual selection of the intervention. It allows the user to choose which classes and in what amount, given in absolute value, will participate and thus be considered beneficiaries, as well as the desired target translated into a specific level. In this case, the level is selected according to energy services, ensuring that each level provides access to a specific set of appliances for various services such as lighting, communication and cooling. It is also given the possibility to pursue two different design strategies and then subsequently choose the best one.

Module 4 represents the final module, in which the expected results and input files for the load curve are presented to the user. Some indices and graphs from Module 2 are presented again, together with a comparison between the expected situation before any intervention and the actual or expected situation resulting from the intervention. This approach allows an ex-ante assessment of the impact on tiers and energy consumption, considering a scenario in which no physical implementation has yet taken place. As a by-product of the tool, an important result is obtained: the load demand curve, which is obtained by processing the data of Module 3 in such a way that it can be directly uploaded to a load curve generator (e.g., RAMP).

Follow a brief scheme of the Multidimensional Needs-to-Strategy Energy Planning tool:

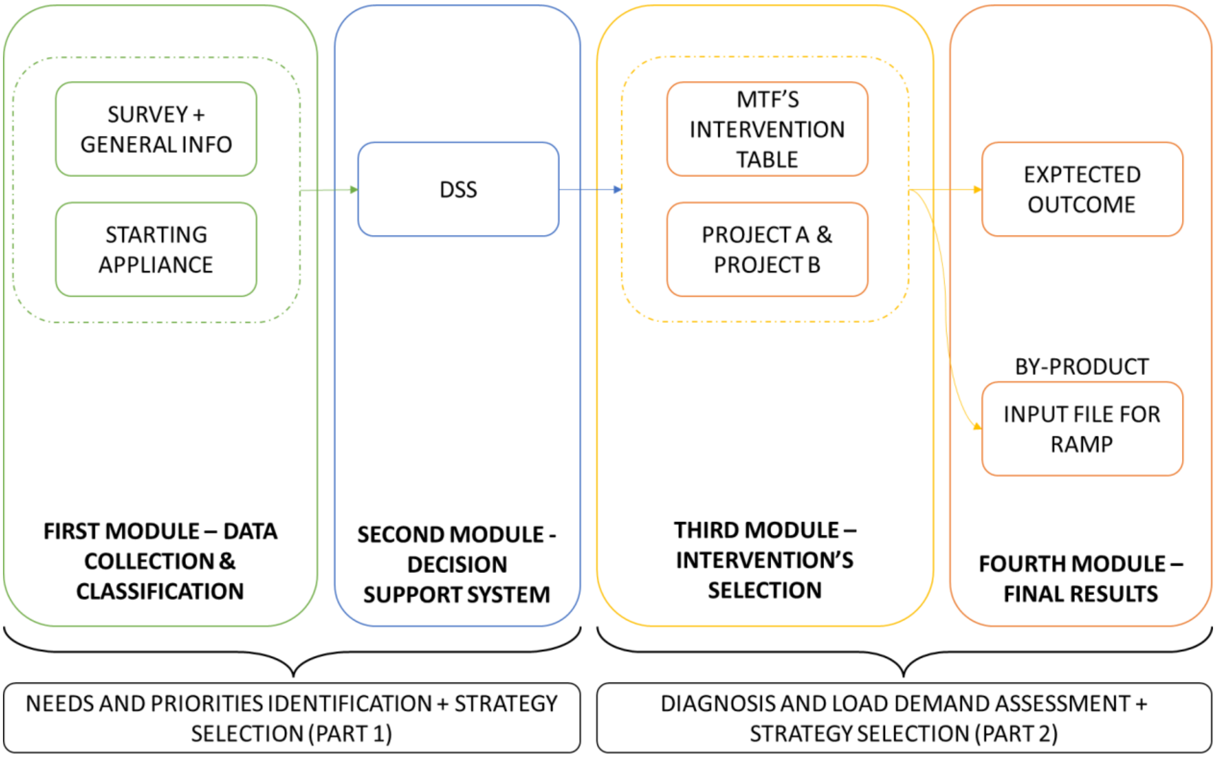


Figure 15. Scheme of the tool, divided in the four modules.

4 Formulation and Implementation of the Multidimensional Needs-to-Strategy Energy Planning tool (MuNStEP)

4.1. Data Collection & Classification – Survey and General Info

The tool is presented with an initial introduction sheet in which instructions are included to guide the user step by step in its use.

The first module "Data Collection & Classification" is divided into two sheets, the first serving to frame the village in general in geographical and social terms, while the second asks for more technical and detailed information regarding the individual electrical appliances they own.

Starting with the first sheet, the information requested concerns both the village as a whole, where an average assessment should therefore be made, and the individual classes in the village, identified a priori by the user on the basis of the survey answers. The first piece of information concerns the geographical location, which is used both to understand the sunrise and sunset times of the place, and the average temperatures throughout the year; this data is taken directly from the NASA site [41] by means of a macro (ANNEX A.1) capable of downloading a .csv file and directly importing the temperatures into a separate sheet of the file.

Next, the average behaviour of the population is studied, the first information concerns the house occupancy (time of exit and return home from work or other activities) by the households, on a usual day, and the maximum tolerable temperature outside for which an air circulation or cooling system should be switched on if there is one. This information, together with the analysis of the average temperature obtained from the localisation, is used to give an estimate of the total time of use of a possible Heating & Cooling (H&C) appliance (fan or air conditioner); this will be used later on in the calculation of the electricity demand curve to have the actual duration and exact time of use by this type of appliance. In detail, what is done is to use the file with the temperatures of the last few years, hour by hour, and then elaborate it by averaging over the days of the same month. In this way, using the temperature limit set by the user and the house occupancy information, it will be possible to know the total usage time and usage window for different fans or air conditioners for each month.

The second information associated with the population as a whole, relates to the use of lights in the house where, by calculating sunrise and sunset and asking how much earlier and how much later on average they keep the lights on in the house, it is possible to estimate the use of lights. The calculation of sunrise and sunset is done using the NOAA (National Oceanic and Atmospheric Administration) algorithm [42] which takes into account factors such as latitude, longitude, time zone and date. Once this calculation is made, the time of the 15th day of each month is taken as a reference. With this calculation, it is possible to assess the total time use of the lights inside the house and also the security lights placed outside, since their use will be from sunset to the next sunrise. These two calculations will be used afterwards to set by default the switching on-and-off times of the lighting and heating & cooling appliances, if any, in order to simplify the user's work and to have precise and accurate data. To facilitate this, the data is reported on a monthly basis rather than annually, allowing for the characterization of seasonal demand patterns and providing more accurate input for the implementation of the mini-grid or chosen technology.

Entering more specifically into the analysis of the population, as anticipated, a critical capacity is required to evaluate the responses given by the individual households in an attempt to classify them. This subdivision must be made according to the supply system, appliances owned and the income they have, so as to be able to group similar households on a technical and economic level. In fact, the former serves to allow the programme to later calculate for each of them the corresponding tier of capacity and availability, while the latter serves to try to then have a category of persons with similar appliances and a fairly similar WTP, useful for further calculations. The program enables very detailed branching, as up to one hundred different classes can be entered, so a high degree of accuracy can be achieved.

As far as the survey is concerned, the questions are taken from those in the MTF survey to try to stick as closely as possible to the chosen methodology. Each attribute corresponds to its own questions, with the addition of a few questions for a deeper understanding. However, unlike the ESMAP survey, in this case the survey has tried to be as concise as possible, so that it is easy to understand and can be carried out by anyone in the field. Making a questionnaire easy to understand and potentially executable by everyone, also gives local actors the opportunity to intervene and obtain more data, thus partly overcoming this problem, i.e., the lack of information and difficulty in obtaining them.

ATTRIBUTES	QUESTION	INPUT
CAPACITY	Which is the supply system that this class use the most in their house?	Classification to differentiate tier calculation for Capacity and Availability, when there are no answers in the specific question
	Is the Capacity of the system available from the name plate? - If 'YES' insert the value in [W] - If 'NO' leave it empty	Direct calculation for Capacity tier
	Storage or Battery Capacity [Wh]	Indirect calculation for Evening Availability tier when battery is pr
AVAILABILITY	On average, how many hours of electricity are available each day and night from the supply system? (max 24 hours)	Direct calculation for Day Availability tier
	On average, how many hours of electricity are available each evening, from 6:00 pm to 10:00 pm from the supply system? (max 4 hours)	Direct calculation for Evening Availability tier
RELIABILITY	In a typical week, how many outages/black out of the grid happen? (only for National Grid and Mini-Grid)	Direct calculation for Reliability tier
AFFORDABILITY	Which is the average income? [$/month]	Direct calculation for Affordability tier and useful data to calculate the specific cost of electricity (togheter with the consumption taken from "Starting Appliance") and energy burden
	In the last month how much did they spend on the electric bill? If Gen-Set is present how much did they spend on fuel? If it's unknown insert the average electric expenditure in the region [$/months]	
	Indicate the willingness to pay (WTP) as a percentage of the monthly income [% of income]	Useful data to calculate the willingness to consume
	If the Household is classified as "No Access" insert a realistic electricity tariff in accordance with the rest of the population [$/kWh]	Useful data to calculate the specific cost for those who don't have any expenditure at the moment
QUALITY	In the last 12 months did any of your appliances get damaged because the voltage was going up and down from the connection? (Yes/No)	Direct calculation for Quality tier
HEALTH & SAFETY	In the last 12 months did any household members died or have permanent limb (badly injury) demage due to the electricity connection? (Yes/No)	Direct calculation for Health & Safety tier
LEGALITY	Is their connection to electricity legal?	Direct calculation for Legality tier

Table 1. Table with the questions taken from the survey and the corresponding input.

Having divided the population into different classes, the second part of the input involves compiling a sheet in which there will be as many tables, like the one in the figure, as there are classes entered; to do this, a macro (ANNEX A.2) was created to count the number of classes entered and then print out the table as many times as necessary. Each table presents a list of appliances, divided by category – lighting, ICT, H&C, cooking and others – which was taken directly from the MTF report [18] and which represents the most common appliances in a dwelling. Blank lines have been left for each appliance category to allow the user to add as required. Only electrical appliances must be entered in this list, and for each one, the user must provide the quantity, nominal power and average daily usage time. This data is useful for calculations to be made later and especially for an evaluation of the energy consumed by households.

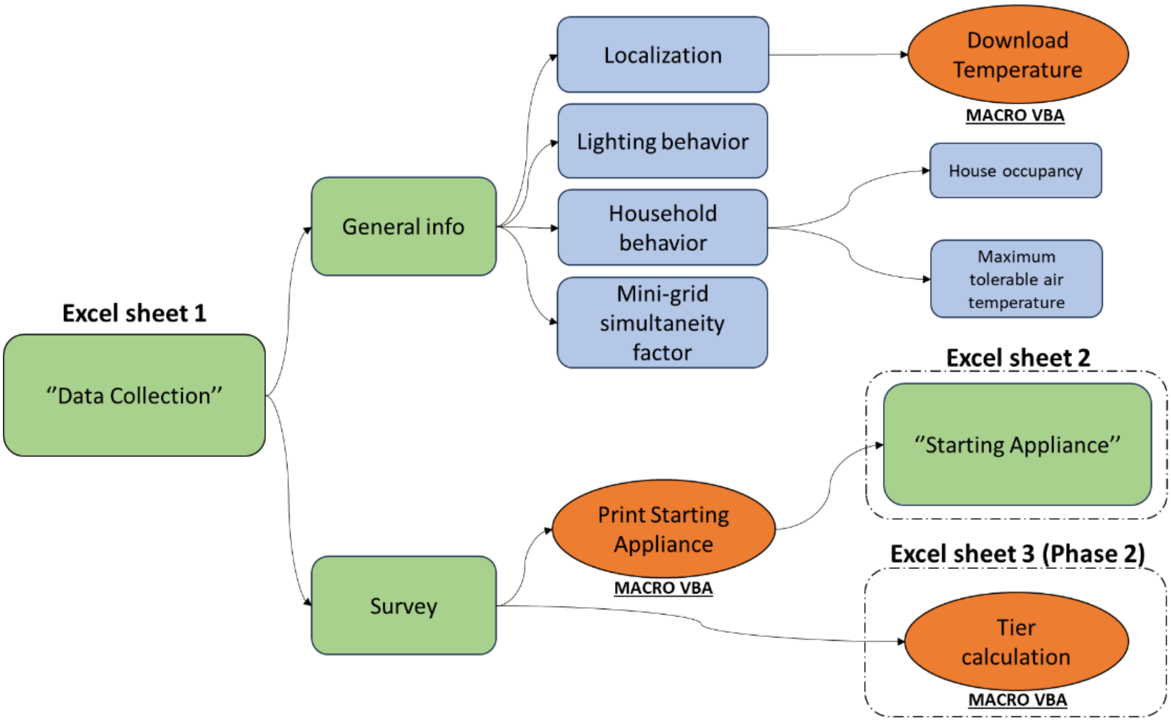
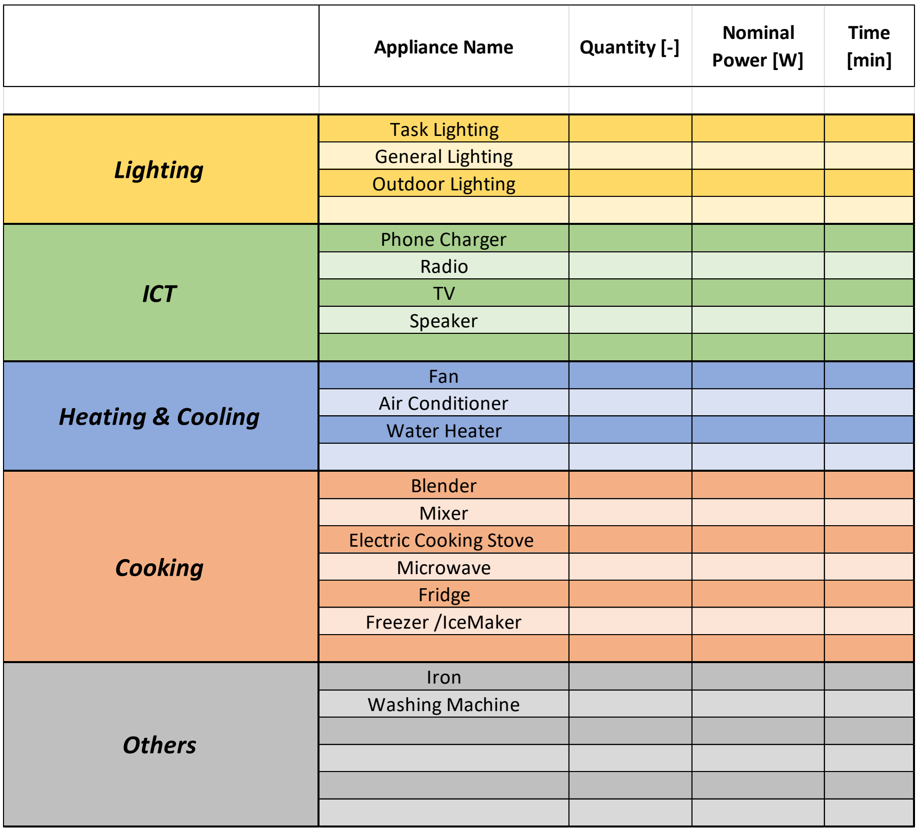


Figure 16. Scheme module 1



	Appliance Name	**Quantity [-]**	**Nominal Power [W]**	**Time [min]**
Lighting	Task Lighting			
	General Lighting			
	Outdoor Lighting			
ICT	Phone Charger			
	Radio			
	TV			
	Speaker			
Heating & Cooling	Fan			
	Air Conditioner			
	Water Heater			
Cooking	Blender			
	Mixer			
	Electric Cooking Stove			
	Microwave			
	Fridge			
	Freezer /IceMaker			
Others	Iron			
	Washing Machine			

Table 2. Appliance's table for Input.

4.2. Decision Support System – Preliminary Results and Decision Analysis

This module is particularly delicate as it aims to provide decision support tools that enable users to better understand the results and gain new insights, thereby facilitating the selection of effective solutions for the project at hand.

As mentioned earlier in the previous chapter, this module is presented in the third sheet titled "DSS" within the Excel file. This sheet is structured into various sections, ensuring a sequential flow of actions and elements to be examined. The sequent sub-sections ensure that the steps are followed in the correct order. There are three subsections in all, and they include the preliminary results of the MTF methodology, the relationships and calculations proposed by the authors – this section is further divided into two to give the proposed CWR index its due prominence – and the choice of graphs, as an additional instrument for interpreting the numerical data.

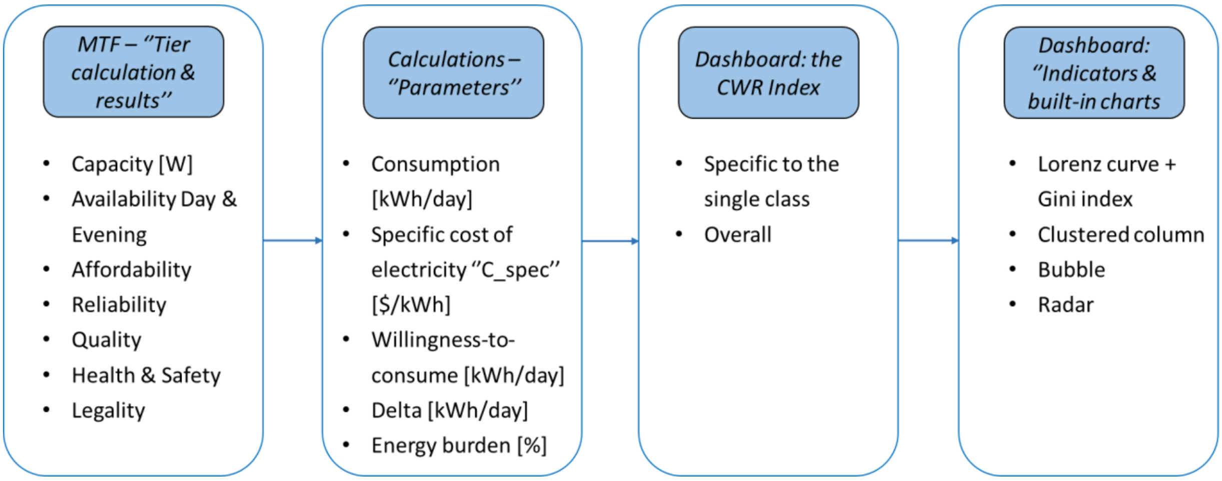


Figure 17. Scheme of Module 2

4.2.1. MTF – Tier Calculation & Results

This section focuses on the calculation of tiers using the MTF methodology. The MTF introduces a comprehensive questionnaire to be administered to the target population. Additionally, it provides alternative methods to determine specific tiers for attributes by utilizing secondary information collected through the questionnaire. To streamline the questionnaire and make it more efficient, only the most crucial questions were selected for direct tier determination. As explained in detail above, the MTF assigns seven attributes to electricity, and this section will provide details on how these attributes have been integrated into the tool.

Notably, the MTF proposes a binary classification of 0 or 5 for the attributes of Quality, Health & Safety, Legality, and Affordability. To assess the attributes of the first three, respondents are asked questions that allow for only “yes” or “no” responses.

- With regard to Affordability, additional essential information is required for further calculations, hence why a “yes” or “no” response is not requested. The MTF proposes a threshold of 5% of income for electricity expenditure. Therefore, respondents are asked to provide their monthly income, absolute electricity expenditure in dollars per month and the WTP expressed as a percentage of income, which will be useful for the DSS. The possibility of entering a monthly energy tariff by the user has also been added to make sure that there are useful benchmarks in later stages for those households that do not pay a bill as may be the case of those classified as “No Access”. In this case, the tariff can be an average of those paid by other classes or already a price decided by the user.
- The attribute Reliability is defined in a quasi-binary manner since tiers are divided into 0-4-5. To calculate the tier associated with this attribute, the numerical value entered in the survey section is compared with the two threshold values proposed by the MTF.

Regarding the attributes of Capacity and Availability, an alternative to the questionnaire has been proposed still inspired by MTF. However, it is crucial to prioritize the survey responses, as the tier determination relies on the provided answers. Distinctions based on the supply system are made for both attributes.

- With regard to Capacity, was used the decision tree described in MTF report [18] readjusting it to the needs of the tool. The following steps are those suggested by the MTF:
    - Type of primary energy source
    - Any written indication (such as the name plate) if available
    - Experience of load limitation (differentiated between medium and high-power load)

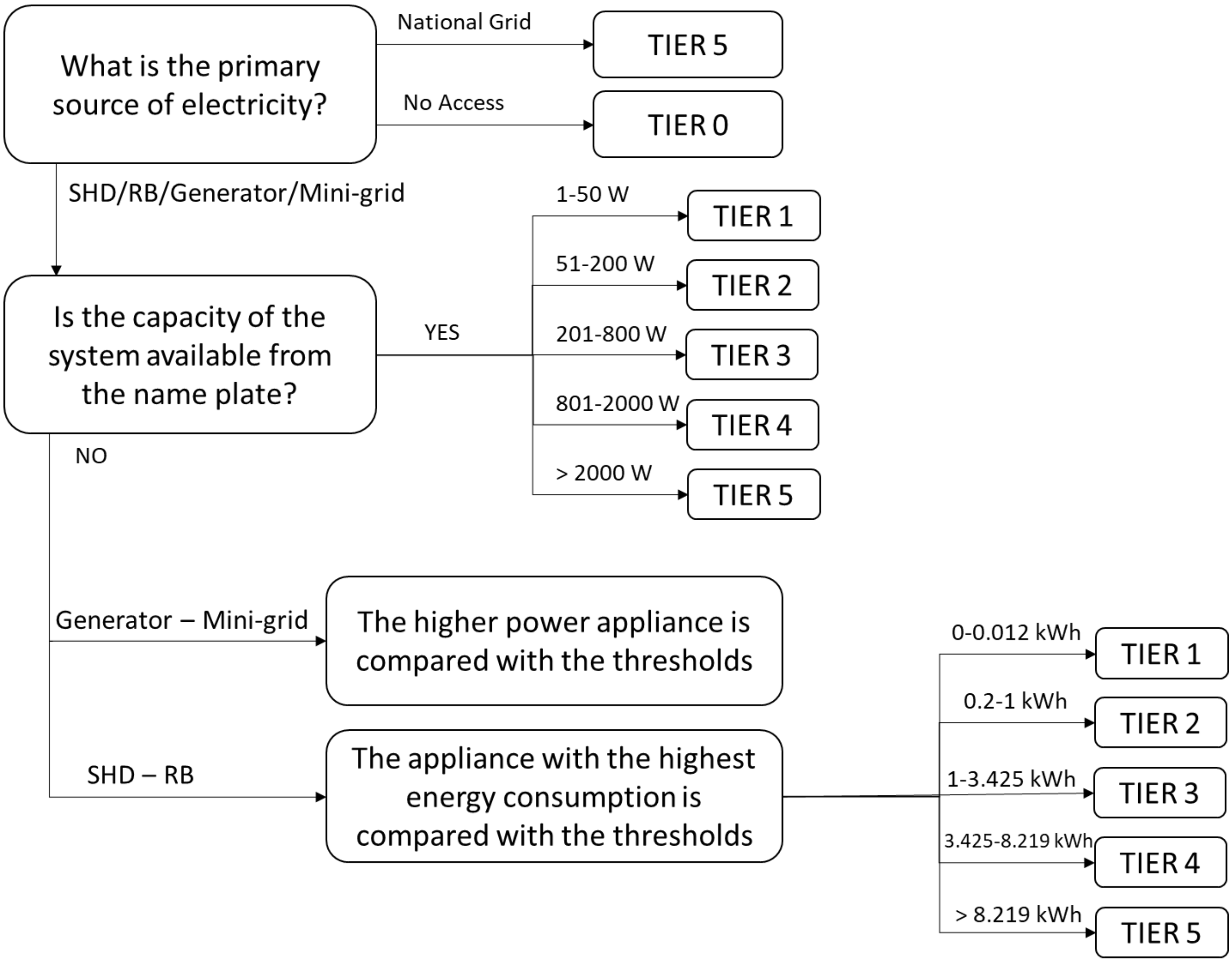


Figure 18. Elaborated decision tree for Capacity of household electricity supply.

For this implementation, the first two steps have been incorporated and the third one has been replaced with a direct comparison of the installed appliances to the table values. It is assumed that the appliance with the highest nominal power reflects the maximum load that the system can support, as no other useful information is available.

For both Capacity and Availability, a distinction was made based on the supply system owned by each household.

For the Capacity attribute, the following holds:

- "National Grid": tier 5 is assigned regardless of the survey or other factors. This is because the national grid does not restrict the use of appliances with high loads (the meter serves as the true limit), but it typically limits energy consumption due to other attributes.
- "No Access": This category does not have a connection to any electricity grid and relies on alternative systems powered by fossil fuels (e.g., kerosene lamps)

or biomass for cooking. Consequently, for this supply system, no value is provided for Capacity or Availability, resulting in a final tier of 0.

- “Mini-grid” & “Generator”: For these categories, a comparison is made between the highest-rated appliance's value and the table values proposed by the MTF. Two options are offered for Capacity: power in Watts (W) or daily consumption in Watt-hour (Wh). Nominal power has been chosen for these supply system as it better reflects the system's capacity to handle a specific load.
- “Solar Home Device” (SHD) & “Rechargeable Battery” (RB): In this case, daily consumption has been chosen to compare the table values with the appliances that consumes the most energy during a day.

About Availability, it has been decided to proceed in this way:

- DAY:
    - Determined solely through the survey, regardless of the supply system. If no answer is given, then no value will be printed.

    - “Generator”: is automatically assigned tier 5 (it exhibits no availability issues as a generator can operate for more than 24 consecutive hours. Has higher operational cost so the limiting factor is usually the Affordability).

- EVENING:
    - Survey responses are prioritized regardless of supply system.

    - “National Grid”: if the questionnaire is not answered, there is not enough information to determine the tier, so no value will be printed.

    - “Generator”: automatically assigned in tier 5.

    - “Mini-grid”: for this supply system a specific parameter, called the simultaneity factor, was introduced to indicate the percentage of watts connected at the same time to the grid. This gives the user the freedom to choose the most appropriate rating. If the worst-case scenario were to be chosen, the capacity would be measured as the ratio of battery storage to all appliances connected to the system. The formula with which the availability hours for the night are calculated is as follows:

$$Evening\ Hours_{Av.-mg} = \frac{Storage\ Capacity\ [Wh]}{overall\ installed\ APP\ Nom.Power\ [W] * \ simultaneity\_factor} \tag{1}$$

- "SHD" & "RB": for these systems, as they are usually reserved for a single household, it was decided to assess the availability of electricity at night by looking at how long the appliance with the highest wattage could run. The formula is the following:

$$Evening\ Hours_{Av-SHD\&RB} = \frac{Battery\ Capacity\ [Wh]}{APP\ with\ the\ highest\ Nom.Power\ [W]} \tag{2}$$

Regarding the implementation of this methodology in the Excel tool, a macro (ANNEX A.3) has been developed, which can be accessed through a button labelled "Tier Calculation" positioned at the top of the third Excel sheet. In this first section of the sheet, a table is also presented showing the results in tier for each electricity attribute and for each class. The Capacity and Availability attributes were both further divided into two to show the "sub-dimensions" of *power* and *energy* for Capacity and of *day* and *evening* for Availability. Finally, a column was added to determine the "Final Tier". Again, according to the MTF instructions, this tier is given by the lowest value of all the attributes. However, in this tool, it was decided to only take Capacity and Availability into account as they are the only ones to have a complete scale of tier values, from 0 to 5. In fact, with all others being binary, a single attribute with a value of 0 would be sufficient to automatically bring the entire class to a final tier of 0.

4.2.2. Calculations – Parameters

This second section shows some of the results elaborated by the authors. Here are listed all of them and, later on, commented in detail one by one:

- Daily Electricity Consumption [kWh/day]
- Willingness To Consume [kWh/day]
- Delta [kWh/day]
- Energy Burden [% of income]
- Specific Cost of Electricity [$/kWh]

- CWR Index – specific to the class & total [-]

Starting with the daily electricity consumption, it is directly calculated from the values entered in the "Starting Appliance" sheet. For each class, the values obtained by multiplying the quantity of the specific appliance by its rated power and the total time of use during the day are summed up.

The Willingness to Consume (WTC) is the first decision support element introduced by the authors. The concept that has been introduced to measure the amount of energy the class can afford is the WTC, which, as its name suggests, takes up the concept of WTP, but with reference to energy. This parameter pushes towards a quantification of the willingness to pay in terms of kWh/day instead of $/day. In this way, the energy needs are assessed and benchmarked with the user's aspiration. This parameter will also support in the calculation of the consumption-willingness ratio (CWR) index. The aim is to highlight a numerical value that could represent a target that directly considers the beneficiaries of the project. The WTC is calculated by dividing the absolute value of the WTP by the actual electricity consumption.

The Delta parameter represents the difference between the WTC and the daily electricity consumption. Its purpose is to show the absolute amount that each class can afford to consume beyond their current level and thereby afford a better service.

The energy burden (EB) represents the percentage of income that a class or group of households spends on energy. This parameter has already been defined in existing literature such as [43]. In this case, the questionnaire specifies that only expenditure related to electricity should be included.

The specific energy cost, in this context, refers to the actual cost of the electricity consumed. It is calculated by dividing the electricity expenditure by the consumption indicated by the first parameter. It is important to note that not everyone incurs expenses, such as those classified as "No Access" or SHD and RB as they may have purchased equipment without ongoing operating costs but only one main investment. For such cases, the questionnaire allows for the direct entry of a charge, which is then considered as the specific cost without any further calculation. Alternatively, respondents can enter an energy cost that aligns with the trend observed among other participants.

The last item on the list is covered in the following sub-section to give it the space and importance it deserves.

4.2.3. Dashboard: Consumption – Willingness Ratio Index (CWR)

This sub-section will illustrate the decision element proposed by the authors, the CWR index.

The CWR index measures the ratio between the actual electricity consumption and the WTC, thus being dimensionless. The formula is as follows:

$$CWR = \frac{Daily\ energy\ consumption\ [\frac{kWh}{day}]}{Willingness\ to\ Consume\ [\frac{kWh}{day}]} \tag{3}$$

The purpose of this index is to establish an optimum situation where each class or family group consumes an amount of electricity that aligns with their economic capacity and preferences. The goal is not to have every population segment achieve tier 5 for all attributes, as it becomes meaningless if they cannot afford to pay for that level of consumption. This dissatisfaction affects both the residents and the grid provider, impacting the feasibility of the investment. While it would be ideal for everyone to consume the same amount and eliminate consumption inequality, it does not align with income distribution. Hence, the authors incorporated the concepts of WTP and WTC into the methodology.

The optimum value of the CWR index is 1, where households consume and spend exactly as much as they desire. This index, in correlation with the MTF results, directs attention to critical points in the energy services, households, and appliances chain. Several case studies can arise:

- CWR < 1 & high MTF: In this scenario, the current connection is functioning well, but households have the potential to consume more. However, their daily energy consumption is lower than desired, possibly due to a lack of availability to purchase appliances. Therefore, interventions should focus on addressing this aspect of the chain.

- CWR < 1 & low MTF: In this case, the problem lies in grid malfunctions that hinder households from consuming as much electricity as they would like. The solution involves primarily addressing network issues, followed by improvements within households.

- CWR > 1 & high MTF: Here, the grid is functioning well, but households are spending more on electricity than desired. Solutions could involve providing incentives to this class of households or reducing the specific cost of electricity post-intervention.

- CWR > 1 & low MTF: This represents the most challenging scenario, as both the grid and households require separate interventions without direct cause-and-effect relationships.

It is important to note that these cases should not be interpreted in a literal sense. A comprehensive analysis should be conducted, examining each attribute of the MTF and the calculations leading to the CWR index. However, the proposed approach establishes a cause-and-effect relationship between the two analysis tools (MTF and DSS).

4.2.4. Dashboard: Indicator and Built-in Charts

To facilitate the comprehension and interpretation of the data, several graphs are provided. These graphs can be categorized into two types: those that aim to depict the current observed situation based on entered data, and those that serve as decision support elements by comparing the current situation with an optimal one. The graphs presented include:

- Lorenz Curve & Gini index
- Clustered Columns Graph
- Bubble Graph
- Radar Graph

The first graph is the Lorenz curve, accompanied by the Gini index. It displays two curves on the same plot: one representing income distribution and the other representing daily electricity consumption. The purpose is to identify discrepancies between the curves and their divergence from the bisector, indicating inequality. Three case studies can be derived:

1. The two curves are perfectly or nearly overlapping.
2. The income curve is closer to the bisector than the consumption curve.
3. The consumption curve is closer to the bisector than the income curve.

In the first case, overlapping curves indicate inequality in both aspects but no relative inequality between income and consumption. This information might suggest a reasonable distribution of consumption and a strong link to the economy of the locality.

The second case could be interpreted as a greater difficulty on the part of households to consume electricity probably due to some kind of barrier. This barrier(s) can be seen by looking at the disaggregated result in tier which is meant to suggest what those barriers might be.

Conversely, the third case can be read from an opposite perspective to the previous one. Thus, having a lower inequality in relation to consumption with respect to income suggests a positive situation in which one or more factors promote consumption.

It should also be noted that income is considered to be constant between the ex-ante and ex-post project situations in the short to medium term, while consumption clearly varies. The decision to present this type of graph is motivated by the fact that in the "Expected Outcome" of the fourth module it will be possible to repropose it and compare the consumption curves between the situation preceding the project and the one following it, thus providing a useful reading and decision support tool.

Additionally, this graph is accompanied by the Gini index for completeness and to quantitatively measure the inequality in both income and consumption.

The second is a clustered column chart. For each class, two columns are shown, one referring to current electricity consumption and the other to WTC. By comparing these values, it becomes apparent if there is space for improvement. If the first column is lower than the second, then this means that there is potential for intervention. Conversely, it suggests a situation in which the class consumes and consequently spends more than desired, likely due to necessity. Addressing the economic aspect and tariffs could help alleviate this burden for those affected.

The following chart to be presented depicts a bubble graph. The x-axis illustrates the disparity between the WTC and the energy consumed, while the y-axis represents the energy consumed. The purpose of this table is analogous to the purpose of the Stakeholder Analysis graph, which established the interests of stakeholders in relation to their importance in the project, with the aim of identifying who should intervene. However, in this case, the graph intends to highlight those with the greatest potential for improvement relative to their current energy consumption. The user's focus should be on the bottom right quadrant, where individuals exhibit a substantial difference between WTC and energy consumed, coupled with a low daily energy consumption. The size of the bubbles corresponds to the magnitude of the respective class, providing an indication of the number of individuals in that particular scenario.

The radar chart is proposed for each individual class and has five spikes that represent the attributes of the MTF. Five because the three binary attributes of Quality, Health & Safety and Legality are merged into one category, in fact, its value becomes their average. The reason is that a seven-pointed graph is more complex and also risks greatly altering the vision of the graph itself, making it more difficult to be interpreted. Also Affordability is binary, but it has an important meaning because the tool places a greater emphasis on this economic parameter. So, the categories included in the radar chart refer to Capacity – Availability – Affordability – Reliability – average between Quality, Health & Safety and Legality.

Furthermore, the graph shows two distinct series. The first is made up with the values calculated previously and shown in the "DSS" sheet and so representing the actual situation. While the second series is set up in such a way as to reflect a mixture of values: on the one hand necessary to guarantee a good functioning of the network or system, on the other hand, which reflects the economic resources of the consumer, thus translating a WTP into WTC.

To be more specific this translates into a series that represents the maximum achievable value in that attribute and so with all binary attribute peaks with value equal to 5 including Availability. The reason for this is related to the fact that ensuring a good electricity service must include a high continuity of service during the day and especially in the evenings. Whereas for Capacity the maximum value is not 5 but is set according to the Tier value corresponding to the WTC determined from the WTP.

These graphs serve to emphasize the fact that the aim should not be to take people to their absolute maximum consumption, but to their maximum consumption in relation to what they can afford to spend. This first step allows people to grow in a sustainable way, based on their own emancipation; in fact, by connecting them in an affordable way, it allows them to improve their business and therefore their income, and then to spend more; in this way, it's possible to allow for growth that is autonomous and not driven by third parties.

4.3. Intervention's Selection

4.3.1. Intervention's table & Electricity Access's table (MTF)

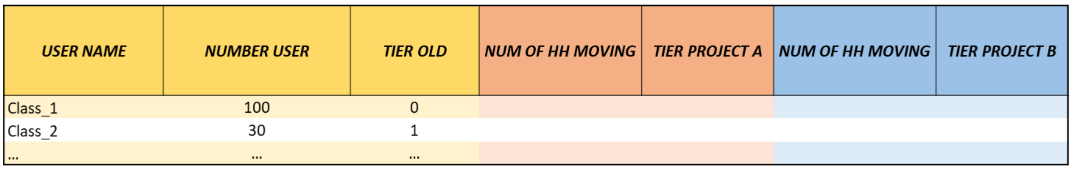
In this section, the electricity access's table proposed in the Bathia and Angelou report is introduced to maintain adherence to the MTF. To support this, an additional table was created, specifically designed for implementing the intervention, Table 3. The authors referred to it as the intervention table due to its purpose. Initially, this table includes the basic information, such as the class name, the number of family groups within each class, and their corresponding consumption capacity tier. The remaining columns are dedicated to specifying the intervention details for evaluation purposes. In this regard, the user is prompted to input the number of household groups that will directly benefit from the project for each class. The value can range from 0 (indicating no participating households) to the maximum number of households in that particular class. Furthermore, the user is also requested, class by class, to indicate the desired or targeted capacity tier for each class.

Based on the provided information, the electricity access index's table, Table 4, along with the subsequent sheet, will be populated, redistributing the population more evenly between the participating and non-participating classes. Additionally, two projects, Project A and Project B, were conducted to facilitate a direct comparison on the MTF intervention table and the final output sheet. To ensure consistency with the target tier, the next sheet for event attendees will be pre-filled with the appliances recommended by the MTF for the selected tier.

Connected directly to the latter, there is the aforementioned electricity's access table from Bathia and Angelou, which is useful for assessing the potential variation in the general index of access to electricity for the entire population between different levels.

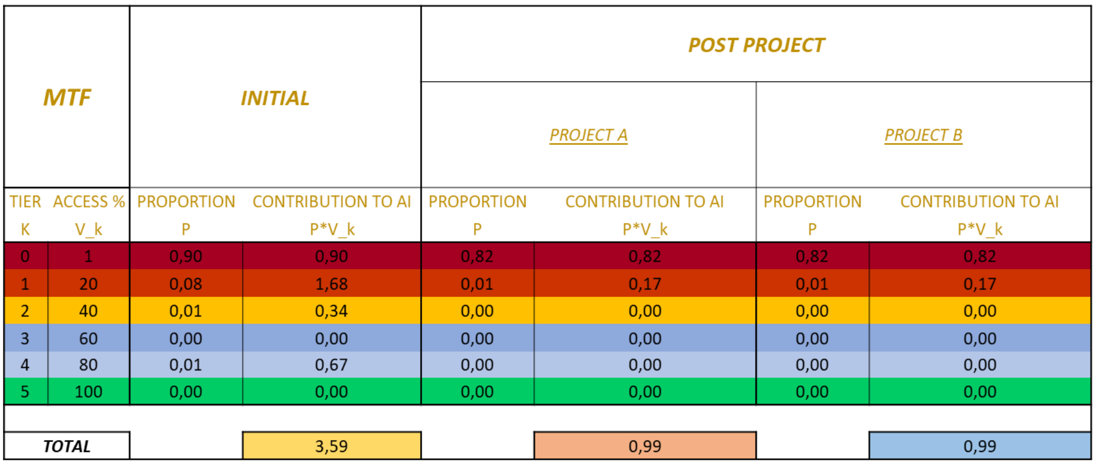
Three methods, namely Access Index, Geometric Mean, and Arbitrary Value, are proposed to evaluate the weight of each tier on overall electricity access. These methods allow for a comparison between the pre-intervention value and an estimate of the post-intervention values. The Table 5 shows the three methods and their relative values. The access index scores the tiers proportionally on a scale of 0 to 5, treating the shift from one tier to another equally across the scale. The geometric mean, on the other hand, represents the logarithm of the access index, giving more weight to shifts between lower tiers. The arbitrary value method allows for the entry of any value for each tier.

Finally, two buttons have been placed in this section to which two macros (ANNEX A.5) have been assigned, one for project A and one for B respectively. The next sub-chapter explains how the two sheets for the two projects are constructed.



USER NAME	NUMBER USER	TIER OLD	NUM OF HH MOVING	TIER PROJECT A	NUM OF HH MOVING	TIER PROJECT B
Class_1	100	0				
Class_2	30	1				
...	...	...				

Table 3. Intervention's table.



MTF		***INITIAL***		***POST PROJECT***			
				PROJECT A		*PROJECT B*	
TIER K	ACCESS % V_k	PROPORTION P	CONTRIBUTION TO AI P*V_k	PROPORTION P	CONTRIBUTION TO AI P*V_k	PROPORTION P	CONTRIBUTION TO AI P*V_k
0	1	0,90	0,90	0,82	0,82	0,82	0,82
1	20	0,08	1,68	0,01	0,17	0,01	0,17
2	40	0,01	0,34	0,00	0,00	0,00	0,00
3	60	0,00	0,00	0,00	0,00	0,00	0,00
4	80	0,01	0,67	0,00	0,00	0,00	0,00
5	100	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL			3,59		0,99		0,99

Table 4. Access Index's table.

TIER VALUE FOR THE THREE METHODES		
Access Index (AI)	Geometric mean Index (GMI)	Free choice Index
1	0	1
20	2,996	30
40	3,689	55
60	4,094	75
80	4,382	95
100	4,605	100

Table 5. Different approach for computing final energy access index.

4.3.2. Project A & Project B

After selecting the strategy and objectives to be undertaken, it is necessary to move on to the next Excel sheets, called "Project A" and "Project B". These sheets share similarities with the "Starting Appliance" sheet, but with substantial structural differences and the aim of establishing the foundation for determining the load curve.

The structure of the sheets is as follows. A table, whose values will now be described, is generated for each class in the new list. This new list is built from the way the project was set up in the intervention table, so there is one specific list for both projects. This list, therefore, will present the name of the classes that do not participate in the same way and, in addition, a distinctive name for each participating class, regardless of how many there are (as long as they are >0), marked with a prefix *"new_"* and with the end part reflecting the goal tier set, for example: *"_TIER_5"*. Thus, the string appearing in the cell for a class participating in the project and named "interview_1" will be of the type: *new_interview_1_TIER_5*.

So, for each class in the new list, it will be displayed the name of the class, the associated number of individuals belonging to the class, a cell to select the month of the year which will be analysed later, and a table.

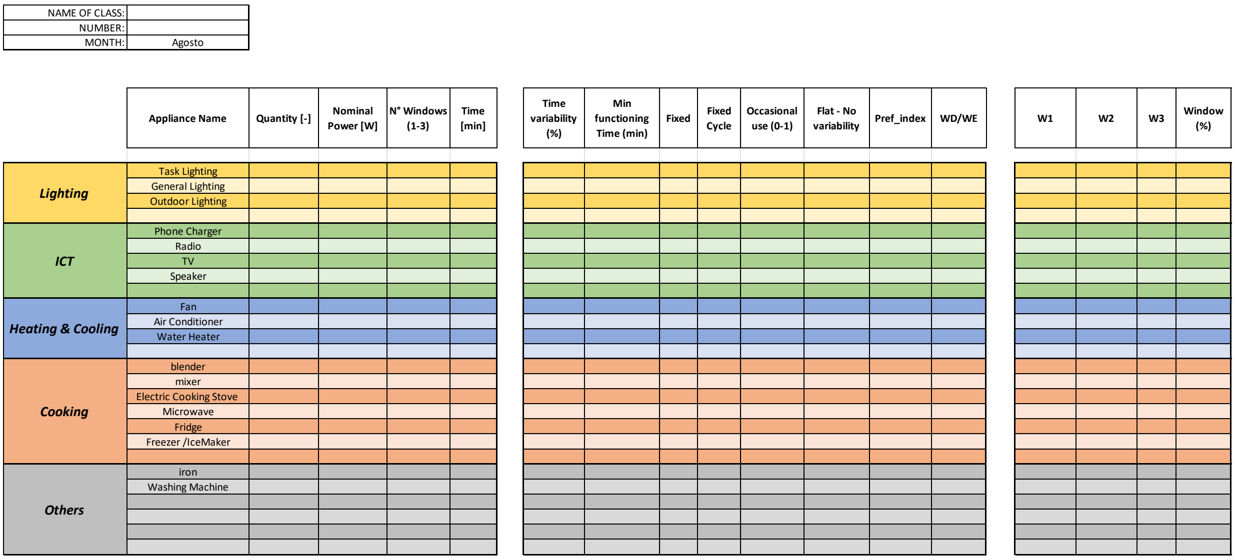
The Table 6 follows a similar format to the one seen in the "Starting Appliance" sheet. It includes a set of appliances and their respective parameters. While some parameters are pre-filled, there are a greater number of parameters in this case. These parameters align with those utilized by the RAMP software, totalling 35 in number. Among all these, those of fundamental importance have been tried to be separated to the software from those that are more superfluous as they can be replaced by default values. In any case, the parameters that have not been defined as fundamental are used to give greater detail to the treatment, trying to come as close as possible to a real case study.

- Core Parameter sets: appliance's name, quantity, nominal power, time, windows and n° windows.
- Non-core parameter sets: time variability, minimum functioning time, fixed, fixed cycle, occasional use, flat (no variability), preference index, weekend & weekdays.
- Parameter sets for appliances with power cycles (e.g.: fridge, freezer, hot water for shower...).

As mentioned earlier, some data sets are already pre-filled. The sequence of operations performed by the "Project A" or "Project B" macro includes:

- Copying the matrix of parameters and appliances from the "back-up" sheet and print it sequentially on the "Project A" and "Project B" sheets.
- Copying the data already entered on the "Starting Appliance" sheet.
- Utilizing the information provided in the "Data Collection" sheet to insert specific formulas for certain parameters referring to specific appliances such as, for example, the time for appliances referring to the lighting and H&C service. Other formulas are included to directly calculate the number of windows and select window intervals based on the month.

The tier selection also assists in pre-compiling the sheet. For each tier, the MTF has defined a table assigning the required appliances and their associated parameters, such as nominal power and time. In this way, the sheet will be partly already pre-filled, greatly simplifying this phase for the user.



NAME OF CLASS:	
NUMBER:	
MONTH:	Agosto

	Appliance Name	Quantity [-]	Nominal Power [W]	N° Windows (1-3)	Time [min]	Time variability (%)	Min functioning Time (min)	Fixed	Fixed Cycle	Occasional use (0-1)	Flat - No variability	Pref_index	WD/WE	W1	W2	W3	Window (%)
Lighting	Task Lighting																
	General Lighting																
	Outdoor Lighting																
ICT	Phone Charger																
	Radio																
	TV																
	Speaker																
Heating & Cooling	Fan																
	Air Conditioner																
	Water Heater																
Cooking	blender																
	mixer																
	Electric Cooking Stove																
	Microwave																
	Fridge																
	Freezer /IceMaker																
Others	iron																
	Washing Machine																

Table 6. RAMP's parameters for appliances for each class initialized.

4.4. Final Result – Expected Outcome and Load Demand Curve

The final module of the tool aims to provide a final report by taking the results obtained so far and comparing them with the post-intervention results and, lastly, the creation of the load demand curve thanks to the software RAMP.

The focus in this part is on the electricity consumed and therefore on the CWR index, since all the information needed to calculate the MTF attributes is meaningless to ask at a time when the intervention is being evaluated and the true impact on the community is not yet known.

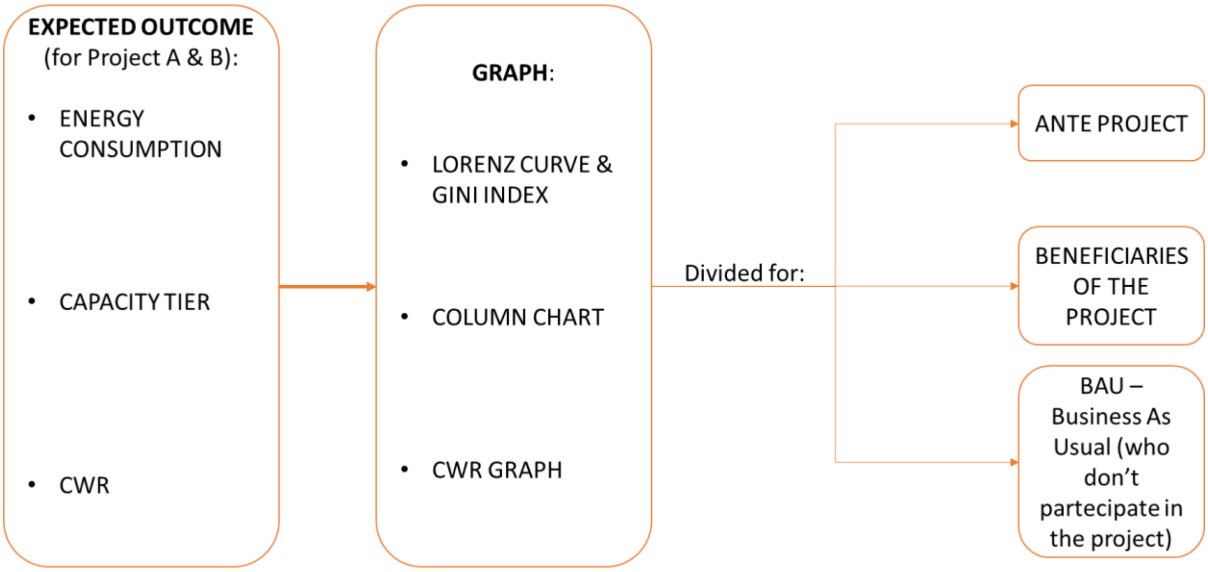


Figure 19. Scheme of module 4.

The first part of the sheet contains the expected outcome for each class and for the two projects A and B, so that a direct comparison can be made between the two. Four different tables are presented with this subdivision. The first table shows the number of people initially in the class and those who later were involved in the intervention with also the percentage value. Then the ex-ante, ex-post and WTC energy consumption is shown. For the post-intervention values are classified divided into two categories, considering separately those who participated respect to those who did not. For the former, the value will be given due to the user's intervention while for the latter the value corresponds to independent growth that would have been happened anyway without the intervention. To do this, of course, it must be the user who enters in the sheet before the non-participating classes or household those appliances that he thinks they would purchase in the short term. In this way, not only it is possible to make an even more accurate estimate of the demand curve so that a correct sizing of the new mini-grid or newly installed supply can be made, but also to have a correct assessment of the impact of the project by being able to overcome the counterfactual problem. This value is called "POST – Business as usual".

The following two type of tables present the tier and CWR index results showing the ex-ante, ex-the post and the variation between the two situations for the beneficiaries only, in absolute terms for the tier and in percentage for the CWR index. The goal must be interpreted as the correspondent tier of capacity related to the WTC. The variation is useful for the user to understand how the intervention impacted those who benefited versus those who were not included in the project.

The last tables show the electricity consumption and CWR index values for all classes and for all beneficiaries only. Similarly, to all previous tables, data are given for the different ante and post situations with the addition of the target value.

The second part of the sheet serves to give a graphical interpretation of the collected data. To achieve this, the following graphs are used:

- Lorenz Curve & Gini Index
- Clustered Column Graph
- CWR Graph

The first two graphs reproduce those already presented in section 4.2.4, with the difference that in this case, also ex-post data are shown. Concerning the Lorenz Curve, in this instance it is presented in three different cases: the first concerns the cumulative consumption of the entire population, including both those who participated and those who did not participate in the projects, comparing the ex-ante data with the ex-post data for both projects in the same plot. The second and third Lorenz curves, on the other hand, refer only to the project beneficiaries of Project A and Project B respectively. In this way, a more specific comparison can be made on the intervention that was carried out for both projects.

The second chart, the column chart, is the same as the one in the "DSS" sheet with the addition of the columns with the specific consumption for the individual household of Project A and Project B.

The last graph instead aims to show the effectiveness of the intervention in terms of affordability for each individual class participating in the project. It is presented with 3 straight lines representing respectively the ex-ante and ex-post trends of the energy consumed in the two projects and the WTC. Thus, the WTC straight line will always remain horizontal while the other two will start from the same point, since the initial consumption is fixed for both, and arrive at different points if the two projects have different directions. This graph serves to show how close the two projects come to the optimal situation, in which the class manages to consume almost their WTC.

After this, the data processing phase is the next to be described. The macro "RAMP_Project_A/B" (ANNEX A.7) will be launched for the corresponding chosen project. The function of this macro is to reorder the file in an additional hidden sheet in such a way that it can reflect the way the RAMP software can read a set of data from an Excel file.

It deletes all empty rows and appliances that have quantity values lower than zero and sets the file with 3 sheets:

- USER

- Appliances
- Profiles

However, this macro has one more very important feature. It does not create a single Excel file but twelve, one for each month of the year. The "Profiles" sheet, in fact, sets the number of profiles to be generated for the demand curve equivalent to the days of the corresponding month. As explained earlier in Chapter 4.1, some of the information required in the first phase, especially those associated with all, has been placed on a month-by-month basis. The macro, therefore, scrolls the drop-down starting with the month of January and proceeding in an orderly fashion until the 12th iteration. In this way, an additional parameter is added to the narrative to give more detail to the results.

The next step is the direct use of RAMP software. In order to be able to use it, the user needs to have it properly installed on his device. It is possible to download it for free from the "GITHUB" platform as it is an open-source file. There are several very similar versions of the same software, but one was created specifically for this use. It was necessary because few lines of code had to be changed so that the program would read the Excel-type files as input and in a sequential manner. With this new alternative version, it will only be necessary to run the file called "Ramp_Run". This will generate a load curve for each file and thus always generate 12 output files. The last step before showing the data is the necessary reordering of the data. The last macro will in fact cause the values of these 12 files to be taken and placed in order, one after the other, in a single file.

The complete file with the demand curve for an entire year can be used as input for the MICRO GRIDS.PY software.

4.5. Limits and Constrains

This paragraph will highlight the limitations, constraints and approximations made now that there is a clear understanding of the objectives and structure of the tool. Some of these limitations may be related to technical constraints, while others may be more dependent on the proposed methodology. In order to be able to mention and analyse them all, a systematic approach has been taken, following each step in the process of compiling the instrument.

Starting with the first module, the first constraint is related to the general info associated with everyone in the same way. These include house occupancy, tolerable outdoor air temperature, and lighting behaviour. By associating these values in the same way for everyone, the uniqueness that would be obtained through the questionnaire completion is lost. Furthermore, the major limitation lies in trying to determine these values in a methodological manner.

Regarding house occupancy, it is difficult to determine the maximum value of the tolerable outdoor air temperature in a methodological way. It would only be possible through an air conditioning calculation, which requires knowledge of a series of parameters that are not straightforward and not easily measurable. In general, one would need to know the structure of the dwelling and assume that all beneficiaries have similar housing. Overall, the limitation of this factor is that it is left to the user's experience, thus moving away from maximum objectivity.

As for lighting behaviour, there are also limitations. Another limitation is associated with geolocation. It is possible to select latitude, longitude and even time zone, but there is no option to enter a potential daylight-saving time associated with the country where the rural area is located. The majority of countries in Africa and Latin America (except for Chile, Paraguay and Uruguay) do not observe daylight saving time, so it should not be a problem since the focus of the study is on developing countries.

A similar discussion – to the one about maximum temperature – could be made for the simultaneity factor for mini grid. It cannot be determined a priori, and it is not appropriate to use a value obtained from another mini-grid since each mini-grid is installed in different contexts.

There is also an operational constraint associated with the maximum number of classes that can be inserted, which is set at one hundred. This choice is justified by a trade-off related to the speed of macro calculations in Excel.

Another limiting aspect, however, is associated with the methodology itself. The tool has been set up only for the household macro-category, excluding productive activities and public services. The reasons for this can be found in the fact that the MTF has proposed a specific questionnaire for each of these macro-categories, which would have required extending the data initialization phase for them and dedicating a separate Excel sheet for each, significantly lengthening the process.

In addition, as far as households are concerned, the assessment of multidimensional access has been limited to electricity only, excluding access related to cooking, as it is not the intention of the authors to propose an instrument that would also cover this issue, as it would require a parallel and not very integrated treatment.

For the “Starting Appliance” sheet, it was decided to use the information provided by the MTF. It suggests a set of appliances, defined as essential for accessing certain energy services. This set lists 18 different appliances. In the proposed tool, the freedom to add one additional appliance for each type has been allowed, with the addition of four additional empty spaces at the end of the list. Overall, a total of 26 appliances can be included for each class.

In the second phase of the methodology, further limitations are encountered. In the first table related to tier results, the final tier is also shown. As explained in the first section of the "Calculation Tier" - paragraph 3.2.1 -, the final tier represents the minimum value between the Capacity and the Availability. This is a limitation imposed by the MTF, which proposes the overall tier as the minimum value among all seven attributes. However, as some of these attributes are binary, the scope has been narrowed down to just the two mentioned above. In this way, however, this index becomes less representative.

5 Validation of Multidimensional Needs-to-Strategy Energy Planning Tool

This chapter focuses on the validation of the proposed tool, demonstrating how the results obtained using the proposed methodology are more accurate and comprehensive compared to those obtained without following the proposed approach. Through this validation study, it becomes possible to provide an example that better illustrates the tool's potential and highlights the considerations that users would need to make in order to fully utilize it.

A prototypical village from the ILUMINA project was chosen as a case study. This project, financed through an open call by the Italian agency for cooperation and development (AICS), had AVSI and COSV as proposing NGOs, and its aim was to implement integrated, sustainable and accessible solutions to promote women's rights and empowerment and to guarantee access to renewable energy in the Cabo Delgado region, particularly in the Montepuez and Balama areas. The village chosen was M'paka, in the Balama area, where it was decided to install a solar mini-grid because of its agricultural and commercial dynamism, and also because the use of mobile phones is more widespread in this area than in the rest of the region, which is necessary to pay for electricity on a pay-as-you-go basis.

The first five sub-chapters of this chapter illustrate the modules of the methodology adopted in the tool, providing a detailed explanation of each. The final sub-chapter 5.6 presents the results obtained and compare them with those obtained in the absence of the proposed methodology.

By conducting this validation, the chapter 5 contributes to the overall understanding and assessment of the tool's effectiveness, showcasing its applicability in real-world scenarios and demonstrating the added value it brings to energy planning and decision-making processes.

5.1. Data Collection & Classification

This village was selected for the application of the tool because the questionnaires recommended by the WB for the MTF implementation were already conducted on the population and made available as part of the ILUMINA project. As a result, most of the questions aligned, enabling an accurate assessment. However, not all the necessary questions for completing the "Data Collection" sheet of the tool were included in the WB's questionnaire. To address this, alternative methods were utilized to gather the missing data and ensure a comprehensive understanding of the village.

The absence of these inputs also influenced the categorization of the population into different classes. As mentioned earlier, this classification is primarily based on three factors: the supply system, income and/or energy expenditure, and the ownership of appliances. While the supply system and appliances were known for all classes, precise information on income and energy expenditure was not provided. Therefore, a decision was made to divide the population into macro-classes based on the existing supply system, and then further subdivide them based on appliance ownership. The diagram below illustrates this subdivision, providing an overview:

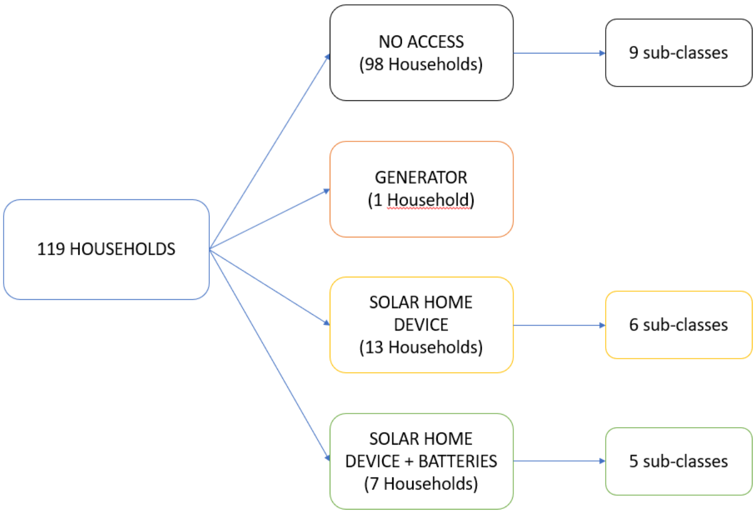


Figure 20. Classification of M'paka dwellers

As observed, it was deemed necessary to provide a subdivision within the "No Access" class, considering the differences in appliances for this group, which primarily rely on battery-powered devices. Moreover, to maintain a disaggregated data sample and obtain more detailed results, the macro-class, representing 80% of the population, was further subdivided into several sub-classes.

In the questionnaires, there was no information regarding income but only expenditure values for each household. Therefore, a decision was made to assume that the income is equal to the sum of all monthly expenditures. This assumption is based on the context of rural areas where individuals typically spend what they earn from their activities and have little to no savings. In the Logical Framework of the project, a list of expenditures divided into categories, along with average values for all villages in the Cabo Delgado region, was presented. The table below displays the expenditure values, disaggregated for different categories:

EXPENDITURE		
Food Expenditure	2028	MT/month
Electricity Expenditure	100	MT/month
Transport Expenditure	1612	MT/month
Health Expenditure	101	MT/month
Education Expenditure	231	MT/month
Cooking Fuel Expenditure	2073	MT/month
Housing Expenditure	677	MT/month

Table 7. Average monthly expenditure for Capo Delgado inhabitants. Source: ILUMINA project

The total sum of these expenditures amounts to 6,822 MT/month, which is approximately 108 $/month. For the "No Access" classes, the electricity expenditure of 100 MT/month was excluded. Additionally, to provide a closer approximation to real-life situations, the income was established as a function of the supply system, introducing a certain percentage variation. An increase in income is assumed for those who own a more advanced supply system. The table below illustrates the average expenditure for each macro-class, the associated percentage change based on the supply system, and the resulting income:

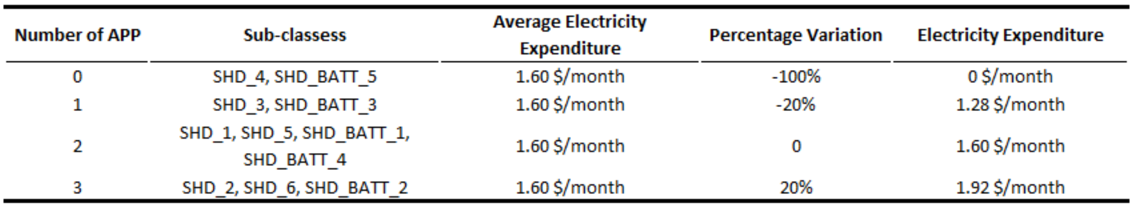
Supply System	Average Expenditure	Percentage Variation	Income
No Access	106 $/month	-5.00%	100 $/month
Solar Devices	108 $/month	3.30%	111.5 $/month
Solar Devices + Batteries	108 $/month	6.60%	115 $/month
Diesel Generator	108 $/month	10.00%	119 $/month

Table 8. Author's elaborated distribution of income for M'paka inhabitants

Regarding electricity expenditure, no responses specific to the single household were provided in the questionnaire, including information on WTP. In the absence of data, the value in Table 3 titled "Electricity expenditure" was adopted. Furthermore, it was decided to vary this value based on the number of appliances owned. This assumption is justifiable considering the limited number of appliances typically owned, particularly ICT-type devices such as telephones and radios.

This method has been applied to the two macro-class of SHD and SHD with Battery while a separate consideration has been made for the generator, where the price of fuel is provided, amounting to 22.70 $/month.

The table below shows the values of the number of appliances owned for each sub-class, the average electricity expenditure, the percentage variation and the resulting electricity expenditure:



Number of APP	Sub-classess	Average Electricity Expenditure	Percentage Variation	Electricity Expenditure
0	SHD_4, SHD_BATT_5	1.60 $/month	-100%	0 $/month
1	SHD_3, SHD_BATT_3	1.60 $/month	-20%	1.28 $/month
2	SHD_1, SHD_5, SHD_BATT_1, SHD_BATT_4	1.60 $/month	0	1.60 $/month
3	SHD_2, SHD_6, SHD_BATT_2	1.60 $/month	20%	1.92 $/month

Table 9. Author's elaborated distribution of electricity expenditure for M'paka inhabitants

For WTP, as there were no available data to derive it, the MTF's proposed threshold of 5% of income was imposed to ensure an affordable connection. In this way it has been assumed that everyone is willing to spend money to have an electricity service. This assumption is very strong but necessary for the validation of the tool. In general, this aspect is of utmost importance for an electrification project. In fact, it is not taken for granted that the whole population would like to have a connection and it is for this reason that it is essential to establish a WTP.

Certain data not captured in the survey, such as house occupancy and lighting behaviour, were included based on the authors' first-hand experience, aiming to approximate local habits.

5.2. Decision Support System Analysis & Results

This chapter will address the decision support system phase by analysing in detail all the results obtained and attempting to provide the reader with an example of how the proposed tools can be interpreted and subsequently used.

5.2.1. MTF Analysis & Results

In this section, it will be analysed the results of the MTF methodology. However, it is important to note that the tier classification for the attributes of Capacity and

Availability was solely based on the information gathered from the population questionnaire. The alternative calculations proposed by the authors were not utilized.

Firstly, it is presented the final tier, which, as explained in chapter 4.2.1, represents the lowest value among the Capacity and Availability tiers. The interesting and practical aspect here is that it becomes easier to identify which attribute may be limiting the specific tier in terms of electrical connection utilization. The results are displayed at the end of this section.

The final tier reveals that only the class SHD_BATT_1 has a particularly high final tier of 4. The "limiting" attribute in this case is the Availability of Day, with the class reporting approximately 20 hours of availability per day. Next, the SHD_BATT_2 class ranks in tier 2, primarily due to the limited capacity of the system itself, with only 150 watts of nominal installed power available. All other classes have been classified between tier 0 and tier 1. Classes categorized under "No Access" are not shown since they have all been classified as tier 0, providing no additional useful information for the narrative. Overall, there does not seem to be a noticeable repeating pattern regarding the assignment of the final tier for classes with a supply system. In fact, the tiers of Capacity and Availability have different values for each class.

An exception is the GEN_1 class, which has a different supply system than all other classes. This class indicates 0 hours of Availability during the day and 3 hours during the evening. This information is highly significant as it demonstrates a specific interest and need for electricity, especially during night-time hours. Later in the narrative, additional elements will be presented that contribute to the improvement of this specific class.

Regarding the other attributes, it can be observed that all classes report a good level of Health & Safety. In terms of Quality of connection, however, there is greater disparity in the results, with seven out of twelve classes reporting at least one appliance being damaged due to low voltage quality. Reliability is significantly better for classes with SHDs with batteries compared to those without and this could mean for example that a battery help stabilize the connection in small systems.

These three attributes hold equal importance as all others since they reflect the quality and effectiveness of the entire power system. Consistent and reliable answers would enable stakeholders in the electricity sector to better identify and address distribution and end consumption-related issues. Focusing solely on energy production would not necessarily lead to better service and consequently to a greater satisfaction among the population regarding the service itself.

Finally, almost all classes confirm the legality of their connections, and in terms of Affordability, all classes are in Tier 5, indicating that their energy burden accounts for less than 5% of their income. The only exception is the GEN_1 class, with a monthly expenditure of 22.7 $/month and an energy burden of 19%.

The following table displays the tier results for all classes, categorized by each electricity attribute, including the final tier and the number of households within each generic class.

			PEAK CAPACITY	AVAILABILITY		RELIABILITY	AFFORDABILITY	QUALITY	LEGALITY	HEALTH & SAFETY
User Name:	Number	FINAL TIER	TIER LEVEL (POWER)	TIER LEVEL (DAY)	TIER LEVEL (EVENING)	TIER LEVEL	TIER LEVEL	TIER LEVEL	TIER LEVEL	TIER LEVEL
SHD_1	1	2	2	5	5	5	5	0	5	5
SHD_2	1	1	2	3	1	0	5	5	5	5
SHD_3	2	1	1	3	5	0	5	0	5	5
SHD_4	2	0	1	0	0	0	5	5	5	5
SHD_5	4	0	1	3	0	0	5	0	5	5
SHD_6	3	1	1	3	1	0	5	0	5	5
SHD_BATT_1	1	4	5	4	5	5	5	0	0	5
SHD_BATT_2	1	2	2	4	5	5	5	0	0	5
SHD_BATT_3	2	0	1	0	2	0	5	0	5	5
SHD_BATT_4	2	1	1	4	5	4	5	5	5	5
SHD_BATT_5	1	1	1	2	1	4	5	5	5	5
GEN_1	1	0	3	0	3	0	0	5	5	5

Table 10. Tier's classification for all classes except for “No Access”.

5.2.2. CWR Index & Other Parameters

In this section, it will be discussed the results obtained for the various parameters presented in the “Calculations” section of the Excel file. The focus will be more on the specific electricity cost parameter (C_spec) and the CWR index, while briefly mentioning the other parameters as they are readily available in the graphs for easier analysis.

As explained in Chapter 4.2.2, the specific cost of electricity is calculated by dividing the monthly electricity expenditure by the actual energy consumption. In cases where energy expenses are known for the generic class, the provided data is used. Alternatively, if the energy expenditure is not available, the selected tariff from the questionnaire is used. In this study, energy expenditure was estimated for all classes with a supply system, so no issues arose. However, two classes, SHD_4 and SHD_BATT_5, reported having a supply system and monthly expenditure but stated not owning any appliances. As a result, their consumption was considered zero kWh per day, and no values were displayed for them or any dependent parameters.

For all “No Access” classes, it was necessary to assume a value. The average C_spec value of the other classes was used, excluding the GEN_1 class, which had a value of 4.20 $/kWh and was deemed an outlier. To perform this calculation, all methodology operations up to this point were carried out without considering the GEN_1 class. The C_spec results for the other classes were analysed, and the average value was calculated for inclusion in the initial phase. Subsequently, the analysis was resumed from the beginning, considering complete information for all classes. The obtained value was 0.93 $/kWh.

Regarding this parameter, it is important to note that C_spec depends on monthly expenditure, which can be assumed constant as a first approximation, and on consumption. Consequently, a class with low consumption compared to other low-consuming classes, and consumption that varies significantly among the population, leads to have the C_spec that varies considerably among the population and with high values. This should not be overlooked, as it has considerable implications for other aspects. For example, the WTC is directly influenced by this parameter. Therefore, a class with low consumption but a relatively high C_spec will have a WTC that is not significantly different from current values. These favours classes that consume more than the average prior to any intervention, potentially biasing the subsequent choice of intervention.

Regarding the other parameters, it is worth noting that, except for the GEN_1 class, all classes have an energy burden of less than 5%. The maximum value is 1.72%, indicating significant gap for increased energy consumption or expenditure. Looking at the delta parameter, all values are positive and quite substantial in relative terms, given the current limited consumption. This information coupled with the fact that in general the level of consumption is low shows that the selected location certainly has a low level of access to electricity, but that at the very least, the initiative has been taken by some household groups to undertake this process by showing a desire to spend more in return for an improved service.

Now, let's shift the attention to the CWR index. Even before examining the obtained values, it is evident that if the WTP is higher than the electricity expenditure for a generic class, the CWR index will be less than unity. This holds true for all classes except for the GEN_1 class. In general, excluding the latter, the results are relatively low, with a maximum of 0.334 [-]. By examining the parameters that directly impact the final value, a more comprehensive perspective can be obtained. Nonetheless, it can be concluded that, considering these low values, there is ample space for the population to consume more. This presents an opportunity to provide more efficient and modern energy services, offering individuals in various family groups new tools that can improve and simplify their lives, thus accelerating the development process.

In Chapter 4.2.3, it has been attempted to provide a method for interpreting this index using the tier results for the different attributes. As mentioned earlier, all classes have a CWR index below unity. Regarding the tiers, only three classes – particularly SHD_1 (Tier 2), SHD_BATT_1 (Tier 4), and SHD_BATT_2 (Tier 2) –, show above-average values. For these classes, the proposed methodology suggests promoting essential appliances to enhance their quality of life. Similarly, for the other categories, the intervention should begin with improving the entire electrical system to ensure a reliable service. Subsequently, it will be necessary to promote the purchase or distribution of important appliances.

The GEN_1 class stands out with a significantly higher CWR index and relatively low tier values. Such a situation is challenging to address, often indicating an inadequate supply system. In this case, relying on diesel generators incurs high operating costs due to fuel purchases, especially in remote areas. Consequently, an alternative solution should be offered where the supply system itself is inadequate.

Lastly, the CWR index for the entire population sample is even lower, at 0.073. This result is influenced by the "No Access" classes, which naturally have zero consumption and represent a substantial portion of the population (80-82%). Comparing the CWR index for the entire population before and after the intervention provides valuable information on the project's effect, demonstrating the overall improvement achieved within the community. Moreover, it is crucial to measure the proposed indicators both before and after a project of this nature, including values for the entire community, district, or region.

5.2.3. Charts

This section presents the graphs described in Chapter 4.2.4, displaying the values obtained from the questionnaire and subsequently processed by the authors. The Excel file contains four types of graphs, which will be analysed in sequential order.

The first graph is the Lorenz curve, illustrating two series: one for income and the other for actual and pre-project electricity consumption. Each series is accompanied by the corresponding Gini index value.

The Lorenz curve for income is closely aligns with the bisector, thus, showing a high level of equality among the classes. In this case, the Gini equals 0.019 [-], very close to zero and thus confirming what has just been said.

Conversely, the consumption curve reveals a clearly contrasting situation. There is significant inequality between classes, with 84% of the sample consuming 0% electricity. While, when examining the information inversely, it becomes apparent that 1% of the population accounts for approximately 20% of the village's electricity consumption. The Gini index for consumption is 0.909 [-], nearing 1, which represents the most extreme level of inequality.

It is important to note that the total consumption of all respondents considered in this case is 1.63 kWh per day, indicating a very low value. Therefore, it takes only a small group of households with a functioning system to exacerbate this seemingly challenging situation.

In this particular case, the Lorenz curve highlights a critical scenario where the population seems to be relatively similar in terms of income distribution. However, concerning energy services, clear barriers hinder the utilization and exploitation of the service itself. Therefore, this tool suggests that action should be taken to ensure access to electricity for the portion of the population currently experiencing zero consumption. Subsequently, further improvements can be pursued, if feasible, with the goal of inclusivity for all community members.

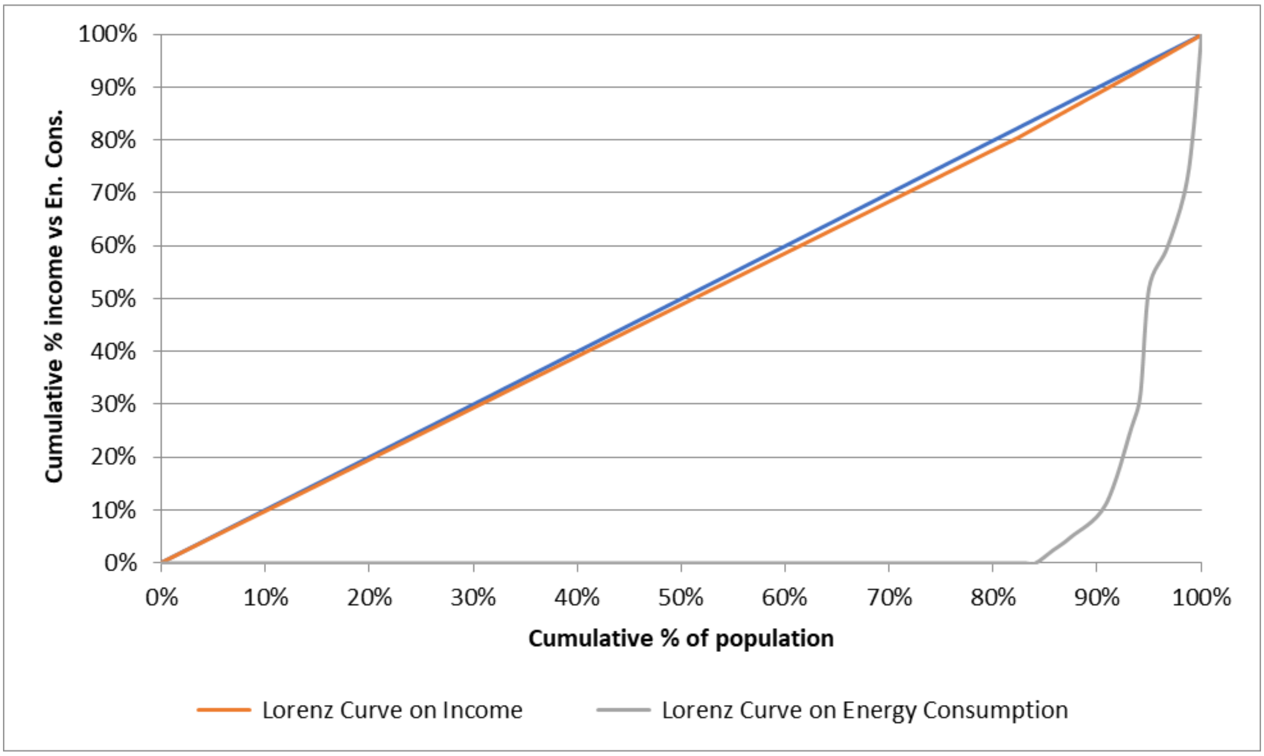


Figure 21. Lorenz Curve - Income vs Electricity Consumption.

The second graph, featuring grouped columns, directly presents the two parameters calculated by the authors in the "Calculations" section: electricity consumption and estimated WTC consumption. This graph is relatively straightforward to analyse and interpret. Merely observing and selecting the classes where the WTC column exceeds the electricity consumption column is sufficient to identify them as potential beneficiaries of the project.

For all classes categorized under the "No Access" supply system, current consumption is zero. However, considering the assumed C_spec, the graph also displays the WTC at 0.18 kWh/day, placing these classes in the corresponding Capacity tier with a value of 1. Although they are close to the threshold value for tier 2, the process should progress gradually, following the recommended steps outlined by the MTF in terms of the supply system to be implemented for these classes.

All other classes exhibit values in both columns, except for classes SHD_4 and SHD_BATT_5, where neither current consumption nor WTC could be estimated based on consumption. These classes also qualify as potential beneficiaries since their WTC exceeds their current consumption. However, an exception remains with class GEN_1, which demonstrates excessive expenditure exceeding a level indicative of good Affordability.

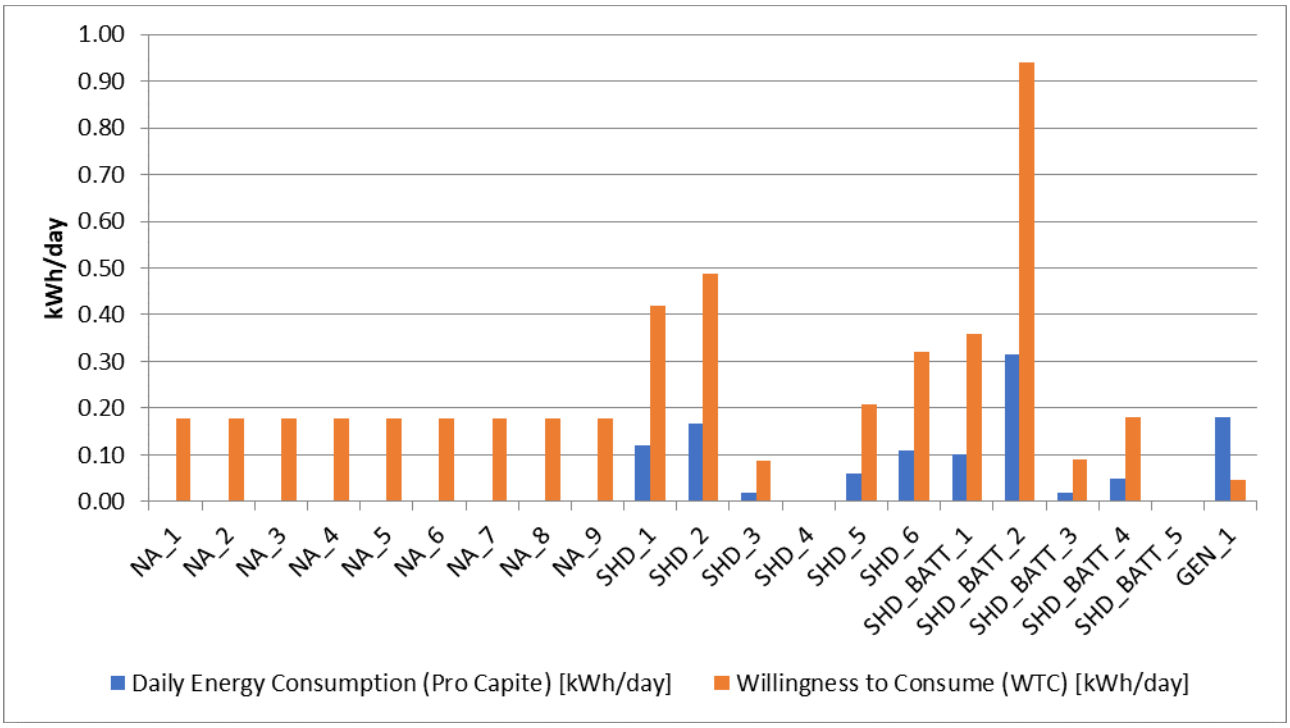


Figure 22. Comparison between Daily Consumption and WTC.

This graph aims to display individual classes and suggest which ones could benefit from further efforts to ensure a modern and efficient electricity service. As previously mentioned in Chapter 4.2.4, the authors proposed that the classes located in the bottom right-hand corner of the graph would be the most suitable candidates for intervention. While there are no absolute values to determine the exact reference point, considering the relative positioning of classes simplifies the analysis. In this specific case, however, all the classes are relatively close to each other in terms of both consumption and Delta. There are two exceptions: the GEN_1 class, which exhibits a negative delta, and the SHD_BATT_2 class, which has the highest values for both current consumption and delta.

With these exceptions aside, all other classes show potential as beneficiaries for a potential electrification project.

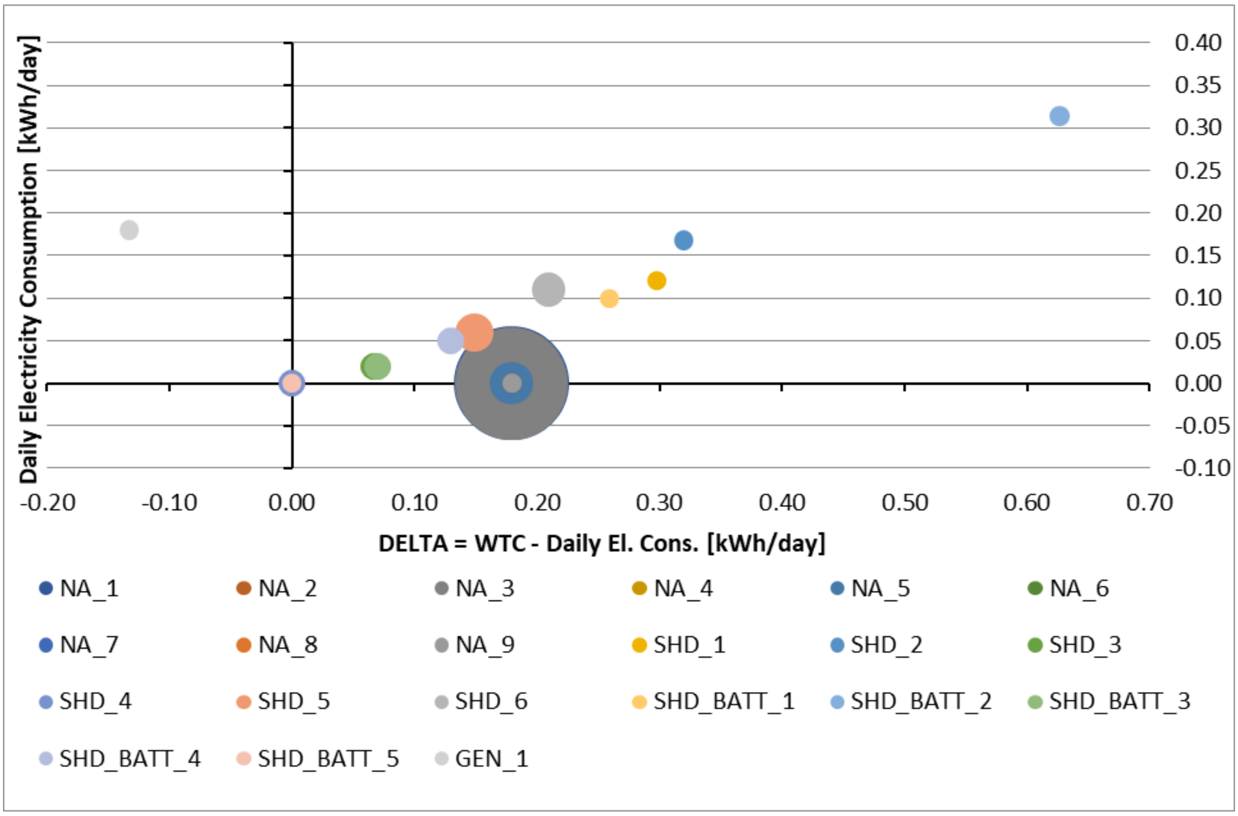


Figure 23. Bubble chart

The final graph presented is the radar graph, which serves as an effective analysis tool for evaluating individual classes. It provides a snapshot of the current situation and identifies specific targets to strive for in each attribute. This makes it easy to identify areas for improvement and set goals accordingly.

To illustrate, let's consider one example. The chosen class is SHD_2, the reasons why this class was chosen is because it has tier values, alternating between the various attributes, so it is possible to show how to interpret the graph and the information it contains. In this case, there is room for improvement in multiple aspects. Notable enhancements are needed in the Affordability and Reliability attributes. It would be advisable to provide a supply system that ensures uninterrupted service, especially during evening hours, such as incorporating a battery into the existing system. Additionally, conducting through checks to minimize unplanned network or system disruptions would be beneficial. As for Capacity, there is relatively less room for improvement, with a maximum potential of reaching Tier 2.

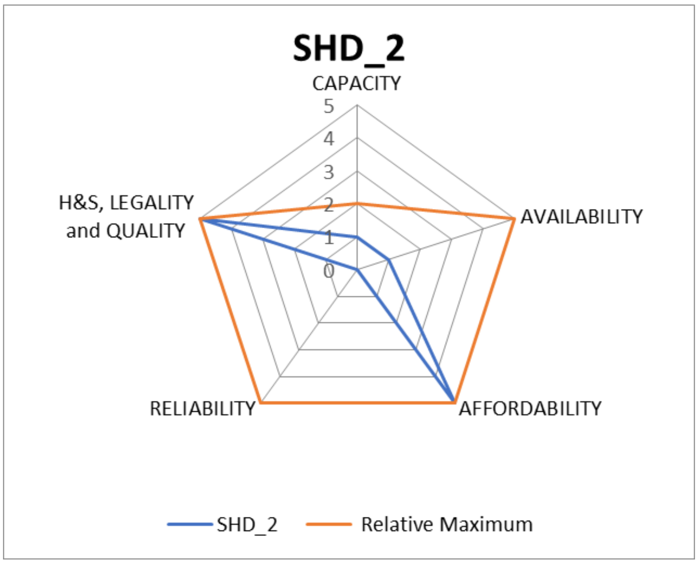


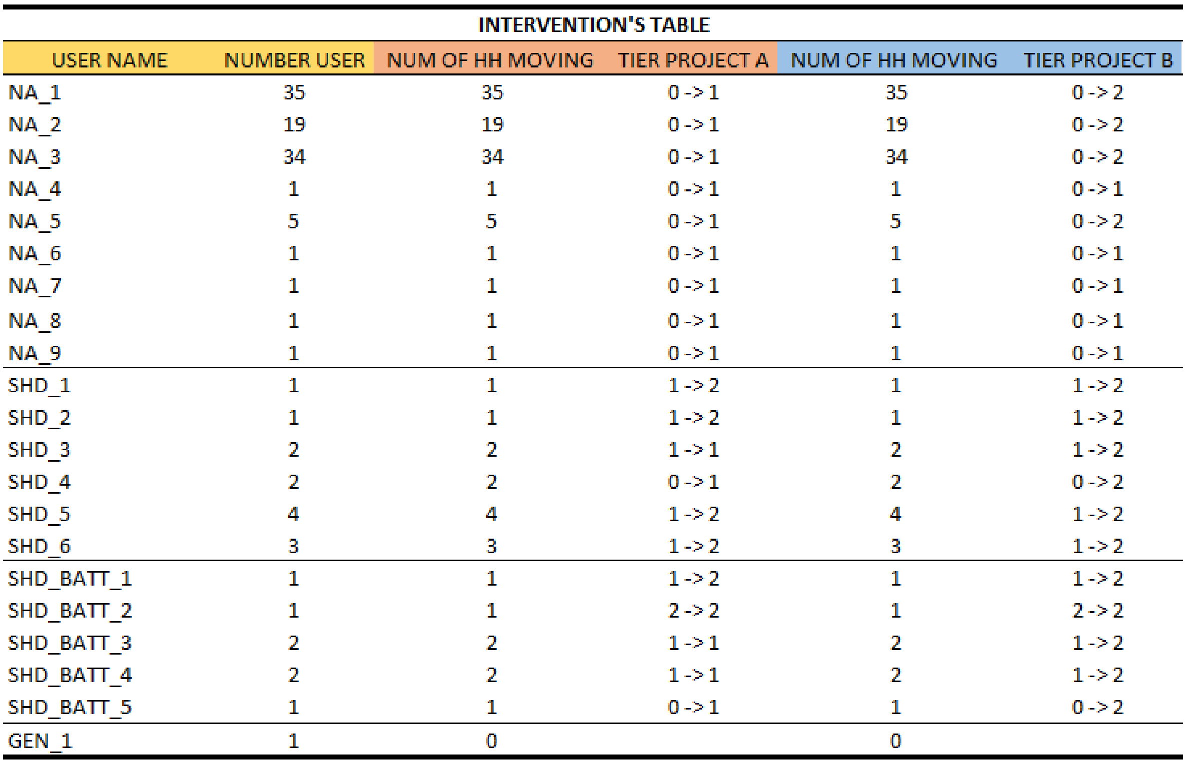
Figure 24. Radar graph for SHD_2 class.

5.3. Intervention's Selection & Assumptions

As mentioned above, the actual intervention of AVSI and COSV in M'paka was to build a mini-grid to connect everyone to a stable and secure supply. However, in the absence of precise information on the post-project behavior of the households initially surveyed, in terms of new appliances purchased or donated, it was not possible to make an accurate assessment of the village post-installation. It was therefore decided to propose two different types of intervention:

- Project A will reflect the suggested capacity tier based on the willingness to consume of each participating class. Except for two classes of households (SHD_4 and SHD_BATT_5) for which the recommended tier was zero because they had no initial consumption despite having a supply system, so it was decided to place them at least at Tier 1.
- Project B, on the other hand, is based partly on an ex-post analysis of the results of Project A, and partly on raising the tier of certain classes and increasing the consumption of those classes that still have potential for improvement.

Specifically, the results of Project A showed that among the "No Access", the first three classes and the fifth class had a rather low post-intervention CWR index, around 0.2, so for Project B it was decided to move them up to Tier 2; also, for all those who already had a supply system, it was decided to move them up to tier 2. Separate considerations have to be made for the classes SHD_1, SHD_2, SHD_6, SHD_BATT_1 and SHD_BATT_2. From the bubble graph it could be seen that these were the ones with a larger delta between WTC and energy consumption, and therefore where more could be done. For the latter, the project didn't move to a higher tier, but simply added a freezer, as the project endline file showed that it was the only new appliance in the list of equipment in the village. In both projects it was decided not to include the owner of the generator, as the only household with a different supply system, dependent on fossil fuels, and with much higher electricity costs than the others. Below is the table of interventions for the two projects:



INTERVENTION'S TABLE

USER NAME	NUMBER USER	NUM OF HH MOVING	TIER PROJECT A	NUM OF HH MOVING	TIER PROJECT B
NA_1	35	35	0 -> 1	35	0 -> 2
NA_2	19	19	0 -> 1	19	0 -> 2
NA_3	34	34	0 -> 1	34	0 -> 2
NA_4	1	1	0 -> 1	1	0 -> 1
NA_5	5	5	0 -> 1	5	0 -> 2
NA_6	1	1	0 -> 1	1	0 -> 1
NA_7	1	1	0 -> 1	1	0 -> 1
NA_8	1	1	0 -> 1	1	0 -> 1
NA_9	1	1	0 -> 1	1	0 -> 1
SHD_1	1	1	1 -> 2	1	1 -> 2
SHD_2	1	1	1 -> 2	1	1 -> 2
SHD_3	2	2	1 -> 1	2	1 -> 2
SHD_4	2	2	0 -> 1	2	0 -> 2
SHD_5	4	4	1 -> 2	4	1 -> 2
SHD_6	3	3	1 -> 2	3	1 -> 2
SHD_BATT_1	1	1	1 -> 2	1	1 -> 2
SHD_BATT_2	1	1	2 -> 2	1	2 -> 2
SHD_BATT_3	2	2	1 -> 1	2	1 -> 2
SHD_BATT_4	2	2	1 -> 1	2	1 -> 2
SHD_BATT_5	1	1	0 -> 1	1	0 -> 2
GEN_1	1	0		0	

Table 11. Intervention's table with project A and B

The expected outcome is that Project A will be more cautious and conservative, while Project B has tried to push the boundaries a little to see how far consumption can go without a significant overall improvement. It should be noted that even for those tiers for which there was no improvement between the old tier and the new tier, this does not mean that the consumption did not increase, because on the basis of what they had before, however, appliances corresponding to the selected tier were added. With regard to the inclusion of appliances in the "Project A" and "Project B" sheets for "No Access", in addition to the standard list proposed by the MTF, all the battery-powered appliances that were previously present were also added. This was done by imagining a switch once connected to the network.

5.4. Expected Outcome

This section shows the post-project values of the entire community for both Project A and Project B. The purpose is to provide advice on how to interpret the data presented and not to discuss its accuracy. Let’s start with the Lorenz curve:

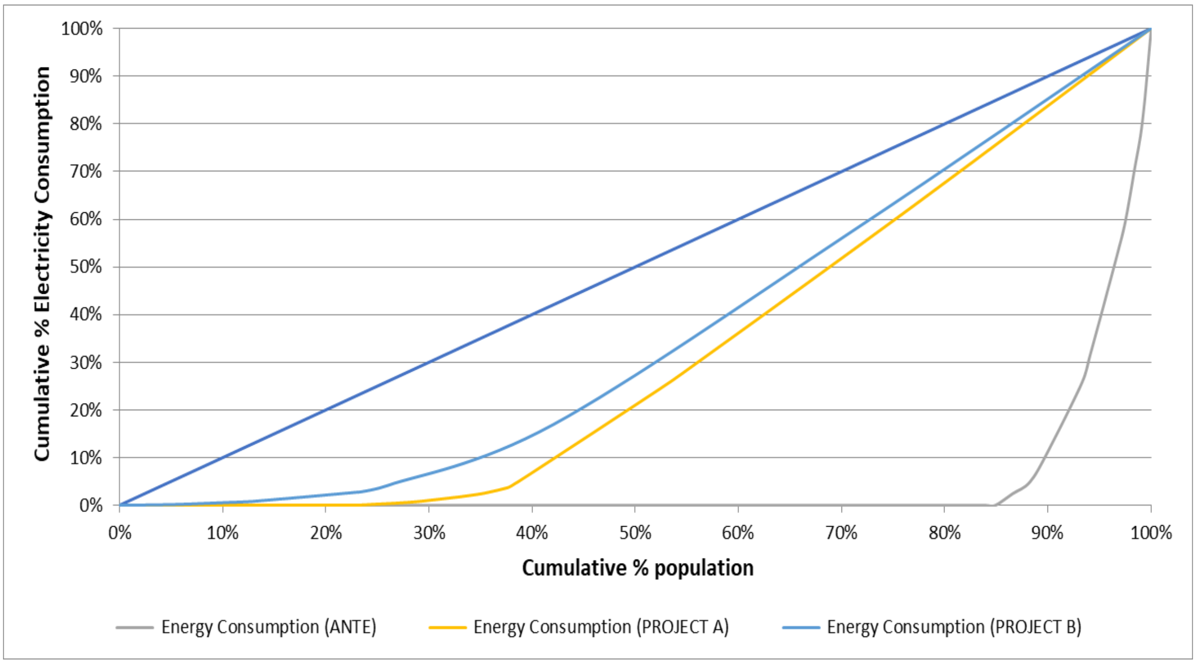
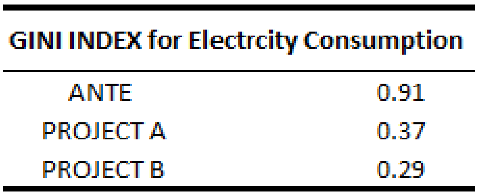


Figure 25. Lorenz curve of energy consumption ANTE and POST for project A and B

The improvement over the baseline situation is immediately apparent from this graph, as before more than 80% of the population had no access to electricity, causing great inequality among the population. In both Project A and Project B, this problem has been partially overcome, as it can be seen that less than 30% of the population in Project A and just over 10% in Project B have almost zero consumption. This is also appreciable when looking at the Gini index values related to these curves:



GINI INDEX for Electrcity Consumption	
ANTE	0.91
PROJECT A	0.37
PROJECT B	0.29

Table 12. Comparison of Gini Index, ANTE vs PROJECT A vs PROJECT B

Project B brings more people onto a common tier and brings the consumption of most of those who were "No Access" closer to that of other households with a supply system, making the situation more equal for the whole community. However, this is not an indication of how good the project is, but rather how electricity consumption is distributed within the population. It is necessary to look at the column chart to understand this data from a more quantitative point of view. This is the same as the one above, but with the addition of post-consumption for both Project A and Project B:

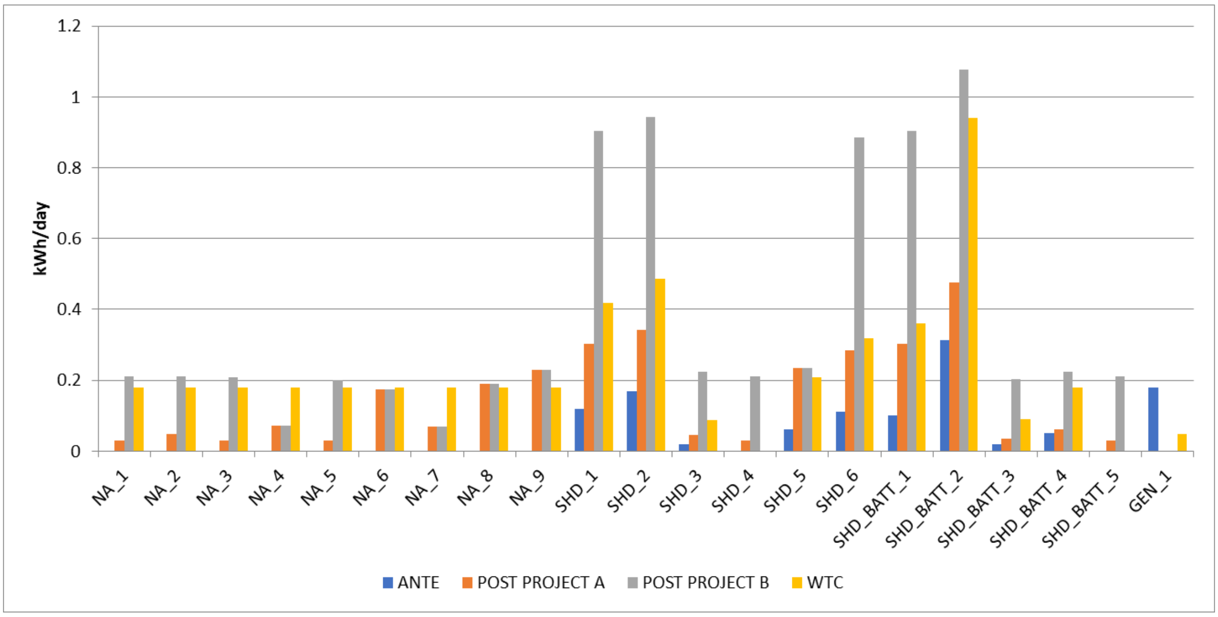


Figure 26. Column chart with electricity consumption per day ANTE, POST and WTC

It can be seen that, with the exception of the peaks due to classes SHD_1, SHD_2 and SHD_BATT_1, the WTC values presented are, on average, around 0.2 kWh per day, which according to the MTF table is the minimum to fall within tier 2 of Capacity, while those of actual consumption are slightly lower for Project A and slightly higher for Project B. Combining the analyses of the first two graphs, it can be noticed that there has been an improvement in the inequality of consumption, from a Gini of 0.91 to 0.37 and 0.29 for Project A and Project B respectively. However, there has been no significant improvement in the absolute level of consumption. Therefore, these two graphs also serve as an indication of what the future direction of the intervention should be, i.e., whether there is a need to increase consumption or instead try to rebalance the distribution within the population a little. Looking at the results class by class, it can be seen from the column chart that for "No Access" Project B is closest to their WTC, in some cases slightly exceeding it, while Project A is quite far from the consumption they could achieve. For the other classes, the same discourse can be made, but in reverse, with Project A approaching their WTC without ever exceeding it, and Project B always being higher. This discourse is very evident when analysing the graph based on the values used to calculate the CWR index, i.e., energy consumption before and after the WTC.

CWR INDEX	
ANTE	0.07
PROJECT A	0.34
PROJECT B	1.33

Table 13. CWR Index for all residents, ANTE vs PROJECT A vs PROJECT B

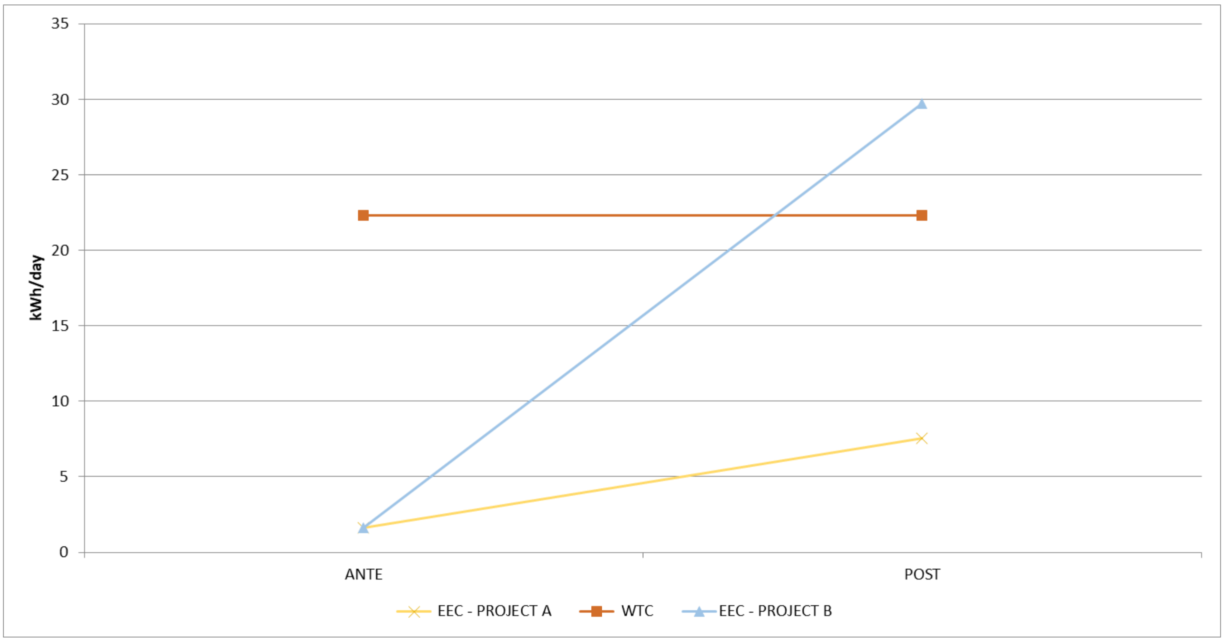


Figure 27. CWR index chart for project A and B

Indeed, the effectiveness of the project based on the energy consumption before and after can be seen from this graph, in which case it is clear that both projects A and B have their criticisms. Project A, by underestimating the consumption of the "No Access" with respect to their WTC - and they are more than 80% of the village - has an overall CWR index of 0.34 [-], while Project B, by overestimating the consumption of certain classes, has an overall CWR index value above unity of 1.33 [-]. This data, together with the graph, is useful in understanding how to act in the post-project phase, e.g., for Project B to get the value closer to unity, it will be necessary to guarantee a cheaper electricity price than they are paying now, or to increase WTP. This can be done either indirectly by increasing the income of the population, or directly by trying to increase people's awareness of the importance of energy for sustainable growth and consequently getting them to pay a higher percentage of their salary.

Now let's get more specific about the two projects and especially for each class, the most interesting cases will be shown to demonstrate how the proposed graphs should be analysed.

5.4.1. Project A

The first graph is the Lorenz curve. It shows the energy consumption of the project beneficiaries only and the Gini index values:

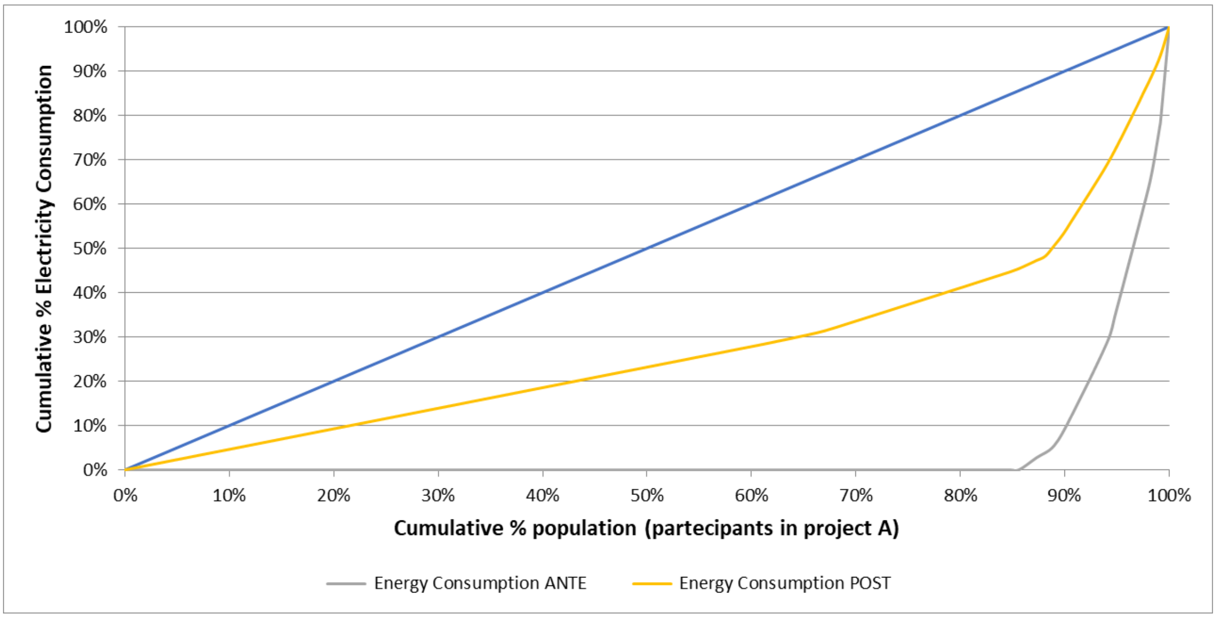


Figure 28. Lorenz curve for electricity consumption of Project A beneficiaries

GINI INDEX for Electrcity Consumption	
ANTE	0.91
BENEFICIARIES PROJECT A	0.46

Table 14. Gini Index for all beneficiaries of Project A, ANTE vs PROJECT A

This graph, compared to the previous one, includes all participants in the project and therefore has a higher Gini index value and a curve that is closer to the bisector. The purpose is to highlight how consumption is distributed among the participants and any inequalities between them. In this case, for example, it is evident that just over 15%

of the population consumes almost 50% of the village's total consumption. So, there is still a huge difference between the different classes, even if the situation has improved.

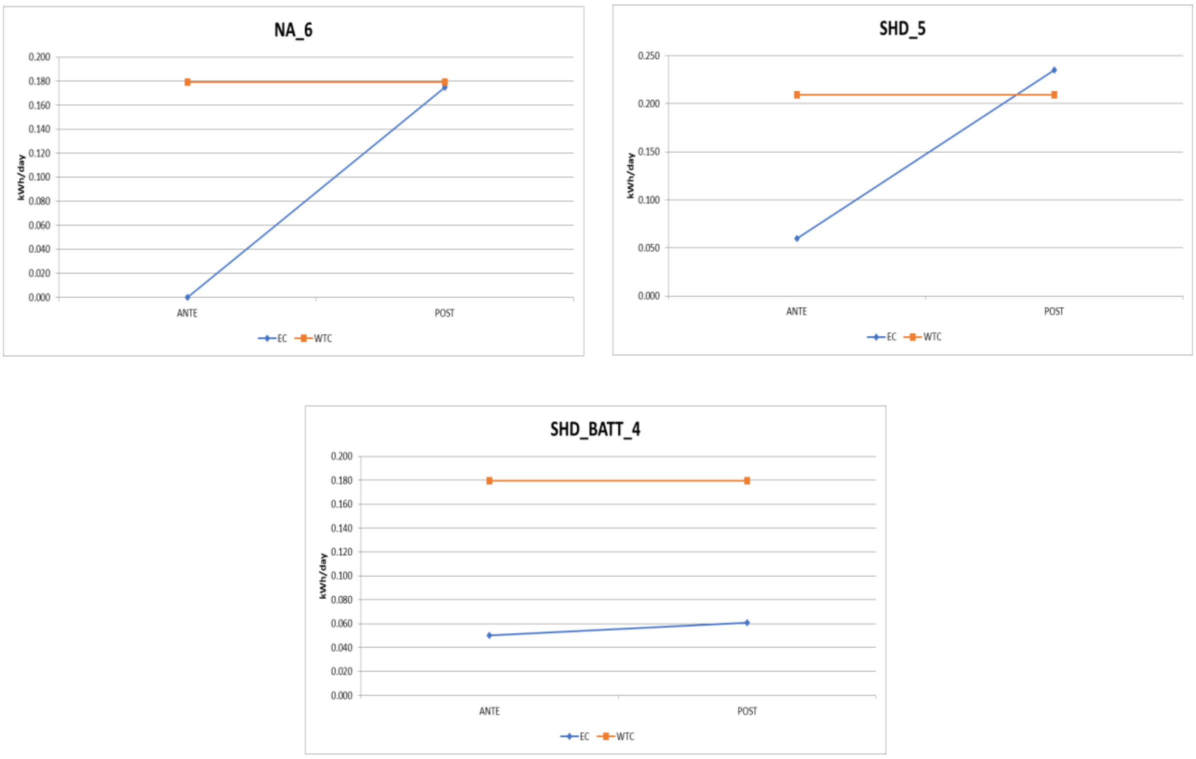


Figure 29. CWR chart for NA_6 class (a), SHD_5 class (b) and SHD_BATT_4 class (c).

These graphs are used to understand the response of each class to the project in relation to its WTC, and then whether the project is affordable for the classes at the current electricity price. In the graphs above, three cases are shown for the three different classes, with very different responses: in the first case, it can be seen that the consumption starting from zero, as they were part of the “No Access” macro-class, comes after the project to consume exactly what they are willing to pay. In this case, it means that the developer has achieved his goal of allowing a certain class to arrive at exactly the consumption they can afford. In this way, there is what is known in economic terms as a win-win situation, because the developer is sure that the proposed service will be paid for, and the household instead has a stable, secure and affordable connection. In the second case (b), however, the post-project energy consumption is slightly higher than the SHD_5’s WTC, in which case small incentives or a slightly lower post-project electricity price than before will be needed to raise the WTC just enough to make the planned consumption affordable. In the third case (c), the intervention is very limited in proportion to the potential of the class concerned; in this case, the intervention will have to be revised or the purchase of new appliances will have to be encouraged to increase consumption, for example through incentives.

5.4.2. Project B

For Project B, the same graphs are shown, trying to compare them with those for Project A and finding out which situation is better than the other. Lorenz curves for the consumption of the beneficiaries alone and the corresponding Gini index are always used as a starting point:

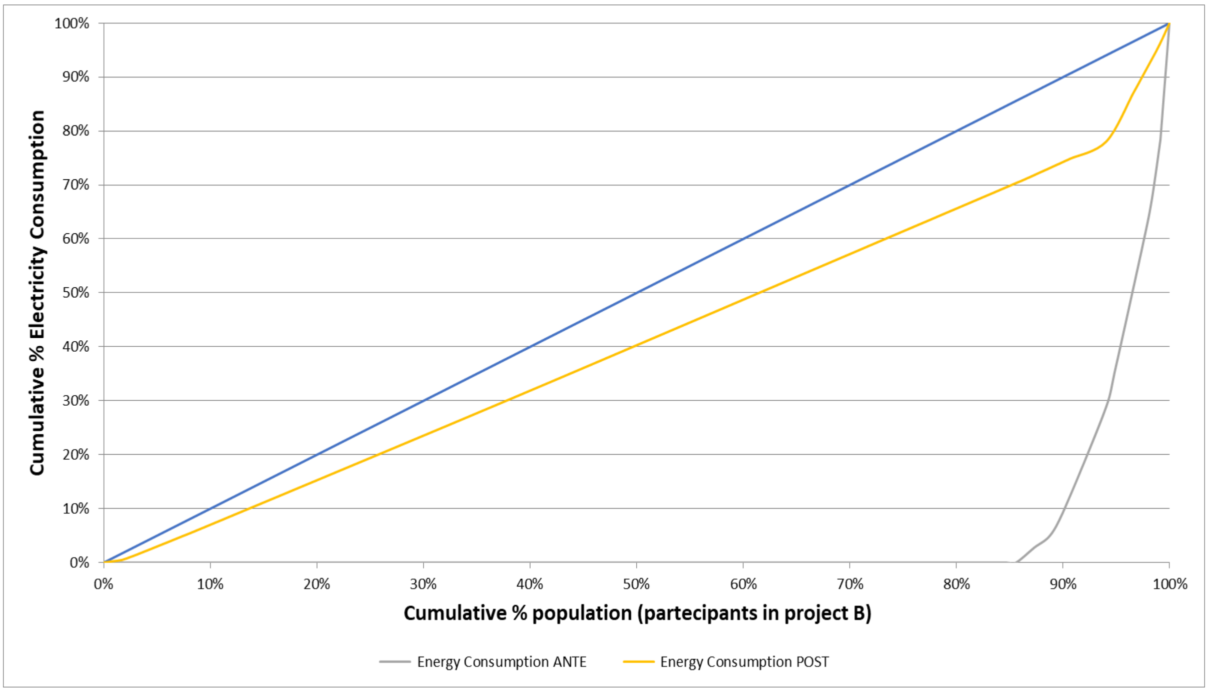
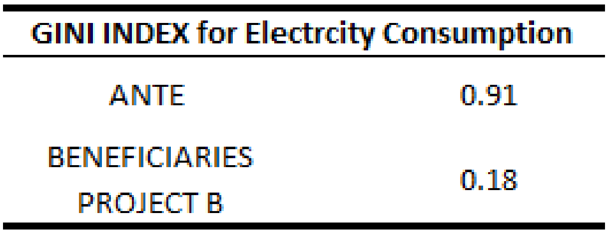


Figure 30. Lorenz curve for electricity consumption of Project A beneficiaries



GINI INDEX for Electrcity Consumption	
ANTE	0.91
BENEFICIARIES PROJECT B	0.18

Table 15. Gini Index for all beneficiaries of Project B, ANTE vs PROJECT B

It is immediately noteworthy the improvement compared to Project A, both in terms of the Lorenz curve and the Gini coefficient. This is not due to the fact that the total consumption has increased, as shown above, but because the consumption of the largest classes (NA_1 and NA_2) is equal to that of the other classes; in fact, it can be seen that just under 10% consume around 20% of the total.

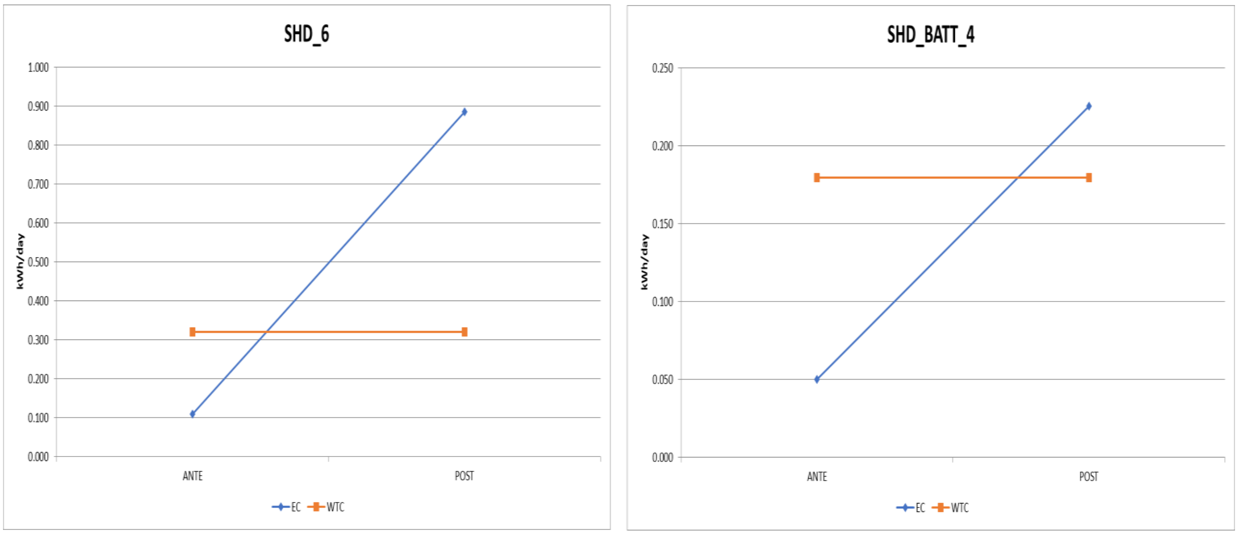


Figure 31. CWR index charts for SHD_6 class (a) and for SHD_BATT_4 class (b)

For Project B, a first case study (a) was shown in which, compared to Project A, only the use of a refrigerator to keep food cool was added. Whereas in Project A the SHD_6 class had a CWR index of 0.89 [-], with the simple addition of an appliance this rose to a value of 2.77 [-]. This shows that it's not easy for a household in a rural village to economically manage the consumption of certain appliances that are taken for granted in everyone's life. In order to solve this problem, it is necessary to intervene on the income side in order to increase the expenditure. For the second graph (b), it was decided to show the same household as for project A, in order to make a direct comparison between the two interventions. Whereas in the previous case the post-consumption was not so high, in Project B the consumption is overestimated and no longer affordable by moving to tier 2. In this case, a trade-off must be made between the two projects and the energy leap required for the class must be reassessed.

5.5. RAMP’s Results

The last aspect to be analysed in this section is the demand curve generated using the RAMP software. The curves associated with the implementation of Project A, Project B, and the case without the methodology are presented and discussed for comparison. Additionally, curves for both projects are shown for two different months to highlight any differences in consumption related to the use of H&C appliances, specifically fans in this specific case.

It is important to note that, as much as possible, the functionalities of the tool were utilized for both projects, suggesting suitable time and usage windows for lighting and H&C appliances. However, for other appliances such as ICT, the parameters were selected based on the author's experience and kept equivalent for both projects to ensure a fair comparison. Detailed information about the selected values and parameters can be found in Annex B.

Figures 36 and Figure 37 present the load curves of the two projects for the month of June. This month was chosen as the tool suggests zero hours of use for H&C appliances since the outside air temperature does not exceed 30 degrees Celsius throughout the day.

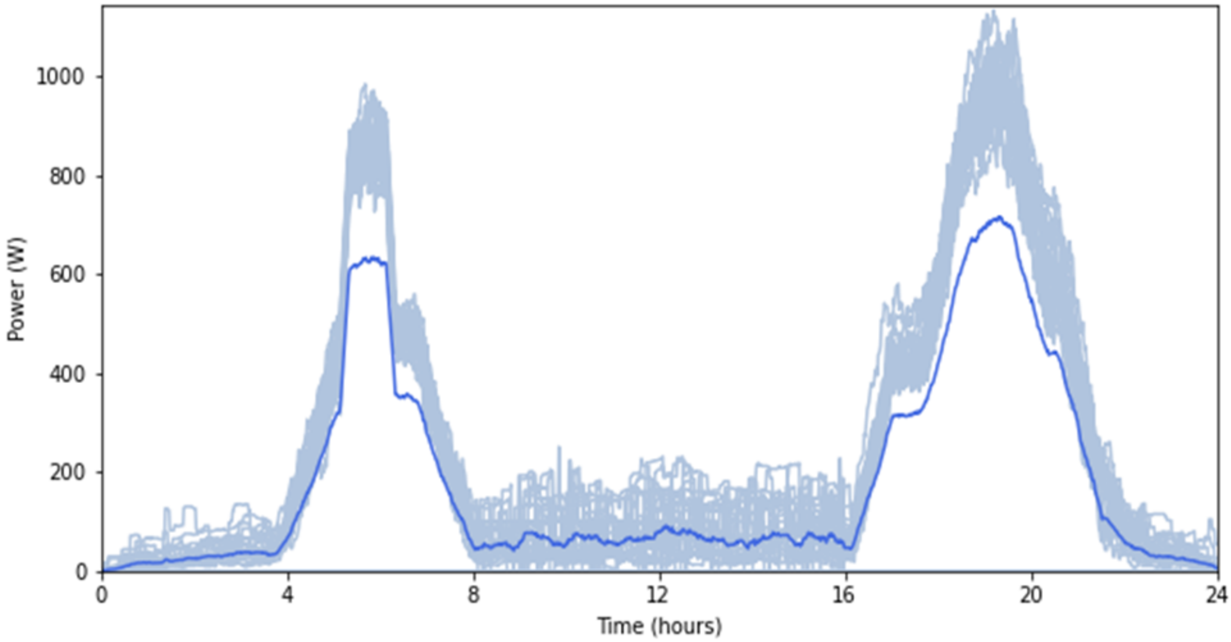


Figure 32. Load demand curve for Project A in June

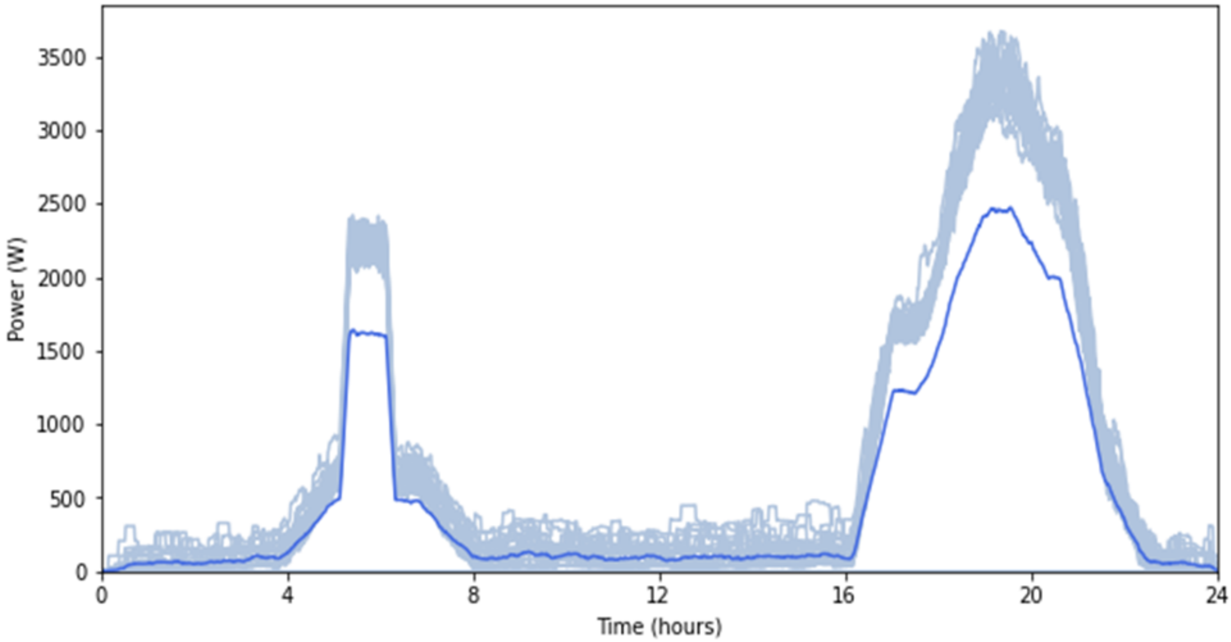


Figure 33. Load demand curve for Project B in June

Upon observation, it can be noticed that the shape of the curve is very similar for both projects. This similarity is attributed to the fact that the house occupancy values are the same for both cases, which strongly influences the utilization windows. The main difference lies in the higher number of tier 2 classes in Project B compared to Project A, resulting in a higher number of appliances, specifically general lighting, TV and fan (the latter being unused for the reason above mentioned). This leads to an increase in consumption peaks. However, these peaks are relatively small, around 1000W for the first case and between 2500W and 3500W for the second case. It is important to note that these electrification projects should be designed with a perspective of continuous improvement in energy access, rather than an immediate jump from no-access to tier 5. The load curve shows two peaks, one in the early morning associated with the use of lights around sunrise, and another in the evening when family members return home and use ICT equipment and lighting from half an hour before sunset until four hours after the event.

The next two figures also pertain to Projects A and B, but for the month of November when the expected usage for 'fans' is two hours. This comparison aims to highlight the load curve even in the worst-case scenario, considering that these appliances are known to consume a significant amount of energy in residential cases with limited access.

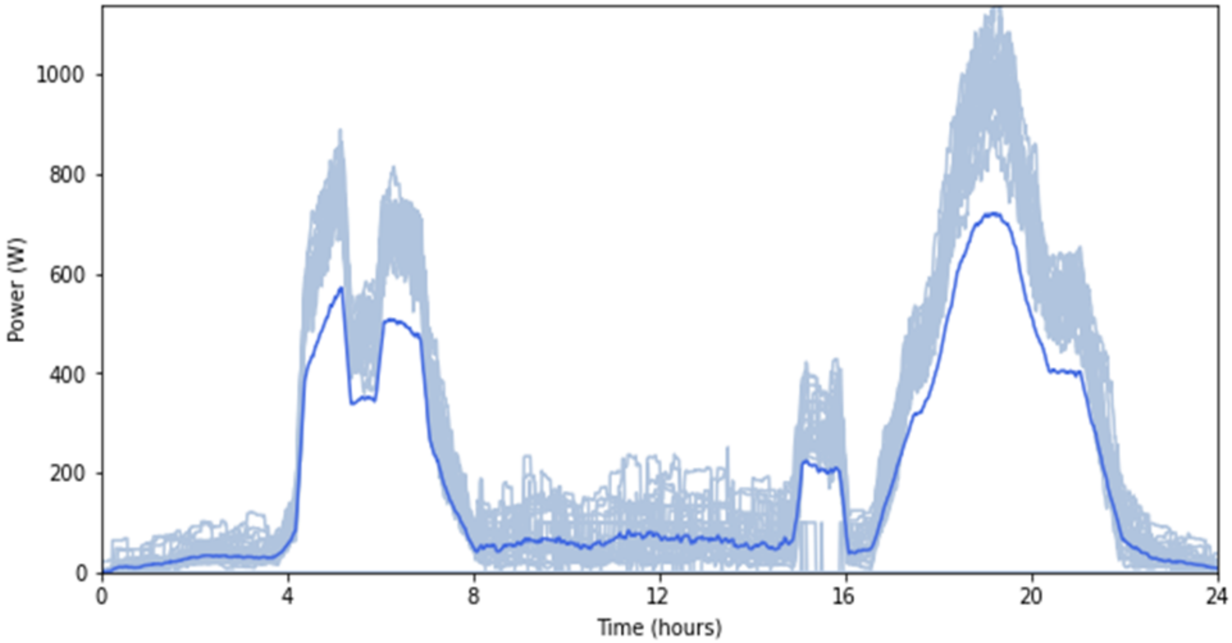


Figure 34. Load demand curve for Project A in November

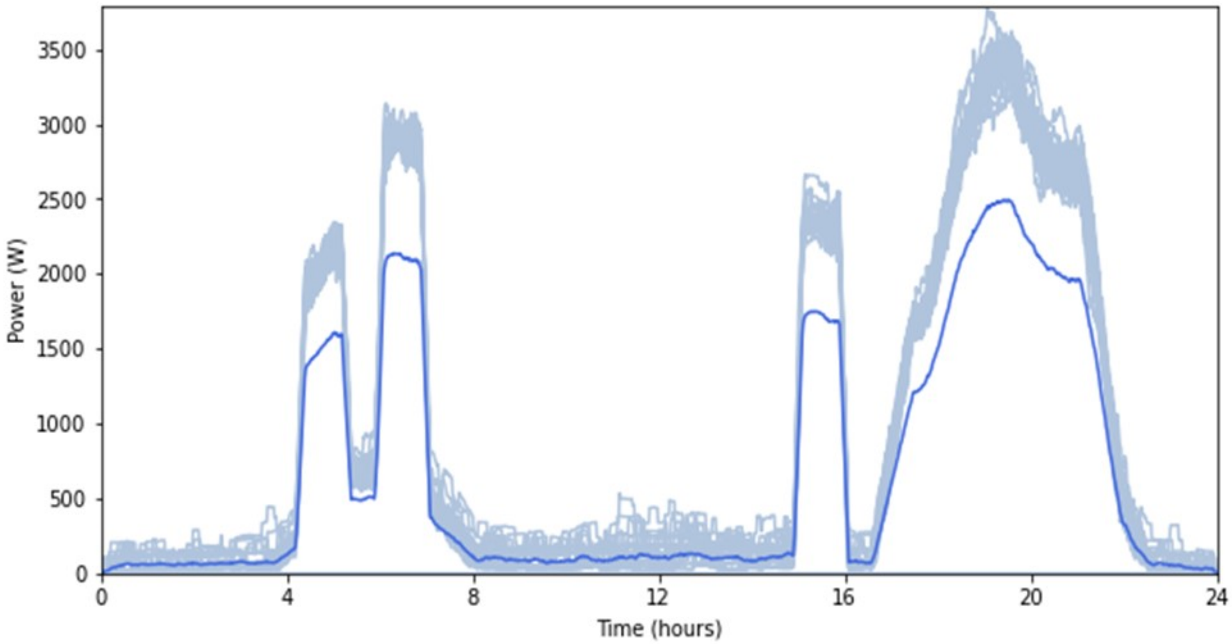


Figure 35. Load demand curve for Project B in November

Once again, the shape of the curves for both projects are quite similar. However, compared to the previous case, additional peaks can be observed when family members leave and return home, specifically at 7 am and 3 pm. These peaks are associated with the use of 'fans,' and in this case, the usage windows do not overlap with each other. As the use of fans does not overlap with that of other appliances, the absolute peaks in November are comparable to those in June.

Finally, it is relevant to compare the two projects with the case obtained without the exploitation of the tool. The sample case was set up by assigning the classes more or less the same set of appliances as in the previous cases, with the addition of a refrigerator for the SHD_BATT classes. All other parameters were manually entered or left with default values, disregarding the proposed tool. For further details, please refer to Annex B.

5.6. Validation of the tool

In this last sub-chapter, we discuss the comparison of the results obtained through the application of the proposed methodology using the tool, with the results obtained without a methodological approach but solely given by the author's choice. Of the two projects carried out, only project B was chosen to be considered for this comparison because, as seen from the results, it is the most accurate and precise. The comparison will initially be made between the energy consumption, divided by class and overall of the village, and then through the corresponding load curves.

Regarding the daily consumption of the entire community, Project B measured an equivalent of 20.63 kWh/day, whereas without using the method, only 9.22 kWh/day was recorded. The difference in these two results can be attributed to the reduced consumption of the “No Access” classes, which significantly impact the final value as they represent more than 80% of the entire population. This discrepancy arises from an underestimation of the forecasted appliance acquisition by these classes in the short to medium term. However, when looking at the values disaggregated by classes, it is observed that the daily consumption for the SHD and SHD_BATT subclasses is quite similar between the two projects.

	Project B		***Traditional Approach***	
Class Name	*Energy Consumption [kWh/day]*	*CWR Index*	*Energy Consumption [kWh/day]*	*CWR Index*
NA_1	0,158	0,882	0,020	0,112
NA_2	0,158	0,882	0,020	0,112
NA_3	0,154	0,859	0,020	0,112
NA_4	0,073	0,407	0,064	0,357
NA_5	0,146	0,815	0,020	0,112
NA_6	0,175	0,977	0,100	0,558
NA_7	0,069	0,385	0,060	0,335
NA_8	0,189	1,055	0,180	1,004
NA_9	0,229	1,278	0,220	1,228
SHD_1	0,410	0,981	0,114	0,273
SHD_2	0,450	0,922	0,402	0,824
SHD_3	0,170	1,952	0,322	3,697
SHD_4	0,158	0,000	0,302	0,000
SHD_5	0,182	0,871	0,326	1,559
SHD_6	0,392	1,227	0,336	1,052
SHD_BATT_1	0,410	1,141	0,377	1,050
SHD_BATT_2	0,584	0,621	0,467	0,497
SHD_BATT_3	0,150	1,670	0,317	3,532
SHD_BATT_4	0,172	0,957	0,339	1,888
SHD_BATT_5	0,158	0,000	0,325	0,000

Table 16. comparison between the two approaches through the Energy Consumption and the CWR index

It is important to note that this result does not justify the effectiveness of the traditional method, as even within the SHD and SHD_BATT classes, there are subclasses that cannot afford such high consumption in economic terms. This is evident when examining the CWR Index for each class, which reveals that classes SHD_3 and SHD_BATT_3 have values of 3.7 [-] and 3.5 [-], respectively. The proposed tool allows for the perception of such differences within the macro-class, enabling individual treatment of each household.

In terms of overall index values, the traditional method yields a value of 0.413 [-], while Project B is associated with a value of 0.924 [-]. The low CWR index value in the traditional method indicates an underestimation of energy consumption compared to what the community could economically claim to consume. This underestimation of energy consumption leads to an altered demand curve and subsequently underestimates the entire energy production system.

The second result presented is the energy demand curve for both cases. The curve associated with the traditional approach is shown in Figure 40, while Figure 39 in the previous chapter refers to Project B for the month of November. Although both curves seem to have a similar shape with two peaks, one in the morning and the other in the evening, they differ significantly in terms of magnitude. The peaks in the Project B curve are three times larger than those in the curve obtained using the traditional method. This discrepancy introduces errors in later stages of the project: in the case of a mini-grid implementation, there would be a risk of continuous blackouts during the two peak times of the day, as the magnitude of the peak would be completely underestimated. In the case of a distributed system, the number of panels allocated to each class would be incorrect, underestimating the “No Access” subclasses and overestimating classes SHD_3 and SHD_BATT_3, resulting in these classes paying a much higher price than they were prepared for.

When comparing the curve of Project B in November with the curve without the methodology, a high variability can be observed in the non-highlighted curves, indicating a high degree of uncertainty in the demand curve. In contrast, the blue-highlighted curve representing the average in Project B shows a more stable pattern.

In conclusion, the MuNStEP tool not only enables an accurate assessment of the current energy situation but also allows for a more precise evaluation of energy consumption for each class within the village.

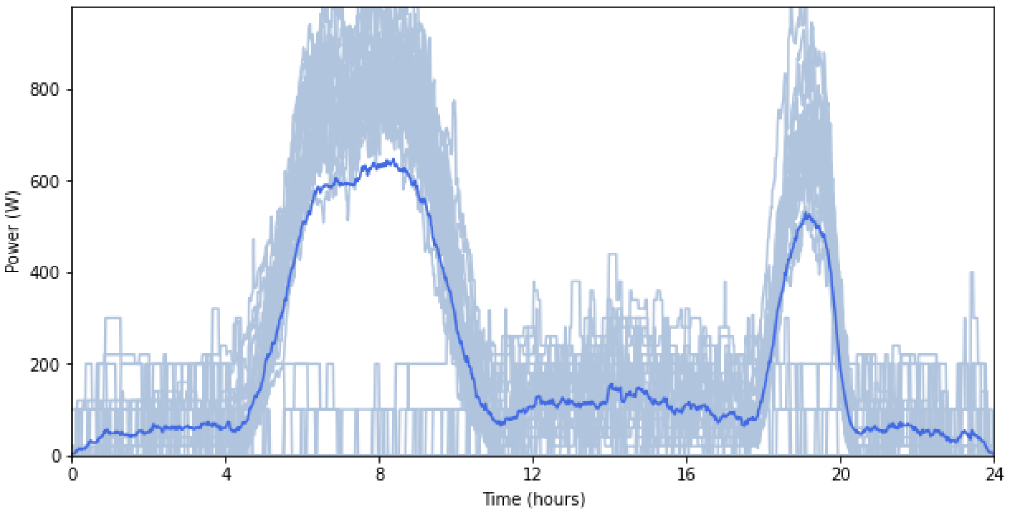


Figure 36. Load demand curve obtained without the exploitation of the tool proposed.

6 Conclusion & Future Improvements

This study addressed the topic of rural community electrification in developing countries, making a significant contribution to the understanding of the initial phase of the planning process for extending the access to electricity. In particular, the focus was on identifying energy needs and priority, and improving the link between this phase and subsequent phases.

The purpose of this study is to present the framework developed by the authors and implemented as a tool in Excel in order to quantify the problem of identifying energy needs and requirements. Furthermore, the framework aims to facilitate the link between this first phase and the subsequent phases of load demand assessment and forecast, and strategy selection, providing a powerful tool that improves the decision-making strategy. On the one hand, the tool connects directly to the RAMP software to estimate the demand curve, while on the other hand it initialises a potential intervention to assess the impact in terms of consumption in advance.

The methodology on which the tool is based was selected after an extensive literature review and is that proposed by the WB and ESMAP, known as MTF. This methodology made it possible to establish a preliminary quantification of consumption levels on a multiple threshold scale and to define how to collect data in the field. Using a multidimensional approach turned out to be a positive choice as it allowed the tool to present a set of results, indices, graphs, etc. referring to a wide range of electricity attributes, thus offering a complete view of the problem.

The contribution to the MTF made by this study consists in the implementation of the tool itself, which can be applied to the information obtained through the MTF approach, offering new tools for analysing a critical phase of projects.

The features of the tool that were found to be crucial in supporting the energy needs identification phase are:

1. Multidimensionality
2. Simplified data collection.

The first feature makes the treatment of energy access more all-encompassing. The second, on the other hand, refers to the simplicity of the data collection phase, which has been made much simpler, without losing important information, by making it possible for the questionnaires to be carried out even by local people. This is very important as it allows much more data to get collected.

The structure of the tool was appropriately designed to make it more user-friendly. Divided into four steps, the tool guides the user through the compilation of data and the execution of macros in a sequential manner. It is important to emphasise that the part relating to calculations and macros is also part of the structure, even if it is not 'visible' to the user.

The tool was tested on a real case of the ILUMINA project implemented in Mozambique, in a community in the Cabo Delgado region. The exercise carried out has the dual functionality of showing the correct use of the tool itself in order to exploit its full potential and validating the effectiveness of the proposed approach. For this purpose, the results obtained with the tool are compared in chapter 5.6 with the results obtained using the RAMP software and without using the proposed approach. In this respect, it can be stated that the CWR index for project B is closer to unity - optimum value - than the one obtained without the approach. The relevant aspect in showing this result is that it is associated with the fact that if one has a target to achieve, it will be possible to intervene more effectively. In short, having a target reduces the risk of over- or underestimating the demand curve.

Some improvements are possible, however. The first of these is the extension of the tool to the entire MTF treatment, which means, on the one hand, introducing the other macro-categories of classes, i.e. productive engagement and public activities such as schools, hospitals, offices, etc., and on the other hand, extending the treatment to other sources of energy consumption in addition to electricity, i.e. energy for cooking and energy for heating or cooling the home or work environment. Another improvement that could be implemented is to go beyond the use of sets of appliances corresponding to the various tier levels and to propose more case study-specific archetypes, as was done in the paper by Falchetta et al. [44]. With the aim of increasing the accuracy of the tool and improving the corresponding demand curve.

Finally, it should be emphasised that access to energy should not be the ultimate goal of the intervention but should be the means by which the community is able to develop new capacities and improve its condition. This is only possible by understanding the true specific needs of the community, treating each case separately and not all as a whole.

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Annex A

A.1 Download Data for Temperature

Download the CVS file from NASA POWER.

```
Sub get_CSV_link()

Dim wsLink As Worksheet
Set wsLink = ActiveWorkbook.Sheets("NASA_parameters")

Dim CSV_link_string As String
CSV_link_string = wsLink.Range("NASAlink").Value

Dim httpNASA As Object
Set httpNASA = CreateObject("MSXML2.XMLHTTP")
httpNASA.Open "GET", CSV_link_string, False
httpNASA.Send

Dim JSON As Object
Set JSON = ParseJson(httpNASA.responseText)

Dim CSVlink_response As String
'CSVlink_response = JSON.Item("parameter")
'wsLink.Range("E25").Value = CSVlink_response

Dim Longitude As Variant, Latitude As Variant
Longitude = JSON.Item("geometry")("coordinates")(1)
Latitude = JSON.Item("geometry")("coordinates")(2)
' Print latitude and longitude updated data for check in sheet "General"

   Worksheets("Input_Data").Range("B4") = Latitude
   Worksheets("Input_Data").Range("B5") = Longitude


End Sub
```

Import the data in the workbook:

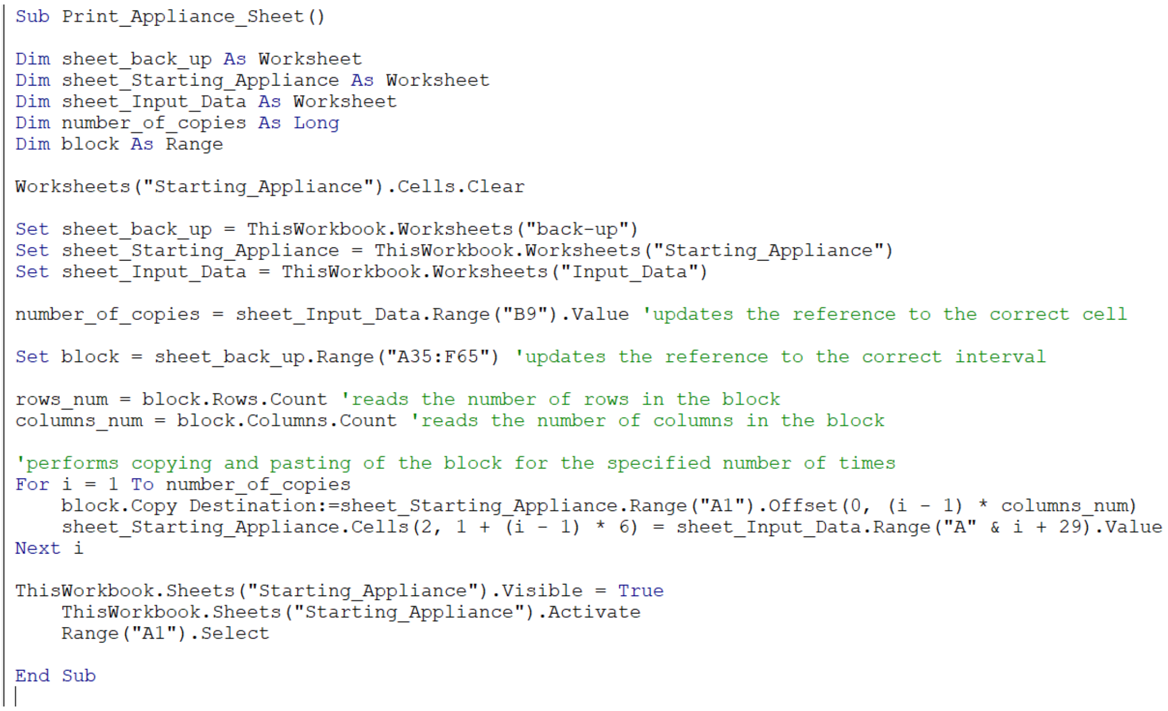
```
'follow link in workbook
    CSV_link = WB_mod.Sheets("NASA_parameters").Range("E25")
    ActiveWorkbook.FollowHyperlink Address:=CSV_link, NewWindow:=False
    Workbooks.Open Filename:=CSV_link
    ActiveWindow.Visible = True
    Set WB_csv = ActiveWorkbook
'text to columns
    With WB_csv.Sheets(1).Columns("A:A")
        .TextToColumns Destination:=Range("A1"), DataType:=xlDelimited, _
        TextQualifier:=xlDoubleQuote, ConsecutiveDelimiter:=False, Tab:=False, _
        Semicolon:=False, Comma:=True, Space:=False, Other:=False, FieldInfo _
        :=Array(Array(1, 1), Array(2, 1)), TrailingMinusNumbers:=True
    End With

'Delete header of PowerV1
    Dim BASE_url As String
    Dim RowH As Integer, Header_end_row As Integer

    ' BASE_url = WB_mod.Sheets("NASA_parameters").Range("BASE_url").Value

    ' If BASE_url = "POWERv1" Then
        For RowH = 1 To 20
            If WB_csv.Sheets(1).Cells(RowH, 1).Value = "-END HEADER-" Then
                Header_end_row = RowH
                Exit For
            End If
        Next

        With WB_csv.Sheets(1).Rows(1 & ":" & Header_end_row)
            .Delete Shift:=xlUp
        End With
    ' End If

'copy and paste data
    WB_csv.Sheets(1).Cells.Copy WB_mod.Sheets("NASA_results").Cells
'close new window
    WB_csv.Close SaveChanges:=False
```

Recalls the previous two subs and processes the data obtained:

```
Sub Get_DATA_online()

Dim StartTime As Double
Dim SecondsElapsed As Double
StartTime = Timer

    With Application
        .DecimalSeparator = "."
        .ThousandsSeparator = ","
        .UseSystemSeparators = False
    End With

'Recalculate merge of text for link:
    Worksheets("NASA_parameters").Calculate
    DoEvents

'Get CSV link from  NasaPower's json response
    Call get_CSV_link

'Opens link and copies it to the workbook
    Call follow_link

'Processes the 10 years data into averages for calculations
    Call Process_yearly_data_online

    Worksheets("Input_Data").Activate

    SecondsElapsed = Round(Timer - StartTime, 2)

    MsgBox "Simulazione completata in " & SecondsElapsed & " secondi", vbInformation


End Sub
```

A.2 Print Starting Appliance

Print initial sets of appliances to be filled in for the number of classes inserted.

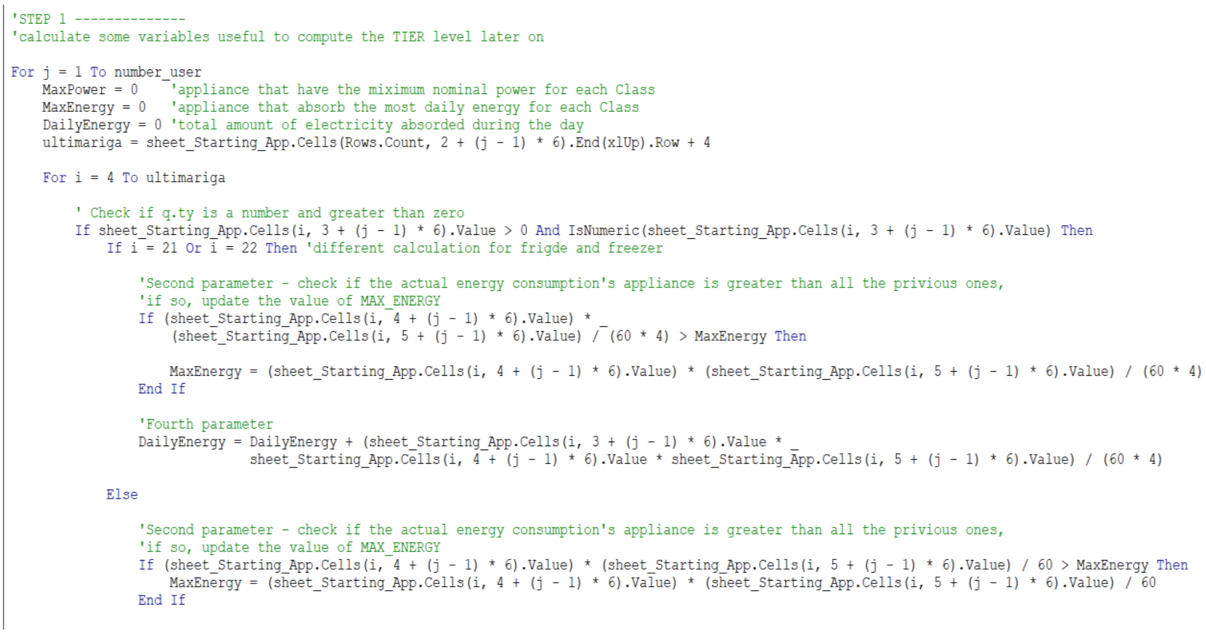


```
Sub Print_Appliance_Sheet()

Dim sheet_back_up As Worksheet
Dim sheet_Starting_Appliance As Worksheet
Dim sheet_Input_Data As Worksheet
Dim number_of_copies As Long
Dim block As Range

Worksheets("Starting_Appliance").Cells.Clear

Set sheet_back_up = ThisWorkbook.Worksheets("back-up")
Set sheet_Starting_Appliance = ThisWorkbook.Worksheets("Starting_Appliance")
Set sheet_Input_Data = ThisWorkbook.Worksheets("Input_Data")

number_of_copies = sheet_Input_Data.Range("B9").Value 'updates the reference to the correct cell

Set block = sheet_back_up.Range("A35:F65") 'updates the reference to the correct interval

rows_num = block.Rows.Count 'reads the number of rows in the block
columns_num = block.Columns.Count 'reads the number of columns in the block

'performs copying and pasting of the block for the specified number of times
For i = 1 To number_of_copies
    block.Copy Destination:=sheet_Starting_Appliance.Range("A1").Offset(0, (i - 1) * columns_num)
    sheet_Starting_Appliance.Cells(2, 1 + (i - 1) * 6) = sheet_Input_Data.Range("A" & i + 29).Value
Next i

ThisWorkbook.Sheets("Starting_Appliance").Visible = True
    ThisWorkbook.Sheets("Starting_Appliance").Activate
    Range("A1").Select

End Sub
```

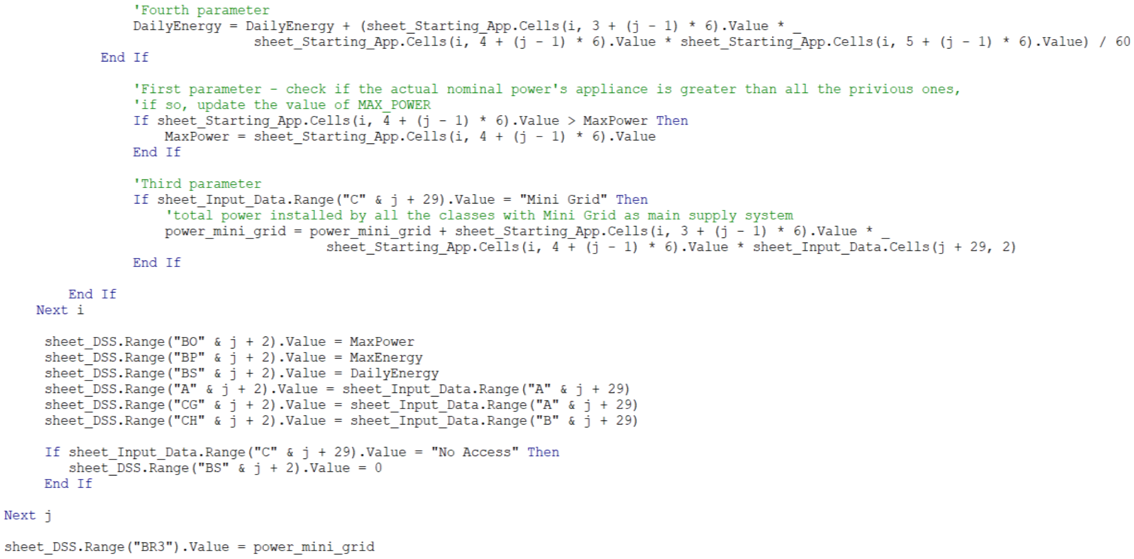
A.3 Tier Calculation

Calculates tiers and parameters for each class entered.

Step 1:

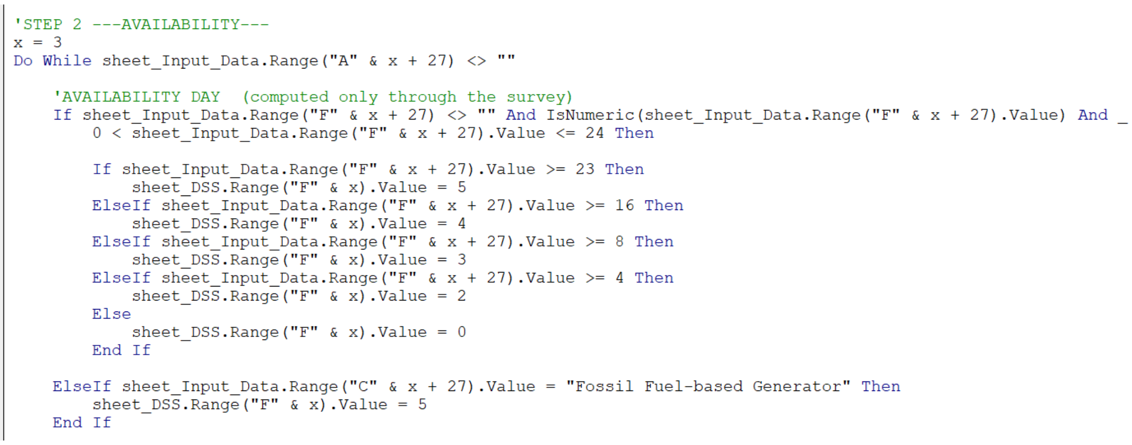


```
'STEP 1 --------------
'calculate some variables useful to compute the TIER level later on

For j = 1 To number_user
    MaxPower = 0    'appliance that have the miximum nominal power for each Class
    MaxEnergy = 0   'appliance that absorb the most daily energy for each Class
    DailyEnergy = 0 'total amount of electricity absorded during the day
    ultimariga = sheet_Starting_App.Cells(Rows.Count, 2 + (j - 1) * 6).End(xlUp).Row + 4

    For i = 4 To ultimariga

        ' Check if q.ty is a number and greater than zero
        If sheet_Starting_App.Cells(i, 3 + (j - 1) * 6).Value > 0 And IsNumeric(sheet_Starting_App.Cells(i, 3 + (j - 1) * 6).Value) Then
            If i = 21 Or i = 22 Then 'different calculation for frigde and freezer

                'Second parameter - check if the actual energy consumption's appliance is greater than all the privious ones,
                'if so, update the value of MAX_ENERGY
                If (sheet_Starting_App.Cells(i, 4 + (j - 1) * 6).Value) * _
                    (sheet_Starting_App.Cells(i, 5 + (j - 1) * 6).Value) / (60 * 4) > MaxEnergy Then

                    MaxEnergy = (sheet_Starting_App.Cells(i, 4 + (j - 1) * 6).Value) * (sheet_Starting_App.Cells(i, 5 + (j - 1) * 6).Value) / (60 * 4)
                End If

                'Fourth parameter
                DailyEnergy = DailyEnergy + (sheet_Starting_App.Cells(i, 3 + (j - 1) * 6).Value * _
                              sheet_Starting_App.Cells(i, 4 + (j - 1) * 6).Value * sheet_Starting_App.Cells(i, 5 + (j - 1) * 6).Value) / (60 * 4)

            Else

                'Second parameter - check if the actual energy consumption's appliance is greater than all the privious ones,
                'if so, update the value of MAX_ENERGY
                If (sheet_Starting_App.Cells(i, 4 + (j - 1) * 6).Value) * (sheet_Starting_App.Cells(i, 5 + (j - 1) * 6).Value) / 60 > MaxEnergy Then
                    MaxEnergy = (sheet_Starting_App.Cells(i, 4 + (j - 1) * 6).Value) * (sheet_Starting_App.Cells(i, 5 + (j - 1) * 6).Value) / 60
                End If
```

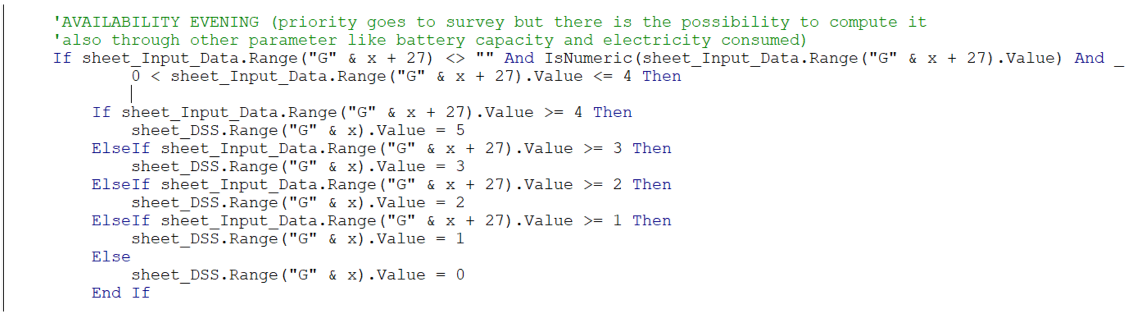


```
                'Fourth parameter
                DailyEnergy = DailyEnergy + (sheet_Starting_App.Cells(i, 3 + (j - 1) * 6).Value * _
                               sheet_Starting_App.Cells(i, 4 + (j - 1) * 6).Value * sheet_Starting_App.Cells(i, 5 + (j - 1) * 6).Value) / 60
            End If

                'First parameter - check if the actual nominal power's appliance is greater than all the privious ones,
                'if so, update the value of MAX_POWER
                If sheet_Starting_App.Cells(i, 4 + (j - 1) * 6).Value > MaxPower Then
                    MaxPower = sheet_Starting_App.Cells(i, 4 + (j - 1) * 6).Value
                End If

                'Third parameter
                If sheet_Input_Data.Range("C" & j + 29).Value = "Mini Grid" Then
                    'total power installed by all the classes with Mini Grid as main supply system
                    power_mini_grid = power_mini_grid + sheet_Starting_App.Cells(i, 3 + (j - 1) * 6).Value * _
                                        sheet_Starting_App.Cells(i, 4 + (j - 1) * 6).Value * sheet_Input_Data.Cells(j + 29, 2)
                End If

        End If
    Next i

     sheet_DSS.Range("BO" & j + 2).Value = MaxPower
     sheet_DSS.Range("BP" & j + 2).Value = MaxEnergy
     sheet_DSS.Range("BS" & j + 2).Value = DailyEnergy
     sheet_DSS.Range("A" & j + 2).Value = sheet_Input_Data.Range("A" & j + 29)
     sheet_DSS.Range("CG" & j + 2).Value = sheet_Input_Data.Range("A" & j + 29)
     sheet_DSS.Range("CH" & j + 2).Value = sheet_Input_Data.Range("B" & j + 29)

     If sheet_Input_Data.Range("C" & j + 29).Value = "No Access" Then
        sheet_DSS.Range("BS" & j + 2).Value = 0
     End If

Next j

sheet_DSS.Range("BR3").Value = power_mini_grid
```

Step 2:



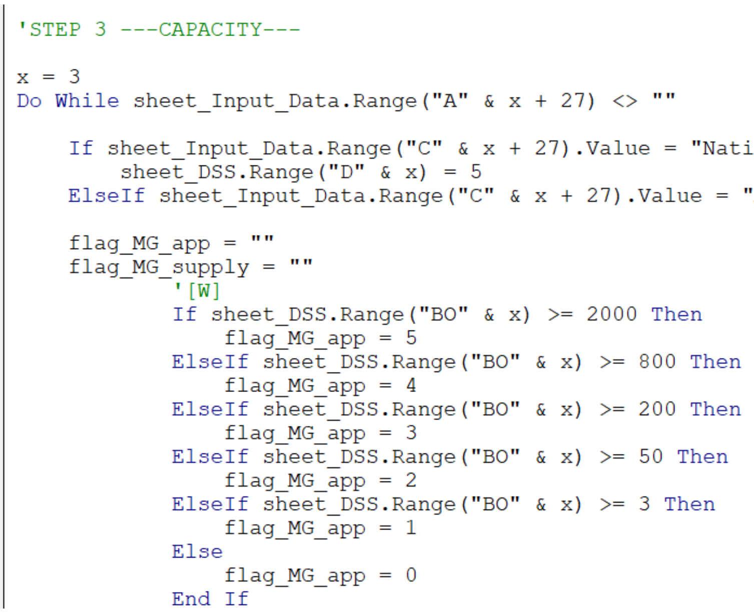
```
'STEP 2 ---AVAILABILITY---
x = 3
Do While sheet_Input_Data.Range("A" & x + 27) <> ""

    'AVAILABILITY DAY  (computed only through the survey)
    If sheet_Input_Data.Range("F" & x + 27) <> "" And IsNumeric(sheet_Input_Data.Range("F" & x + 27).Value) And _
        0 < sheet_Input_Data.Range("F" & x + 27).Value <= 24 Then

        If sheet_Input_Data.Range("F" & x + 27).Value >= 23 Then
            sheet_DSS.Range("F" & x).Value = 5
        ElseIf sheet_Input_Data.Range("F" & x + 27).Value >= 16 Then
            sheet_DSS.Range("F" & x).Value = 4
        ElseIf sheet_Input_Data.Range("F" & x + 27).Value >= 8 Then
            sheet_DSS.Range("F" & x).Value = 3
        ElseIf sheet_Input_Data.Range("F" & x + 27).Value >= 4 Then
            sheet_DSS.Range("F" & x).Value = 2
        Else
            sheet_DSS.Range("F" & x).Value = 0
        End If

    ElseIf sheet_Input_Data.Range("C" & x + 27).Value = "Fossil Fuel-based Generator" Then
        sheet_DSS.Range("F" & x).Value = 5
    End If
```



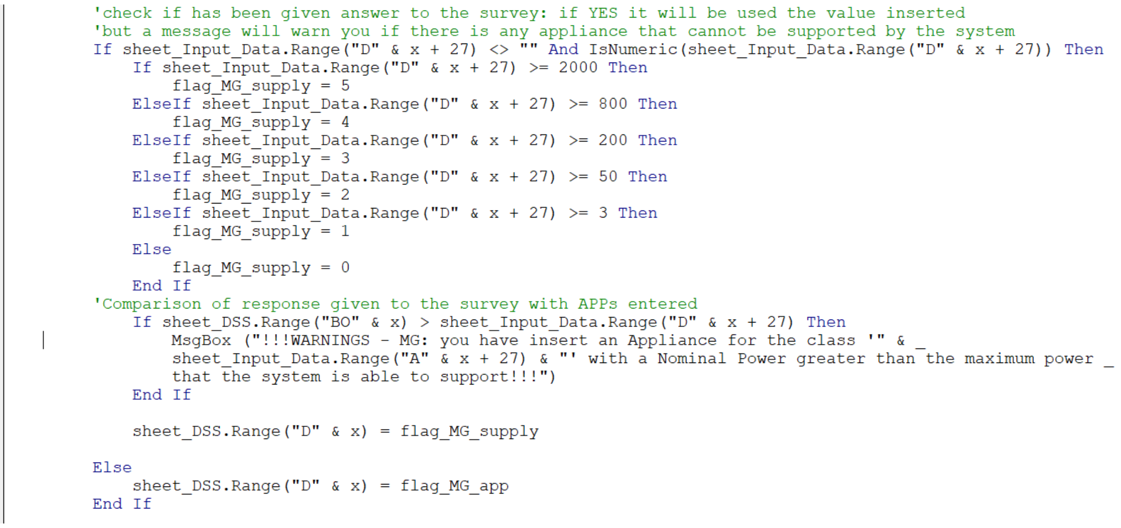
```
    'AVAILABILITY EVENING (priority goes to survey but there is the possibility to compute it
    'also through other parameter like battery capacity and electricity consumed)
    If sheet_Input_Data.Range("G" & x + 27) <> "" And IsNumeric(sheet_Input_Data.Range("G" & x + 27).Value) And _
        0 < sheet_Input_Data.Range("G" & x + 27).Value <= 4 Then

        If sheet_Input_Data.Range("G" & x + 27).Value >= 4 Then
            sheet_DSS.Range("G" & x).Value = 5
        ElseIf sheet_Input_Data.Range("G" & x + 27).Value >= 3 Then
            sheet_DSS.Range("G" & x).Value = 3
        ElseIf sheet_Input_Data.Range("G" & x + 27).Value >= 2 Then
            sheet_DSS.Range("G" & x).Value = 2
        ElseIf sheet_Input_Data.Range("G" & x + 27).Value >= 1 Then
            sheet_DSS.Range("G" & x).Value = 1
        Else
            sheet_DSS.Range("G" & x).Value = 0
        End If
```

```
    ElseIf sheet_Input_Data.Range("C" & x + 27).Value = "Mini Grid" Then
        numerator = sheet_Input_Data.Range("E" & x + 27).Value
        denominator = sheet_DSS.Range("BR3").Value
        'check if division is possible or not
        If denominator <> 0 And IsNumeric(numerator) And IsNumeric(denominator) Then
            Evening_hours_Av_MG = numerator / (denominator * sheet_Input_Data.Cells(25, 2).Value)
        Else
            MsgBox "Error of division by zero or non-numeric values"
        End If

        sheet_DSS.Range("BQ" & x).Value = Evening_hours_Av_MG
        If Evening_hours_Av_MG >= 4 Then
            sheet_DSS.Range("G" & x).Value = 5
        ElseIf Evening_hours_Av_MG >= 3 Then
            sheet_DSS.Range("G" & x).Value = 3
        ElseIf Evening_hours_Av_MG >= 2 Then
            sheet_DSS.Range("G" & x).Value = 2
        ElseIf Evening_hours_Av_MG >= 1 Then
            sheet_DSS.Range("G" & x).Value = 1
        Else
            sheet_DSS.Range("G" & x).Value = 0
        End If

    ElseIf sheet_Input_Data.Range("C" & x + 27).Value = "Solar Based Devices" Or _
            sheet_Input_Data.Range("C" & x + 27).Value = "Rechargeable Batteries" Then

        numerator = sheet_Input_Data.Range("E" & x + 27).Value
        denominator = sheet_DSS.Range("BO" & x).Value
        'check
        'If denominator <> 0 And IsNumeric(numerator) And IsNumeric(denominator) Then
            Evening_hours_Av = numerator / denominator
       ' Else
       '     MsgBox "Error of division by zero or non-numeric values"
       ' End If

        sheet_DSS.Range("BQ" & x).Value = Evening_hours_Av

        If Evening_hours_Av >= 4 Then
            sheet_DSS.Range("G" & x).Value = 5
        ElseIf Evening_hours_Av >= 3 Then
            sheet_DSS.Range("G" & x).Value = 3
        ElseIf Evening_hours_Av >= 2 Then
            sheet_DSS.Range("G" & x).Value = 2
        ElseIf Evening_hours_Av >= 1 Then
            sheet_DSS.Range("G" & x).Value = 1
        Else
            sheet_DSS.Range("G" & x).Value = 0
        End If

    ElseIf sheet_Input_Data.Range("C" & x + 27).Value = "Fossil Fuel-based Generator" Then
        sheet_DSS.Range("G" & x).Value = 5

    End If

x = x + 1
Loop
```

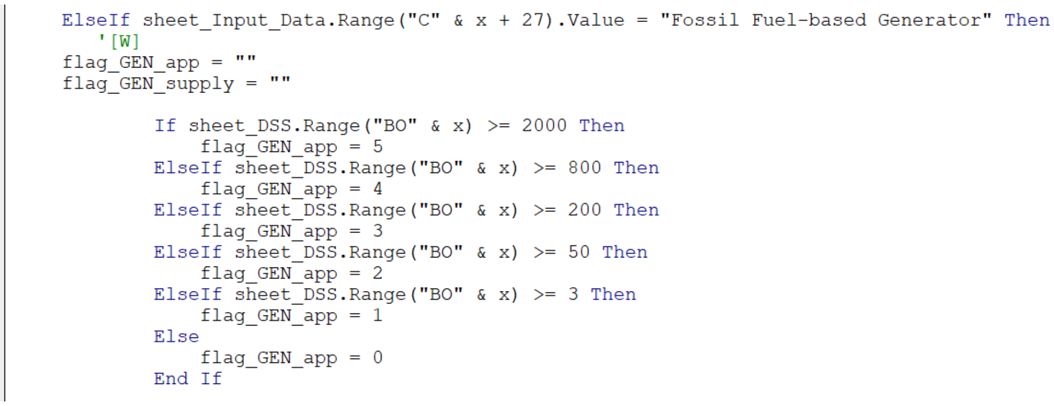
Step 3:



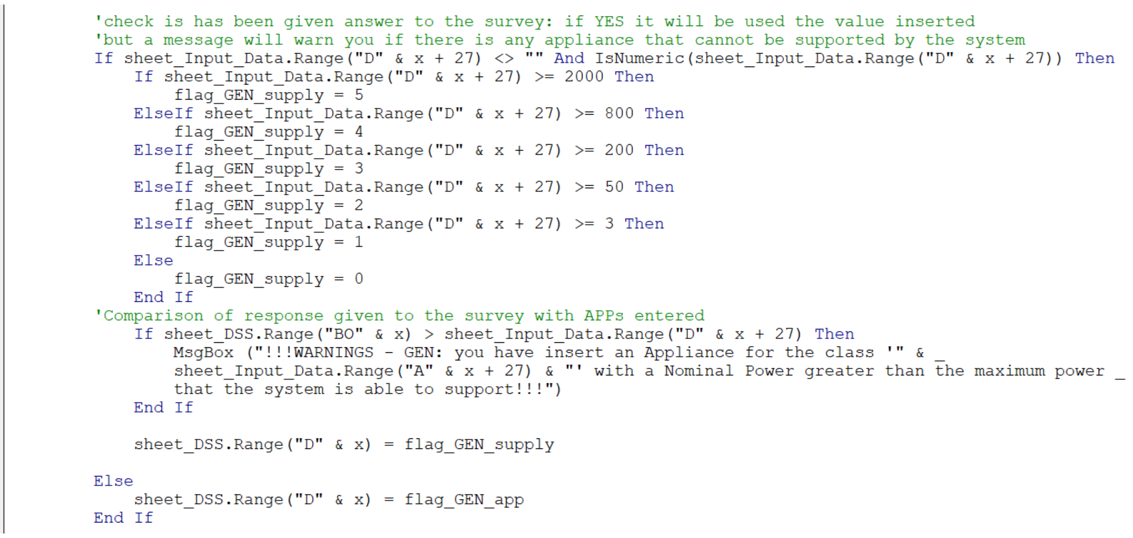
```
'STEP 3 ---CAPACITY---

x = 3
Do While sheet_Input_Data.Range("A" & x + 27) <> ""

    If sheet_Input_Data.Range("C" & x + 27).Value = "National Grid" Then
        sheet_DSS.Range("D" & x) = 5
    ElseIf sheet_Input_Data.Range("C" & x + 27).Value = "Mini Grid" Then

    flag_MG_app = ""
    flag_MG_supply = ""
            '[W]
            If sheet_DSS.Range("BO" & x) >= 2000 Then
                flag_MG_app = 5
            ElseIf sheet_DSS.Range("BO" & x) >= 800 Then
                flag_MG_app = 4
            ElseIf sheet_DSS.Range("BO" & x) >= 200 Then
                flag_MG_app = 3
            ElseIf sheet_DSS.Range("BO" & x) >= 50 Then
                flag_MG_app = 2
            ElseIf sheet_DSS.Range("BO" & x) >= 3 Then
                flag_MG_app = 1
            Else
                flag_MG_app = 0
            End If
```



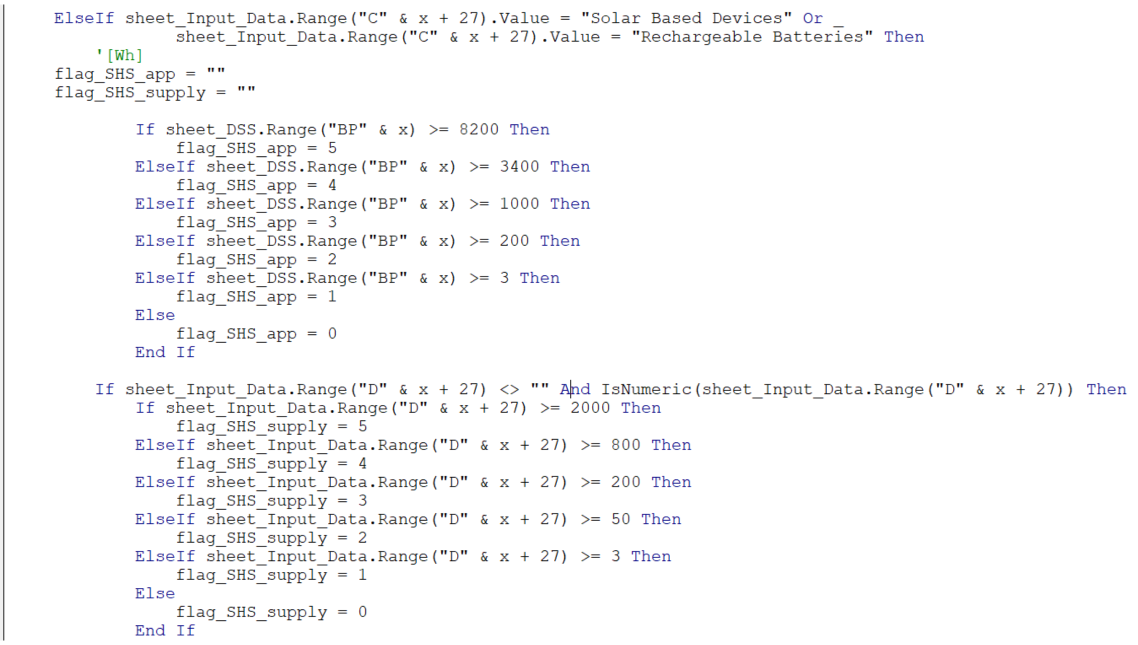
```
        'check if has been given answer to the survey: if YES it will be used the value inserted
        'but a message will warn you if there is any appliance that cannot be supported by the system
        If sheet_Input_Data.Range("D" & x + 27) <> "" And IsNumeric(sheet_Input_Data.Range("D" & x + 27)) Then
            If sheet_Input_Data.Range("D" & x + 27) >= 2000 Then
                flag_MG_supply = 5
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 800 Then
                flag_MG_supply = 4
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 200 Then
                flag_MG_supply = 3
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 50 Then
                flag_MG_supply = 2
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 3 Then
                flag_MG_supply = 1
            Else
                flag_MG_supply = 0
            End If
        'Comparison of response given to the survey with APPs entered
            If sheet_DSS.Range("BO" & x) > sheet_Input_Data.Range("D" & x + 27) Then
                MsgBox ("!!!WARNINGS - MG: you have insert an Appliance for the class '" & _
                sheet_Input_Data.Range("A" & x + 27) & "' with a Nominal Power greater than the maximum power _
                that the system is able to support!!!")
            End If

            sheet_DSS.Range("D" & x) = flag_MG_supply

        Else
            sheet_DSS.Range("D" & x) = flag_MG_app
        End If
```



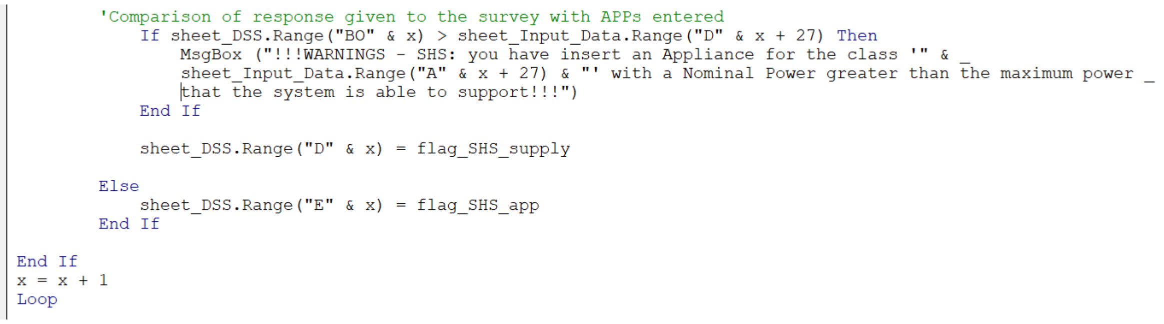
```
    ElseIf sheet_Input_Data.Range("C" & x + 27).Value = "Fossil Fuel-based Generator" Then
        '[W]
    flag_GEN_app = ""
    flag_GEN_supply = ""

            If sheet_DSS.Range("BO" & x) >= 2000 Then
                flag_GEN_app = 5
            ElseIf sheet_DSS.Range("BO" & x) >= 800 Then
                flag_GEN_app = 4
            ElseIf sheet_DSS.Range("BO" & x) >= 200 Then
                flag_GEN_app = 3
            ElseIf sheet_DSS.Range("BO" & x) >= 50 Then
                flag_GEN_app = 2
            ElseIf sheet_DSS.Range("BO" & x) >= 3 Then
                flag_GEN_app = 1
            Else
                flag_GEN_app = 0
            End If
```



```
        'check is has been given answer to the survey: if YES it will be used the value inserted
        'but a message will warn you if there is any appliance that cannot be supported by the system
        If sheet_Input_Data.Range("D" & x + 27) <> "" And IsNumeric(sheet_Input_Data.Range("D" & x + 27)) Then
            If sheet_Input_Data.Range("D" & x + 27) >= 2000 Then
                flag_GEN_supply = 5
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 800 Then
                flag_GEN_supply = 4
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 200 Then
                flag_GEN_supply = 3
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 50 Then
                flag_GEN_supply = 2
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 3 Then
                flag_GEN_supply = 1
            Else
                flag_GEN_supply = 0
            End If
        'Comparison of response given to the survey with APPs entered
            If sheet_DSS.Range("BO" & x) > sheet_Input_Data.Range("D" & x + 27) Then
                MsgBox ("!!!WARNINGS - GEN: you have insert an Appliance for the class '" & _
                sheet_Input_Data.Range("A" & x + 27) & "' with a Nominal Power greater than the maximum power _
                that the system is able to support!!!")
            End If

            sheet_DSS.Range("D" & x) = flag_GEN_supply

        Else
            sheet_DSS.Range("D" & x) = flag_GEN_app
        End If
```

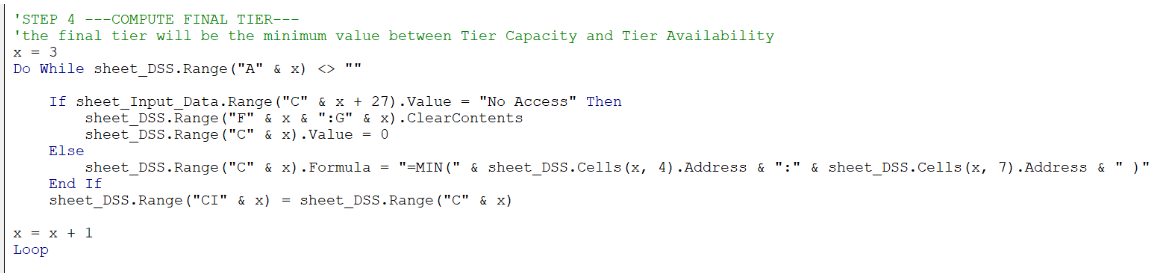


```
    ElseIf sheet_Input_Data.Range("C" & x + 27).Value = "Solar Based Devices" Or _
                sheet_Input_Data.Range("C" & x + 27).Value = "Rechargeable Batteries" Then
        '[Wh]
    flag_SHS_app = ""
    flag_SHS_supply = ""

            If sheet_DSS.Range("BP" & x) >= 8200 Then
                flag_SHS_app = 5
            ElseIf sheet_DSS.Range("BP" & x) >= 3400 Then
                flag_SHS_app = 4
            ElseIf sheet_DSS.Range("BP" & x) >= 1000 Then
                flag_SHS_app = 3
            ElseIf sheet_DSS.Range("BP" & x) >= 200 Then
                flag_SHS_app = 2
            ElseIf sheet_DSS.Range("BP" & x) >= 3 Then
                flag_SHS_app = 1
            Else
                flag_SHS_app = 0
            End If

        If sheet_Input_Data.Range("D" & x + 27) <> "" And IsNumeric(sheet_Input_Data.Range("D" & x + 27)) Then
            If sheet_Input_Data.Range("D" & x + 27) >= 2000 Then
                flag_SHS_supply = 5
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 800 Then
                flag_SHS_supply = 4
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 200 Then
                flag_SHS_supply = 3
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 50 Then
                flag_SHS_supply = 2
            ElseIf sheet_Input_Data.Range("D" & x + 27) >= 3 Then
                flag_SHS_supply = 1
            Else
                flag_SHS_supply = 0
            End If
```



```
        'Comparison of response given to the survey with APPs entered
            If sheet_DSS.Range("BO" & x) > sheet_Input_Data.Range("D" & x + 27) Then
                MsgBox ("!!!WARNINGS - SHS: you have insert an Appliance for the class '" & _
                sheet_Input_Data.Range("A" & x + 27) & "' with a Nominal Power greater than the maximum power _
                that the system is able to support!!!")
            End If

            sheet_DSS.Range("D" & x) = flag_SHS_supply

        Else
            sheet_DSS.Range("E" & x) = flag_SHS_app
        End If

End If
x = x + 1
Loop
```

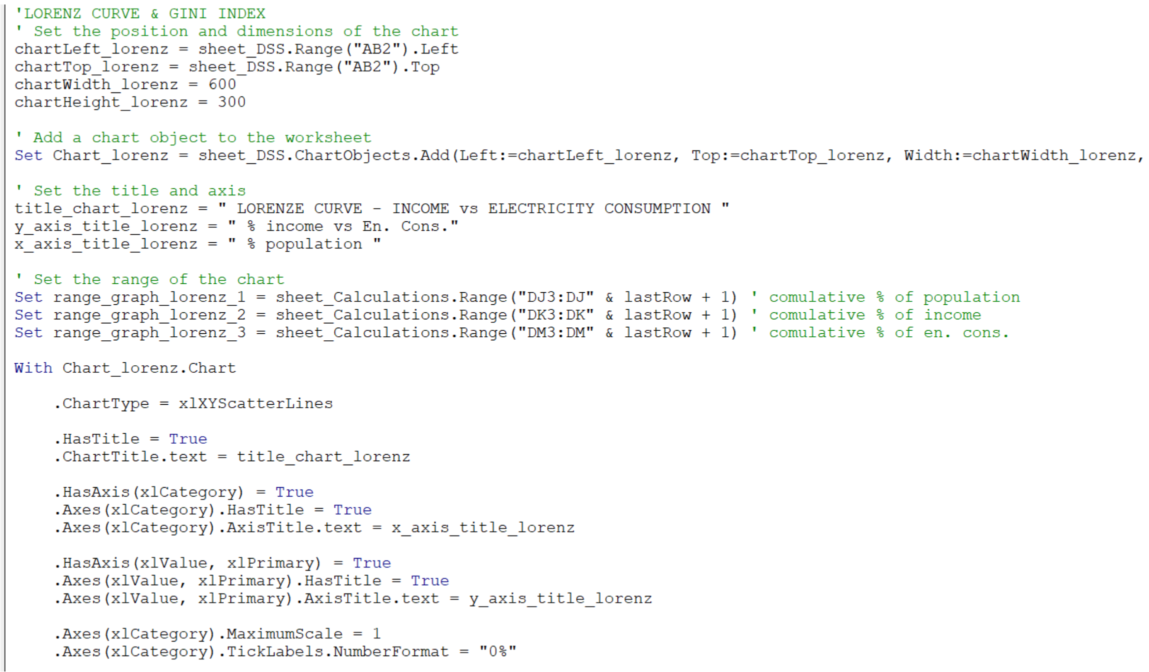
Step 4:

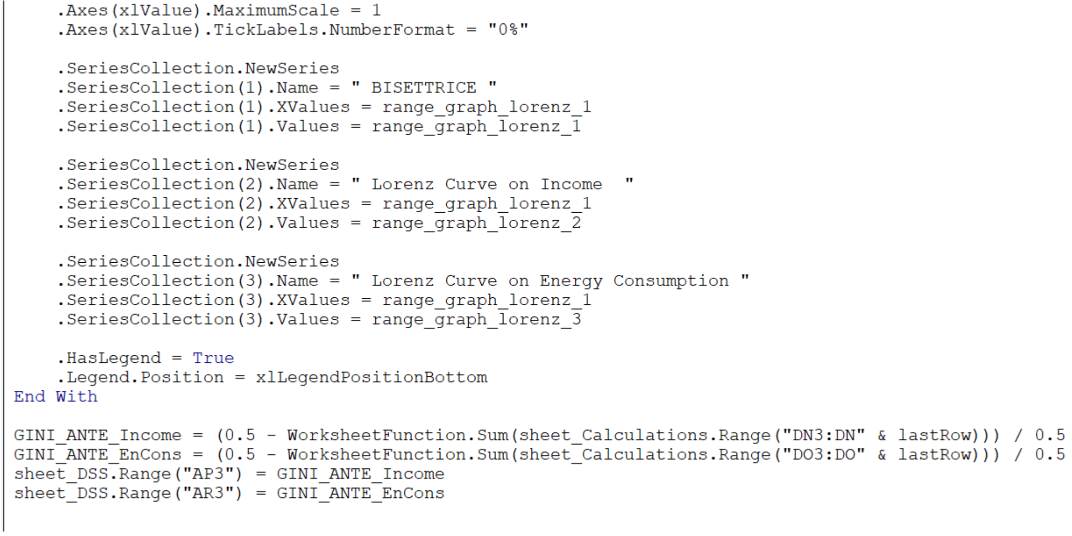


```
'STEP 4 ---COMPUTE FINAL TIER---
'the final tier will be the minimum value between Tier Capacity and Tier Availability
x = 3
Do While sheet_DSS.Range("A" & x) <> ""

    If sheet_Input_Data.Range("C" & x + 27).Value = "No Access" Then
        sheet_DSS.Range("F" & x & ":G" & x).ClearContents
        sheet_DSS.Range("C" & x).Value = 0
    Else
        sheet_DSS.Range("C" & x).Formula = "=MIN(" & sheet_DSS.Cells(x, 4).Address & ":" & sheet_DSS.Cells(x, 7).Address & " )"
    End If
    sheet_DSS.Range("CI" & x) = sheet_DSS.Range("C" & x)

x = x + 1
Loop
```

A.4 Plot Chart for DSS module

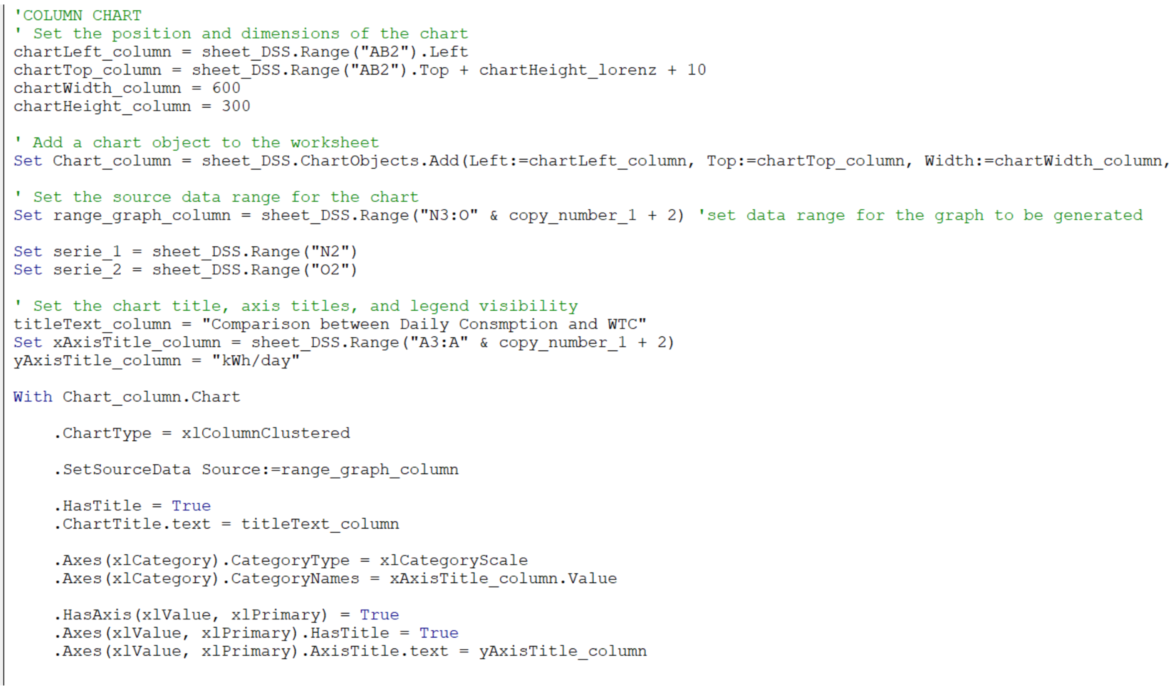
Lorenz Curve and Gini Index:



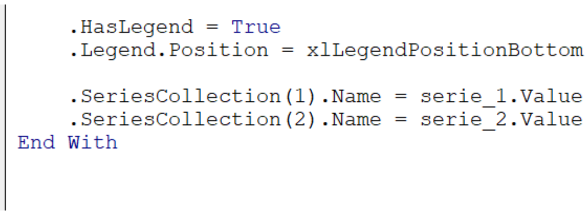


```
'LORENZ CURVE & GINI INDEX
' Set the position and dimensions of the chart
chartLeft_lorenz = sheet_DSS.Range("AB2").Left
chartTop_lorenz = sheet_DSS.Range("AB2").Top
chartWidth_lorenz = 600
chartHeight_lorenz = 300

' Add a chart object to the worksheet
Set Chart_lorenz = sheet_DSS.ChartObjects.Add(Left:=chartLeft_lorenz, Top:=chartTop_lorenz, Width:=chartWidth_lorenz,

' Set the title and axis
title_chart_lorenz = " LORENZE CURVE - INCOME vs ELECTRICITY CONSUMPTION "
y_axis_title_lorenz = " % income vs En. Cons."
x_axis_title_lorenz = " % population "

' Set the range of the chart
Set range_graph_lorenz_1 = sheet_Calculations.Range("DJ3:DJ" & lastRow + 1) ' comulative % of population
Set range_graph_lorenz_2 = sheet_Calculations.Range("DK3:DK" & lastRow + 1) ' comulative % of income
Set range_graph_lorenz_3 = sheet_Calculations.Range("DM3:DM" & lastRow + 1) ' comulative % of en. cons.

With Chart_lorenz.Chart

    .ChartType = xlXYScatterLines

    .HasTitle = True
    .ChartTitle.text = title_chart_lorenz

    .HasAxis(xlCategory) = True
    .Axes(xlCategory).HasTitle = True
    .Axes(xlCategory).AxisTitle.text = x_axis_title_lorenz

    .HasAxis(xlValue, xlPrimary) = True
    .Axes(xlValue, xlPrimary).HasTitle = True
    .Axes(xlValue, xlPrimary).AxisTitle.text = y_axis_title_lorenz

    .Axes(xlCategory).MaximumScale = 1
    .Axes(xlCategory).TickLabels.NumberFormat = "0%"

    .Axes(xlValue).MaximumScale = 1
    .Axes(xlValue).TickLabels.NumberFormat = "0%"

    .SeriesCollection.NewSeries
    .SeriesCollection(1).Name = " BISETTRICE "
    .SeriesCollection(1).XValues = range_graph_lorenz_1
    .SeriesCollection(1).Values = range_graph_lorenz_1

    .SeriesCollection.NewSeries
    .SeriesCollection(2).Name = " Lorenz Curve on Income  "
    .SeriesCollection(2).XValues = range_graph_lorenz_1
    .SeriesCollection(2).Values = range_graph_lorenz_2

    .SeriesCollection.NewSeries
    .SeriesCollection(3).Name = " Lorenz Curve on Energy Consumption "
    .SeriesCollection(3).XValues = range_graph_lorenz_1
    .SeriesCollection(3).Values = range_graph_lorenz_3

    .HasLegend = True
    .Legend.Position = xlLegendPositionBottom
End With

GINI_ANTE_Income = (0.5 - WorksheetFunction.Sum(sheet_Calculations.Range("DN3:DN" & lastRow))) / 0.5
GINI_ANTE_EnCons = (0.5 - WorksheetFunction.Sum(sheet_Calculations.Range("DO3:DO" & lastRow))) / 0.5
sheet_DSS.Range("AP3") = GINI_ANTE_Income
sheet_DSS.Range("AR3") = GINI_ANTE_EnCons
```

Column Chart:

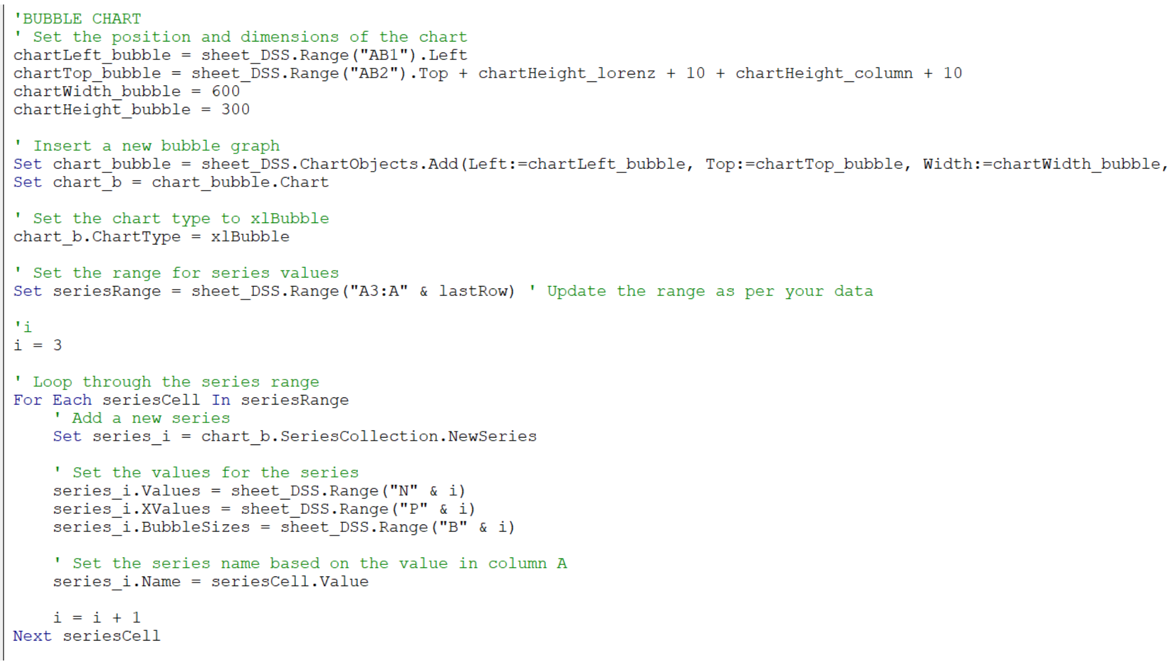


```
'COLUMN CHART
' Set the position and dimensions of the chart
chartLeft_column = sheet_DSS.Range("AB2").Left
chartTop_column = sheet_DSS.Range("AB2").Top + chartHeight_lorenz + 10
chartWidth_column = 600
chartHeight_column = 300

' Add a chart object to the worksheet
Set Chart_column = sheet_DSS.ChartObjects.Add(Left:=chartLeft_column, Top:=chartTop_column, Width:=chartWidth_column,

' Set the source data range for the chart
Set range_graph_column = sheet_DSS.Range("N3:O" & copy_number_1 + 2) 'set data range for the graph to be generated

Set serie_1 = sheet_DSS.Range("N2")
Set serie_2 = sheet_DSS.Range("O2")

' Set the chart title, axis titles, and legend visibility
titleText_column = "Comparison between Daily Consmption and WTC"
Set xAxisTitle_column = sheet_DSS.Range("A3:A" & copy_number_1 + 2)
yAxisTitle_column = "kWh/day"

With Chart_column.Chart

    .ChartType = xlColumnClustered

    .SetSourceData Source:=range_graph_column

    .HasTitle = True
    .ChartTitle.text = titleText_column

    .Axes(xlCategory).CategoryType = xlCategoryScale
    .Axes(xlCategory).CategoryNames = xAxisTitle_column.Value

    .HasAxis(xlValue, xlPrimary) = True
    .Axes(xlValue, xlPrimary).HasTitle = True
    .Axes(xlValue, xlPrimary).AxisTitle.text = yAxisTitle_column
```

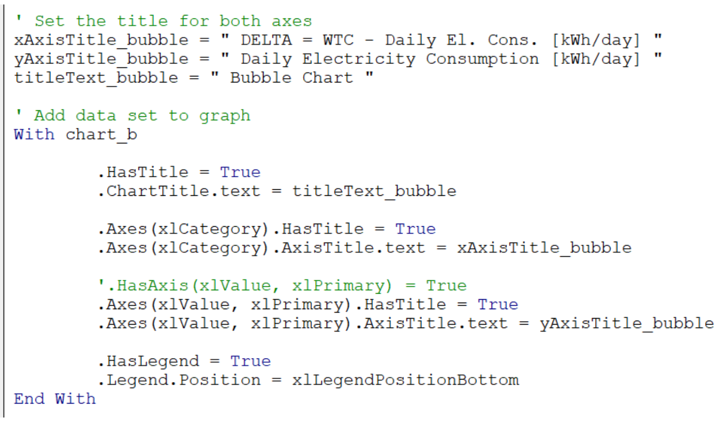


```
    .HasLegend = True
    .Legend.Position = xlLegendPositionBottom

    .SeriesCollection(1).Name = serie_1.Value
    .SeriesCollection(2).Name = serie_2.Value
End With
```

Bubble Chart:

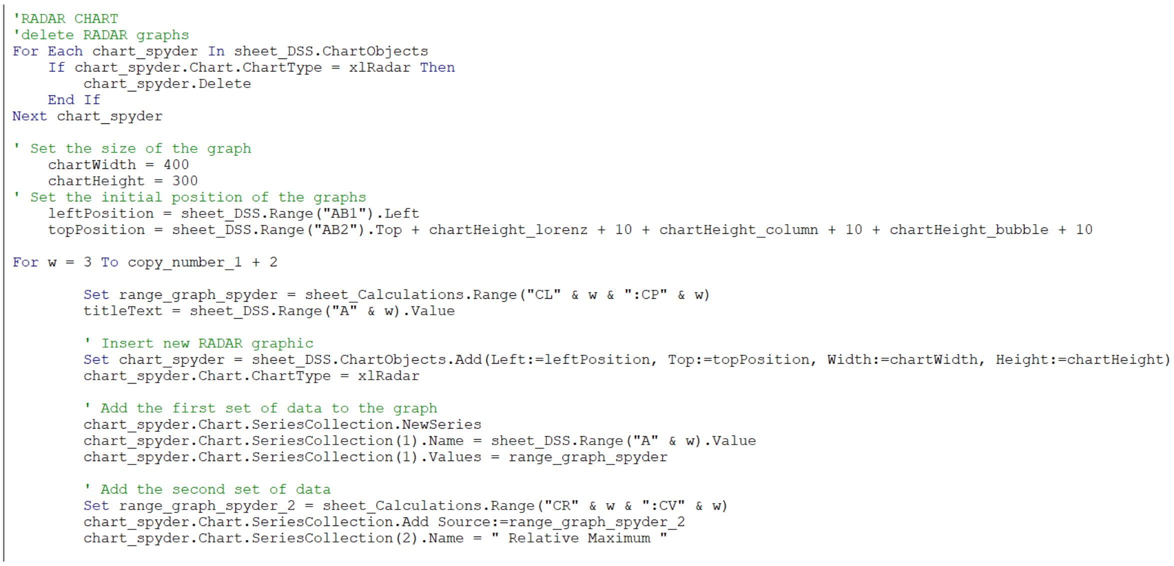


```
'BUBBLE CHART
' Set the position and dimensions of the chart
chartLeft_bubble = sheet_DSS.Range("AB1").Left
chartTop_bubble = sheet_DSS.Range("AB2").Top + chartHeight_lorenz + 10 + chartHeight_column + 10
chartWidth_bubble = 600
chartHeight_bubble = 300

' Insert a new bubble graph
Set chart_bubble = sheet_DSS.ChartObjects.Add(Left:=chartLeft_bubble, Top:=chartTop_bubble, Width:=chartWidth_bubble,
Set chart_b = chart_bubble.Chart

' Set the chart type to xlBubble
chart_b.ChartType = xlBubble

' Set the range for series values
Set seriesRange = sheet_DSS.Range("A3:A" & lastRow) ' Update the range as per your data

'i
i = 3

' Loop through the series range
For Each seriesCell In seriesRange
    ' Add a new series
    Set series_i = chart_b.SeriesCollection.NewSeries

    ' Set the values for the series
    series_i.Values = sheet_DSS.Range("N" & i)
    series_i.XValues = sheet_DSS.Range("P" & i)
    series_i.BubbleSizes = sheet_DSS.Range("B" & i)

    ' Set the series name based on the value in column A
    series_i.Name = seriesCell.Value

    i = i + 1
Next seriesCell
```

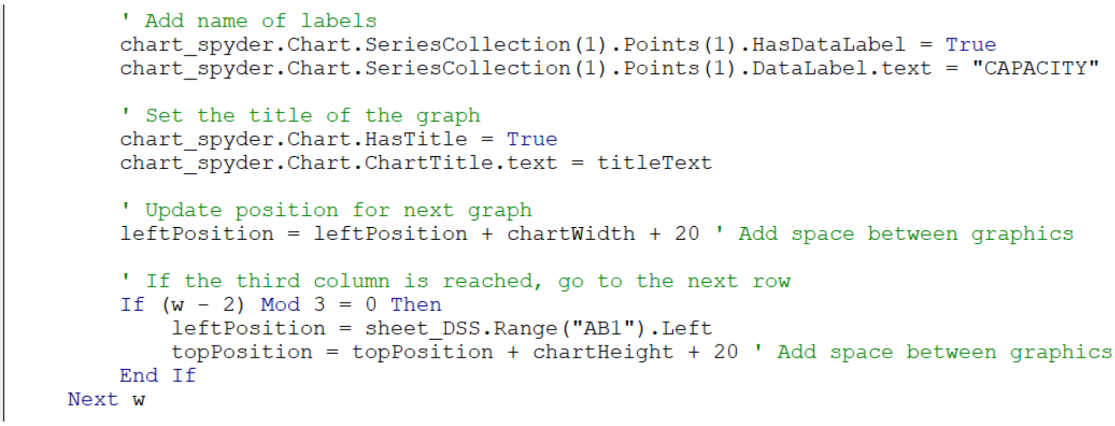


```
' Set the title for both axes
xAxisTitle_bubble = " DELTA = WTC - Daily El. Cons. [kWh/day] "
yAxisTitle_bubble = " Daily Electricity Consumption [kWh/day] "
titleText_bubble = " Bubble Chart "

' Add data set to graph
With chart_b

        .HasTitle = True
        .ChartTitle.text = titleText_bubble

        .Axes(xlCategory).HasTitle = True
        .Axes(xlCategory).AxisTitle.text = xAxisTitle_bubble

        '.HasAxis(xlValue, xlPrimary) = True
        .Axes(xlValue, xlPrimary).HasTitle = True
        .Axes(xlValue, xlPrimary).AxisTitle.text = yAxisTitle_bubble

        .HasLegend = True
        .Legend.Position = xlLegendPositionBottom
End With
```

Radar chart:



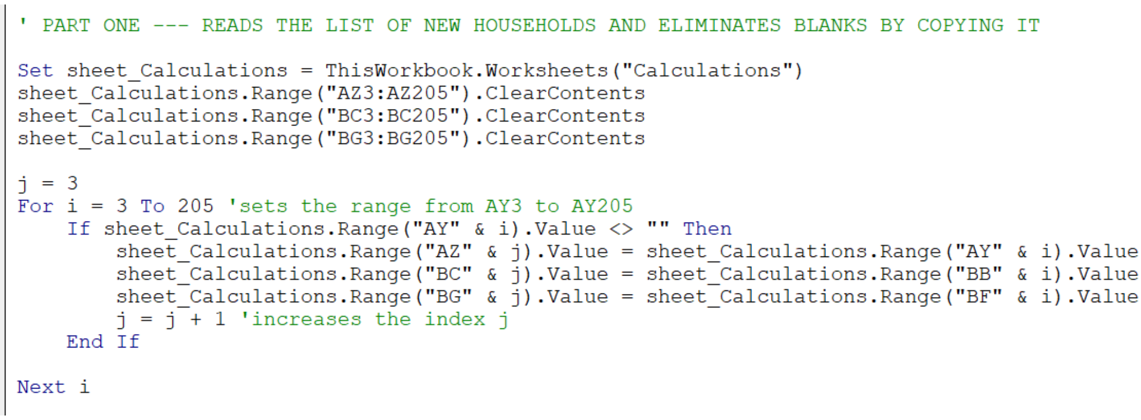
```
'RADAR CHART
'delete RADAR graphs
For Each chart_spyder In sheet_DSS.ChartObjects
    If chart_spyder.Chart.ChartType = xlRadar Then
        chart_spyder.Delete
    End If
Next chart_spyder

' Set the size of the graph
    chartWidth = 400
    chartHeight = 300
' Set the initial position of the graphs
    leftPosition = sheet_DSS.Range("AB1").Left
    topPosition = sheet_DSS.Range("AB2").Top + chartHeight_lorenz + 10 + chartHeight_column + 10 + chartHeight_bubble + 10

For w = 3 To copy_number_1 + 2

        Set range_graph_spyder = sheet_Calculations.Range("CL" & w & ":CP" & w)
        titleText = sheet_DSS.Range("A" & w).Value

        ' Insert new RADAR graphic
        Set chart_spyder = sheet_DSS.ChartObjects.Add(Left:=leftPosition, Top:=topPosition, Width:=chartWidth, Height:=chartHeight)
        chart_spyder.Chart.ChartType = xlRadar

        ' Add the first set of data to the graph
        chart_spyder.Chart.SeriesCollection.NewSeries
        chart_spyder.Chart.SeriesCollection(1).Name = sheet_DSS.Range("A" & w).Value
        chart_spyder.Chart.SeriesCollection(1).Values = range_graph_spyder

        ' Add the second set of data
        Set range_graph_spyder_2 = sheet_Calculations.Range("CR" & w & ":CV" & w)
        chart_spyder.Chart.SeriesCollection.Add Source:=range_graph_spyder_2
        chart_spyder.Chart.SeriesCollection(2).Name = " Relative Maximum "
```



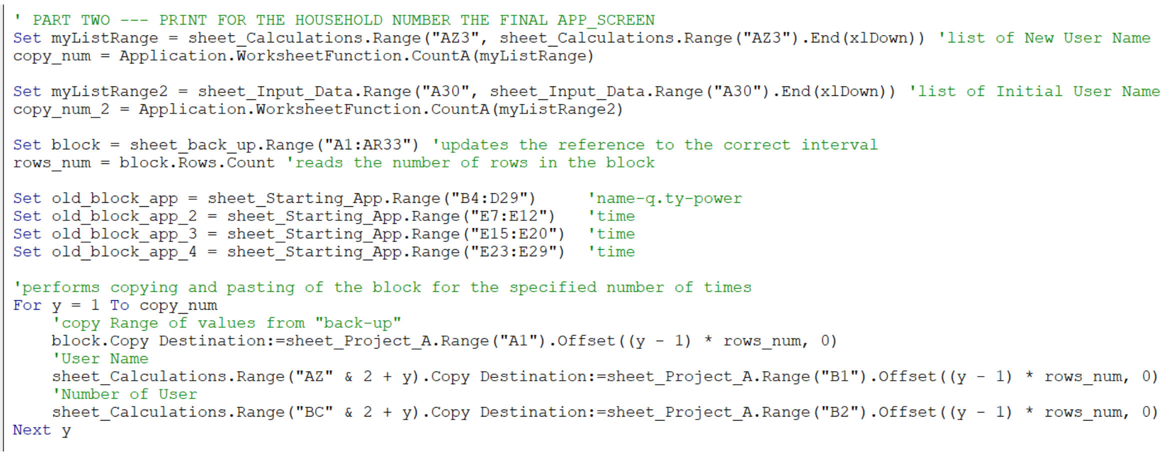
```
        ' Add name of labels
        chart_spyder.Chart.SeriesCollection(1).Points(1).HasDataLabel = True
        chart_spyder.Chart.SeriesCollection(1).Points(1).DataLabel.text = "CAPACITY"

        ' Set the title of the graph
        chart_spyder.Chart.HasTitle = True
        chart_spyder.Chart.ChartTitle.text = titleText

        ' Update position for next graph
        leftPosition = leftPosition + chartWidth + 20 ' Add space between graphics

        ' If the third column is reached, go to the next row
        If (w - 2) Mod 3 = 0 Then
            leftPosition = sheet_DSS.Range("AB1").Left
            topPosition = topPosition + chartHeight + 20 ' Add space between graphics
        End If
    Next w
```

A.5 Appliance Project A

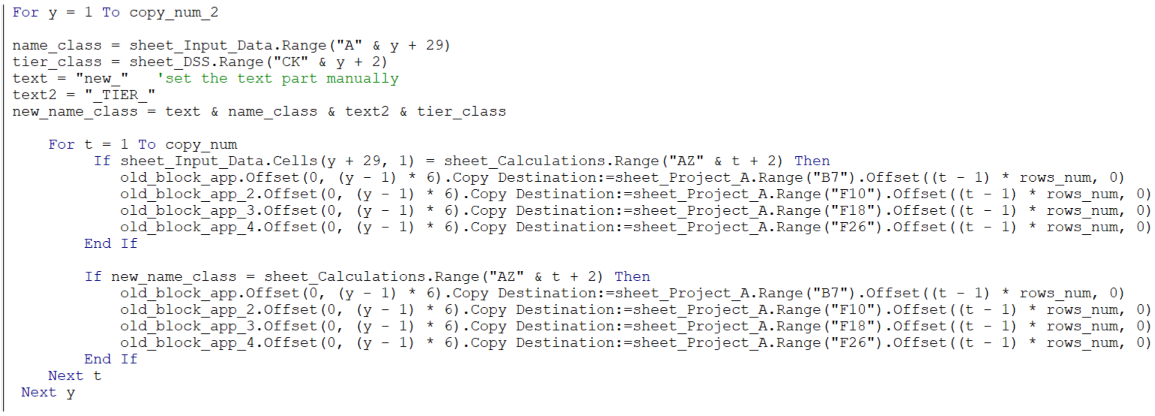
Prints the already assembled set of devices according to the desired class level, dividing those who participate from those who don't.



```
' PART ONE --- READS THE LIST OF NEW HOUSEHOLDS AND ELIMINATES BLANKS BY COPYING IT

Set sheet_Calculations = ThisWorkbook.Worksheets("Calculations")
sheet_Calculations.Range("AZ3:AZ205").ClearContents
sheet_Calculations.Range("BC3:BC205").ClearContents
sheet_Calculations.Range("BG3:BG205").ClearContents

j = 3
For i = 3 To 205 'sets the range from AY3 to AY205
    If sheet_Calculations.Range("AY" & i).Value <> "" Then
        sheet_Calculations.Range("AZ" & j).Value = sheet_Calculations.Range("AY" & i).Value
        sheet_Calculations.Range("BC" & j).Value = sheet_Calculations.Range("BB" & i).Value
        sheet_Calculations.Range("BG" & j).Value = sheet_Calculations.Range("BF" & i).Value
        j = j + 1 'increases the index j
    End If

Next i
```



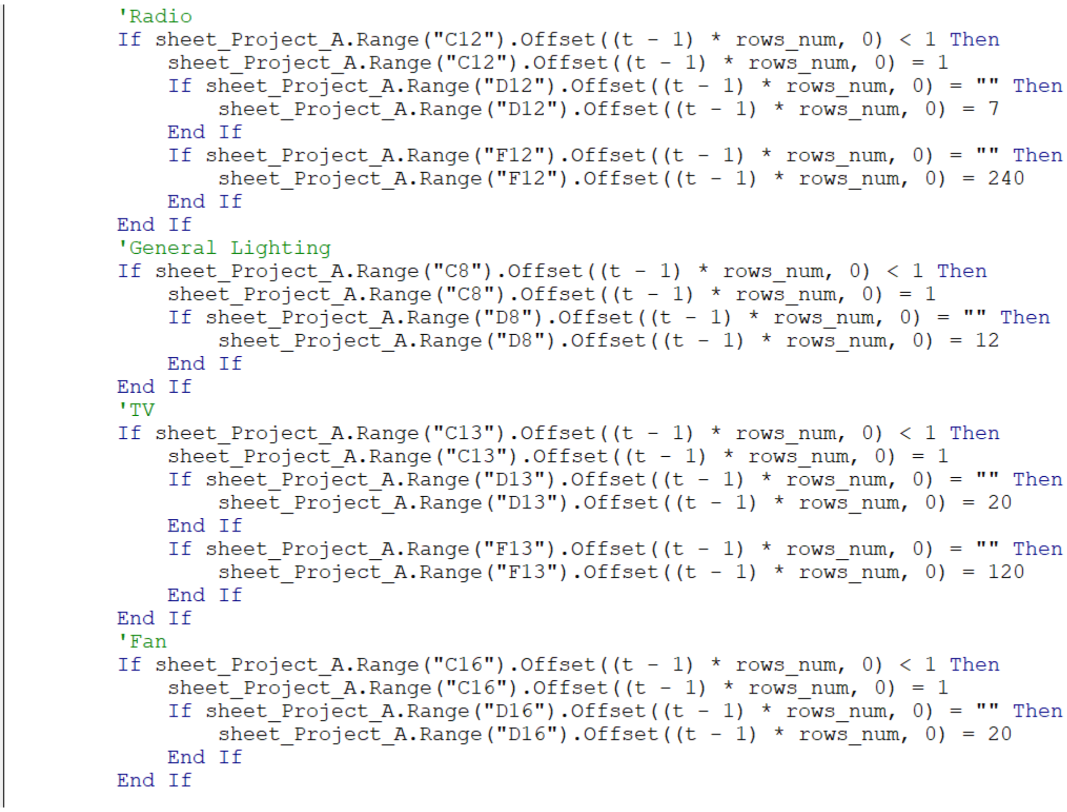
```
' PART TWO --- PRINT FOR THE HOUSEHOLD NUMBER THE FINAL APP_SCREEN
Set myListRange = sheet_Calculations.Range("AZ3", sheet_Calculations.Range("AZ3").End(xlDown)) 'list of New User Name
copy_num = Application.WorksheetFunction.CountA(myListRange)

Set myListRange2 = sheet_Input_Data.Range("A30", sheet_Input_Data.Range("A30").End(xlDown)) 'list of Initial User Name
copy_num_2 = Application.WorksheetFunction.CountA(myListRange2)

Set block = sheet_back_up.Range("A1:AR33") 'updates the reference to the correct interval
rows_num = block.Rows.Count 'reads the number of rows in the block

Set old_block_app = sheet_Starting_App.Range("B4:D29")      'name-q.ty-power
Set old_block_app_2 = sheet_Starting_App.Range("E7:E12")    'time
Set old_block_app_3 = sheet_Starting_App.Range("E15:E20")   'time
Set old_block_app_4 = sheet_Starting_App.Range("E23:E29")   'time

'performs copying and pasting of the block for the specified number of times
For y = 1 To copy_num
    'copy Range of values from "back-up"
    block.Copy Destination:=sheet_Project_A.Range("A1").Offset((y - 1) * rows_num, 0)
    'User Name
    sheet_Calculations.Range("AZ" & 2 + y).Copy Destination:=sheet_Project_A.Range("B1").Offset((y - 1) * rows_num, 0)
    'Number of User
    sheet_Calculations.Range("BC" & 2 + y).Copy Destination:=sheet_Project_A.Range("B2").Offset((y - 1) * rows_num, 0)
Next y
```



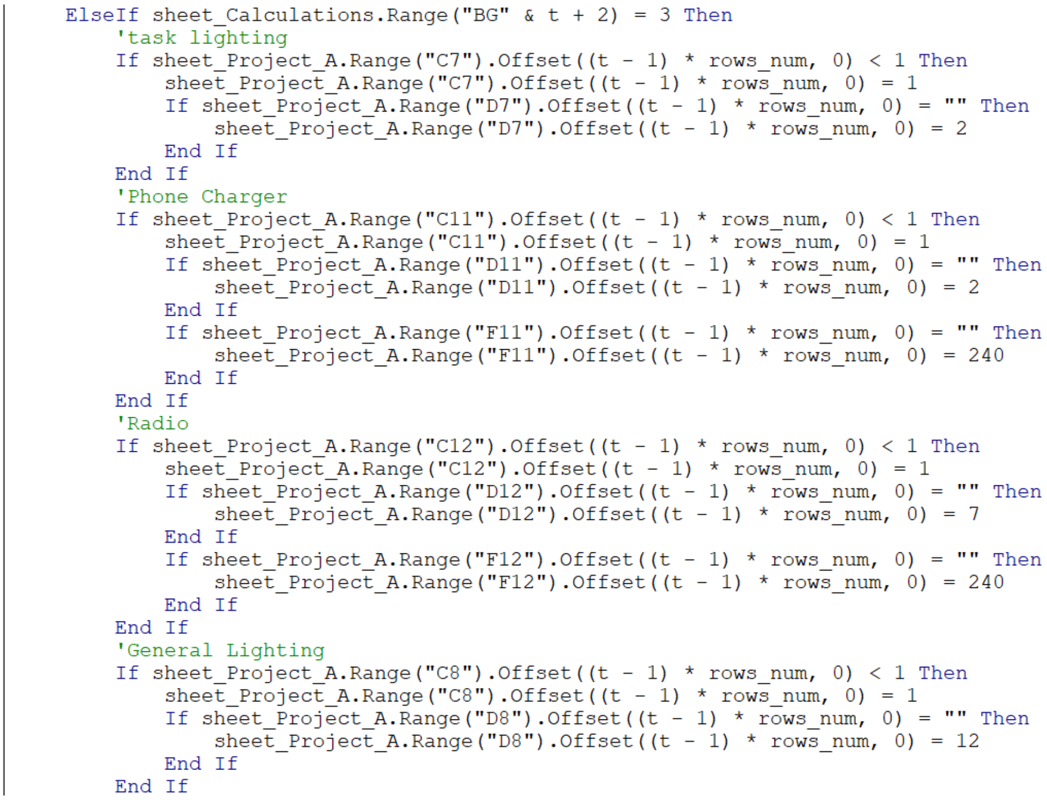
```
For y = 1 To copy_num_2

name_class = sheet_Input_Data.Range("A" & y + 29)
tier_class = sheet_DSS.Range("CK" & y + 2)
text = "new_"   'set the text part manually
text2 = "_TIER_"
new_name_class = text & name_class & text2 & tier_class

    For t = 1 To copy_num
         If sheet_Input_Data.Cells(y + 29, 1) = sheet_Calculations.Range("AZ" & t + 2) Then
            old_block_app.Offset(0, (y - 1) * 6).Copy Destination:=sheet_Project_A.Range("B7").Offset((t - 1) * rows_num, 0)
            old_block_app_2.Offset(0, (y - 1) * 6).Copy Destination:=sheet_Project_A.Range("F10").Offset((t - 1) * rows_num, 0)
            old_block_app_3.Offset(0, (y - 1) * 6).Copy Destination:=sheet_Project_A.Range("F18").Offset((t - 1) * rows_num, 0)
            old_block_app_4.Offset(0, (y - 1) * 6).Copy Destination:=sheet_Project_A.Range("F26").Offset((t - 1) * rows_num, 0)
        End If

        If new_name_class = sheet_Calculations.Range("AZ" & t + 2) Then
            old_block_app.Offset(0, (y - 1) * 6).Copy Destination:=sheet_Project_A.Range("B7").Offset((t - 1) * rows_num, 0)
            old_block_app_2.Offset(0, (y - 1) * 6).Copy Destination:=sheet_Project_A.Range("F10").Offset((t - 1) * rows_num, 0)
            old_block_app_3.Offset(0, (y - 1) * 6).Copy Destination:=sheet_Project_A.Range("F18").Offset((t - 1) * rows_num, 0)
            old_block_app_4.Offset(0, (y - 1) * 6).Copy Destination:=sheet_Project_A.Range("F26").Offset((t - 1) * rows_num, 0)
        End If
    Next t
 Next y
```

```
'CHECK TIER LEVEL

For y = 1 To copy_num_2

name_class = sheet_Input_Data.Range("A" & y + 29)
tier_class = sheet_DSS.Range("CK" & y + 2)
text = "new_"
text2 = "_TIER_"
new_name_class = text & name_class & text2 & tier_class

For t = 1 To copy_num
    If new_name_class = sheet_Calculations.Range("AZ" & t + 2) Then

    If sheet_Calculations.Range("BG" & t + 2) = 1 Then
        'task lighting
        If sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = 2
            End If
        End If
        'Phone Charger
        If sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = 2
            End If
            If sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = 120
            End If
        End If
```

```
        'Radio
        If sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = 7
            End If
            If sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = 120
            End If
        End If

    ElseIf sheet_Calculations.Range("BG" & t + 2) = 2 Then
        'task lighting
        If sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = 2
            End If
        End If
        'Phone Charger
        If sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = 2
            End If
            If sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = 240
            End If
        End If
```



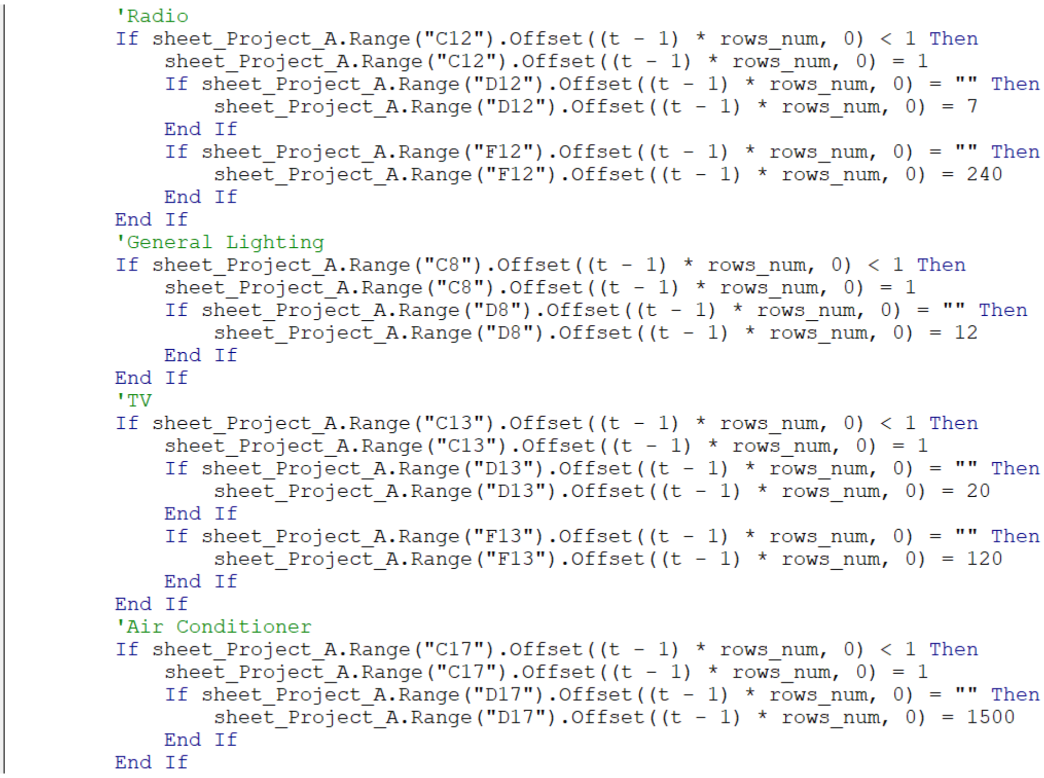
```
    'Radio
    If sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = 7
        End If
        If sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = 240
        End If
    End If
    'General Lighting
    If sheet_Project_A.Range("C8").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C8").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D8").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D8").Offset((t - 1) * rows_num, 0) = 12
        End If
    End If
    'TV
    If sheet_Project_A.Range("C13").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C13").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D13").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D13").Offset((t - 1) * rows_num, 0) = 20
        End If
        If sheet_Project_A.Range("F13").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("F13").Offset((t - 1) * rows_num, 0) = 120
        End If
    End If
    'Fan
    If sheet_Project_A.Range("C16").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C16").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D16").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D16").Offset((t - 1) * rows_num, 0) = 20
        End If
    End If
```



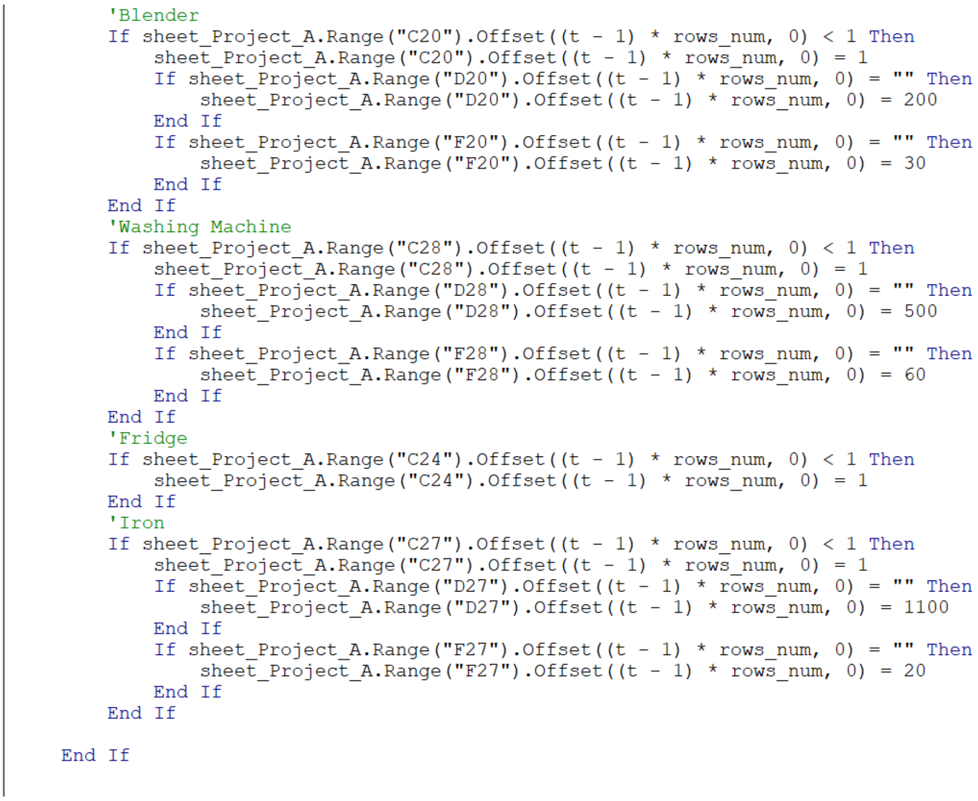
```
ElseIf sheet_Calculations.Range("BG" & t + 2) = 3 Then
    'task lighting
    If sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = 2
        End If
    End If
    'Phone Charger
    If sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = 2
        End If
        If sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = 240
        End If
    End If
    'Radio
    If sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = 7
        End If
        If sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = 240
        End If
    End If
    'General Lighting
    If sheet_Project_A.Range("C8").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C8").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D8").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D8").Offset((t - 1) * rows_num, 0) = 12
        End If
    End If
```

```
        'TV
        If sheet_Project_A.Range("C13").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C13").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D13").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D13").Offset((t - 1) * rows_num, 0) = 20
            End If
            If sheet_Project_A.Range("F13").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F13").Offset((t - 1) * rows_num, 0) = 120
            End If
        End If
        'Fan
        If sheet_Project_A.Range("C16").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C16").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D16").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D16").Offset((t - 1) * rows_num, 0) = 20
            End If
        End If
        'Blender
        If sheet_Project_A.Range("C20").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C20").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D20").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D20").Offset((t - 1) * rows_num, 0) = 200
            End If
            If sheet_Project_A.Range("F20").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F20").Offset((t - 1) * rows_num, 0) = 30
            End If
        End If
        'Washing Machine
        If sheet_Project_A.Range("C28").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C28").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D28").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D28").Offset((t - 1) * rows_num, 0) = 500
            End If
            If sheet_Project_A.Range("F28").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F28").Offset((t - 1) * rows_num, 0) = 60
            End If
        End If

    ElseIf sheet_Calculations.Range("BG" & t + 2) = 4 Then
        'task lighting
        If sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = 2
            End If
        End If
        'Phone Charger
        If sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = 2
            End If
            If sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = 240
            End If
        End If
        'Radio
        If sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = 7
            End If
            If sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = 240
            End If
        End If
        'General Lighting
        If sheet_Project_A.Range("C8").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C8").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D8").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D8").Offset((t - 1) * rows_num, 0) = 12
            End If
        End If
```

```
        'TV
        If sheet_Project_A.Range("C13").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C13").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D13").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D13").Offset((t - 1) * rows_num, 0) = 20
            End If
            If sheet_Project_A.Range("F13").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F13").Offset((t - 1) * rows_num, 0) = 120
            End If
        End If
        'Fan
        If sheet_Project_A.Range("C16").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C16").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D16").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D16").Offset((t - 1) * rows_num, 0) = 20
            End If
        End If
        'Blender
        If sheet_Project_A.Range("C20").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C20").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D20").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D20").Offset((t - 1) * rows_num, 0) = 200
            End If
            If sheet_Project_A.Range("F20").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F20").Offset((t - 1) * rows_num, 0) = 30
            End If
        End If
        'Washing Machine
        If sheet_Project_A.Range("C28").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C28").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D28").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D28").Offset((t - 1) * rows_num, 0) = 500
            End If
            If sheet_Project_A.Range("F28").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F28").Offset((t - 1) * rows_num, 0) = 60
            End If

        'Fridge
        If sheet_Project_A.Range("C24").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C24").Offset((t - 1) * rows_num, 0) = 1
        End If
        'Iron
        If sheet_Project_A.Range("C27").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C27").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D27").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D27").Offset((t - 1) * rows_num, 0) = 1100
            End If
            If sheet_Project_A.Range("F27").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F27").Offset((t - 1) * rows_num, 0) = 20
            End If
        End If

    ElseIf sheet_Calculations.Range("BG" & t + 2) = 5 Then
        'task lighting
        If sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C7").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D7").Offset((t - 1) * rows_num, 0) = 2
            End If
        End If
        'Phone Charger
        If sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) < 1 Then
            sheet_Project_A.Range("C11").Offset((t - 1) * rows_num, 0) = 1
            If sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("D11").Offset((t - 1) * rows_num, 0) = 2
            End If
            If sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = "" Then
                sheet_Project_A.Range("F11").Offset((t - 1) * rows_num, 0) = 240
            End If
        End If
```



```
    'Radio
    If sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C12").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D12").Offset((t - 1) * rows_num, 0) = 7
        End If
        If sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("F12").Offset((t - 1) * rows_num, 0) = 240
        End If
    End If
    'General Lighting
    If sheet_Project_A.Range("C8").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C8").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D8").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D8").Offset((t - 1) * rows_num, 0) = 12
        End If
    End If
    'TV
    If sheet_Project_A.Range("C13").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C13").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D13").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D13").Offset((t - 1) * rows_num, 0) = 20
        End If
        If sheet_Project_A.Range("F13").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("F13").Offset((t - 1) * rows_num, 0) = 120
        End If
    End If
    'Air Conditioner
    If sheet_Project_A.Range("C17").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C17").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D17").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D17").Offset((t - 1) * rows_num, 0) = 1500
        End If
    End If
```



```
    'Blender
    If sheet_Project_A.Range("C20").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C20").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D20").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D20").Offset((t - 1) * rows_num, 0) = 200
        End If
        If sheet_Project_A.Range("F20").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("F20").Offset((t - 1) * rows_num, 0) = 30
        End If
    End If
    'Washing Machine
    If sheet_Project_A.Range("C28").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C28").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D28").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D28").Offset((t - 1) * rows_num, 0) = 500
        End If
        If sheet_Project_A.Range("F28").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("F28").Offset((t - 1) * rows_num, 0) = 60
        End If
    End If
    'Fridge
    If sheet_Project_A.Range("C24").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C24").Offset((t - 1) * rows_num, 0) = 1
    End If
    'Iron
    If sheet_Project_A.Range("C27").Offset((t - 1) * rows_num, 0) < 1 Then
        sheet_Project_A.Range("C27").Offset((t - 1) * rows_num, 0) = 1
        If sheet_Project_A.Range("D27").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("D27").Offset((t - 1) * rows_num, 0) = 1100
        End If
        If sheet_Project_A.Range("F27").Offset((t - 1) * rows_num, 0) = "" Then
            sheet_Project_A.Range("F27").Offset((t - 1) * rows_num, 0) = 20
        End If
    End If

End If
```

For Project B the macro is the same, change only the reference sheet and cells.

A.6 Output Calculation

Calculates the expected outcome for each class according to the previously completed sheets.

```
Set myListRange = sheetCalculations.Range("AZ3", sheetCalculations.Range("AZ3").End(xlDown)) 'list of New User Name
copy_num = Application.WorksheetFunction.CountA(myListRange)

Set myListRange2 = sheetINPUT.Range("A30", sheetINPUT.Range("A30").End(xlDown)) 'list of Initial User Name
copy_num2 = Application.WorksheetFunction.CountA(myListRange2)

sheet_Expected_Outcome.Range("N4:O104").ClearContents
sheet_Expected_Outcome.Range("R4:S104").ClearContents


For y = 1 To copy_num2

name_class = sheetINPUT.Range("A" & y + 29)
tier_class_A = sheetDSS.Range("CK" & y + 2)
tier_class_B = sheetDSS.Range("CM" & y + 2)
text = "new_"   'set the text manually
text2 = "_TIER_"
new_name_class_A = text & name_class & text2 & tier_class_A
new_name_class_B = text & name_class & text2 & tier_class_B
```

```
    'PROJECT A
    For t = 1 To copy_num

        Daily_En_Consumption = 0

        If sheetINPUT.Cells(y + 29, 1) = sheetCalculations.Range("AZ" & t + 2) Then
            For i = 7 + 33 * (t - 1) To 32 + 33 * (t - 1)
                If i = 24 + 33 * (t - 1) Or i = 25 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_A.Range("C" & i) * _
                                          sheet_Project_A.Range("D" & i) * sheet_Project_A.Range("F" & i) / (60 * 4)
                ElseIf i = 9 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_A.Range("C" & i) * _
                                          sheet_Project_A.Range("D" & i) * sheetCalculations.Range("AD20") / 60
                ElseIf i = 16 + 33 * (t - 1) Or i = 17 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_A.Range("C" & i) * _
                                          sheet_Project_A.Range("D" & i) * sheetCalculations.Range("AD2") / 60
                Else
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_A.Range("C" & i) * _
                                          sheet_Project_A.Range("D" & i) * sheet_Project_A.Range("F" & i) / 60
                End If
            Next i
        sheet_Expected_Outcome.Range("O" & y + 3) = Daily_En_Consumption / 1000   'from Wh to kWh
        End If
```

```
        'Daily_En_Consumption = 0
        If new_name_class_A = sheetCalculations.Range("AZ" & t + 2) Then
            For i = 7 + 33 * (t - 1) To 32 + 33 * (t - 1)
                If i = 24 + 33 * (t - 1) Or i = 25 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_A.Range("C" & i) * _
                                          sheet_Project_A.Range("D" & i) * sheet_Project_A.Range("F" & i) / (60 * 4)
                ElseIf i = 9 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_A.Range("C" & i) * _
                                          sheet_Project_A.Range("D" & i) * sheetCalculations.Range("AD20") / 60
                ElseIf i = 16 + 33 * (t - 1) Or i = 17 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_A.Range("C" & i) * _
                                          sheet_Project_A.Range("D" & i) * sheetCalculations.Range("AD2") / 60
                Else
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_A.Range("C" & i) * _
                                          sheet_Project_A.Range("D" & i) * sheet_Project_A.Range("F" & i) / 60
                End If
            Next i
        sheet_Expected_Outcome.Range("N" & y + 3) = Daily_En_Consumption / 1000   'from Wh to kWh
        End If

    Next t
```

```
    'PROJECT B
    For t = 1 To copy_num

        Daily_En_Consumption = 0
        If sheetINPUT.Cells(y + 29, 1) = sheetCalculations.Range("AS" & t + 2) Then
            For i = 7 + 33 * (t - 1) To 32 + 33 * (t - 1)
                If i = 24 + 33 * (t - 1) Or i = 25 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_B.Range("C" & i) * _
                                            sheet_Project_B.Range("D" & i) * sheet_Project_B.Range("F" & i) / (60 * 4)
                ElseIf i = 9 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_B.Range("C" & i) * _
                                            sheet_Project_B.Range("D" & i) * sheetCalculations.Range("AD20") / 60
                ElseIf i = 16 + 33 * (t - 1) Or i = 17 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_B.Range("C" & i) * _
                                            sheet_Project_B.Range("D" & i) * sheetCalculations.Range("AD2") / 60
                Else
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_B.Range("C" & i) * _
                                            sheet_Project_B.Range("D" & i) * sheet_Project_B.Range("F" & i) / 60
                End If
            Next i
        sheet_Expected_Outcome.Range("S" & y + 3) = Daily_En_Consumption / 1000   'from Wh to kWh
        End If
```

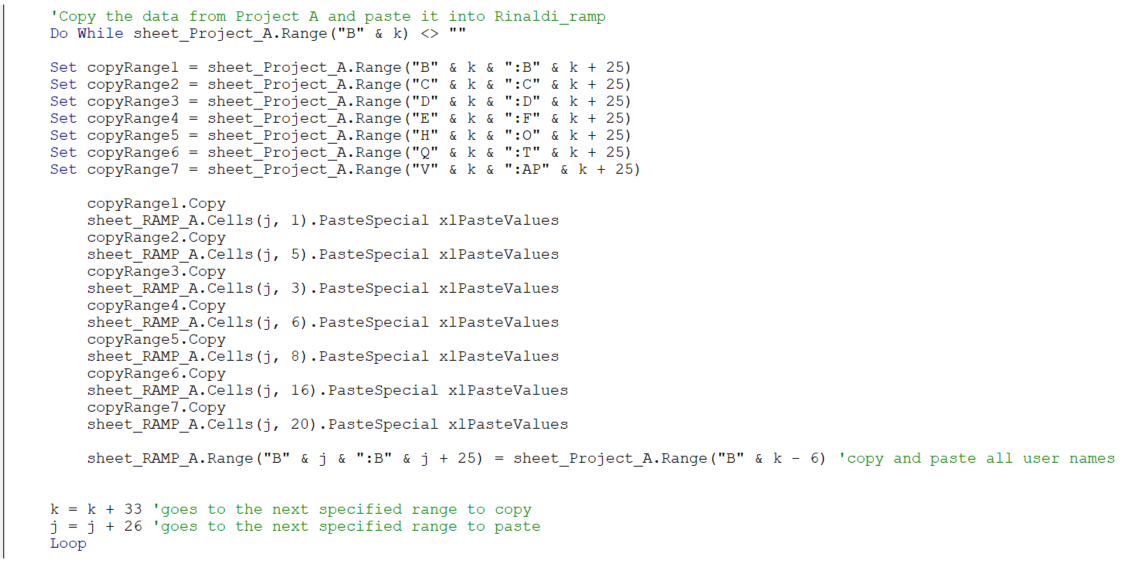
```
        If new_name_class_B = sheetCalculations.Range("AS" & t + 2) Then
            For i = 7 + 33 * (t - 1) To 32 + 33 * (t - 1)
                If i = 24 + 33 * (t - 1) Or i = 25 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_B.Range("C" & i) * _
                                            sheet_Project_B.Range("D" & i) * sheet_Project_B.Range("F" & i) / (60 * 4)
                ElseIf i = 9 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_B.Range("C" & i) * _
                                            sheet_Project_B.Range("D" & i) * sheetCalculations.Range("AD20") / 60
                ElseIf i = 16 + 33 * (t - 1) Or i = 17 + 33 * (t - 1) Then
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_B.Range("C" & i) * _
                                            sheet_Project_B.Range("D" & i) * sheetCalculations.Range("AD2") / 60
                Else
                    Daily_En_Consumption = Daily_En_Consumption + sheet_Project_B.Range("C" & i) * _
                                            sheet_Project_B.Range("D" & i) * sheet_Project_B.Range("F" & i) / 60
                End If
            Next i
        sheet_Expected_Outcome.Range("R" & y + 3) = Daily_En_Consumption / 1000   'from Wh to kWh
        End If

    Next t

Next y
```

A.7 RAMP – Project A

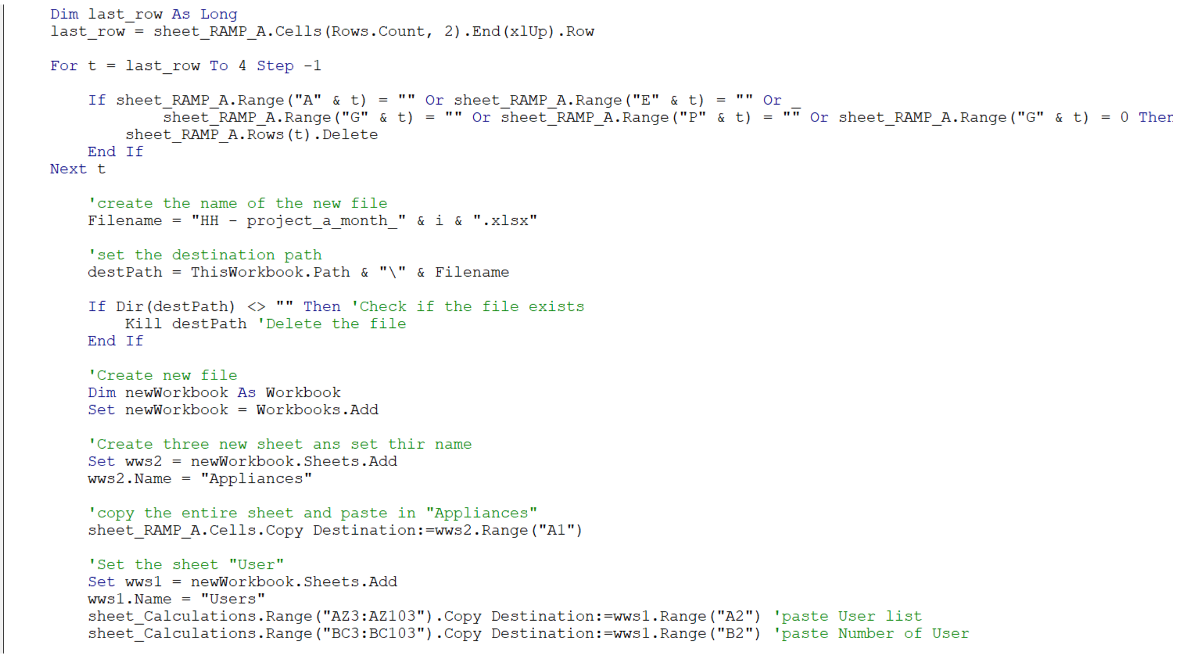
It copies the appliance data into a separate sheet and through this sheet creates the twelve input files for RAMP.

```
Sub RAMP_PROJECT_A()

Dim sheet_Project_A, sheet_RAMP_A, sheet_back_up, sheet_Calculations As Worksheet
Dim wws1, wws2, wws3 As Worksheet
Dim r As Range
Dim i, j, k, t, z As Integer
Dim Filename As String
Dim destPath As String
Dim num_new_user As Integer
Dim number_user As Integer

Set sheet_Project_A = ThisWorkbook.Sheets("Project A")
Set sheet_RAMP_A = ThisWorkbook.Sheets("RAMP_PROJECT_A")
Set sheet_back_up = ThisWorkbook.Sheets("back-up")
Set sheet_Calculations = ThisWorkbook.Sheets("Calculations")

sheet_RAMP_A.Rows("5:" & sheet_RAMP_A.Rows.Count).ClearContents
number_user = sheet_Calculations.Range("BE3").Value

' Loop through each value in the dropdown list
For i = 1 To 12

k = 7
j = 4

    ' Select next month for all users
    For z = 1 To number_user
        sheet_Project_A.Range("B" & 3 + (z - 1) * 33).Value = sheet_back_up.Range("AR" & i).Value
    Next z
```

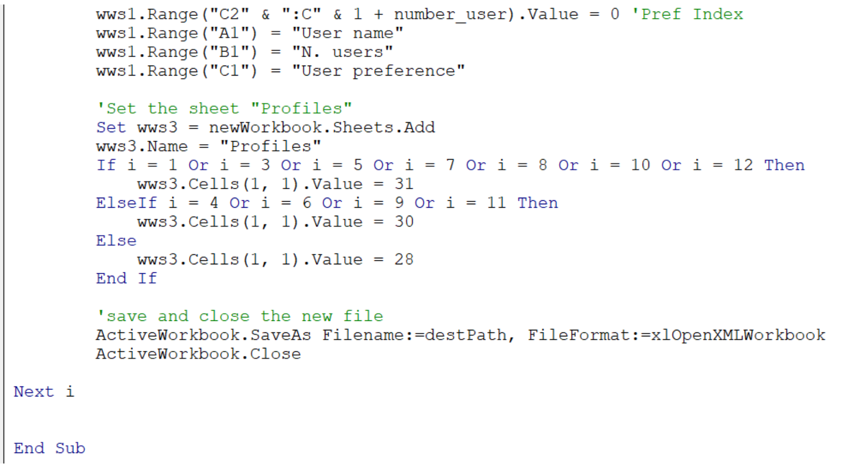
ANNEX B



```
    'Copy the data from Project A and paste it into Rinaldi_ramp
    Do While sheet_Project_A.Range("B" & k) <> ""

    Set copyRange1 = sheet_Project_A.Range("B" & k & ":B" & k + 25)
    Set copyRange2 = sheet_Project_A.Range("C" & k & ":C" & k + 25)
    Set copyRange3 = sheet_Project_A.Range("D" & k & ":D" & k + 25)
    Set copyRange4 = sheet_Project_A.Range("E" & k & ":F" & k + 25)
    Set copyRange5 = sheet_Project_A.Range("H" & k & ":O" & k + 25)
    Set copyRange6 = sheet_Project_A.Range("Q" & k & ":T" & k + 25)
    Set copyRange7 = sheet_Project_A.Range("V" & k & ":AP" & k + 25)

        copyRange1.Copy
        sheet_RAMP_A.Cells(j, 1).PasteSpecial xlPasteValues
        copyRange2.Copy
        sheet_RAMP_A.Cells(j, 5).PasteSpecial xlPasteValues
        copyRange3.Copy
        sheet_RAMP_A.Cells(j, 3).PasteSpecial xlPasteValues
        copyRange4.Copy
        sheet_RAMP_A.Cells(j, 6).PasteSpecial xlPasteValues
        copyRange5.Copy
        sheet_RAMP_A.Cells(j, 8).PasteSpecial xlPasteValues
        copyRange6.Copy
        sheet_RAMP_A.Cells(j, 16).PasteSpecial xlPasteValues
        copyRange7.Copy
        sheet_RAMP_A.Cells(j, 20).PasteSpecial xlPasteValues

        sheet_RAMP_A.Range("B" & j & ":B" & j + 25) = sheet_Project_A.Range("B" & k - 6) 'copy and paste all user names


    k = k + 33 'goes to the next specified range to copy
    j = j + 26 'goes to the next specified range to paste
    Loop
```



```
    Dim last_row As Long
    last_row = sheet_RAMP_A.Cells(Rows.Count, 2).End(xlUp).Row

    For t = last_row To 4 Step -1

        If sheet_RAMP_A.Range("A" & t) = "" Or sheet_RAMP_A.Range("E" & t) = "" Or _
                sheet_RAMP_A.Range("G" & t) = "" Or sheet_RAMP_A.Range("P" & t) = "" Or sheet_RAMP_A.Range("G" & t) = 0 Ther
            sheet_RAMP_A.Rows(t).Delete
        End If
    Next t

        'create the name of the new file
        Filename = "HH - project_a_month_" & i & ".xlsx"

        'set the destination path
        destPath = ThisWorkbook.Path & "\" & Filename

        If Dir(destPath) <> "" Then 'Check if the file exists
            Kill destPath 'Delete the file
        End If

        'Create new file
        Dim newWorkbook As Workbook
        Set newWorkbook = Workbooks.Add

        'Create three new sheet ans set thir name
        Set wws2 = newWorkbook.Sheets.Add
        wws2.Name = "Appliances"

        'copy the entire sheet and paste in "Appliances"
        sheet_RAMP_A.Cells.Copy Destination:=wws2.Range("A1")

        'Set the sheet "User"
        Set wws1 = newWorkbook.Sheets.Add
        wws1.Name = "Users"
        sheet_Calculations.Range("AZ3:AZ103").Copy Destination:=wws1.Range("A2") 'paste User list
        sheet_Calculations.Range("BC3:BC103").Copy Destination:=wws1.Range("B2") 'paste Number of User
```



```
        wws1.Range("C2" & ":C" & 1 + number_user).Value = 0 'Pref Index
        wws1.Range("A1") = "User name"
        wws1.Range("B1") = "N. users"
        wws1.Range("C1") = "User preference"

        'Set the sheet "Profiles"
        Set wws3 = newWorkbook.Sheets.Add
        wws3.Name = "Profiles"
        If i = 1 Or i = 3 Or i = 5 Or i = 7 Or i = 8 Or i = 10 Or i = 12 Then
            wws3.Cells(1, 1).Value = 31
        ElseIf i = 4 Or i = 6 Or i = 9 Or i = 11 Then
            wws3.Cells(1, 1).Value = 30
        Else
            wws3.Cells(1, 1).Value = 28
        End If

        'save and close the new file
        ActiveWorkbook.SaveAs Filename:=destPath, FileFormat:=xlOpenXMLWorkbook
        ActiveWorkbook.Close

Next i

End Sub
```

For Project B the macro is the same.

ANNEX B

Module 1 – Data collection & classification

General info:

INPUT DATA - ALL COMMUNITY			
Location	Latitude	-13.19°	
	Longitude	38.54°	
	Time Zone	2	
Household Behavior	leaving home hour	7	A.M.
	home-coming hour	15	P.M.
	Maximum Tolerable Outdoor Air Temperature	30	°C
Lighting Behavior	Time Before Sunrise	30	min
	Time After Sunrise	30	min
	Time Before Sunset	30	min
	Time After Sunset	240	min

Survey & classification into classes:

		CAPACITY			**AVAILABILITY**		**RELIABILITY**	**AFFORDABILITY**				**QUALITY**	**HEALTH & SAFETY**	**LEGALITY**
User Name:	***Number of Households belonging to this Class***	*Which is the **supply system** that this Class use the most in their house?*	*Is the **Capacity of the system** available from the name plate? - If **'YES'** insert the value in [W] - If **'NO'** leave it empty*	***Storage or Battery Capacity [Wh]***	*On average, how many **hours** of electricity are **available each day and night** from the supply system? (**max 24 hours**)*	*On average, how many hours of electricity are available **each evening, from 6:00 pm to 10:00 pm** from the supply system? (**max 4 hours**)*	*In a typical week, how many **outages/black** out of the grid happen? (**only for National Grid and Mini-Grid**)*	***Average Income [$/month]***	*In the last month how much did they **spend** on the **electric bill**? If Gen-Set is present how much did they spend on **fuel**? If it's **unknown** insert the average electric expenditure in the region [$/months]*	*indicate the willingness to pay (WTP) as a percentage of the monthly income [% of income]*	If the Household is classified as **"No Access"** insert a realistic electricity tariff in accordance with the rest of the population [$/kWh]	*In the last 12 months did any of your appliances get **damaged because the voltage** was going up and down from the connection? (Yes/No)*	*In the last 12 months did any household members died or have **permanent limb** (badly injury) **demage** due to the electricity connection? (Yes/No)*	*Is their connection to electricity **legal**?*
NA_1	35	No Access						100		5%	0,93			
NA_2	19	No Access						100		5%	0,93			
NA_3	34	No Access						100		5%	0,93			
NA_4	1	No Access						100		5%	0,93			
NA_5	5	No Access						100		5%	0,93			
NA_6	1	No Access						100		5%	0,93			
NA_7	1	No Access						100		5%	0,93			
NA_8	1	No Access						100		5%	0,93			
NA_9	1	No Access						100		5%	0,93			
SHD_1	1	Solar Based Devices	100		24	4	0	111,5	1,6	5%		YES	NO	YES
SHD_2	1	Solar Based Devices	50		12	1	15	111,5	1,92	5%		NO	NO	YES
SHD_3	2	Solar Based Devices	40		12	4	20	111,5	1,28	5%		YES	NO	YES
SHD_4	2	Solar Based Devices	15		3	0	15	111,5	0	5%		NO	NO	YES
SHD_5	4	Solar Based Devices	15		15	0	17	111,5	1,6	5%		YES	NO	YES
SHD_6	3	Solar Based Devices	10		8	1	18	111,5	1,92	5%		YES	NO	YES
SHD_BATT_1	1	Solar Based Devices	2000		20	4	0	115	1,6	5%		YES	NO	NO
SHD_BATT_2	1	Solar Based Devices	150		20	4	0	115	1,92	5%		YES	NO	NO
SHD_BATT_3	2	Solar Based Devices	35		3	2	20	115	1,28	5%		YES	NO	YES
SHD_BATT_4	2	Solar Based Devices	25		18	4	10	115	1,6	5%		NO	NO	YES
SHD_BATT_5	1	Solar Based Devices	15		6	1	12	115	0	5%		NO	NO	YES
GEN_1	1	Fossil Fuel-based Generator	500		3	3	17	119	22,7	5%		NO	NO	YES

Starting appliances:

Starting Appliances

Class Name	Appliance owned	Quantity [-]	Nominal Power [W]	Time [min]
NA_1	none	-	-	-
NA_2	Phone Charger	2	2	120
	Radio	1	7	240
NA_3	Phone Charger	1	2	120
NA_4	Phone Charger	2	2	120
	Speaker	1	20	120
NA_5	Radio	1	4	240
NA_6	Radio	10	2	240
	Speaker	2	20	120
NA_7	Speaker	1	20	120
NA_8	TV	1	40	120
	Speaker	2	20	120
NA_9	Phone Charger	1	2	120
	Sewing Machine	1	100	120
SHD_1	Radio	1	10	240
	Speaker	2	20	120
SHD_2	Phone Charger	2	2	120
	Radio	2	10	240
	Speaker	2	20	120
SHD_3	Phone Charger	2	5	120
SHD_4	none	-	-	-
SHD_5	Phone Charger	2	5	120
	Radio	1	10	240
SHD_6	Phone Charger	1	5	120
	Radio	2	10	240
	Speaker	1	10	120
SHD_BATT_1	Phone Charger	2	5	120
	Speaker	2	20	120
SHD_BATT_2	General Lighting	3	12	240
	Phone Charger	3	5	120
	Radio	1	10	120
	Speaker	3	20	120
SHD_BATT_3	Radio	1	10	120
SHD_BATT_4	Phone Charger	3	5	120
	Radio	1	10	120
SHD_BATT_5	none	-	-	-
GEN_1	Phone Charger	2	5	120
	TV	1	40	120
	Speaker	2	20	120

Module 3 – Intervention’s selection

Appliances selection for Project A:

Basic information															*Windows*			
User name	*Appliance name*	*Nominal power*	*Power variability*	*Number*	*N. of windows*	*Tot functioning time*	*Variable time*	*Min functioning time*	*Clustered*	*N. of duty cycles*	*Occasion al use*	*No variability*	*Preference index*	*Weekend /weekday*	*Window 1*	*Window 2*	*Window 3*	*Variability*
_default	_default	0	0	1	1	0	0	1	no	0	1	no	0	2	0,0	0,0	0,0	0
GEN_1	Phone Charger	5		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	TV	40		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_1_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
new_NA_2_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
new_NA_3_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
new_NA_4_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	Speaker	20		1	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_5_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	4		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
new_NA_6_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	2		10	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_7_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	Speaker	20		1	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_8_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	40		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_9_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	Sewing Machine	100		1	1	120									480,960			
new_SHD_1_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	240	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_2_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		2	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_3_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
new_SHD_4_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
new_SHD_5_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_6_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		2	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	10		1	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_BATT_1_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_BATT_2_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		3	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		3	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		3	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_BATT_3_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
new_SHD_BATT_4_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		3	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
new_SHD_BATT_5_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2

Appliances selection for Project B:

Basic information															Windows			
User name	*Appliance name*	*Nominal power*	*Power variability*	*Number*	*N. of windows*	*Tot functioning time*	*Variable time*	*Min functioning time*	*Clustered*	*N. of duty cycles*	*Occasional use*	*No variability*	*Preference index*	*Weekend/ weekday*	*Window 1*	*Window 2*	*Window 3*	*Variability*
_default	_default	0	0	1	1	0	0	1	no	0	1	no	0	2	0,0	0,0	0,0	0
GEN_1	Phone Charger	5		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	TV	40		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_1_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	240	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_NA_2_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_NA_3_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_NA_4_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	Speaker	20		1	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_5_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	240	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	4		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_NA_6_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	2		10	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_7_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	Speaker	20		1	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_8_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	40		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_NA_9_TIER_1	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	Sewing Machine	100		1	1	120	0,25	10	yes	0	1	no	0	0	480,960			
new_SHD_1_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	240	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
	Fridge	100		1	1	96	0,1	5	no	0	1	no	0	0	0,1440			0
new_SHD_2_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		2	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
	Fridge	100		1	1	96	0,1	5	no	0	1	no	0	0	0,1440			0
new_SHD_3_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_4_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	240	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_5_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		2	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_6_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		1	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		2	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	10		1	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
	Fridge	100		1	1	96	0,1	5	no	0	1	no	0	0	0,1440			0
new_SHD_BATT_1_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger							***5***								***0,1440***		
	Radio	*7*		*1*	*2*	*240*	*0,4*	*20*	*no*	*0*	*0,8*	*no*	*0*	*0*	*260,450*	*1080,1200*		*0,2*
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		2	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
	Fridge	100		1	1	96	0,1	5	no	0	1	no	0	0	0,1440			0
new_SHD_BATT_2_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		3	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		3	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Speaker	20		3	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
	Fridge	100		1	1	96	0,1	5	no	0	1	no	0	0	0,1440			0
new_SHD_BATT_3_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	240	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_BATT_4_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	5		3	1	120	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	10		1	2	120	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1
new_SHD_BATT_5_TIER_2	Task Lighting	2		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	General Lighting	12		1	2	330	0,1	10	no	0	1	no	0	0	264,324	1037,1307		0,1
	Phone Charger	2		1	1	240	0,2	30	no	0	1	no	0	0	0,1440			0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	260,450	1080,1200		0,2
	TV	20		1	1	120	0,25	30	no	0	0,8	no	0	0	1080,1320			0,15
	Fan	20		1	2	60	0,2	30	no	0	1	no	0	0	360,420	900,900		0,1

Appliances selection for the case obtained without using the tool:

Basic information															*Windows*			
User name	*Appliance name*	*Nominal power*	*Power variability*	*Number*	*N. of windows*	*Tot functioning time*	*Variable time*	*Min functioning time*	*Clustered*	*N. of duty cycles*	*Occasional use*	*No variability*	*Preference index*	*Weekend/ weekday*	*Window 1*	*Window 2*	*Window 3*	*Variability*
_default	_default	0	0	1	1	0	0	1	no	0	1	no	0	2	0,0	0,0	0,0	0
new_NA_1_TIER_1	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
new_NA_4_TIER_1	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		2	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Speaker	20		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
new_NA_5_TIER_1	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Speaker	20		2	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
new_NA_7_TIER_1	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
new_NA_8_TIER_1	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	40		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		2	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
new_NA_9_TIER_1	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Sewing Machine	100		1	1	120									480,960			
new_SHD_1_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	240	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
new_SHD_2_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		2	2	240	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		2	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
new_SHD_3_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		2	2	240	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	10		1	2	240	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		1	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_SHD_4_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	240	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		1	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_SHD_5_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	5		2	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	10		1	2	240	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		1	1	120	0,4	20	no	0	0,8	no	0	0	0,1440			0,2
new_SHD_6_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	5		1	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	10		2	2	240	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
new_SHD_BATT_1_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	5		2	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		2	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Fan	20		1	1	120	0,2	30	no	0	1	no	0	0	600,1080			0,1
	fridge	100		1	1	96									0,1440			
new_SHD_BATT_2_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		3	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	5		3	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	10		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		3	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Fan	20		1	1	120	0,2	30	no	0	1	no	0	0	600,1080			0,1
	fridge	100		1	1	96									0,1440			
new_SHD_BATT_3_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	240	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	10		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Fan	20		1	1	120	0,2	30	no	0	1	no	0	0	600,1080			0,1
	fridge	100		1	1	96									0,1440			
new_SHD_BATT_4_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	5		3	2	120	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	10		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Fan	20		1	1	120	0,2	30	no	0	1	no	0	0	600,1080			0,1
	fridge	100		1	1	96									0,1440			
new_SHD_BATT_5_TIER_3	Task Lighting	2		1	2	60	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	General Lighting	12		1	2	120	0,1	10	no	0	1	no	0	0	300,600	1080,1200		0,1
	Phone Charger	2		1	2	240	0,2	30	no	0	1	no	0	0	300,600	1080,1200		0,1
	Radio	7		1	2	240	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	TV	20		1	2	120	0,25	30	no	0	0,8	no	0	0	300,600	1080,1200		0,15
	Speaker	20		1	2	120	0,4	20	no	0	0,8	no	0	0	300,600	1080,1200		0,2
	Fan	20		1	1	120	0,2	30	no	0	1	no	0	0	600,1080			0,1
	fridge	100		1	1	96									0,1440			