LEAP-RE

Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

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Business model for standalone solar cooking appliance

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Authors:
Teresa Simões, João P. Cardoso, António Couto (LNEG), Sheila Chepkorir (SU); Dominique Savio (AESG), Boaventura Cuamba (UEM)

Contributors: Jorge Facão, Carlos Rodrigues, David Loureiro (LNEG); Ephantus Kamweru (REREC), Sandra Banda, Vincent Kinyua, Anne Wambugu (SU); Gustavo De Miguel (UCO)

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Abbreviations and Acronyms

Acronym	Description
CCF	Clean Cooking Fund
CCS	Clean Cooking Solutions
CH	Calinski-Harabasz criterion
EDCL	and The Energy Development Corporation Limited (EDCL)
EPC	Electric Pressure Cooker
ESMAP	Energy Sector Management Assistant Program
EUCL	Energy Utility Corporation Limited
GDP	Gross Domestic Product
HIC	High Impact Country
ICS	Improved cooking stove
IEA	International Energy Agency
LPG	Liquid Petroleum Gas
MCFA	Modern Cooking Facility for Africa
MECS	Modern Energy Cooking Services
MFI	Microfinance Institutions
MTF	Multi-Tier Framework
Nefco	Nordic Environment Finance Corporation
PV	Photovoltaic

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PVPEPC	Consists of PV panels (with the respective mountings) connected by electrical cables to a regulator and this equipment to the electric pressure cooker.
REG	Rwanda Energy Group
REREC	Rural Electrification and Renewable Energy Corporation
SACCOS	Savings and Credit Co-Operative Societies
SEforALL	Sustainable Energy for All
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
TMY	Typical Meteorological year
UN	United Nations
WASAC	Water and Sanitation Corporation

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Summary

The present report was developed as part of the research activities of the PURAMS project *Task 10.1 - Resource assessment and business model development*. PURAMS aims to promote the development and increased access to clean cooking technologies.

This report presents the business model for the PURAMS's project related to the use of solar e-cooking using PV systems and storage capabilities. It analyses the socio-economic context in African countries with a particular focus on three case study countries – Kenya, Rwanda and Mozambique. To this end, the project conducted three surveys and two experimental campaigns using Electric Pressure Cooking (EPC) devices in order to understand the energy needs and dimension the systems for an efficient use.

For this work, the CANVAS model was used to identify the main actors in the e-cooking process, such as key suppliers, users and other intervenient, as well as the value propositions for this type of business. The most common business models in clean cooking have been analysed and serve as a basis for the development of this report. The main results of this work are related with the key economic indicators of the e-cooking system and the potential users. From the results, it is possible to conclude that the costs associated to its dissemination need a strong intervention from the governments in what concerns the granting of incentives and support to the possible users, together with the establishment of actions for stakeholders' involvement that can potentiate de dissemination of clean cooking in African countries.

Keywords

Solar e-cooking, cooking habits, PV systems, storage

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1. Introduction

The LEAP-RE project aims to establish a long-term partnership between African and European stakeholders in the field of renewable energy, including eight research and innovation projects under its Pillar 2. The work developed and presented in this report was performed under the auspices of the "*Productive Use in Rural African Markets using Standalone Solar*" (PURAMS) project (LEAP-RE Work Package 10, WP10). The main objective of PURAMS is to develop a standalone solar cooker to address the problems caused by traditional cooking methods used in African communities, targeting three countries: Kenya, Mozambique, and Rwanda. In doing so, PURAMS aims to promote the development and increase access to clean cooking technologies, contributing to the targets set by the United Nations within the Sustainable Development Goal 7, "*Ensure access to affordable, reliable, sustainable and modern energy*". The present report was developed as part of the research activities of the PURAMS project, Task 10.1: "*Resource assessment and business model development*". This report constitutes deliverable D10.3, dealing with the development of business plans to the deployment of solar cookers in the three target countries.

In the next sections, a summarized state of the art on solar cooking context in African countries and business models development will be presented. Also, a description of the developed work in terms of system dimensioning and corresponding costs analysis is also presented. Finally, a review on the impacts related with the transition to solar e-cooking will be presented and recommendations to accelerate the transition to clean cooking is discussed. Overview on solar cooking status in African countries

In the past years, several studies have been conducted to evaluate the cooking habits in Africa, being a large part dedicated to sub-Saharan Africa (SSA). The conclusions of these studies highlight the fact that, by 2023, almost 1 billion people (approximately one-third of the inhabitants of that region) still use highly polluting fuels to cook, which constitutes a severe public health problem and results in harm to the environment. (Perros, Tomei, & Parikh, 2024) The Sustainable Development Goal (SDG) 7 addresses this problem and calls for universal access to affordable, reliable and sustainable modern energy by 2030 (UN, 2024), including clean cooking technologies. However, several experts in the area consider the SDG 7 target to be very ambitious for several regions in the world, and especially for SSA. To make an effort to meet this goal, the development of clean cooking appliances has begun to receive more attention in recent years and more funds have been made available to support the different initiatives that have appeared in the energy sector (Perros, Tomei, & Parikh, 2024).

In 2021 the Modern Cooking Facility for Africa (MCFA) was established as a joint initiative between Sweden and the Nordic Environment Finance Corporation – Nefco, the Facility Manager. This initiative has as a main goal to provide access to clean cooking solutions to around 4 million people until 2027. In addition, the facility intends to support the development of new markets on the clean cooking sector and accelerate access to modern and affordable cooking equipment to consumers, fund projects in SSA in this area and provide job opportunities with a focus on women's empowerment (MCFA, 2024).

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In 2019 the Energy Sector Management Assistant Program (ESMAP) launched a Clean Cooking Fund (CCF) at the United Nations Climate Summit, with a value of US$500 million, to scale up investments in the clean cooking sector (ESMAP, 2024). The CCF's portfolio includes projects in several countries, such as Burundi, Ghana, Mozambique, Rwanda and Uganda. The Rwanda Energy Access and Quality Improvement Project was the first approved, being the largest African clean cooking operation funded by development finance it pretends to deliver clean cooking to around 2.5 million people.

Besides the health hazards, the use of traditional methods for cooking also presents negative impacts at the economic and human development level, namely due to the time spent on fuel collection, especially by women and children. According to the International Energy Agency (IEA), the effort in SSA households without access to clean cooking, involves a large part of the day spent gathering biomass, preparing the fires and cooking, which can take up to 5 hours. Typically, an average of 2 hours per day is spent collecting fuel and an additional 3 hours for cooking and food preparation. The collection time varies according to the proximity to woodlands or location of the fuel used (Perros, Tomei, & Parikh, 2024).

In the past years, different solutions for (standalone) electric clean cooking have been studied to meet the needs of users without demanding too much change in their habits and ensuring affordability. Generally, electric cooking devices are divided according to their heat transfer mechanism, power requirements, speed and versatility. The five most efficient electric cookers are the rice cooker, microwave, insulated electric frying pan, thermo-pot, and electric pressure cooker (EPC) (Shuma, et al., 2021) (Figure 1).

Figure 1: Rice cooker, insulated frying pan, thermos-pot, microwave and EPC (Jumia, 2024)

Based on experiments conducted by (Shuma, et al., 2021) the EPC is the cooker with higher potential to transform and meet cooking practices. Compared to hot plates, it is more energy efficient in what concerns hard food cooking and enables to cook over 90% of the typical dishes on countries like Tanzania, Kenya and Zambia. In addition, the users find the EPC easy to use and fast, according to the surveys conducted in some of these countries. Unfortunately, the market for this type of devices is still underdeveloped, and there is still the need to strengthen it and support end-users.

According to the World Economic Forum there is a shortfall on investment in clean cooking, especially in African countries. The number of companies involved in this activity is reduced and did not achieve significant representativeness (WeForum, 2026). In addition, very few

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clean cooking businesses reached efficient sales' volumes. The opposite of this situation is referred to PV power business that has grown tremendously in the past years achieving very low prices and making it accessible to the public. Subsequently, the use of PV power in clean cooking solutions has begun to get the attention of investors worldwide. Although there is still a long way to go, in terms of technology integration, increased communities' sensibilization and awareness for its advantages, and governmental support, different potential solutions have been studied in the past years and new business models for this activity are being developed.

The following section gives an overview of the types of business models and financial schemes under study for this end according to the literature and shared experiences.

1.1 Barriers to the dissemination of clean cooking and most used business models

Several barriers to the development of sustainable clean cooking in African countries have been identified and not only in what concerns the use of electricity. The larger set of barriers is concerned to financing, which makes it the most important constraint to achieve the SDG7 access target. In addition, the main conclusion in the studies already developed for this purpose highlight the need of large volumes of public and private funding (Coldrey, Lant, & Ashworth, 2023).

The financial aspects have not been given the right attention in the clean cooking as a relevant support instrument for its sustainable development. The definition of suitable financial schemes that can reach new businesses development, complement existing businesses and make products affordable for public – especially in rural areas – still needs further development. In the case of the product developed in the scope of this project, this is an important aspect since it is mainly directed to rural population with scarce or no access to electricity.

The consumers' available income is a relevant limit to the clean cooking financial flows, being its level and particularly linked to increased access to clean cooking products by end-users. The affordability is therefore one of the most sensitive parts of the overall process when launching a product in the market. Mechanisms as subsidies and financial products (pay-as-you-go, for example), may be a suitable solution for the consumers, although they bring a significant financial burden on the selling companies. Nevertheless, the consumer´s available income is, as referred, the most important constraint to the adoption of clean cooking solutions (Coldrey, Lant, & Ashworth, 2023).

In July 2015, the World Bank and SEforALL, conceived the Multi-Tier Framework for clean cooking access (MTF) which incorporates aspects such as adequacy of the energy source, availability when needed, reliability, quality, convenience, affordability, legal, healthy, and safe (Coldrey, Lant, & Ashworth, 2023) (WorldBank, 2024) (SE4All, 2021) (Figure 2).

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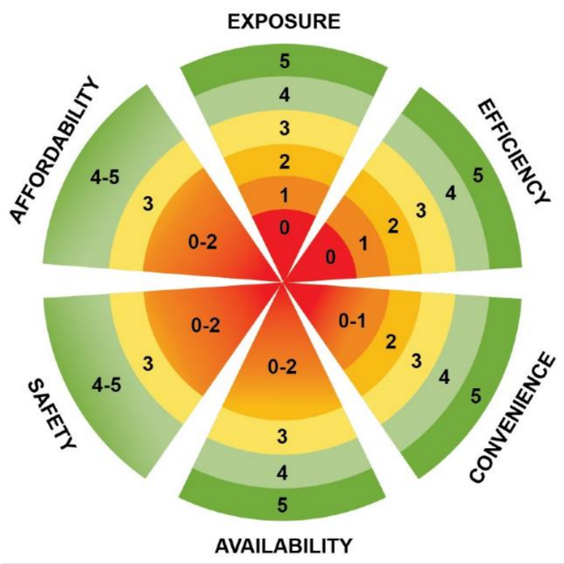

Figure 2: MTF attributes to evaluate a household (WorldBank, 2024).

According to the World Bank a household reaches modern energy cooking services if it scores at least four in each of the six attributes of the MTF. The six attributes presented in Figure 2 can be detailed as follows:

- "Efficiency: combination of combustion and heat-transfer efficiency
- Exposure: personal exposure to pollutants, which depends on both stove emissions and ventilation (higher tiers indicate lower exposure)
- Convenience: time collecting / purchasing fuel and preparing the stove
- Availability: readiness of the fuel when needed by user
- Safety: severity of injuries caused by the stove over the past year
- Affordability: share of household budget spent on fuel (higher tiers indicate lower share of spending)".

These attributes can be related with clean cooking solutions and used to classify the pre-commercial products to understand their feasibility and future acceptance in the market.

Besides the great importance of financing, other aspects need to be taken into account, as for example, the lack of knowledge on the benefits of clean cooking and promotion of behavioural changes in using these technologies. Also, the lack of policy intervention in this area is an important barrier, such as the limited or non-inclusion of clean cooking promotion actions in national policies. All the identified barriers, together, raise uncertainty in the financial sector and prevent the funding of projects and businesses, limiting the participation of the main actors in the markets and reinforcing the need to look at these barriers to find solutions to achieve SDG7 targets in what concerns clean sustainable cooking in African countries.

In the last years, the e-cooking sector has been changing in several countries, mainly due to the investment made by funding organizations and the effort dedicated to raising awareness on the health issues provoked by the smoke emitted when using traditional cooking methods such as firewood and charcoal. In addition, some efforts have been made

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in funding projects for the development of clean cooking solutions using electricity. Figure 3 shows the distribution of incentives in clean cooking projects in the last years in high impact countries – HICs (the countries with the highest absolute gaps in access to electricity and Clean Cooking). Figure 4 presents the commitment in clean cooking and percentage of people without access to clean technologies and fuels for cooking in a set of countries in Africa and Asia.

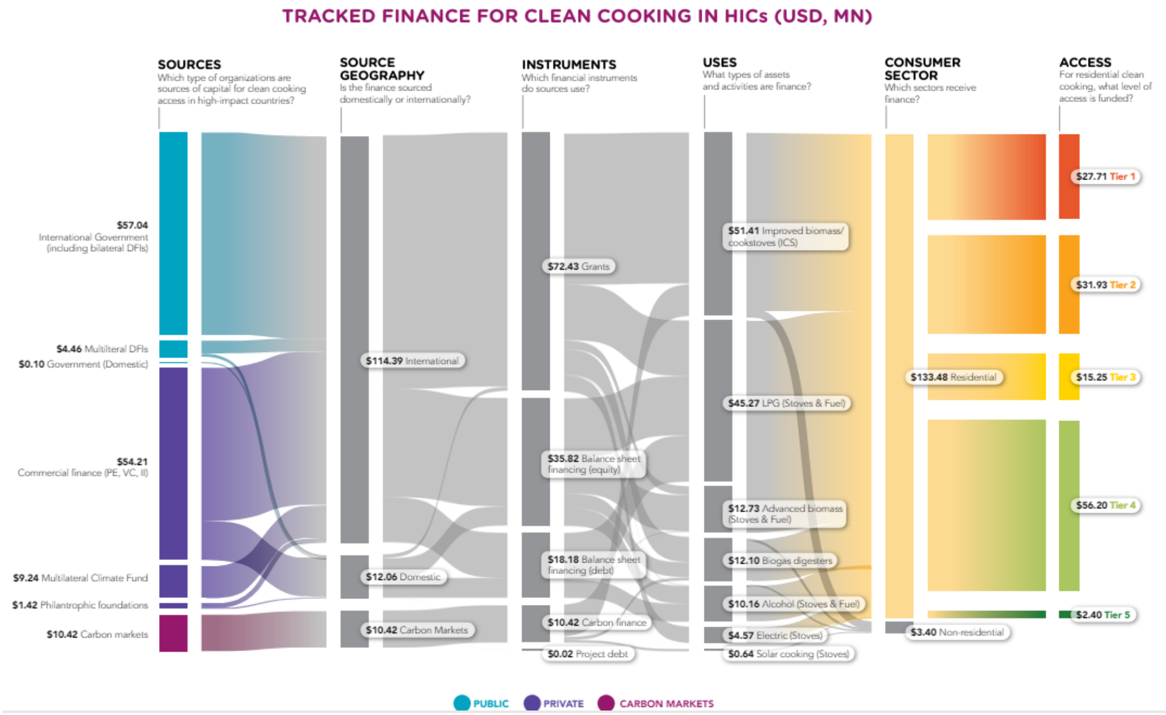

Figure 3: Investment (donor funded clean cooking programs) in clean cooking projects in the last years in high impact countries (SSA and India) (SE4All, 2021).

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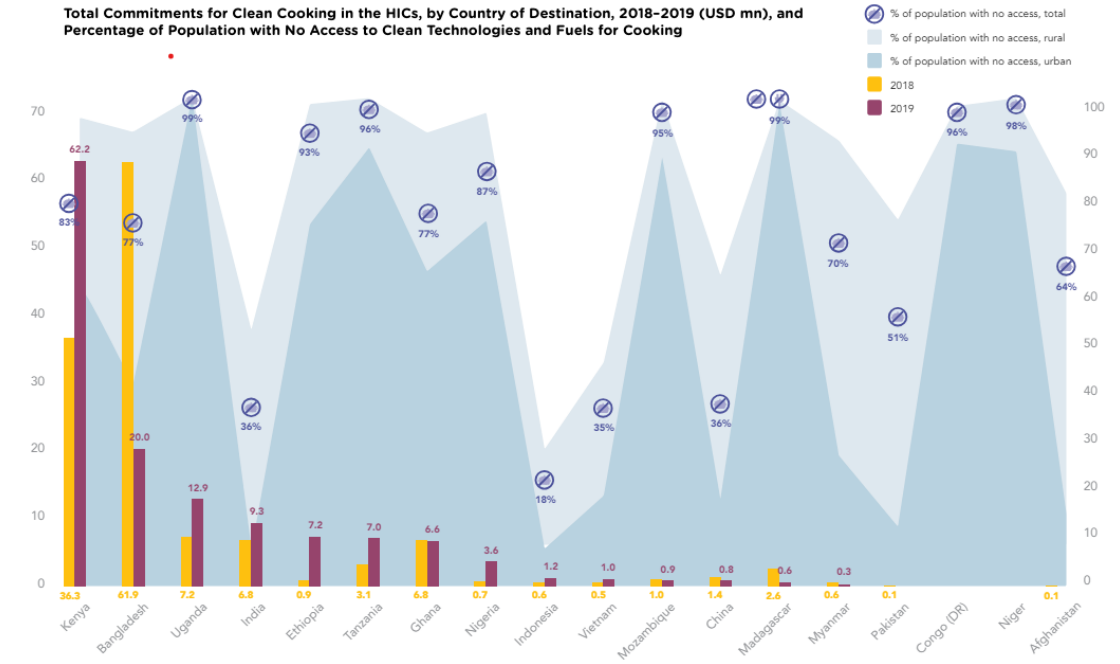

Figure 4: Funding commitment for clean cooking (USD mn) and percentage of people without access to clean technologies and fuels for cooking in a set of countries (SE4All, 2021).

In addition, it is reported that, until 2019, the amount of investment in clean cooking on high impact countries was still under the required amounts (Figure 5).

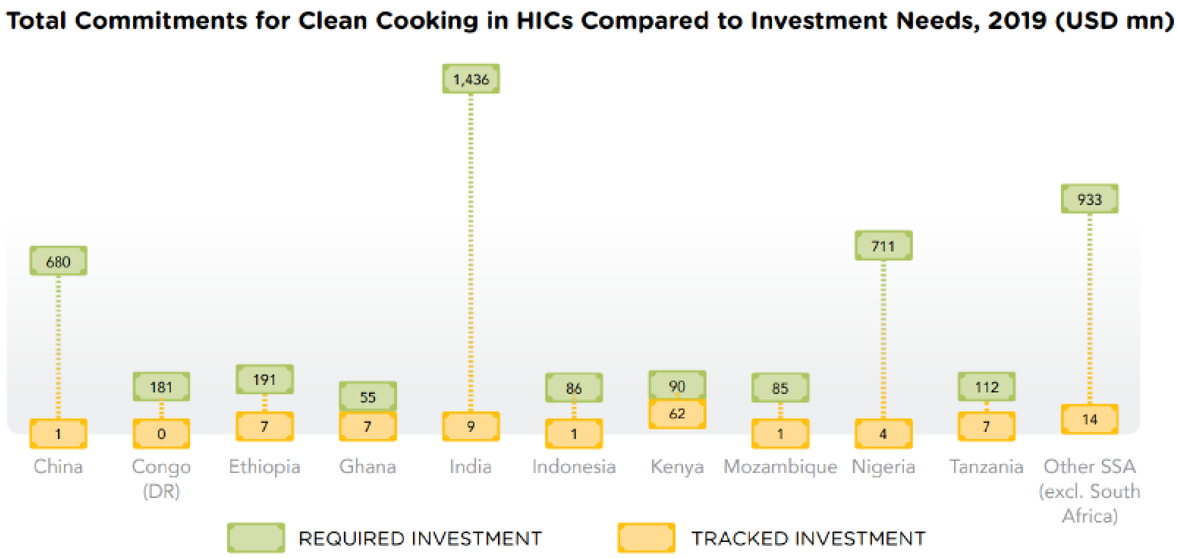

Figure 5: Funding commitment for clean cooking in HICs compared to investment needs (SE4All, 2021).

The main barriers to integrate clean cooking solutions (CCS) identified for the PURAMS target countries are presented in table 1.

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Kenya	Rwanda	Mozambique
High implementation / technology costs.	High implementation / technology costs.	High implementation / technology costs.
Lack of awareness and illiteracy.	Lack of awareness and limited access to Clean Cooking Solutions (CCS).	Lack of awareness and limited access to the Clean Cooking Solutions.
Poor engagement with stakeholders, hence resistance to the adoption of new cooking tools/methods.	Lack of alternative and supportive commercial instruments.	Limited access to after-sales services for modern energy-efficient electric cooking appliances, especially outside of the major cities.
Poor financial and political support.	Reduced availability of skilled human resources	Unreliable electricity supply and Low limited access to electricity amongst the rural population.
		Fiscal benefits for renewable energy investors, but not applicable to cooking.

Table 1: Main barriers identified to integrate CCS in the target countries.

1.2 Funding and business models

In what concerns the most used business models, a literature review points out "Pay as you go" models as the preferred ones and are mostly applied to Liquid Petroleum Gas (LPG) solutions (Perros, Tomei, & Parikh, 2024). This method is advantageous because, since most end-users are in rural areas where incomes are very low and unsteady, this type of scheme enables the users to manage their expenses according to their possibilities.

Other possible models are the "Tool-only" and "Tool and Fuel" models. The "Tool only" mechanisms refer to the companies that only sell the cooking equipment to the users, while with the "tool and fuel" mechanisms, the companies sell the equipment at low cost and celebrate a loyalty contract with the buyers, for the fuels, with, an average duration of three years. In this last case, the companies' revenue is mostly through selling fuels and related services. To ensure their profitability, "tool and fuel" companies celebrate protocols/agreements with large fuel companies to access lower fuel prices (MECS, 2022).

According to Modern Energy Cooking Services (MECS), business models following procedures such as "Tool-only", "Tool and Fuel" and "Pay as you go", or Pay-Go in case of products, have been applied in several high impact countries (including Kenya), showing that they can be a suitable solution to be replicated in other geographies (MECS, 2022).

A different program is the Pro Poor RBF project. This is a market-based financial support project in Rwanda, which seeks to accelerate access to electricity for low-income households in off-grid areas using targeted incentives. The companies apply for this project and receive a financial incentive per each solar home system they sell to an eligible household without electricity access in off-grid areas in pre-selected districts in Rwanda.

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This constitutes a way to promote solar power for any application, including cooking (Endev, 2024).

It is important to note that according to the experience of the stakeholders[1], there is a great demand for clean cooking appliances. However, due to the reality of the incomes for most of the population in the target countries being very low, this demand is based on loan supported purchases. This originates the adoption of very low interest rates on loans that are not proportionate due to the upfront cost. The best remedy for this is consumer finance. However, most of the appliances are not fitted with smart gadgets to aid in the "pay-go" initiative. Those fitted present extra operational and fitting cost. Thus, some of the stakeholders selling CCS, take the risk of selling out the appliances on credit. Although this might increase the numbers of CCS being used, it might not be sustainable since some of these stakeholders may go bankrupt due to high default rates in their clients' loans payments. Stakeholders complain that they either take the loan default risk, or risk being left out in the CCS sales campaigns. A sustainable e-cooking strategy must try to address this challenge.

Working with Microfinance Institutions (MFI) and Savings and Credit Co-Operative Societies (SACCOS) presents its own challenges, since most just stock and will give revenue once the products are sold and paid in full. Moreover, since this is not their main business, the products become secondary in their campaigns and don't sell as fast as other products. In this sense, there is a big challenge on how to overcome high default rates without subsidies or similar incentives and how to enable CCS suppliers to meet the end-users ability to pay, especially for companies that couldn't have access to programs such as the Clean Cooking Results-based Financing subsidy scheme in Rwanda.

2. Country Characterization

As previously mentioned, PURAMS targets three countries: Kenya, Mozambique and Rwanda. A socio–economic analysis of those countries was carried out to identify the relevant socio-economic boundary conditions for the development and implementation of clean e-cooking solutions and related business models. The following sections describe the different socio-economic aspects of each country.

2.1 Kenya

Socio-economic background and context

Kenya's population is projected to reach 51.52 million by mid-2023, with a GDP growth of 5.6%. Despite significant social and economic development, the country continues to face several challenges, namely a poverty rate of 38.6% as of 2023 (KNBS, 2021), income

[1] Information obtained on a Forum for Clean Cooking with the participation of some LEAP-RE partners. Not documented as it was the result of discussions.

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inequality, youth unemployment, issues with transparency and accountability, climate change, weak private sector investment, and overall economic vulnerability. Kenya's economy experienced a growth rate of 4.8% between 2015 and 2019 (WoldBank, 2024). However, in 2020, the COVID-19 pandemic adversely affected the economy, causing the growth rate to drop to -0.3% according to the Kenya National Bureau of Statistics (KNBS). The economy showed resilience and recovered in 2021, achieving a growth rate of 7.5%.

In the fiscal year 2023/24, national government revenues are projected to increase by 30%, with 88.6% of this revenue expected to come from taxes. The agricultural sector has shown improvement in 2023, growing by 7%, primarily due to fertilizer subsidies.

Energy system background and context

The energy supply in Kenya in 2023 is diversified, with 49% coming from renewable sources such as geothermal, hydro and wind power, 48% from household sources like firewood and charcoal, 1% from imports, and 2% from industrial sources (EPRA, 2021)

The electric system in Kenya uses energy sources such as geothermal, wind, oil, hydro, biofuels and solar. Kenya has a total installed power capacity of 2984 MW of which the largest source is geothermal energy with an installed capacity of 863.1 MW and one of the smallest is solar energy with 90.25 MW (EPRA, 2021). Except for the COVID pandemic year of 2020, primary energy production and consumption has increased. This increase has been driven by increased access, expansion of the economy and population growth .

Kenya has shown remarkable progress in enhancing electricity accessibility and using renewable energy sources that account for nearly 90% of the total energy production in 2021, compared to about 75% in 2017. Despite the rapid expansion of access to electricity in the last 10 years, reliability and access to electricity in rural and slum areas is a challenge (Wagner, Rieger, Bedi, Vermeulen, & Demena, 2021). Due to this, there has been a higher installation rate of Solar Home Systems in rural Kenya as this is the best alternative to grid power being a new opportunity for people in marginalized communities in off-grid areas [3]. In Kenya, various financing models are available to consumers for purchase of fuels. They include Pay-As-You-Go (PAYGO), Micro Financing and Bank Financing and Savings and Credit Cooperative Organizations (SACCOs) (MEPK, 2024), Fee-for-service and Hire purchase (ESRC, 2014).

Use of energy for cooking

In Kenya, 75% of the population use solid fuels, with 68% relying on wood, 7.8% on kerosene, and 23.9% on LPG (AECF, 2022). Despite a high adoption rate of renewable energy, only 3% of households cook with electricity . The type of energy used for cooking in Kenyan households is dependent on the socioeconomic status of the household. High socioeconomic status households use cleaner fuels for cooking such as electricity and LPG, while low income households use cheaper fuel like charcoal (SID, 2024).

The Kenyan Govt has been scaling up the LPG as a household fuel. 29 of the 47 counties in Kenya use firewood as the primary fuels source. The top 5 counties being Wajir (89.5%),

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Bomet(84%), West Pokot (87.9%), Elgeyo Marakwet (87.1%) and West Pokot (87.9%). Kerosene is mostly used in the counties: Mombasa (32.1%), Nairobi (26.5%), Machakos (11.1%), and Kajiado (12.7%). Charcoal is most commonly used in Tana River (31%), Lamu (27%), Nakuru (23.9%), and Isiolo (23.9%). LPG is mostly used in; Nairobi (67.2%), Kiambu (58.1%), Kajiado (47.2%) and Mombasa (37.5%) (MEPK, 2024).

2.2 Mozambique

Mozambique is located on the southeastern coast of the Indian Ocean, with an area of about 800 000 km^2, and a coastline of about 2 800 km. The country is very rich in natural resources, among which the following stand out: (i) About 5 650 000 ha of arable land, of which only 10% are being used; (ii) Water resources, being the country crossed by about 100 hydrographic basins, some originating in Mozambique and others in neighboring countries, with lakes and ponds in addition to groundwater. Additionally, the country is bathed by the Indian Ocean in an extension of about 2 800 km; (iii) Mineral resources, including heavy sands, granites, precious stones; (iv) Coal and natural gas; (v) Biological diversity, which translates into rich ecosystems; (vi) Renewable energy resources (the country has solar, wind, hydro, geothermal, oceanic, biomass energy, among other forms of renewable energy); and (vii) Forests (the country has extensive areas of native forest).

Historically, Mozambique is the country most affected by natural disasters in the Southern African region. Mozambique has recorded a total of 53 disasters in the last 45 years, representing an average of 1.17 disasters per year. These disasters displaced 500 000 people, destroyed infrastructures and had a very negative impact on the national economy. The main disasters faced are of a meteorological nature, mainly droughts, floods, cyclones and storms (MICOA, 2007).

The country has comparative advantages in many areas, of which the following stand out, among others (i) Extremely privileged strategic location, as it is the natural way out for most of its landlocked Neighbors; (ii) Ecosystems that allow you to have coastal and inland tourism; (iii) Neighborhood with South Africa, a regional power.

Socio-economic background and context

The total population of the country in 2020 was estimated at 32 163 000 inhabitants (INE, 2023). The population density was 39.75 inhabitants per square kilometer and the annual growth was 2.88%. The population living and working in rural areas is around 67%. Mozambique is one of the poorest countries in the world, ranking 181 out of 189 countries (2020) in terms of the human development index (DW, 2022). Gross domestic product (GDP) in 2020 was US$450, which is low compared to many other countries in the region, with neighboring Malawi having a GDP of US$407, Zambia US$981, Tanzania at US$1 090 and Eswatini at US$3 504. The main diseases that affect the country are malaria, anemia in children and HIV/AIDS. The average level of schooling is 3.5 years, and the adult literacy rate is 60.7% (KNOEMA, 2022). The total population with access to potable water is 50.3 % (UNICEF, 2022), and with access to energy from the national electricity grid is 35%.

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Energy system background and context

Mozambique is rich in both fossil fuel based and renewable energy-based resources. Mozambique holds 1 975 million tons (MMst) of proven coal reserves as of 2016, ranking 26th in the world (Worldometer, 2022). Mozambique holds 100 trillion cubic feet (Tcf) of proven gas reserves as of 2017, ranking 14th in the world and accounting for about 1% of the world's total natural gas reserves of 6 923 Tcf (Worldometer, 2022). As far as renewable energy resources potential is concerned, solar is the most abundant one, with 23 000 GW, hydro with 18 GW, wind with 4.5 GW, and biomass with 2 GW (EnergyPedia, 2022).

Mozambique's electric power balance in 2019, was constituted by 85% of hydroelectric energy, 14% of natural gas and 1% of solar energy (CountryEconomy, 2022). However, over the last decade, Mozambique has started to actively develop its large reserves of coal, natural gas and hydropower. Once developed, Mozambique can become a major player in regional and global energy markets.

Over the last two decades, Mozambique's energy balance already shows a considerable expansion of the energy sector, unprecedented in the country's history. Since 2000, on average and by approximation, energy production has increased by 6% a year, imports by 10%, exports by 20% and final consumption by 4% (CountryEconomy, 2022). This expansion is largely driven by developments in the natural gas and electricity markets. Despite the emerging production and use of modern forms of energy, traditional biomass energy sources (firewood and charcoal) still dominate Mozambique's energy balance: it currently represents more than 60% of final energy consumption. About 95% of the total energy demand of families are still met with firewood and charcoal. In urban areas, charcoal quickly became the predominant fuel, accounting for approximately 50% of all energy consumption expenditures. Currently, households are responsible for around 60% of total energy consumption, followed by the transport sector (30%) and industry (8%).

In recent years there have been initiatives to promote programs to increase, the access to energy services in areas not covered by the national electricity grid, in line with the Gobal Agenda 2030. Significant efforts to develop regulatory instruments for the energy sector have been taking place.

Use of energy for cooking

Energy for household cooking accounts for the major fraction of household energy demand in Mozambique. In Mozambique, biomass is the main source of household energy (Mudombi, et al., 2018). The most common source of household energy for cooking is biomass. Indeed, Urban households are heavily dependent on biomass, with charcoal being the most used biomass fuel, either exclusively or in combination with other cooking fuels such as firewood, LPG and/or electricity. In the purely rural settlements, the most common source of energy for household cooking is firewood. Special circumstances may result in the adoption of livestock manure, crop residues, agricultural wastes and forest residues as

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cooking fuels. The Mozambican main cities were found to be charcoal-reliant as follows: Maputo and Matola 87%, Beira 85% and Nampula 92%, used either exclusively or in combination with LPG, electricity or firewood. The city of Maputo had also another energy source: ethanol (Mudombi, et al., 2018).

Use of clean cooking solutions

There had been efforts to shift from unsafe cooking fuels and devices to cleaner and efficient cooking fuels and devices. These included ethanol stoves, improved cook stoves and good cooking practices. Indeed, ethanol cook stoves have been widely spread in Maputo by the Ethanol and Cooking Fuel Project (CleanStar, Lda) (Atanassov, Andrade, Falcão, Fernandes, & Mahumane, 2012). Apart from this initiative, different projects introduced cleaner and more efficient charcoal/firewood cook stoves in Maputo funded by different organizations. Therefore, cleaner cooking solutions are fairly known in urban households. However, for different reasons, low acceptance has been achieved in the rural areas. As an example, in Maputo urban households, 96.12% use charcoal for cooking with around 30% using only charcoal. The remaining households combine charcoal with LPG (32.8%), electricity (22,9%), ethanol (17%) or firewood (12%) (Mudombi, et al., 2018). The rest of the country is more reliant on biomass fuels than Maputo and has fewer modem fuels alternatives available.

2.3 Rwanda

Rwanda is a small land-locked country of 26 338 km^2 in in the Eastern part of Africa. Its territory is divided in five provinces, namely Northern, Southern, Eastern, Western and Kigali City province, corresponding to its capital, the City of Kigali. Despite its small size, it is a densely populated country in comparison to other African countries. The National Institute of Statistics of Rwanda projects the country population at 12.9 million in 2021 (NISR, 2021). In 2020, Gross Domestic Product was estimated at 823 USD/capita, ranking 180 in the world. Despite a convulse recent history, Rwanda has made significant achievements in its recovery since the 1994 Genocide against the Tutsi. In the last decade, the country has experienced important socio-economic progress with a rapid and consistent economic growth rate (average annual growth of 7.2%, among the fastest in the world) coupled with substantial progress in poverty reduction, which fell from 77.2% in 2001 to 55.5% in 2017, according to the latest Integrated Household Living Conditions Survey (EICV5) (NISR, 2018). Rwanda has become a frontrunner among African economies in the 'Ease of Doing Business' indicators, moving from a global rank of 148 in 2008 to 38 in 2020, which is second in Sub-Saharan Africa after Mauritius (WorlBank, 2019).

According to Vision 2050 (MINALOC, 2015), the country's long term strategic plan, Rwanda aims to become an upper-middle-income country by 2035 and high-income country by 2050, guided by the Sustainable Development Goals (SDGs), the Africa Union Agenda 2063 (AfricanUnion, 2023) and the East African Community Vision 2050 (EAC -2050). To achieve this long-term vision, the GoR laid out a seven-year implementation instrument, the National Strategy for Transformation (NST) in 2017 (GoR, 2017). The objective of the NST

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is to lay the foundation for decades of sustained growth and transformation that will accelerate the transition towards high standards of living for all Rwandans. The first phase, NST 1 (2017- 2024), continues the efforts set out by the previous Economic Development and Poverty Reduction Strategy (EDPRS 2, 2013-2018) policy (GoR, 2013), with the development of the private sector at the helm (GoR, 2017). The NST 1 is based on three pillars: economic transformation, social transformation and transformational governance. With this new strategy, Rwanda's public policy will focus on developing and transforming Rwandans into capable and skilled people ready to compete in a global environment. The NST 1 is composed of Sector Strategic Plans covering specific areas such as education, energy, health, and agriculture. The NST also includes District Developments Strategies integrating national and sectoral priorities with the local policies and specificities of each province. Energy is a cross-cutting area of focus under both the economic transformation pillar and social transformation pillar, with targets in generation, quality and reliability of supply, and access.

Rwanda is a country of few natural resources, and the economy is based mostly on subsistence agriculture by local farmers using simple tools. An estimated 90% of the working population farms, and agriculture comprised an estimated 42% of GDP in 2010. Crops grown in the country include coffee, tea, pyrethrum, bananas, beans, sorghum and potatoes. Coffee and tea are the major cash crops for export, with the high altitudes, steep slopes and volcanic soils providing favourable conditions. Reliance on agricultural exports makes Rwanda vulnerable to shifts in their prices. By 2002 tea became Rwanda's largest export, with export earnings from tea reaching US$18 million equating to 15 000 tons of dried tea. Rwanda's natural resources are limited. A small mineral industry provides about 5% of foreign exchange earnings. The economy of Rwanda has undergone rapid industrialisation due to a successful governmental policy. Since the early-2000s, Rwanda has witnessed an economic boom, which improved the living standards of many Rwandans.

Energy system background and context

Rwanda has undertaken reforms in the energy and water sector which have been concretized by the separation of energy from water operations. The main objectives being: to have sector focused and efficient operations; attract more investment; improve planning and accountability; and increase access to services by the population to drive sector performance towards the targets envisaged in the EDPRS II and other national goals.

To this end, the government adopted the corporatization model as a vehicle to implement the required reforms. The law repealing EWSA Law of 97/2013 of January 31, 2014 paved the way for the creation of two corporate entities which were subsequently incorporated in July 2014 with 100% government shareholding. The Rwanda Energy Group Limited (REG) and its two subsidiaries; The Energy Utility Corporation Limited (EUCL) and The Energy Development Corporation Limited (EDCL) entrusted with energy development and utility service delivery while the Water and Sanitation Corporation (WASAC) has the mandate to develop and operate water and sanitation infrastructure and deliver related services in the country.

The objective of creating these subsidiaries amongst others was to ensure focused attention to enhancing efficiency in utility operations on one hand and ensure more timely and cost efficient implementation of development projects on the other. Moreover, the REG

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holding structure provides the overall coordination and ensures effective development of energy and investment plans.

The installed power capacity in Rwanda is at 238.36 Megawatt [MW] (REG, 2021), and the energy mix is made up by Hydro, Diesel & Heavy Fuel, Methane gas, eat, Solar and imports.

The total installed power of 238.36 MW is not steadily available. The operation of the hydro units is limited by the water level in the upstream and their interdependence, and hydro availability lowers significantly during the dry season. In addition, the Photovoltaic Solar capacity is not significantly available during the evening peak hours. Further, losses are incurred on the transmission and distribution lines (about 2 per cent of the total installed power) and some of the units may be unavailable during certain periods due to maintenance or failure.

Use of energy for cooking

The National Energy Policy and Strategy recognizes the use of traditional cooking technologies as having serious hazardous environmental implications when not properly managed. In this regard, it is imperative that forests and woodlots be more productively managed, and charcoal consumption more effectively reduced with the use of clean cooking technologies.

The current national cooking technologies balance statistics show that biomass (mostly wood fuel) account for about 83% of the total cooking energy consumption, followed by petroleum at 9.7%, electricity at 1.3%, and others at about less than 0.5%. In rural areas, the reliance on biomass is over 90%. Most Rwandans live in rural areas where traditional biomass, mainly wood fuel has remained the leading source of energy for cooking. The average household uses around 1.8 tons of firewood each year to satisfy its cooking needs with a traditional stove. The average monthly consumption per household on fuelwood is RWF 1 930.

Private sector-led efforts are distributing cookstoves that are up to three times more efficient than the traditional 3-stone stove and can reduce biomass consumption by anywhere between 68% to 94%. If effectively applied, this will free up the time spent by women and children in collecting firewood, giving them more time to study and undertake more productive commercial activities.

Improved cooking stove (ICS)

An improved cooking stove (ICS) is a stove that needs far less biomass than a traditional stove to cook the same amount of food and consequently also produces far less smoke than a traditional stove. This reduction in smoke is made by either having far better combustion or by having an excess of air, or with a combination of both. It can save up to 75% of fuelwood compared to the traditional stoves. It is cheap and easy to operate, there is no need to blow the fire. ICSs save on fuel and improve hygiene in the kitchen and

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provide direct benefits to the women and girl children by reducing the time and drudgery related to procuring firewood.

In Rwanda, ICS has now become a government policy whereby efforts are being made so that it can be widely used in rural communities. EPD has 9 operational member companies who have managed to manufacture and distribute 394,239 ICSs since 2016 up to now.

Biogas

Since 2008, the Government of Rwanda announced a policy to introduce biogas digesters in all schools (estimated at around 600), large health centers, and institutions with canteens. Through this Institutional biogas program, 86 Institutional biogas digesters were constructed in secondary schools and prisons. Since the beginning of the program, 10 200 domestic biogas digesters have been installed in households.

EPD has 2 operational member companies in the Biogas business who installed 8 677 domestic biogas digesters to households and public institutions and monthly expenditure is estimated at RWF 9 024. From 2016 up to now, the biogas systems installed in the schools and prisons have reduced firewood consumption by close to 60% and 40% respectively, along with significantly improved hygienic conditions and cost savings.

Pellets and briquettes

The promotion of pellets and briquettes is another proposed intervention of biomass dependence reduction strategy to move from 83% to 42% by 2024 and this would be done through:

- Providing technical support to pellets and briquettes producers and carrying out extensive decentralized awareness campaigns.
- Attracting the private sector to develop pellet and briquette-making factories and training producers to make quality products.
- Facilitating factories to access raw materials (e.g providing forest concessions to pellets makers)

The household monthly expenditure of pellets and briquettes is estimated around RWF 9 277.

Use of clean cooking solutions

Rwanda Energy Group (REG), in partnership with its stakeholders, is carrying out a countrywide awareness campaign on the use of safe, effective and clean cooking technologies to ensure that Rwanda meets its targets to reduce the use of biomass energies to cook in households.

Extensive use of biomass energy has potentially serious environmental implications and may be non-renewable unless properly managed. In this regard it is imperative that forests and woodlots be more productively managed, and charcoal more efficiently produced.

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Failure in this realm could result in accelerated deforestation as the demand for energy due to the increasing population increases.

The energy policy proposes more efficient production and use of biomass energy by households and that this should be complemented by promoting other sources of energy, including biogas, pellets, briquettes and LPG.

Liquefied Petroleum Gas (LPG)

Rwanda has no domestic production of natural gas. The country relies on imported gas especially LPG from other countries. The LPG market in Rwanda is dominated by 10 importers including Société Pétrolière-SP, Kobil, Sulfo Rwanda, Rwanda Oxygène, Merez, Hashi energy, Abbarci Petroleum, Safe gas Lake Petroleum Rwanda, RUCSA Investment. Retail distribution is done through service stations, independent distributors, and supermarkets in an assortment of cylinder sizes ranging from 3 kg to 50 kg and also the tanks from 500 kg to 5 000 kgs are available for big Institutions.

The use of LPG has started to attract the attention of cooking energy consumers but its penetration has not yet reached a satisfactory level to see its impact on the reduction of biomass use. At household level, the progress is promising, looking at the quantity of the imported LPG and sales of the companies involved in this business and increase in the use of LPG in institutions, which before was quite inexistent in public institutions with bigger consumption amount of firewood that contributed significantly to deforestation. A national survey report published on 08/12/2020 by the Centre for Economic and Social Studies in partnership with the European Union on Cooking Fuel Energy and Technologies in Households, Commercial and Public Institutions in Rwanda, showed public institutions' LPG annual consumption as found in the table 2:

Institution	Consumption [Kg]
Restaurants	1 359 413
Hotels	1 337 470
Police Stations	163 860
Military Camps	89 280
Refugee Camps	21 396
Boarding Schools	18 996
Prisions	360

Table 2: LPG annual consumption in Rwanda

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3. Technical assessment of photovoltaic powered electric pressure cookers

A technical and economic assessment of photovoltaic powered electric pressure cookers (PVPEPC) was developed to support the development of business models. The assessment took into consideration information collected in the surveys and the experimental campaigns carried out in Kenya and Rwanda to derive average consumption profiles and establish average costs with energy for meal preparations. The PVPEPC was modelled in TRNSYS v18 (Klein, 2017) and a simulation study was performed for different PVPEPC configurations to analyse the ability of the system to cover the profile demand and estimate a simplified return of investment period. Economic analysis is presented in section 4 of this document.

3.1 Energy demand profiles

An experimental data collection campaign was carried out in Kenya (from June 2021 till January 2022) and Rwanda (from June 2022 till September 2022) to assess the electricity demand of EPCs operated under real use conditions. EPCs and smart meters were distributed through selected households in both countries. Information about the electricity consumption of EPCs was collected and processed for 105 households in Kenya and 50 households in Rwanda (Cardoso, et al., 2023).

The resulting information was used to establish typical demand profiles as follows. The average daily profile of the energy consumption of each household was determined from the data collected in the experimental campaign. The first step involves determining, for each household and hour, the average consumption and the total number of uses. Then, a time-based filter was used to purge the hours corresponding to sporadic uses of the EPC from the profiles. It was assumed that if fa household did not meet a certain number of usages in a specific hour, the average energy value for that hour would be set to zero. This approach aims to reduce the sporadic nature of the usage, which is not the focus of the business plan that targets a regular use of the EPCs.

A statistical clustering technique, k-medoids (Park & Jun, 2009), was applied to the filtered daily profiles aiming to cluster households with similar consumption patterns. For each cluster, the most representative household was identified considering the group median, i.e., the consumption of a specific household. The hourly consumption for this representative household was then determined for each day of the week, and it was assumed that these consumption patterns remain consistent throughout the entire year for the same day of the week.

The Calinski-Harabasz (CH) criterion (Calinski & Harabasz, 1974) was used to determine the optimal k value. For both Kenya and Rwanda the optimum number of household clusters was identified as 4, however, for Rwanda only 3 profiles will be considered in the analysis, since one of the profiles (*Rwanda–3*) corresponds to a cluster of households with very little or significantly dispersed utilization of the EPC. Therefore, the simulation study

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will consider 4 different demand profiles for Kenya and 3 for Rwanda. Table 3 presents the percentage of households from the experimental campaign that correspond to each cluster and each cluster's average, minimum and maximum daily energy consumption for cooking with EPCs.

Country - Cluster	Households distribution [%]	Average daily energy consumption [kWh]	Minimum average daily energy consumption [kWh]	Maximum average daily energy consumption [kWh]
Kenya – 1	44	0.922	0.532	1.063
Kenya – 2	17	0.427	0	0.817
Kenya – 3	16	0.794	0.509	1.093
Kenya – 4	23	0.411	0.282	0.477
Rwanda - 1	23	1.032	0.689	1.426
Rwanda – 2	16	0.602	0.323	0.944
Rwanda – 3	18	N/A	N/A	N/A
Rwanda - 4	43	0.865	0.216	1.237

Table 3: Main characteristics of the energy demand profile clusters

Kenyan's cluster 1 and 3 present higher average, minimum and maximum daily energy consumption in comparison with cluster 2 and 4. The average daily energy consumption across the 4 Kenyan household clusters varies between 0.411 kWh (cluster 4) and 0.922 kWh (cluster 1) with maximum average values ranging from 0.477 kWh (cluster 4) to 1.093 kWh (cluster 3). In Rwanda, the average daily energy consumption across the 3 household clusters varies between 0.602 kWh (cluster 2) and 1.032 kWh (cluster 1) with maximum average values ranging from 0.944 kWh (cluster 2) to 1.426 kWh (cluster 1). Another noticeable feature of the collected and processed data is the fact that although the average daily energy consumption in both countries present similar maximum values, around 1 kWh, the maximum value of the average daily energy consumption is higher in Rwanda (1.426 kWh) than in Kenya (1.093 kWh).

Figures 6 presents the average daily demand profiles for Kenian households. Cluster 1 profile, associated with approximately 44% of the surveyed households, is characterized by the existence of two periods of electricity demand for cooking during all 7 days of the week. The first period occurs in the morning period, between 9h00 and 11h00 and a second period at the end of the day, between 19h00 and 22h00. Cluster 2 profile (17% of surveyed households) presents a single energy demand period during the morning hours, between 7h00 and 9h00 during all days of the week except for Saturday, when no energy demand is registered, and Sundays, when on average very little energy is required for cooking. Cluster 3 profile (16% of surveyed households) has two energy demand periods, the first

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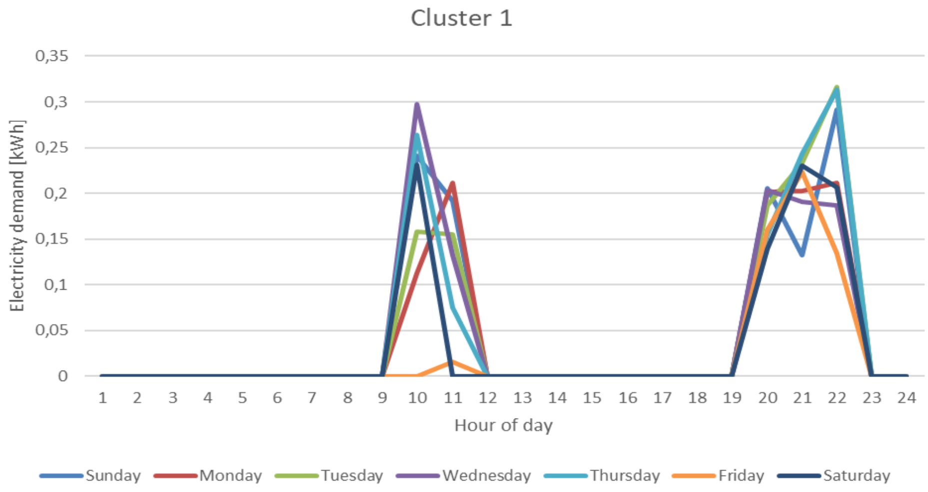
one during the mid of the day, around lunch time, between 12h00 and 14h00 and the second at the end of the day, during dinner time, between 19h00 and 20h00. Finally, cluster 4, associated with approximately 23% of the surveyed households, has a profile with two periods of electricity demand for cooking, the first between 13h00 and 15h00 and the second between 20h00 and 22h00.

Assuming that for each period corresponds the preparation of one meal, the number of meals prepared in a year per cluster profile is the following: cluster 1 - 730 meals; cluster 2 – 313 meals; cluster 3 - 678 meals; cluster 4 – 730 meals.



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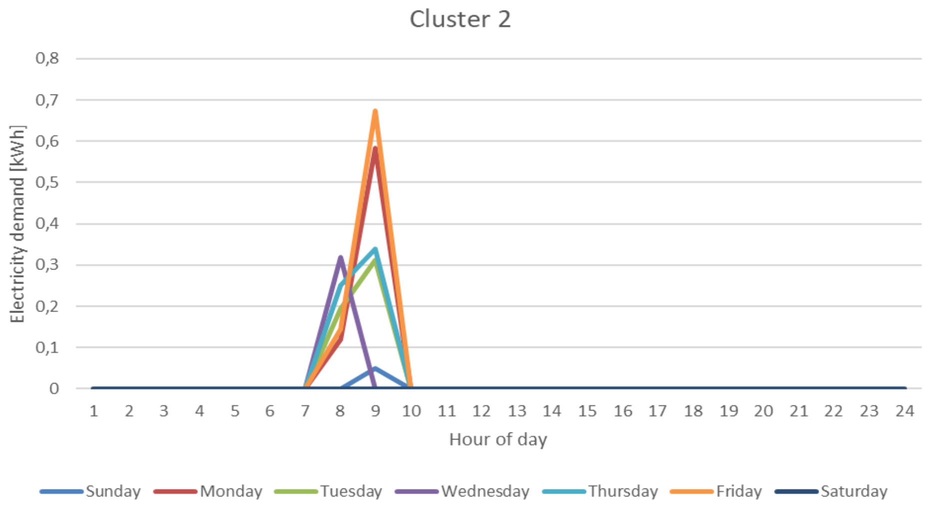

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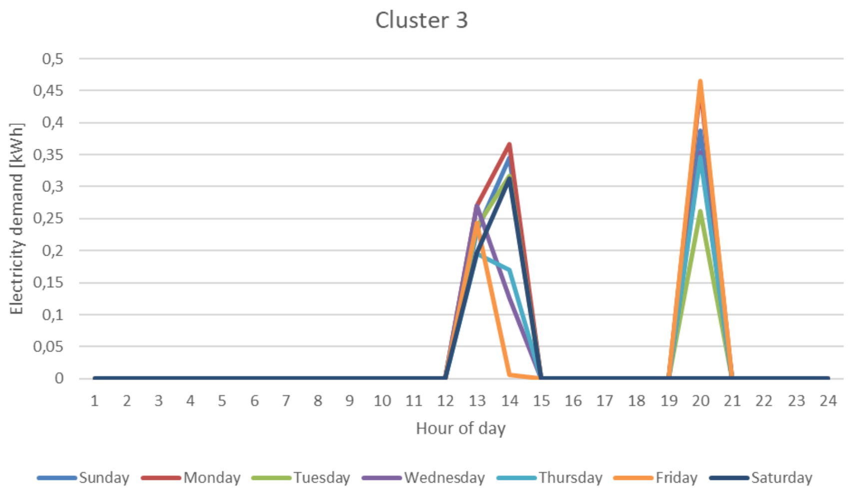

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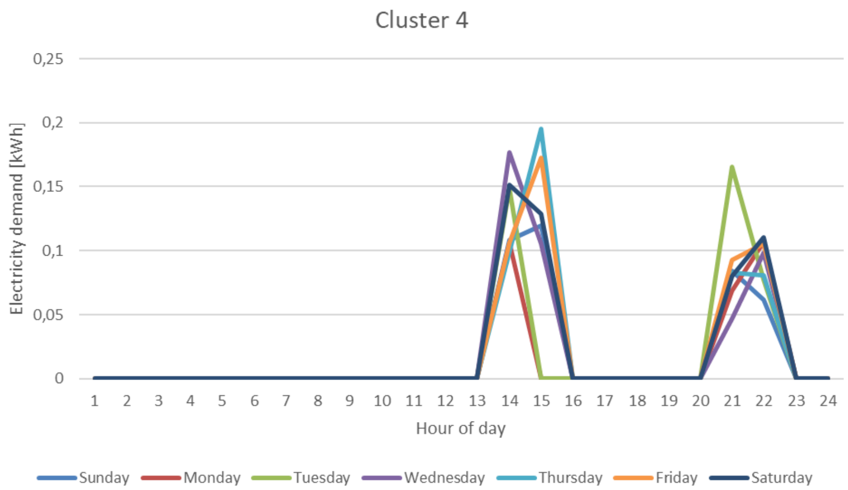

(d)

Figure 6: Average daily demand profiles for Kenian households

Figure 7 presents the average daily demand profiles for Rwandan households. Cluster 1 profile, associated with approximately 23% of the surveyed households in Rwanda, is characterized by the existence of one period of electricity demand for cooking during all 7 days of the week, between 19h00 and 22h00. A second peak occurs around lunch time, between 12h00 and 13h00, on Mondays, Wednesdays, Thursdays and Saturdays and a third peak occurs on all days, except Sunday and Wednesday, between 15h00 and 16h00.

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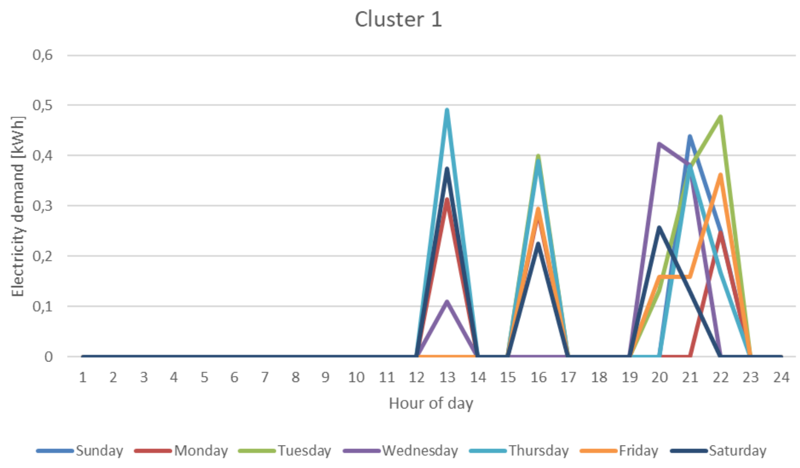

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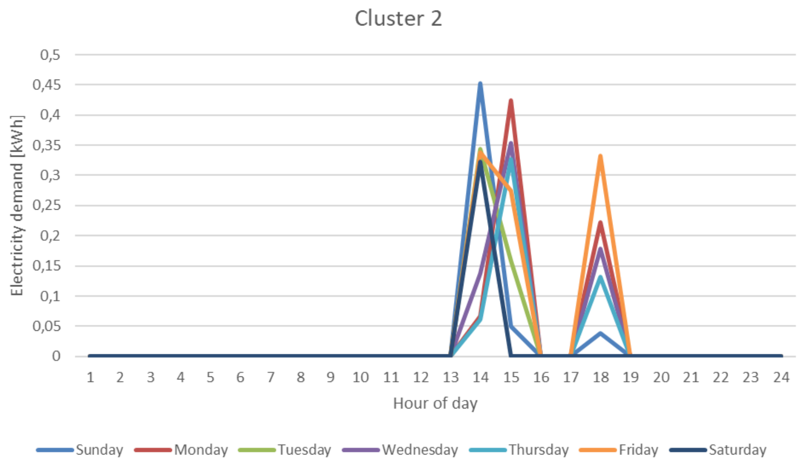

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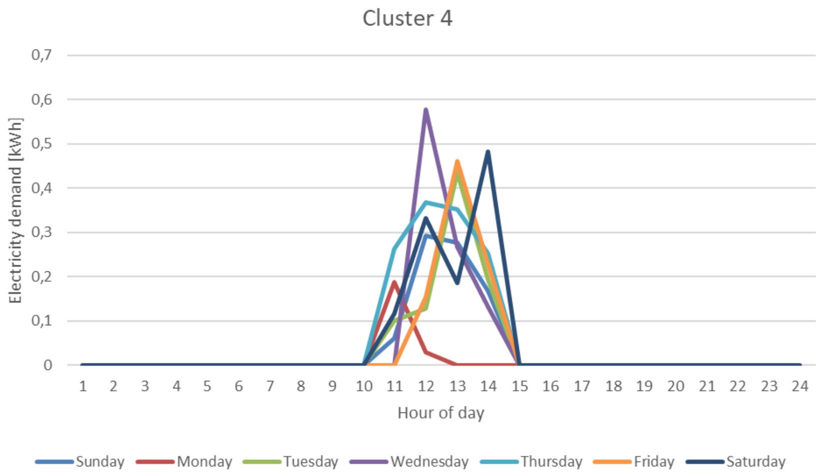

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Figure 7: Average daily demand profiles for Rwandan households

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Cluster 2 profile (associated with 16% of surveyed households) presents two demand periods, the first between 13h00 and 15h00, occurring all days of the week, and the second between 17h00 and 18h00 occurring all day of the week with the exception of Tuesdays and Saturdays. Finally, cluster 4 (encompassing 43% of the surveyed households) presents a single peak during the middle of the day, occurring between 10h00 and 14h00.

Assuming that each period corresponds to the preparation of one meal, the number of meals prepared in a year per cluster profile is the following: cluster 1 - 834 meals; cluster 2 – 626 meals; cluster 4 - 365 meals.

3.2 PVPEPC systems

As discussed in a previous PURAMS report (Couto, et al., 2022), the basic design of a PVPEPC consists of (a or set of) PV panels (with the respective mountings) connected by electrical cables to a regulator and this equipment to the electric pressure cooker. If AC cookers are used, an inverter is also required, however, since the prototypes developed under the PURAMS project all use DC EPCs (Banda, et al., 2024), no inverter is considered.

A previous study (Cardoso, et al., 2023) showed that even for scenarios with high installed solar capacity, storage solutions are required to enable the PVPEPC system to supply more than half of the demand for cooking meals. Thus, for this assessment, all systems under consideration include batteries.

Figure 8 presents the basic layout of the PVPEPC system considered for the purpose of this technical and economic assessment. The electricity generated by the PV modules (A) is directed to a charge regulator (C) that controls the energy flow of the system and ensures the PV modules operate at every moment at their maximum operating point. If there is electricity demand from the load (B) the regulator directs energy from the PV panels and, if needed, from the battery (D) to the load. If the battery is not charged and energy is available from the PV panels, the regulator enables the charging of the battery. Finally, if the battery is charged above its minimum operating state of charge and there is not enough energy coming from the PV panels, the charge regulator enables the discharge of the battery in order to provide the load with enough energy.

The main equipment characteristics were set taking into consideration the energy demand profiles derived from the data collected during the experimental campaign and the equipment used in the development of the prototypes. Tables 4, 5 and 6 present the main characteristics of the equipment considered for the purposes of this analysis.

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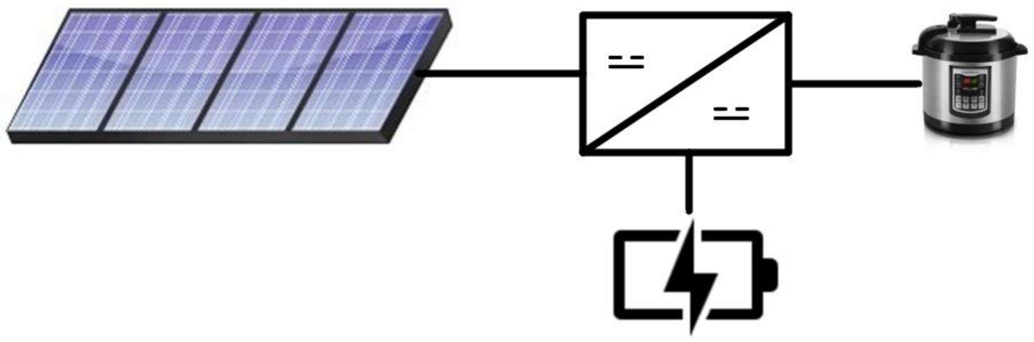

Figure 8: Basic layout of the PVEPC system

Parameter	Value
Exterior dimensions	1 722 mm x 1 134 mm
Total surface	1,95 m2
Nominal STC power (P_{mpp})	405 W
Open Circuit voltage (V_{oc})	37,23 V
Short circuit current (I_{sc})	13,87 A
Nominal STC power (P_{mpp})	405 W
PV Module Efficiency	20,7 %
Number and type of cells	108 monocrystalline half cells
Temperature coefficient of P_{mpp}	-0,35 %/K

Table 4: Main characteristics of the PV panel considered for this assessment

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Parameter	Value
Type	Valve regulated lead–acid (VRLA)
Nominal voltage	12 V
Number of cells	6
Nominal Capacity C_{100}	300 Ah
Capacity C_{10}	250 Ah
Exterior dimensions	522 mm x 268 mm x 225 mm

Table 5: Main characteristics of the battery considered for this assessment

Parameter	Value
Nominal battery voltage	12 V, 24 V, 48 V
Nominal PV power	860 W, 1720 W, 3440 W
Max PV open circuit voltage	150 V
Max PV charge current	60 A

Table 6: Main characteristics of 60 A regulator considered as reference for this assessment

For the viability assessment, 4 different PVPEPC systems were designed, being their main characteristics presented in Table 7. System A corresponds to a system with a single 405 W PV module connected to a 35 A charge controller and a 3.6 kWh battery bank. System B corresponds to a system with two parallel connected 405 W PV modules linked to a 70 A charge controller and a 3.6 kWh battery bank. System C corresponds to a system with two parallel connected 405 W PV modules linked to a 35 A charge controller and a 7.2 kWh battery bank. Finally, system D corresponds to a system with three parallel connected 405 W PV modules linked to a 60 A charge controller and a 7.2 kWh battery bank.

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Equipment	System A	System B	System C	System D
System voltage [V]	12	12	24	24
PV modules [W]	405	810	810	1 215
Battery bank [kWh]	3.6	3.6	7.2	7.2
Charge Controller [A]	35	70	35	60

Table 7: Main characteristics of the PVPEPC systems

Table 8 presents the costs in Euros associated to each system. The costs vary between approximately 1 000€ to 2 000€ and are based on equipment market prices identified in May 2024.

Costs [€]	System A	System B	System C	System D
PV Modules	165	330	330	495
Battery bank	410	410	820	820
Charge controller	245	490	245	420
Cables, accessories and structures	77	111	124	158
Total PV system	**897**	**1341**	**1519**	**1893**
EPC	100	100	100	100
Total PVPEPC System	**997**	**1441**	**1619**	**1993**

Table 8: Costs of PVPEPC systems

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3.3 TRNSYS model of a photovoltaic powered electric pressure cookers

A TRNSYS model was developed to simulate the PV systems that power the EPCs for each combination of systems / demand profiles, enabling the study of their performance and behaviour. The layout of this model and the main model constituents can be seen in figure 9 and table 9, respectively.

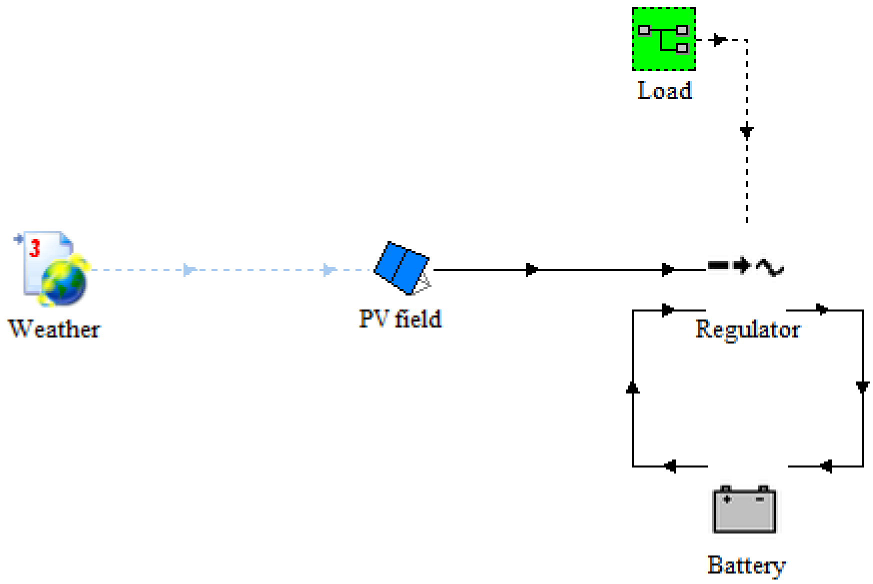

Figure 9: Layout of the TRNSYS model developed to simulate PVEPC systems

Name	TRNSYS type	Description	Function
Weather	15	Meteorological data reader and radiation processor	Reads and processes the weather file of the location, providing radiation values, solar angles, temperatures and wind velocity.
PV field	190	Array of photovoltaic modules	Models the photovoltaic modules array, yielding its electrical performance and produced electricity.
Regulator	48	Charge regulator	Manages the DC power from the PV field to a battery bank and from the PV field and battery bank to the load.

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Battery	47	Lead-acid battery bank	Models the operation of a battery bank, specifying how the battery state of charge varies over time.
Load	9	Data reader	Determines the load demand by reading and interpolating hourly load profiles.

Table 9: TRNSYS model main constituents

The simulation was performed for a typical meteorological year (TMY) and different load profiles (corresponding to cluster profiles developed from the experimental campaign data). Although the meteorological and load profile data have hourly time steps, the simulation was performed with a 5-minute time step, being the input data interpolated as needed by the model components.

Meteorological data

The model identifier in TRNSYS (Type) 109 was used to process meteorological data provided in a TMY3 file generated with Meteonorm v8 for two locations corresponding to the areas where the experimental campaigns occurred: location between Kisumu and Kericho in Kenya (0°11'02.4"S 34°57'39.6"E) and a location between Nyamata and Mwogo in Rwanda (2°06'57.6"S 30°07'48.0"E). According to this data, yearly global horizontal irradiation (GHI) reaches 2376 kWh/m^2 and 2085 kWh/m^2 in the Kenyan and Rwandan sites, respectively, with an uncertainty of 4%. Figure 10 presents the GHI monthly distribution for both sites.

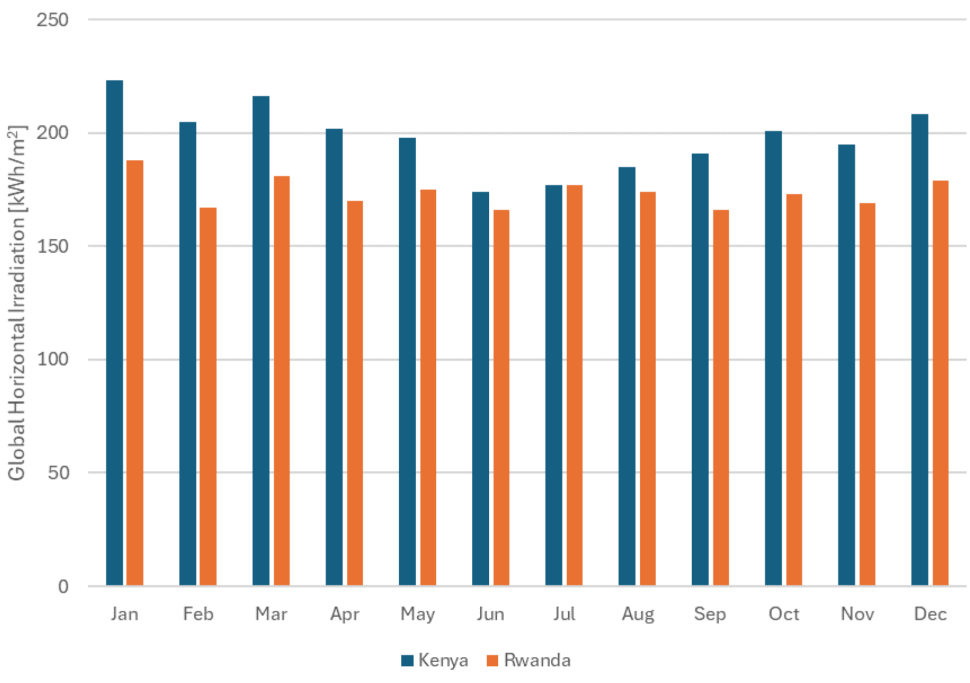

Figure 10: Monthly distribution of the global horizontal irradiation

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PV field

Type 190 was used to model an array of PV modules with the characteristics presented in Table and subject to a maximum power point tracking. The array orientation is identical in both locations and the PV modules are assumed to be oriented towards the equator with an inclination of 5º, maximizing the annual electricity generation, while ensuring some inclination remains to help the cleaning of the PV modules during raining periods. Soiling effects and degradation of the PV modules are not considered in the model or the analysis of the data. Therefore, the results will correspond to a best-case scenario for solar electricity generation.

Battery bank

Type 47 was used to model the operation of the battery bank composed of lead-acid batteries with the characteristics presented in Table 4. This type models the battery state of charge and its variation over time, given the rate of charge or discharge imposed by the regulator following the Hyman battery model (modified Shepherd equations).

Regulator

Type 48 was used to model a charge regulator with the characteristics presented in Table 5. This type models a charge regulator with maximum power point tracking and battery state of charge and voltage monitoring. It takes into account the limits of the battery bank voltage when charging and discharging, as well as the charge and discharge rates and its fractional state of charge (maximum, minimum).

3.4 PVPEPC simulation study

A set of simulations were performed using the presented TRNSYS model in order to study the behavior of the PVPEPC and its yearly performance for different configurations and load profiles. A parametric study was performed using the PVPEPC systems presented in Table 6 to determine the influence of the peak power of the PV system (i.e. the number of PV panels), the battery bank capacity and the load demand profile.

Technical viability assessment

Kenya

For Kenya, a total of 16 simulations were performed for a typical meteorological year, corresponding to the application of the 4 PVPEPC systems to the 4 demand profiles established for this country. Table 10 presents the results of the annual simulations performed for Kenya in terms of energy.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

System/ Profile	Load demand [kWh]	Energy to load [kWh]	Curtailed PV Energy [kWh]	Energy gap [kWh]	Satisfied meals [%]
A / 1	336,03	331,44	0,00	4,59	94.25
B / 1	336,03	336,03	389,82	0,00	100.00
C / 1	336,03	336,03	419,42	0,00	100,00
D / 1	336,03	336,03	1 263,03	0,00	100,00
A / 2	156,11	156,11	671,83	0,00	100,00
B / 2	156.11	156.11	1 537.95	0.00	100.00
C / 2	156.11	156.11	1 537.22	0.00	100.00
D / 2	156.11	156.11	2 401.13	0.00	100.00
A / 3	289.81	288.35	0.00	1.46	98.67
B / 3	289.81	289.66	74.50	0.15	99.85
C / 3	289.81	289.66	0.00	0.15	99.85
D / 3	289.81	289.81	705.87	0.00	100.00
A / 4	150.26	150.26	340.84	0.00	100.00
B / 4	150.26	150.26	1 191.49	0.00	100.00
C / 4	150.26	150.26	1 199.66	0.00	100.00
D / 4	150.26	150.26	2 055.01	0.00	100.00

Table 10: Annual simulation results for Kenya load profiles - energy: load demand, energy delivered to load, curtailed PV energy, missing energy for cooking and percentage of satisfied meals

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The simulation results show that there are only four scenarios (combinations of systems with profiles) where the PVPEPC is unable to provide for all meals. Those scenarios only occur for the first and third demand profiles. However, even in the worst scenario (system A / profile 1) the PVPEPC can provide up to approximately 94% of the meals (688 out of 730). The other 3 cases have the system providing more than 98% of the meals (system A / profile 3) and nearly 99,9% of the meals, i.e. all meals of the year but one (system B / profile 3 and system C / profile 3). All scenarios, with exception of system A / profiles 1 and 3 and system C / profile 3, yield an excess of PV electricity production that has to be curtailed. This excess can be used to accommodate the sporadic uses of the EPCs, which were not considered in the previous analysis. Additionally, it opens the opportunity to use those systems to provide electricity (an average of approximately 1 MWh per year, varying from a minimum of 74 kWh up to a maximum of 2.4 MWh per year, in the worst case) for other applications, which might help to make the investment in the PVPEPC system more feasible.

Rwanda

For Rwanda, a total of 12 simulations for a typical meteorological year were performed, corresponding to the application of the 4 PVPEPC systems to the 3 demand profiles established for this country. Table 11 presents the results of the annual simulations performed for Kenya in terms of energy.

System/ Profile	Load demand [kWh]	Energy to load [kWh]	Curtailed PV Energy [kWh]	Energy gap [kWh]	Satisfied meals [%]
A / 1	376.45	358.57	0.00	17.89	91.61
B / 1	376.45	375.23	121.27	1.22	99.28
C / 1	376.45	375.69	61.13	0.77	99.64
D / 1	376.45	376.45	780.64	0.00	100.00
A / 2	220.12	219.58	250.68	0.54	99.36
B / 2	220.12	220.12	944.57	0.00	100.00
C / 2	220.12	220.12	951.06	0.00	100.00
D / 2	220.12	220.12	1 708.27	0.00	100.00
A / 4	315.54	315.54	421.79	0.00	100.00

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System/ Profile	Load demand [kWh]	Energy to load [kWh]	Curtailed PV Energy [kWh]	Energy gap [kWh]	Satisfied meals [%]
B / 4	315.54	315.54	1 189.03	0.00	100.00
C / 4	315.54	315.54	1 185.52	0.00	100.00
D / 4	315.54	315.54	1 944.26	0.00	100.00

Table 11: Annual simulation results for Rwanda load profiles - energy: load demand, energy delivered to load, curtailed PV energy, missing energy for cooking and percentage of satisfied meals

The simulation results show that there are only four scenarios where the system designed is unable to provide the necessary energy for all meals. Those scenarios only occur for the first and second demand profiles. However, even in the worst scenario (system A / profile 1) the PVPEPC can provide more than 91% of the meals (764 out of 834). The other 3 cases have the system providing nearly 99% of the meals, i.e., all meals of the year but 6 (system B / profile 1), 4 (system A / profile 2) and 3 (system C / profile 1).

With the exception of system A / profile 1, all scenarios have periods with excess of PV electricity production that has to be curtailed. Like in the Kenyan case, the system can be used to prepare more meals and it opens the opportunity to use those systems to provide electricity (an average of approximately 870 kWh per year, from a minimum of approximately 61 kWh per year up to a maximum of 1.9 MWh *per* year) for other applications, which might help to make the investment in the PVPEPC system more feasible.

Considering these results, it is deemed technically feasible to use PVPEPC systems, with electrochemical batteries and DC EPCs, to satisfy the cooking demand in Kenya and Rwanda.

3.5 Future orientations in the target countries in terms of energy and clean cooking

The policy in the target countries encompasses a set of measures directed at energy, in which clean e-cooking can be included in a general way. The following paragraphs present some of the plans and measures taken by each country in what concerns clean cooking.

Kenya

Kenya aims to produce green hydrogen by 2030, facilitated by a German-funded fertilizer plant using geothermal energy. The European Investment Bank (EIB) will also support this initiative with $1.9 million in grants for large green hydrogen projects. Additionally, Kenya plans to double its geothermal power output by 2030 with new technologies from GreenFire Energy Company (MEPK, 2023).

The Rural Electrification and Renewable Energy Corporation (REREC) will connect 300 households and implement 73 new projects across six counties. Hydrobox has commissioned a 750 kW hydroelectric plant in Muranga County, benefiting educational institutions, businesses, and over 2000 households. Kenya's energy grid will be modernized through a collaboration between the Ministry of Energy and Petroleum and China Energy Engineering Company. By 2030, Kenya aims for universal access to clean energy, supported by $70 million from the Climate Investment Fund, through measures to incentivize the private sector incentives,promote rural electrification, develop renewable energy, and improve energy efficiency (MEPK, 2023).

Rwanda

Rwanda's National Strategy for Transformation (NST1) aims for the country to achieve middle-income status by 2035 and high-income status by 2050. As one of its core objectives, the strategy targets universal electricity access by 2024. The Sustainable Development Goals defines universal access to electricity for households as having an electricity connection in their house. The Electricity Sector Strategic Plan (ESSP) associated to the NST1 lays out how to provide electricity to all households in Rwanda by 2024. The ESSP's specifies that universal access will be achieved through on-grid and off-grid electrification technologies. NST1 target will be achieved through connecting households to the National grid (52 %) using off-grid solutions -Stand Alone Solar Systems (SAS) and Micro grid (48%) for the rest of the country as an interim solution. To date, 65% of Rwandan households have access to electricity. These include 47.2% of households connected to the national grid and 17.8% connected to off-grid systems. To guide investments in electrification and achieve the access targets within the framework defined by the NST1 and ESSP, EDCL/REG has developed a 7-year Electricity Access Development Plan deduced from the National Electrification Plan ('NEP 2018-2024') subject to periodic revisions, according to the electrification status in the country.

According to Rwanda's NST-1 target, LPG use must increase from 6% of the population in 2020 to approximately 40% in 2024. To make it a reality, the Government has set the Plan that considers three action options:

- To develop new policies to improve LPG access and direct public institutions to transition to LPG from Biomass use and full implementing the Branded Cylinder Recirculation Model (BCRM) plan;
- Mobilize industry and financial sector to expand LPG cylinder inventories and distribution networks;
- High plus requiring urban residential and institutional users to switch to LPG and prohibiting biomass supply and use for cooking in the urban markets through awareness campaigns.

Electricity for cooking, while included in Rwandan policies among the potential alternatives to traditional fuels, has received reduced attention to date, highlighting a gap in the cooking

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sector, considering the country is aiming for universal electrification. Despite this, a small number of companies are starting to develop and offer products such as electric pressure cookers or electric hot plates, and developing pilot projects to better understand customer behavior and needs when using electric cooking solutions. While upfront costs of electric cooking appliances (from USD 40 to 85) are still in comparative ranges in relation to other clean and modern cooking solutions, the excess electricity generation capacity, the increase of electricity access and electricity supply reliability across the country offer a much more positive prospect for the development of the electric cooking sector. This is particularly relevant if further incentives are set around for the importing, manufacture and purchase of appliances or the use of electricity for cooking.

Mozambique

For future cleaner and efficient cooking solutions, at household level, it is estimated that, in the Maputo metropolitan area, natural gas will be the most probable solution to be adopted. However, in the other towns, the spread of cleaner fuels is less probable to take place. Additionally, there's a need to perform pre-studies on socio-economic factors influencing the choice of fuels and cooking devices. This should include the retrieval of past experiences and full characterization of the different cultural and behavioral habits according to different socio-cultural backgrounds found in the urban and peri urban areas. For rural communities, improved cooking stoves are most unlikely to succeed unless appropriate measures are undertaken in partnership with sociologist scientists. Indeed, every solution implemented so far has advantages and disadvantages from the economic point of view as well as from the socio-cultural perspective. These aspects demand confirmation and must be addressed while designing future cooking solutions for these communities. In fact, in the past, a program on improved cook stoves showed the advantage of a participatory design of customized improved cook stoves in a rural community near Maputo City.

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4. CANVAS model for solar cooking appliances

To develop a business model for solar cooking appliances, it was necessary to identify the most common elements that enable to understand the context, key players and activities that enable the business to survive beyond prototype phase. In this sense, the basis for the development of this business model was the well-known "Business Model Canvas" (2016 UN Women). For that end the needed descriptors/elements are detailed in table 12.

Element	Description	Solution
A) Value Proposition	Identification of the problem that is intended to be solved with the product to be marketed/distributed or the need to improve the quality of life of a specific socioeconomic group.	The product will allow its users to cook faster and increase the time available for other tasks or leisure, increasing their quality of life. Moreover, it will bring health benefits by reducing exposure to combustion fumes.
B) Target customers	Identification of the users of the product and how their problems can be solved.	The customers are the users of the stoves that can be domestic, or providers of meal services from home or in commercial establishments – fairs, markets or similar.
C) Distribution channels:	How to reach the target customers. These can be physical channels, such as stores or markets, or virtual channels, such as websites that advertise local businesses, among others.	The dissemination channels will be mixed. Actions will be carried out to disseminate and raise awareness of the use of this type of equipment for a more sustainable kitchen.
D) Customer relations	Demonstrate to customers the added value of the product and prove that it is necessary, keep customers satisfied with the product and loyal to it, and increase the number of customers. To do this, it is necessary to add value and differentiate the product from other competitors.	The use of the renewable system is the added value to be strengthened in this business. In this aspect, some models of stove and electric supply system will be studied in order to develop a product with competitive cost.
E) Return on Investment Channels (Revenue)	Means of generating revenue from the sale of the product, maintenance (if necessary), sale of accessories, advertising, among others.	The revenue is achieved through the selling of the overall equipment that constitutes the system, but especially through installation services that can be done by specialized companies at the beginning but will tendentially end-up being performed also by the seller.
F) Resources necessary for the implementation of the business	They can be divided into: Physical resources - factory, raw materials, distribution vehicles, machinery, etc.; Human resources; Intellectual resources – trademarks, patents, copyrights, etc., and financial resources – credits and the like.	Stil ongoing discussion at the date of this report.

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G) Key activities	What the company must do to make the business model work. Development of a product or provision of a service, or both.	Product development, user training, sale of equipment and accessories, maintenance, etc.
H) Key partners	These are the partners who will contribute to the operationalization of the business. In this case, it is necessary to make an effective selection of the partners to be included, such as suppliers, advertising agents, among others.	In the particular case of this product, some partners to be included correspond to suppliers, maintenance technicians, advertising agents, local trade agencies and residents, etc.
I) Cost Structure	Identification of the costs associated with operating the business, including rent, employees, materials, business registration, and other costs associated with key activities, key partners, and resources.	See section 4.2 of this report
J) Prototyping and testing	Development of the prototype and testing with potential users.	Laboratorial testing of the prototypes and experimental campaigns in targeted communities to test the prototypes and promote the interaction with potential users. At this date the last tests are not yet finished.
K) Business registration	This will be the final stage of the business model and signals the start of the new project.	Applicable to companies starting their businesses, especially in the case as the commercial entity decides to dedicate the activity to this product, considering the overall system. When bringing a new product to an existing business this is not applicable.

Table 12: CANVAS elements adapted to the PURAMS project's outcomes

In what concerns element E) referred to revenue, it is important to note, that at this time, standard EPCs are already available in the market, which can make the dissemination of the prototype developed in this project easier to distribute and reach the end users. Also, PV panels are on the market as well as batteries and charge regulators. In this sense, it is not likely that at the very beginning of this business, the overall system is sold by one sole provider, but it is expected that in the medium-long term, the companies will develop protocols and end up selling the EPC, PV Pannels and Storage system all together. In this sense, key activities, G), are very relevant for the success of this product/business. Capacity building is a key aspect to consider, in the solar resource basic characteristics and power assessment, as well as on the installation and configuration and use of the equipment.

In this project a set of training modules was already performed in previous LEAP-RE stakeholders' forums related with solar resource assessment, that are accessible for different types of publics. Also, at the end of the LEAP-RE project, a set of training modules are also foreseen targeting different renewables areas.

In addition, PV suppliers can also provide training actions for installers, which can be a very relevant asset, and there are several universities involved in the development of this system that already involved students in the process giving them the basic skills for the installation of the systems and able to enter the job market in this area.

Regarding the element F), once again, it is not likely that the overall system is sold altogether (adapted EPC + batteries + PV) at the very beginning of the product's distribution. Relations with the EPC developers will be needed so that they can start incorporating the new changes in the current EPCs, creating a new line of business or create a small factory for this end. This work is still under discussion at the date this report publication, so it will be incorporated in the final project's report.

Finaly, it is important to refer that there is the need to involve stakeholders in the different sectors (also in element H)). In the scope of this project a large set of stakeholders was identified and consulted about Clean Cooking to understand their interest in this product and collect suggestions for future developments and dissemination of these ideas.

A list of stakeholders identified in this project in each country and further developed in the scoped of T10.3. As an example, below a list of the relevant stakeholders is presented for Kenya and Rwanda:

- **Policy stakeholders -** Kenya: EPRA, County Government Energy Planners, Ministry of Energy, Clean cooking inter-ministerial committee, County Energy Centres, KPLC, KOSAP (Ministry of Energy or SNV), Rural Electrification And Renewable Energy Corporation(REREC), Kenya Revenue Authority (KRA), Ministry of Environment, Ministry of Health, Ministry of Planning and Finance/Treasury, Kenya Bureau of Standards. Rwanda: National Industrial Research and Development Agency, GIZ, Rwanda Utility Regulation Authority, Ministry of Environment, Ministry of Infrastructure.

- **Technology Oriented Stakeholders –** Kenya: AMDA (African Mini-grid Developers Association), Industry associations (GOGLA, CCAK,etc), innovation labs (UON Fablab, Gearbox, Mideva), Kenya-based clean cooking appliance manufacturers (BURN), Utility, mini grid and smart meter developers, KIRDI,TVETS(RIAT) and KCIC. Rwanda: Energy Development Corporation Ltd, Rwanda Utility Regulation Authority.

- **Finance Stakeholders** - CLASP, PayGo service providers(MKOPA, StimaCo, Angaza), Climate Care, GCF and KCIC, RBF administrators and funders(CLASP, EnDev, SNV, etc), GIZ, Energy for Impact (formerly GVEP), ESMAP - World Bank, Loan Microfinance Banks, Africa Development Bank and MECS - Challenge Fund. Rwanda: Development Bank of Rwanda.

- **Awareness, advocacy, and outreach-oriented stakeholders -** Kenya: Consumers (Households and institutions), Food bloggers (Jikoni Magic, Nimoh's Kitchen), TV/radio producers, KPLC's Pika and Power, Mini-gris & SHS sector knowledge platforms (GMG Facility, SNV, AMDA, CrossBoundary), County Energy Centres, CARITAS-KITUI, SCODE, Women's Groups, CCAK. Rwanda: GIZ, Rwanda Utility Regulation Authority.

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In addition to the points presented above for the development of the business, there are other issues to take care of related to social and economic aspects. One of the most relevant issues is the fact that it is necessary to promote a change in their habits among potential users. The surveys conducted in the three countries reinforce this need and present promising results in terms of peoples' habits as well as their satisfaction when using e-cooking, more details can be found on (Cardoso, et al., 2023). In the next section an analysis of the socio-economic part of the surveys is presented.

4.1 Information from the surveys – Kenya, Rwanda and Mozambique

4.1.1 Social characterization of the respondents

According to the different surveys conducted in the target countries, the next paragraphs show the social characterization of the households that participated in the EPCs experiment to understand the context of the users before the EPC experiment was conducted. In the case of Kenya, the analysed sample corresponded to 105 respondents, in Kenya 51 and in Mozambique 20.

In what concerns economy component, the prices of the fuels and cookstoves were analysed and used in the calculation of economic indicators and are presented in the section 4.1.3.

In a general way, and supporting the analysis presented in section 1 of this report, on the three countries, the great majority of the respondents are women, which are also the person that in charge of cooking, and therefore more exposed to the harmful effects of the traditional fuels. Figure 11 presents the gender distribution of the respondents when asked about who cooked in the household on the target countries.

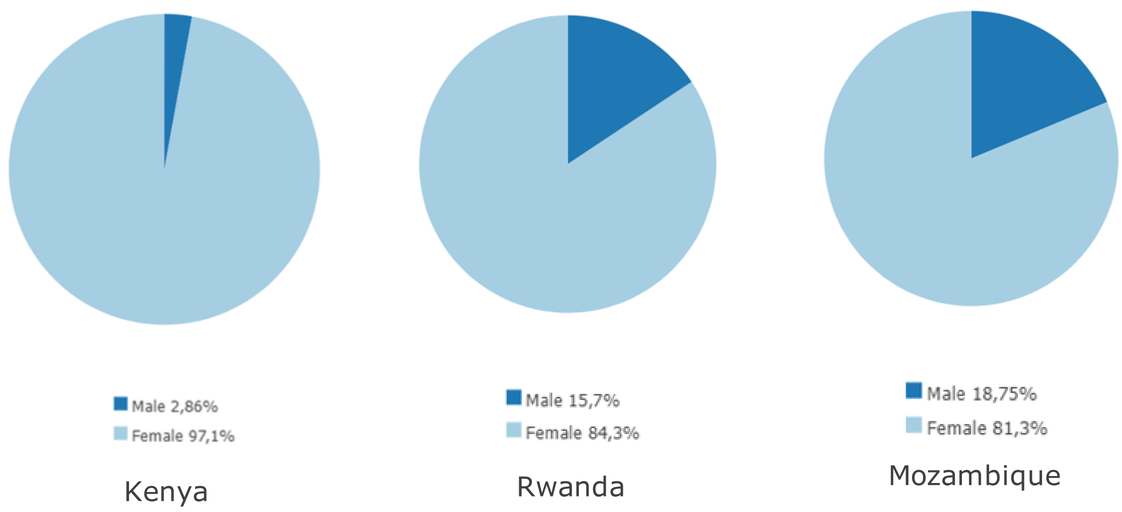

Figure 11: Gender distribution of the respondents in Kenya, Rwanda and Mozambique

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In what concerns the age of the respondents, they are mostly in the 30-40 years old range.

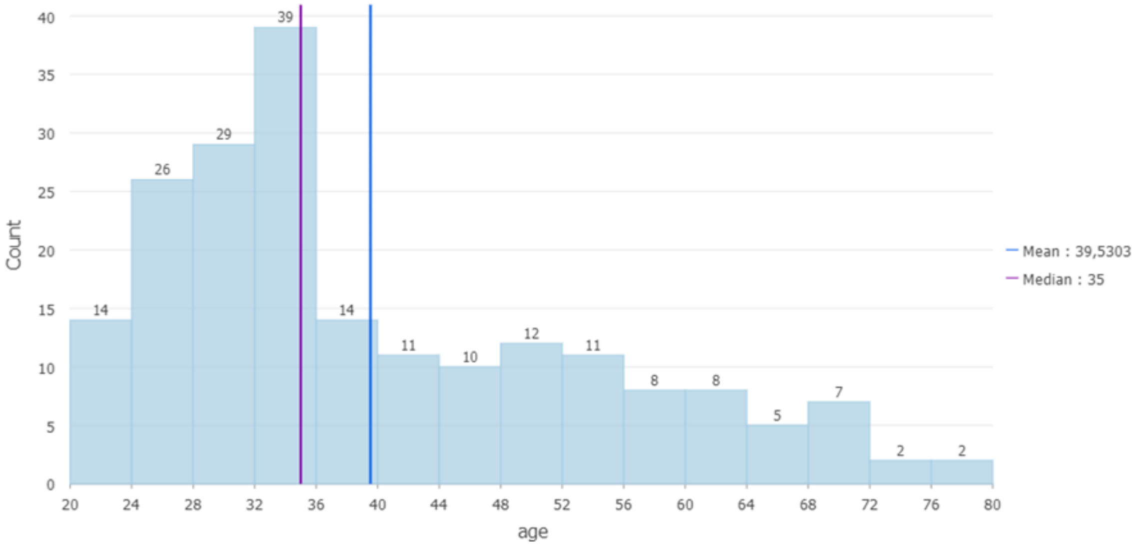

Figure 12: Ages distribution in Kenya

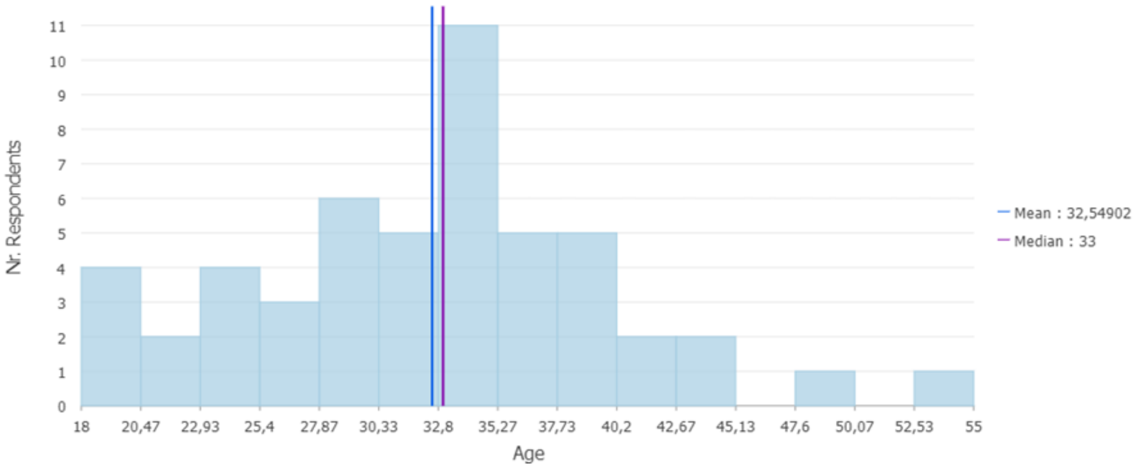

Figure 13: Ages distribution in Rwanda

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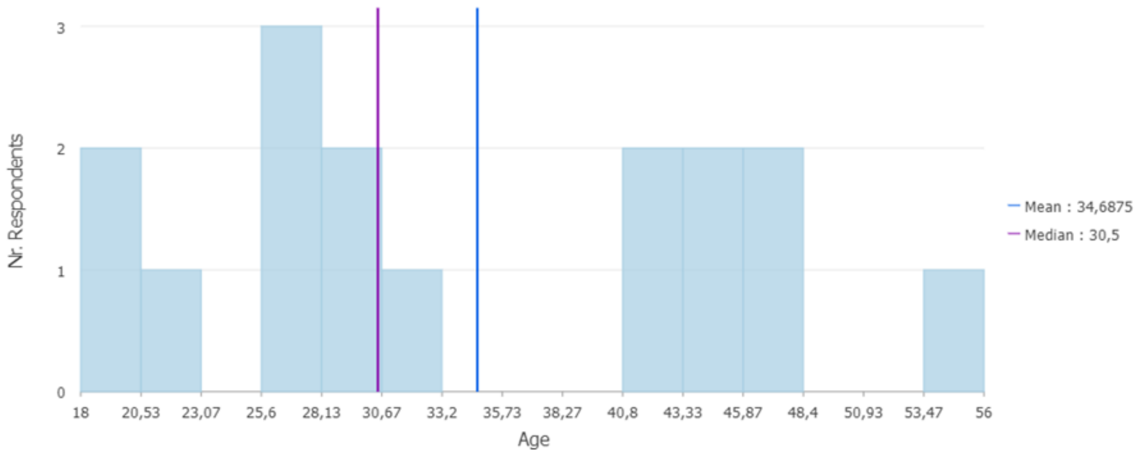

Figure 14: Ages distribution in Mozambique

In terms of marriage status, the great majority of the respondents in the three countries is married and living with their spouse.

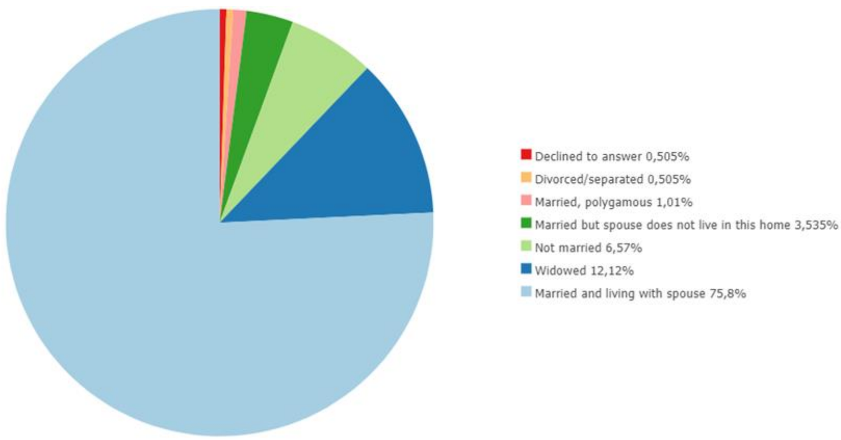

Figure 15: Marriage status in Kenya

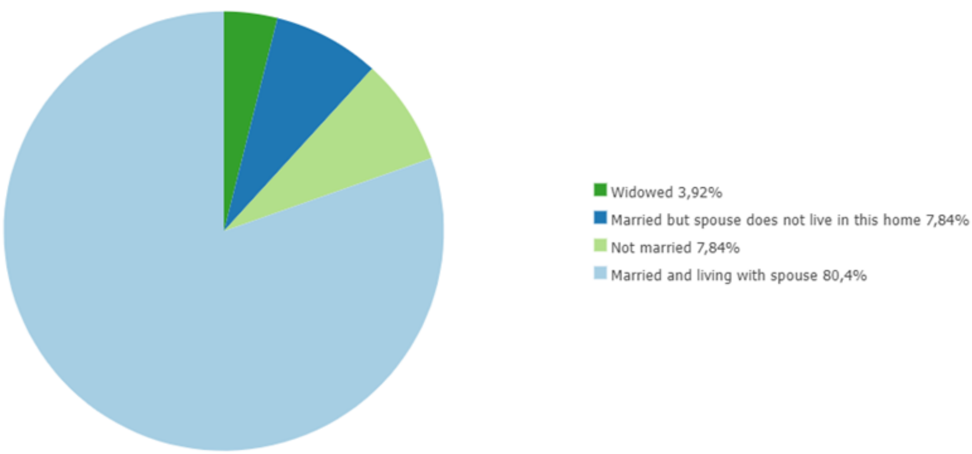

Figure 16: Marriage status in Rwanda

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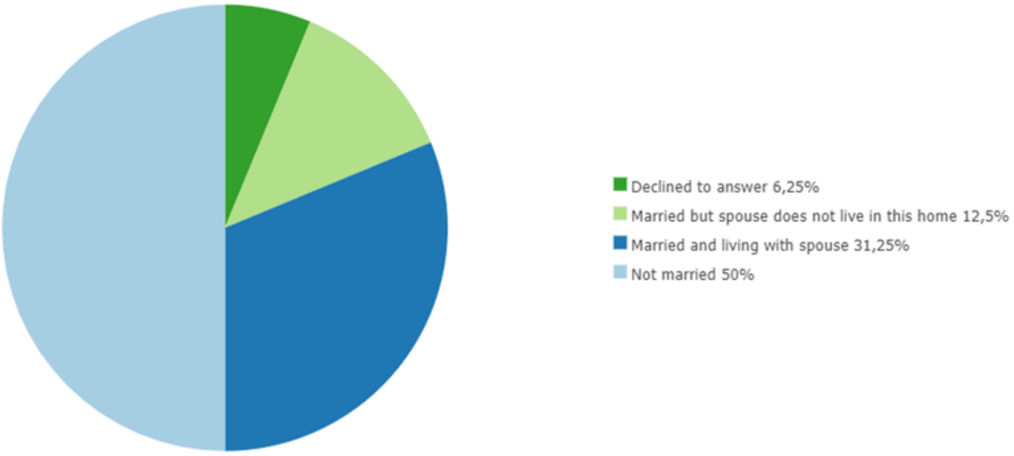

Figure 17: Marriage status in Mozambique

The education level and the professional activities (or occupation) of the respondents was also analyzed.

In these two descriptors, there are notorious differences amongst the respondents. In what concerns the level of education. In Kenya there is a great variety of education levels amongst the respondents, while on the other two countries, there are very few variations.

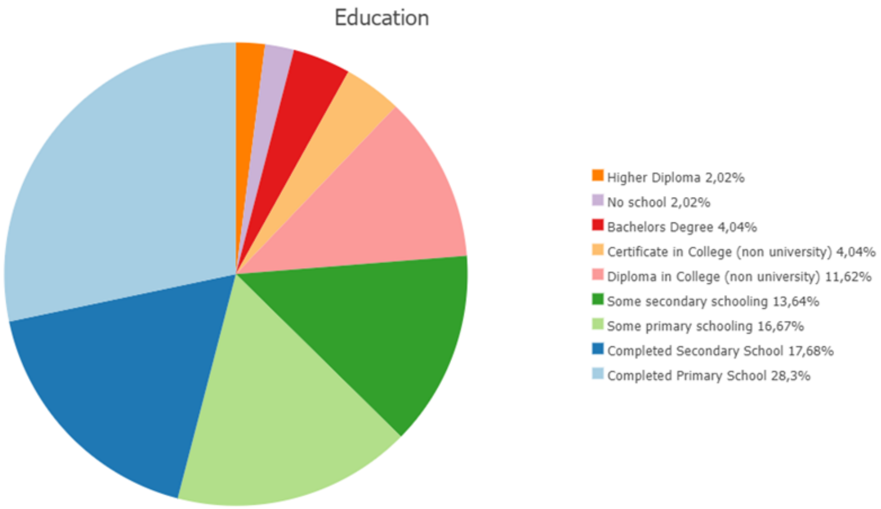

Figure 18: Education level distribution in Kenya

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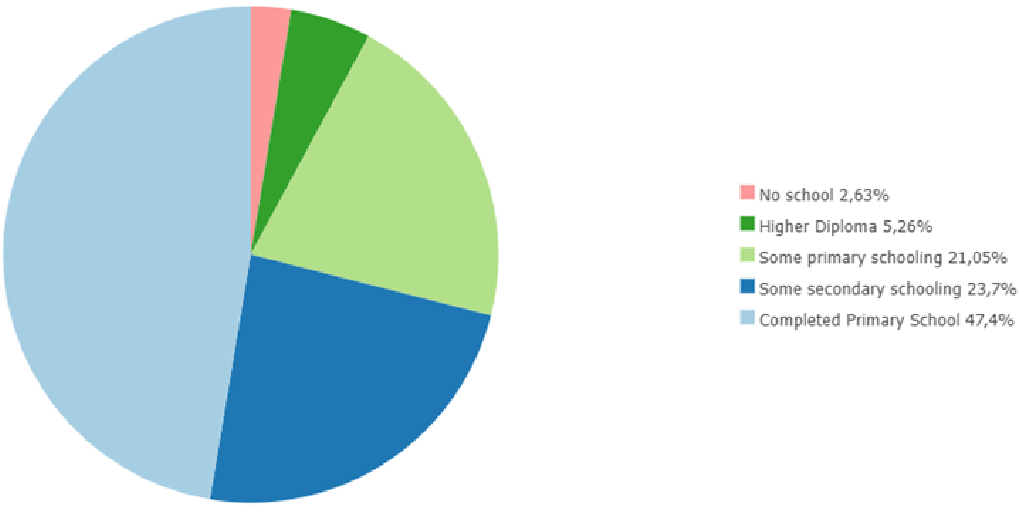

Figure 19: Education level distribution in Rwanda

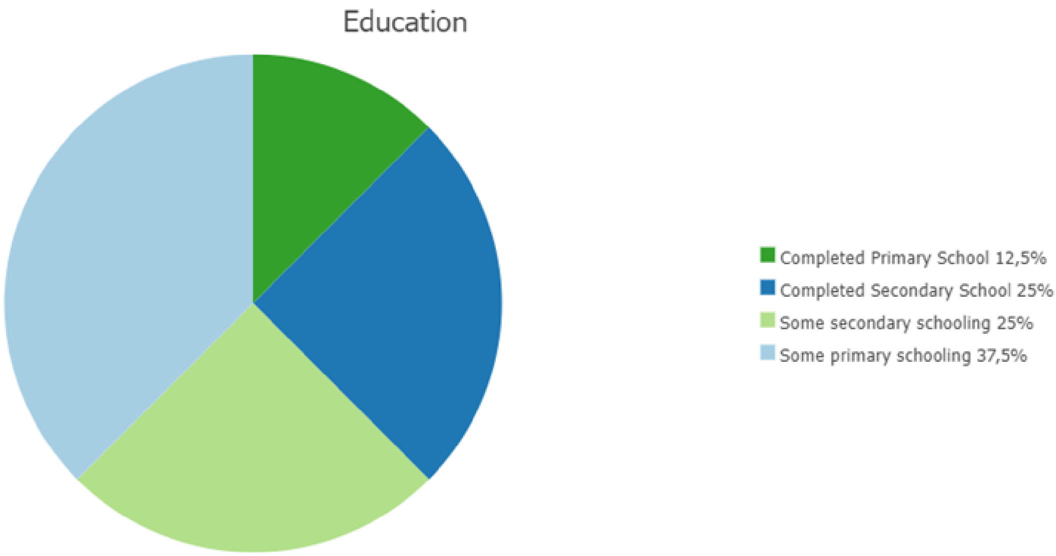

Figure 20: Education level distribution in Mozambique

In Kenya, the most part of the respondents are working in the trading/commercial sector or in the agricultural sector, but there is a wide variety of other types of professional activities. On the other hand, in Rwanda the largest percentage works on the agricultural sector, with almost 50% of the respondents being farmers.

In Mozambique, the objective was to select mainly businesses in the food sector and not households. In this sense, the main activities reported by the respondents are on the food business sector. The samples in Kenya and Rwanda didn't meet that sector.

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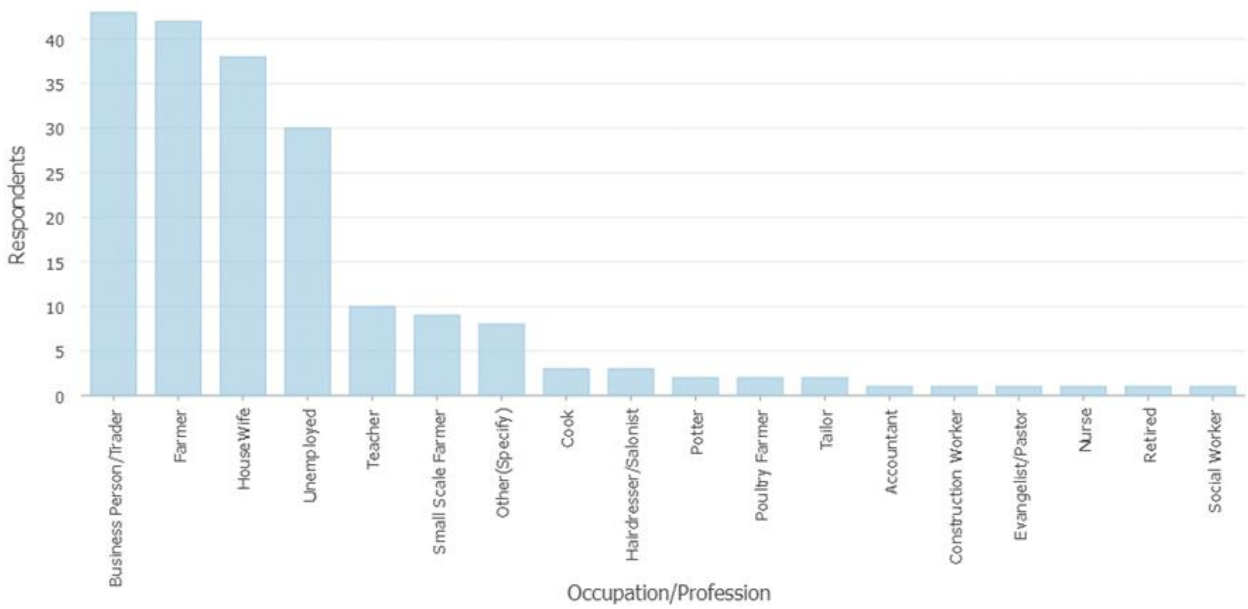

Figure 21: Distribution of the professional activity of the respondents-Kenya

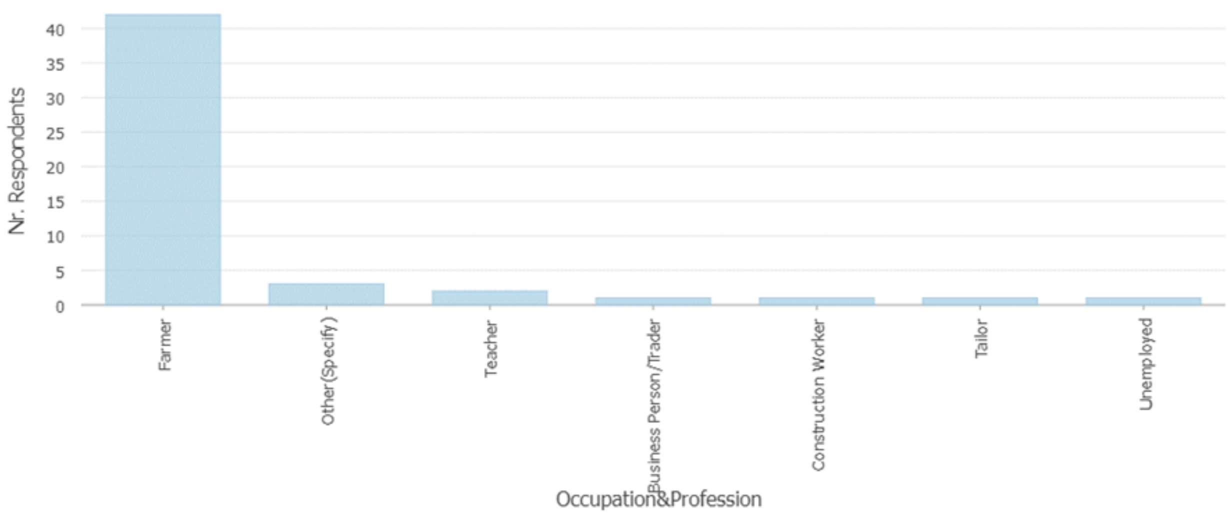

Figure 22: Distribution of the professional activity of the respondents-Rwanda

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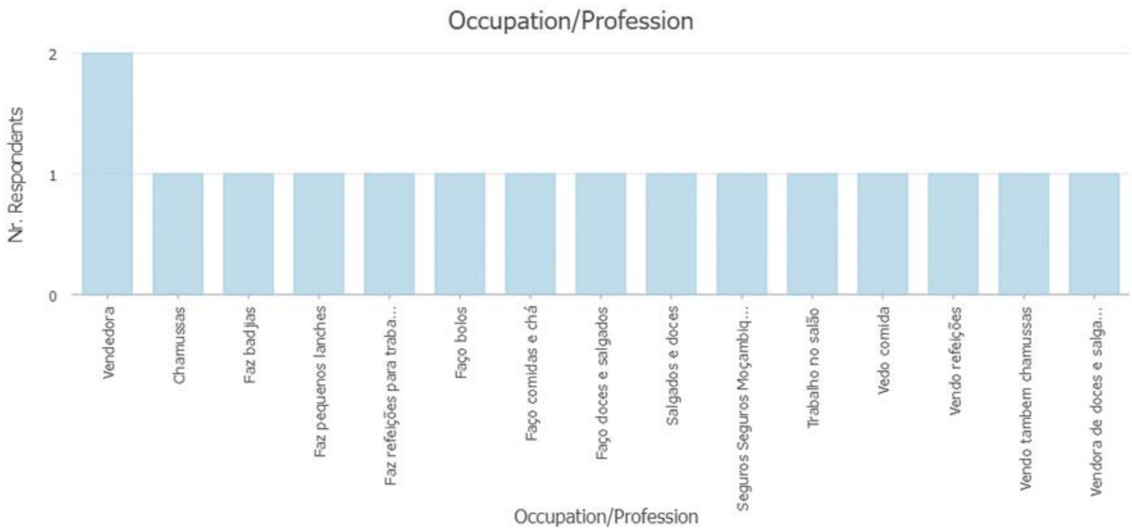

Figure 23: Distribution of the professional activity of the respondents- Kenya

Despite the differences between the target countries' user samples, it is important to refer that despite the limited dimension of the three samples here presented, the professional activities are all relevant for the use of the solar cookers and especially in what concerns standalone systems. In this sense, the results of these surveys enable to collect important data for the identification of the potential users' needs in term of sustainable clean cooking.

In addition to this characterization, the type of fuel and cookstove most used by the selected households is also relevant for this study and to identify the differences that the end-users will experience in terms of quality of life and also to compare the costs sent by the families before and after the EPCs experiments.

4.1.2 Energy needs and system dimensioning

According to the literature and the surveys conducted in the three countries, the most used fuel is firewood with exception of Mozambique where charcoal is the preferred fuel. This is especially notorious in Rwanda where more than 80% of the households that participated in the surveys use this type of fuel. Table 13 presents the distribution of the most used fuels and cookstoves in the three countries.

Element	Kenya	Rwanda	Mozambique
Fuel			
Firewood	68.70%	86.30%	6.25%
Charcoal	7.58%	11.76	62.50%
Biogas	0.51%		

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Gas	18.20%		31.25%
Kerosene	2.02%		
Electricity	0.51%		
None	2.53%	1.98%	
Cookstoves			
Traditional 3 stone cooker	40.90%	54.90%	
13kg gas stove	4.04%	1.96%	18.75%
6kg gas stove	12.63%		
3kg gas stove	0.51%		
Charcoal stove made of iron sheets			75%
Inbuilt firewood meko	28.30%	13.73%	6.25%
Jiko with clay lining	8.59%	7.84%	
Jiko la mabati	1.01%	9.80%	
Ethanol cookstove	0.51%		
Paraffin stove	1.01%		
Jikokoa	2.02%		
Other	0.51%	7.84%	
Not applicable		3.92%	

Table 13: Most used fuels and cookstoves in the three target countries

In terms of the cooking time, in a general way in the three countries, the data show that in average, with the traditional methods, breakfast is cooked in 30 minutes, lunch in 50 minutes and dinner in 1 hour. Some responses refer to larger times that can go up to 3 hours for lunch and dinner. However, it is not clear from the responses, if in the cases that there is the need, for example, to collect firewood, the collection time is included in the response.

Also, the cooking time related with specific types of food is variable, and a study developed in the scope of this project compared the times of cooking on the preferred types of food with traditional methods and EPCs. The results show that there is a significant saving of time when cooking with EPCs. Details can be found in (Cardoso, et al., 2023).

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4.1.3 Average income on the target countries

In order to understand if the families are able to pay for a clean e-cooking system with storage, it was necessary to evaluate the monthly and yearly earnings of the general population, especially the rural inhabitants and estimate the effort each family should make to by such a system.

In Rwanda, around 37% of the working population earn between 20000 RWF (14.6 €) and 29999 RWF (21.9 €) per month (NISR, 2024). From these, 47% refers to rural activities. In Kenya, the medium wage is between 30,000 and 130,000 Kenyan Shillings (KES) per month (210€ to 914€) and the minimum wage is around KES 15,201 (101€) (StandardMEdia, 2023) (KNBS, 2022) and in Mozambique, the minimum is around 5800MTn (89€) and corresponds to agricultural sector. Other sectors can earn up to 16061 MTn (230€) (MeuSalario, 2022).

According to the prototypes built in the scope of this project, a system for clean e-cooking and storage can cost around 1000€ to 2000€, which represents a very large effort from the families. In the cases of households selling cooked food, market and fair businesses, this effort can be reduced, although it was not possible, at this time, to estimate the earnings from this type of activity. Moreover, given the lack of economic viability, the necessity of having government incentives to support the use of such equipment is clear.

4.2 Costs analysis for cooking appliances

The analysis of the benefit of the transition to e-cooking also includes an economic assessment and the understanding of the costs related with the traditional cooking are very relevant for this study. In this sense, the information obtained from the surveys that were conducted in the three target countries, was used to analyse the economic indicators that are relevant for the decision making on the use of these systems. The following paragraphs show the responses conclusions in terms of fuel and stove costs in Kenya and Rwanda. For Mozambique the sample was very short, so it was not considered for this part of the study.

The main procedure was to identify the households where, at least, 5 people had the 3 regular meals a home. In addition, the households IDs were compared with the database from the EPCs experiment to understand the time of use and food that was most cooked in each of the identified households. These options were important for several steps of this work, from the economic point of view and also to use the data related with the most regular uses.

4.2.1 Costs on Fuels used prior to e-cookers

In the case of Kenya and considering the households using firewood as preferred fuel, the costs were in average 12 KES per day (maximum 20 KES), which corresponds to an average of 370 KES per month and 4435 KES per year. This amount of money is sufficient

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to feed in average, 5 people, according to the information collected in the survey. Some of the responses indicated more than 5 people, with a maximum of 12 people, in some cases.

In this case, the most used stove is the "Traditional 3 stone cooker" which is reported as free of charge and can be used for long periods of time (at least one respondent reported 50 years). Some few responses refer to the type "Jiko la Mabati" which price is referred by the participants of around 2500KES, or the type "Jiko with clay lining - Kawaida jiko" which costs between 400 and 500 KES.

In the cases where charcoal is the preferred fuel, the costs correspond to 1 sack per month that costs in average 1250 KES (between 1000 and 1500 KES), which corresponds to 15000KES per year.

The cookstove used by the respondents that use this fuel is mostly Jiko with clay lining - Kawaida jiko and on average it costs around 300KES, varying from 200 to 500 KES. Some respondents refer to cooker Jikokoa that can cost between 3000 and 4000KES. The references to this cooker are minor. In the case of the households using LPG as preferred fuel, the related costs are on average 1000 KES per month corresponding to 12000KES per year.

Based on these costs, the value per meal and per day were estimated and are presented in table 14.

Fuel	Daily Costs (KES)	Nr. Reg. meals	Daily Costs (€)	Value per meal (€)
Firewood	12	3	0.084	0.028
Charcoal	41.67	3	0.292	0.097
Gas (LPG)	33.33	3	0.233	0.078
1 KES=0.0070€				

Table 14: Costs of fuels and meals in Kenya according to the preferred fuel – traditional cooking methods

The same analysis was performed for Rwanda and, in this case, the monthly costs using Firewood as preferred fuel corresponds to 660 RWF and per year 7920 RWF. The higher costs are related with the use of charcoal and LPG that reach 83880RWF per year and 70920RWF respectively. Costs associated to the cookstoves were not available and, therefore, are not presented in this report. In the case of Mozambique, as referred previously on this report, the costs related with the fuels and cookstoves are not available on the survey that was conducted. Results for Rwanda are presented in table 15.

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Fuel	Daily Costs (RWF)	Nr. Reg. meals	Daily Costs (€)	Value per meal (€)
Firewood	22	3	0.016	0.005
Charcoal	233	3	0.165	0.055
Gas (LPG)	197	3	0.14	0.047
1 RWF =0.00071€				

Table 15: Costs of fuels and meals in Kenya according to the preferred fuel – traditional cooking methods

4.2.2 Economic viability assessment

The economic viability of using PVPEPC systems in Kenya and Rwanda rural and peri-urban areas was assessed by comparing the simplified return of investment (ROI) period of the systems with their estimated life expectancy. The simplified return of investment period was computed dividing the total cost of the PVPEPC system by the annual savings with purchase of conventional fuels (firewood and charcoal) resulting from the use of the PVPEPC system.

The conventional fuel costs were computed taking into consideration the results of the household surveys carried out by PURAMS partners in Kenya and Rwanda (Tables 14 and 15 on previous section). All values were converted to euros using the following exchange rates: 0,0070 €/KES and 0,00071€/RWF (ExchangeRates, 2024).

The savings will depend on the fuel being replaced by the PVPEPC, thus, two limit situations were considered for the ROI period analysis: households using only charcoal or only firewood. The ROI period results for households using a mix of these two fuels will be contained within the results obtained for these two extreme cases.

Table 16 summarizes the results of the economic analysis of the different scenarios considered for Kenya. It is clear from its analysis that all scenarios but two (System A / profile 1 and 4, when replacing charcoal) do not present economic viability, since even a simplified return of investment period analysis yields periods that surpass the typical lifetime of these systems (up to 15 years). Moreover, the savings are so small in comparison with the system cost that even a sensibility analysis will yield similar results. For example, the doubling of the savings will result in the system being viable only for scenarios where households currently use a mix of 100% of charcoal, however, this analysis does not account for negative effects, such as the efficiency reduction of the PV modules and batteries with time, which will contribute to worsen these results.

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System/ Profile	System cost [€]	Annual savings – firewood [€]	Annual savings – charcoal [€]	Simplified Return of Investment – firewood [years]	Simplified Return of Investment – charcoal [years]
A / 1	997.00	19.26	66.74	*	14.9
B / 1	1 441.00	20.41	70.71	*	*
C / 1	1 619.00	20.44	70.81	*	*
D / 1	1 993.00	20.44	70.81	*	*
A / 2	997.00	8.76	30.36	*	*
B / 2	1 441.00	8.76	30.36	*	*
C / 2	1 619.00	8.76	30.36	*	*
D / 2	1 993.00	8.76	30.36	*	*
A / 3	997.00	18.73	64.89	*	15.4
B / 3	1 441.00	18.96	65.67	*	*
C / 3	1 619.00	18.96	65.67	*	*
D / 3	1 993.00	18.98	65.77	*	*
A / 4	997.00	20.44	70.81	*	14.1
B / 4	1 441.00	20.44	70.81	*	*
C / 4	1 619.00	20.44	70.81	*	*
D / 4	1 993.00	20.44	70.81	*	*

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*Higher than expected lifetime of equipment

Table 16: Annual simulation results for Kenyan load profiles - economics: system cost, annual savings in consumption of firewood and charcoal and corresponding simplified period of return of the investment

Table 17 summarizes the results of the economic analysis of the different scenarios considered for Rwanda. It is clear from its analysis that none of the scenarios present economic viability, since even a simplified return of investment period analysis yields periods that far surpass the typical lifetime of these systems (up to 15 years). Moreover, even more than for the Kenyan case, the savings are so small in comparison with the system cost that even a sensibility analysis with significant increase of the savings will yield similar results. For example, the doubling of the savings will result in the system being viable only for a couple of scenarios where households currently use a mix of 100% of charcoal.

System/ Profile	System cost [€]	Annual savings – firewood [€]	Annual savings – charcoal [€]	Simplified Return of Investment – firewood [years]	Simplified Return of Investment – charcoal [years]
A / 1	997.00	3.82	42.02	*	*
B / 1	1 441.00	4.14	45.54	*	*
C / 1	1 619.00	4.16	45.71	*	*
D / 1	1 993.00	4.17	45.87	*	*
A / 2	997.00	3.11	34.21	*	*
B / 2	1 441.00	3.13	34.43	*	*
C / 2	1 619.00	3.13	34.43	*	*
D / 2	1 993.00	3.13	34.43	*	*
A / 4	997.00	1.83	20.08	*	*
B / 4	1 441.00	1.83	20.08	*	*
C / 4	1 619.00	1.83	20.08	*	*

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D / 4	1 993.00	1.83	20.08	*	*

*Higher than expected lifetime of equipment

Table 17: Annual simulation results for Rwandan load profiles - economics: system cost, annual savings in consumption of firewood and charcoal and corresponding simplified period of return of the investment

As a general conclusion, notwithstanding the high uncertainty associated with the demand profiles and fuel costs estimated from the experimental campaigns and surveys, it is possible to infer from these results that the analysed PVPEPC systems' high costs, in comparison with the conventional fuels costs, does not allow the systems to be economically viable. Therefore, the use of PVPEPC systems in both countries will require the establishment of subsidy schemes. It should be noticed, however, that this is a simplified analysis that does not take into consideration the value of positive externalities resulting from the use of the PVPEPC such as the value of time saved when cooking and purchasing/collecting cooking fuels, the environmental and health benefits due to the reduction of biomass combustion and exposure to the resulting fumes, or the value of the excess electricity that can be used for other purposes (productive or non-productive).

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5. Final notes and Recommendations

It is well known that the use of traditional cooking methods using burning fuels has a significant impact on the environment and on public health. Besides the smoke emissions, and the use of burning fuels like firewood originates high deforestation rates and imposes a high impact on peoples' lives, which reflects not only in health but also in quality time for tasks that cannot be done when collecting firewood, for example.

The product developed under this project, is one of the solutions that can be used to mitigate the impacts that the traditional cooking methods cause to public health. However, although these solutions are needed, and urgent, there are important barriers to overcome, and the most relevant is the funding and domestic finance of the users. This report presented the most relevant elements that are needed to select the suitable business model to disseminate this product in African countries.

From the mechanisms analyzed, the "pay-go" is the most suitable and also the most used in African countries. However, according to the simulations performed in the economic analysis of this report, it is shown that for very few exceptions, the prototypes developed under this project and, eventually, most of the PV e-cooking solutions still represent a huge effort to the families, especially the ones that are in rural areas, which are the major focus of this project. Therefore, there is a strong need for the government's intervention, by establishing funding mechanisms and benefits, to support the buyers and also the vendors.

On the other hand, funding through tenders or similar programs (as what is taking place in Rwanda) are also a solution and can support the vendors enabling them to apply pay-go business models with lower risk of bankruptcy. This type of initiative is valuable and should be more replicated in other countries with similar problems.

Under Task 10.3 in this project, there was a stakeholder's consultation to understand the needs of the most relevant actors in the clean cooking market, and also, to collect their suggestions. The main outcomes enable to summarize the following a set of recommendations that are listed below.

- Engage the community in the policy making is of utmost importance (involvement in the initialization, formulation and implementation of policies).

- There is a need for sustainable financing mechanism towards stakeholder engagements, including sensitization of the main actors, so that policy and regulatory frameworks can be effective.

- The need to adopt technological advancement in e-cooking cannot be overemphasized.

- Public participation of involved stakeholders in decision making process;

- Introduction of favourable tax environment to attract clean cooking investment / Infrastructure;

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- Introduction of rigorous campaigns for awareness creation;
- Foster the realization of access to affordable e-cooking solutions;
- Introduce tariff for e-cooking to enhance adoption;
- Promote solar powered cookers in rural areas;
- Ensure development realizable & well-structured strategies towards clean cooking promotion.

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ANNEX I – Country Characterization Forms

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LEAP-RE

Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

Research & Innovation Action

January 2022

Country Characterization Questionnaire

Kenya

Authors:
Sheila Shepkorir, Sandra Banda (SU)

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

1. Socio-economic background and context

Here write max. 1 page about the current socio-economic characterization of your country, including regional specificities.

The population projection of Kenya as of mid-2023 stands at 51.52 million, with a GDP growth of 5.6%. Despite significant social and economic development, the country continues to face challenges such as a poverty rate of 38.6% as at 2023[1], inequality, youth unemployment, issues with transparency and accountability, climate change, weak private sector investment, and overall economic vulnerability. Prior to the COVID-19 pandemic, Kenya's economy experienced a growth rate of 4.8% between 2015 and 2019[2]. However, in 2020, the pandemic adversely affected the economy, causing the growth rate to drop to -0.3% according to the Kenya National Bureau of Statistics (KNBS). The economy showed resilience and recovered in 2021, achieving a growth rate of 7.5%.

In the fiscal year 2023/24, national government revenues are projected to increase by 30%, with 88.6% of this revenue expected to come from taxes. The agricultural sector has shown improvement in 2023, growing by 7%, primarily due to fertilizer subsidies. The energy supply in Kenya in 2023 is diversified, with 49% coming from environmental sources such as hydro and wind power, 48% from household sources like firewood and charcoal, 1% from imports, and 2% from industrial sources[1].

2. Energy system background and context

Here write max. 1 page about the energy supply and demand panorama at the national level (include regional specificities if needed). Please include information about available energy purchase models for the consumers (both for electricity and fuels).

The energy system in Kenya comprises Solar ,Geothermal, wind, Thermal, Hydro and Biomass. Kenya has a total of 2984 MW installed capacity 90.25 being from Solar Energy [KPLC] and the highest being geothermal energy with an installed capacity of 863.1 MW. In summary, production of primary energy and consumption has increased

[1] 'Kenya National Bureau of Statistics - Kenya's Top Data Site', 23 December 2021. https://www.knbs.or.ke/.

[2] World Bank. 'Overview'. Text/HTML. Accessed 30 May 2024. https://www.worldbank.org/en/country/kenya/overview.

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except for the year 2020 due to the pandemic . The increase has been driven by increased access, expansion of the economy and population growth[3].

Kenya has shown remarkable progress in enhancing electricity accessibility, renewable sources accounting for nearly 90% of the total energy production and consumption in 2021, compared to about 75% in 2017. Nonetheless, despite these efforts, a significant portion of the global population still lacks access to electricity, with approximately 770 million individuals with no electricity, and around 2.6 billion lacking access to clean cooking facilities. Despite the rapid expansion of access to electricity in the last 10 years, reliability and access of KPLC electricity in rural and slum areas is a challenge[4]. Due to this, there has been a higher installation rate of Solar Home Systems in rural Kenya as this is the best alternative to Solar energy being a new opportunity for people in marginalized communities in off-grid areas[5]. In Kenya, various financing models are available for purchase by consumers for fuels. They include Pay-As-You-Go (PAYGO), Micro Financing and Bank Financing and Savings and Credit Cooperative Organizations (SACCOs)[6], Fee-for-service and Hire purchase[7].

3. Use of energy for cooking

Here write max. 10 lines about the current situation regarding use of energy for cooking in your country, including regional differences.

In Kenya, 75% of the population use solid fuels, with 68% relying on wood, 7.8% on kerosene, and 23.9% on LPG[8]. Despite a high adoption rate of renewable energy, only

[3] 'ENERGY & PETROLEUM STATISTICS REPORT 2021 – Energy and Petroleum Regulatory Authority'. Accessed 30 May 2024. https://www.epra.go.ke/wp-content/uploads/2022/02/EPRA-Energy-Statistics-Report-2021.pdf.

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This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

3% of households cook with electricity[9]. The type of energy used for cooking in Kenyan households is dependent on the socioeconomic status of the household. High socioeconomic status households use cleaner fuels such as electricity while low income households use cheaper fuel like charcoal for cooking[10].

The Kenyan Govt has been scaling up the LPG as a household fuel. 29 of the 47 counties in Kenya use firewood as the primary fuels source. The top 5 counties being Wajir(89.5%), Bomet(84%), West Pokot (87.9%), Elgeyo Marakwet(87.1%) and West Pokot (87.9%). Kerosene is mostly used in the counties: Mombasa (32.1%), Nairobi (26.5%), Machakos (11.1%), and Kajiado (12.7%). Charcoal is most commonly used in Tana River(31%), Lamu(27%), Nakuru(23.9%), and Isiolo(23.9%). LPG is mostly used in; Nairobi (67.2%), Kiambu (58.1%), Kajiado (47.2%) and Mombasa (37.5%)[6].

4. Use of clean cooking solutions

Here write max. 10 lines about the current use of clean cooking in your country and perspectives for the future, including regional differences. At least, both thermal and electricity based solar cookers should be addressed.

A baseline ecooking study indicates that 64.9% of Kenyans are ready to transition to electric cooking, which means 68.7% of households could potentially adopt clean cooking through ecooking. However, this transition is limited by issues such as electricity access, socio-cultural factors, and economic constraints. The clean cooking challenge is significant, with 81% of the population still using biomass fuel. Government initiatives have promoted improved cookstoves, but high abandonment rates after initial acceptance pose a challenge. Nonetheless, the high electricity access rate (75%) shows potential for adopting clean cooking solutions[11].

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7 million Kenyans use charcoal as their primary fuel. Kenya has seen a rise in charcoal prices since 2019, prompting people to seek alternative fuels, making electric pressure cookers (EPCs) an attractive option, especially for boiling foods like beans. Solar technology has also been explored as a cooking fuel solution[11]. In Kakuma refugee camp, thousands have used sun-fueled ovens since 1995, thanks to American NGOs[12]. Advances in technology and reduced costs of solar panels and lithium batteries have led to new initiatives for cost-effective and reliable off-grid ecooking solutions. Key actors in Kenya's emerging solar ecooking sector include; Strathmore University, Village Infrastructure Angels, SCODE, MECS and Athel Technology.

5. Future orientations

Here write max. 10 lines about ideas for future development (5 to 10 years) of the energy sector in your country, including supply and demand sides.

Kenya aims to produce green hydrogen by 2030, facilitated by a German-funded fertilizer plant using geothermal energy. The European Investment Bank (EIB) will also support this initiative with $1.9 million in grants for large green hydrogen projects. Additionally, Kenya plans to double its geothermal power output by 2030 with new technologies from GreenFire Energy Company[13].

The Rural Electrification and Renewable Energy Corporation (REREC) will connect 300 households and implement 73 new projects across six counties. Hydrobox has commissioned a 750 kW hydroelectric plant in Muranga County, benefiting educational institutions, businesses, and over 2000 households[13].

Kenya's energy grid will be modernized through a collaboration between the Ministry of Energy and Petroleum and China Energy Engineering Company. By 2030, Kenya aims for universal access to clean energy, supported by $70 million from the Climate Investment Fund,through measures to incentivize the private sector incentives,promote rural electrification, develop renewable energy, and improve energy efficiency[13].

6. Local entities responsible for the data publishing on the sectors to characterize social, economic and technological data

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[12] Solar Cooking. 'Kakuma Refugee Camp'. Accessed 30 May 2024. https://solarcooking.fandom.com/wiki/Kakuma_Refugee_Camp.

[13] 'Homepage | Energy'. Accessed 30 May 2024. https://energy.go.ke/sites/default/files/KAWI/Kenya-ETIP-2050%202.pdf

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

(Please fill the google spreadsheet available at https://docs.google.com/spreadsheets/d/1csuhWsKf54bohNwe3C3si72epX5sg2krHNcsupR_P2E/edit?usp=sharing*)*

7. Stakeholders

Here put a bullet list identifying the most relevant stakeholders of the solar cooker (including research, SME, industry, local entities and user types) that should be targeted by the project.

- **Policy stakeholders** - EPRA, County Government Energy Planners, Ministry of Energy, Clean cooking inter-ministerial committee, County Energy Centres, KPLC, KOSAP (Ministry of Energy or SNV), Rural Electrification And Renewable Energy Corporation(REREC), Kenya Revenue Authority (KRA), Ministry of Environment, Ministry of Health, Ministry of Planning and Finance/Treasury, Kenya Bureau of Standards.
- **Technology Oriented Stakeholders** - AMDA (African Mini-grid Developers Association), Industry associations (GOGLA, CCAK,etc), innovation labs (UON Fablab, Gearbox, Mideva), Kenya-based clean cooking appliance manufacturers (BURN), Utility, mini grid and smart meter developers, KIRDI,TVETS(RIAT) and KCIC.
- **Finance Stakeholders** - CLASP, PayGo service providers(MKOPA, StimaCo, Angaza), Climate Care, GCF and KCIC, RBF administrators and funders(CLASP, EnDev, SNV, etc), GIZ, Energy for Impact (formerly GVEP), ESMAP - World Bank, Loan Microfinance Banks, Africa Development Bank and MECS - Challenge Fund.
- **Awareness, advocacy, and outreach-oriented stakeholders** - Consumers(Households and institutions), Food bloggers(Jikoni Magic, Nimoh's Kitchen), TV/radio producers, KPLC's Pika an Power, Mini-gris & SHS sector knowledge platforms (GMG Facility, SNV, AMDA, CrossBoundary), County Energy Centres, CARITAS-KITUI, SCODE, Women's Groups, CCAK.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

Research & Innovation Action

August 2023

Country Characterization Questionnaire

Rwanda

Authors:
Dominique Savio Barahira (AESG)

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

1. Socio-economic background and context

Here write max. 1 page about the current socio-economic characterization of your country, including regional specificities.

Rwanda is a small land-locked country of 26,338 km2 in in the Eastern part of Africa. Its territory is divided in five provinces, namely Northern, Southern, Eastern, Western and Kigali City province, corresponding to its capital- the City of Kigali. Despite its small size, it is a densely populated country in comparison to other African countries. The National Institute of Statistics of Rwanda projects the country population at 12,9 million in 2021 (NISR, 2021). In 2020, Gross Domestic Product was estimated at 823 USD/capita, ranking 180 in the world (Statista, 2021). Despite a convulse recent history, Rwanda has made significant achievements in its recovery since the 1994 Genocide against the Tutsi. In the last decade, the country has experienced important socio-economic progress with a rapid and consistent economic growth rate (average annual growth of 7.2%, among the fastest in the world) coupled with substantial progress in poverty reduction, which fell from 77.2% in 2001 to 55.5% in 2017, according to the latest Integrated Household Living Conditions Survey (EICV5) (NISR, 2018). Rwanda has become a frontrunner among African economies in the 'Ease of Doing Business' indicators, moving from a global rank of 148 in 2008 to 38 in 2020, which is second in Sub-Saharan Africa after Mauritius (World Bank, 2020a).

According to Vision 2050 (MINALOC, 2020), the country's long term strategic plan, Rwanda aims to become an upper-middle-income country by 2035 and high-income country by 2050, guided by the Sustainable Development Goals (SDGs), the Africa Union Agenda 2063 (African Union, 2013) and the East African Community Vision 2050 (EAC, 2015). To achieve this long-term vision, the GoR laid out a seven-year implementation instrument, the National Strategy for Transformation (NST) in 2017 (GoR, 2017). The objective of the NST is to lay the foundation for decades of sustained growth and transformation that will accelerate the transition towards high standards of living for all Rwandans. The first phase, NST 1 (2017- 2024), continues the efforts set out by the previous Economic Development and Poverty Reduction Strategy (EDPRS 2, 2013-2018) policy (GoR, 2013), with the development of the private sector at the helm (GoR, 2017). The NST 1 is based on three pillars: economic transformation, social transformation and transformational governance. With this new strategy, Rwanda's public policy will focus on developing and transforming Rwandans into capable and skilled people ready to compete in a global environment. The NST 1 is composed of Sector Strategic Plans covering specific areas such as education, energy, health, and agriculture. The NST also includes District Developments Strategies integrating national and sectoral priorities with the local policies and specificities of each province. Energy is a cross-cutting area of focus under both the economic transformation pillar and social transformation pillar, with targets in generation, quality and reliability of supply, and access.

Rwanda is a country of few natural resources, and the economy is based mostly on subsistence agriculture by local farmers using simple tools. An estimated 90% of the working population farms, and agriculture comprised an estimated 42.0% of GDP in 2010.Crops grown in the country include coffee, tea, pyrethrum, bananas, beans, sorghum and potatoes. Coffee and tea are the major cash crops for export, with the high altitudes, steep slopes and volcanic soils providing favourable conditions. Reliance on agricultural exports makes Rwanda vulnerable to shifts in their prices. By 2002 tea became Rwanda's largest export, with export earnings from tea reaching US$18 million equating to 15,000 tons of dried tea. Rwanda's natural resources are limited. A small mineral industry provides about 5% of foreign exchange earnings. The economy of Rwanda has undergone rapid industrialisation due to a successful governmental policy. Since the early-2000s, Rwanda has witnessed an economic boom, which improved the living standards of many Rwandans. The Government's progressive visions have been the catalyst for the fast-transforming economy.

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2. Energy system background and context

Here write max. 1 page about the energy supply and demand panorama at the national level (include regional specificities if needed). Please include information about available energy purchase models for the consumers (both for electricity and fuels).

The Government of Rwanda has undertaken reforms in the energy and water sector which have been concretized by the separation of energy from water operations. The main objectives being; to have sector focused and efficient operations; attract more investment; improve planning and accountability; and increase access to services by the population to drive sector performance towards the targets envisaged in the EDPRS II and other national goals.

To this end, Government adopted the corporatization model as a vehicle to implement the required reforms. The law repealing EWSA Law of 97/2013 of January 31, 2014 paved the way for the creation of two corporate entities which were subsequently incorporated in July 2014 with 100% government shareholding.

The Rwanda Energy Group Limited (REG) and its two subsidiaries; The Energy Utility Corporation Limited (EUCL) and The Energy Development Corporation Limited (EDCL) entrusted with energy development and utility service delivery while the Water and Sanitation Corporation (WASAC) has the mandate to develop and operate water and sanitation infrastructure and deliver related services in the country.

The Rwanda Energy Group (REG) was incorporated to expand, maintain and operate the energy infrastructure in the Country through its two subsidiaries the Energy Utility Corporation Limited (EUCL) and the Energy Development Corporation Limited (EDCL). The object of creating these subsidiaries amongst others was to ensure focused attention to enhancing efficiency in utility operations on one hand and ensure more timely and cost efficient implementation of development projects on the other. Moreover, the REG holding structure provides the overall coordination and ensures effective development of energy and investment plans

The power Installed capacity in Rwanda is at 238.36 Megawatt [MW] (REG, Accessed 2021) .The evolution of installed capacity since 2010 is shown in Figure 1. Energy mix is made up by Hydro, Diesel & Heavy Fuel, Methane gas, Peat, Solar and imports as shown by figure 2.

The total installed power of 238.36 MW is not available steadily. The operation of the hydro units is limited by the water level in the upstream and their interdependence, and hydro availability lowers significantly during the dry season. In addition, the Photovoltaic Solar capacity is not significantly available during the evening peak hours. Further, losses are incurred on the transmission and distribution lines (about 2 per cent of the total installed power) and some of the units may be unavailable during certain periods due to maintenance or failure.

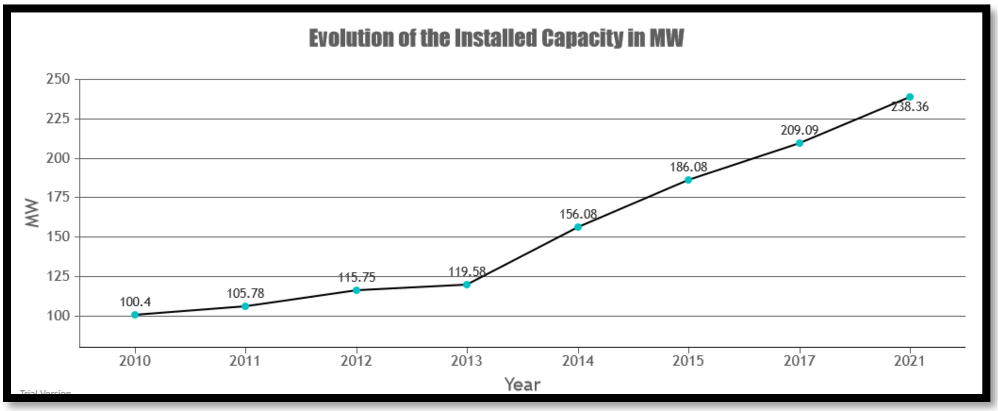

Fig1. Installed capacity in MW

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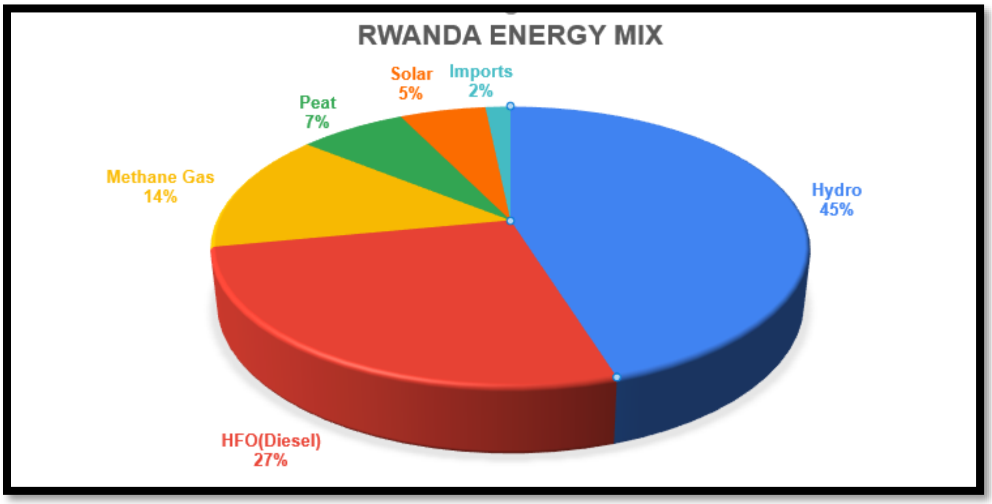

Fig2. **Rwanda Energy Mix** (REG, Accessed 2021)

Rwanda targets to generate electricity from all possible energy sources and diversify its energy mix by 2024 as shown by figure 3.

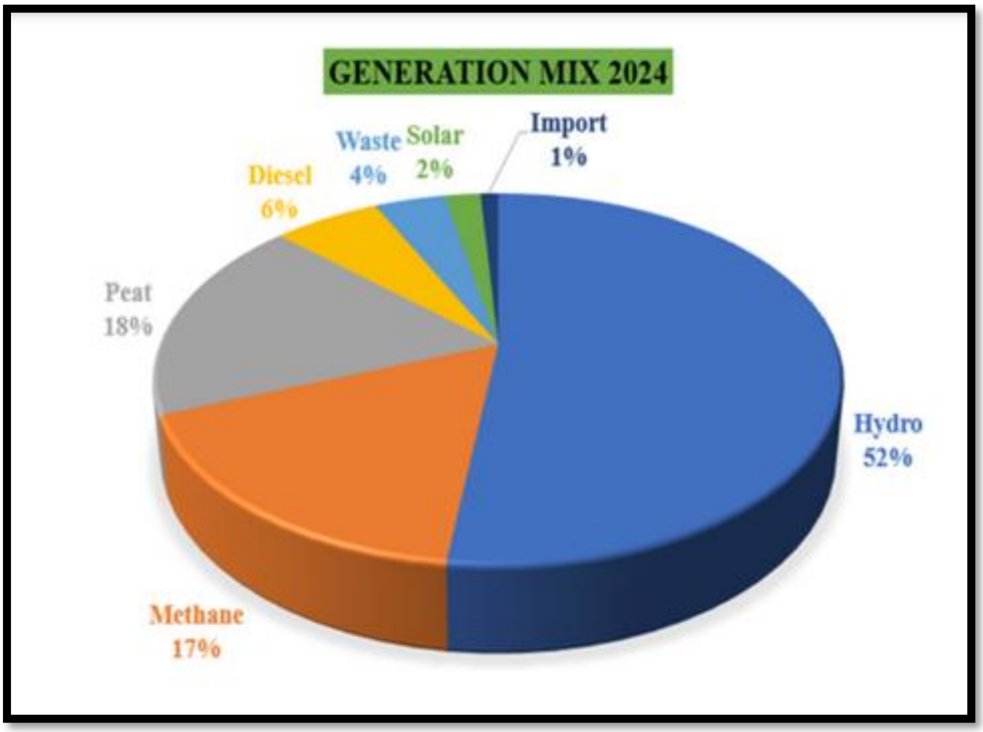

Fig.3 Generation mix target (REG, Accessed,2021)

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3. Use of energy for cooking

Here write max. 10 lines about the current situation regarding use of energy for cooking in your country, including regional differences.

The National Energy Policy and Strategy recognizes the use of clean cooking technologies as having serious hazardous environmental implications when not properly managed. In this regard, it is imperative that forests and woodlots be more productively managed, and charcoal more efficiently reduced with the use of clean cooking technologies.

The current national cooking technologies balance statistics show that methods deployed (mostly wood fuel) account for about 83% of the total cooking energy consumption, followed by petroleum at 9.7%, electricity at 1.3%, and others at about less than 0.5%. In rural areas, the reliance on biomass is over 90%. Most Rwandans live in rural areas where traditional biomass, mainly wood fuel has remained the leading source of energy for cooking. The average household uses around 1.8 tons of firewood each year to satisfy its cooking needs with a traditional stove. The average monthly consumption per household on fuelwood is RWF 1,930.

Private sector-led efforts are distributing cookstoves that are up to three times more efficient than the traditional 3-stone stove and can reduce biomass consumption by anywhere between 68-94%. If effectively applied, this will free up the time spent by women and children in collecting firewood, giving them more time to study and undertake more productive commercial activities.

Improved cooking stove (ICS)

An improved cooking stove (ICS) is a stove that needs far less biomass than a traditional stove to cook the same amount of food and consequently also produces far less smoke than a traditional stove. This reduction in smoke is made by either having far better combustion or by having an excess of air, or with a combination of both. It can save up to 75% of fuelwood compared to the traditional stoves. It is cheap and easy to operate, there is no need to blow the fire. ICSs save on fuel and improve hygiene in the kitchen and provide direct benefits to the women and girl children by reducing the time and drudgery related to procuring firewood.

In Rwanda, ICS has now become a government policy whereby efforts are being made so that it can be widely used in rural communities. EPD has 9 operational member companies who have managed to manufacture and distribute 394,239 ICSs since 2016 up to now.

Biogas

Since 2008, the Government of Rwanda announced a policy to introduce biogas digesters in all schools (estimated at around 600), large health centers, and institutions with canteens. Through this Institutional biogas program, 86 Institutional biogas digesters were constructed in secondary schools and prisons. Since the beginning of the program, 10,200 domestic biogas digesters have been installed in households.

EPD has 2 operational members companies in the Biogas business who installed 8,677 domestic biogas digesters to households and public institutions and monthly expenditure is estimated at RWF 9,024. From 2016 up to now, the biogas systems installed in the schools and prisons have reduced firewood consumption by close to 60% and 40% respectively, along with significantly improved hygienic conditions and cost savings.

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Pellets and briquettes

The promotion of pellets and briquettes is another proposed intervention of biomass dependence reduction strategy to move from 83% to 42% by 2024 and this would be done through:

- Providing technical support to pellets and briquettes producers and carrying out extensive decentralized awareness campaigns.
- Attracting the private sector to develop pellet and briquette-making factories and training producers to make quality products.
- Facilitating factories to access raw materials (e.g providing forest concessions to pellets makers)

The household monthly expenditure of pellets and briquettes is estimated around RWF 9,277.

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Research and Innovation Program under Grant Agreement 963530.

4. Use of clean cooking solutions

Here write max. 10 lines about the current use of clean cooking in your country and perspectives for the future, including regional differences. At least, both thermal and electricity based solar cookers should be addressed.

Rwanda Energy Group (REG), in partnership with its stakeholders, is carrying out a countrywide awareness campaign on the use of safe, effective and clean cooking technologies to ensure that Rwanda meets its targets to reduce the use of biomass energies to cook in households.

Extensive use of biomass energy has potentially serious environmental implications and may be non-renewable unless properly managed. In this regard it is imperative that forests and woodlots be more productively managed, and charcoal more efficiently produced. Failure in this realm could result in accelerated deforestation as the demand for energy due to the increasing population increases.

The energy policy proposes more efficient production and use of biomass energy by households and that this should be complemented by promoting other sources of energy, including biogas, pellets, briquettes and LPG.

Liquefied Petroleum Gas (LPG)

Rwanda has no domestic production of natural gas. The country relies on imported gas especially LPG from other countries. The LPG market in Rwanda is dominated by 10 importers including Société Pétrolière-SP, Kobil, Sulfo Rwanda, Rwanda Oxygène, Merez, Hashi energy, Abbarci Petroleum, Safe gas Lake Petroleum Rwanda, RUCSA Investment. Retail distribution is done through service stations, independent distributors, and supermarkets in an assortment of cylinder sizes ranging from 3 kg to 50 kg and also the tanks from 500 kg to 5000 kgs are available for big Institutions.

The use of LPG has started to attract the attention of cooking energy consumers but its penetration has not yet reached a satisfactory level to see its impact on the reduction of biomass use. At household level, the progress is promising looking at the quantity of the imported LPG and sales of the companies involved in this business and increase in the use of LPG in institutions which before was quite inexistent in public institutions with bigger consumption amount of firewood that contribute much to deforestation. A national survey report published on 08/12/2020 by the Centre for Economic and Social Studies in partnership with the European Union on Cooking Fuel Energy and Technologies in Households, Commercial and Public Institutions in Rwanda showed public institutions' LPG annual consumption as found in the table below:

Institution	Consumption in Kg
Restaurants	1,359,413
Hotels	1,337,470
Police Stations	163,860
Military Camps	89,280
Refugee Camps	21,396
Boarding schools	18,996
Prisons	360

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5. Future orientations

Here write max. 10 lines about ideas for future development (5 to 10 years) of the energy sector in your country, including supply and demand sides.

Rwanda's National Strategy for Transformation (NST1) aims for the country to achieve middle-income status by 2035 and high-income status by 2050. As one of its core objectives, the strategy targets universal electricity access by 2024. The Sustainable Development Goals defines universal access to electricity for households as having an electricity connection in their house. The Electricity Sector Strategic Plan (ESSP) associated to the NST1 lays out how to provide electricity to all households in Rwanda by 2024. The ESSP's specifies that universal access will be achieved through on-grid and off-grid electrification technologies. NST1 target will be achieved through connecting households to the National grid (52 %) as whereas off-grid solutions -Stand Alone Solar Systems (SAS) and Micro grid (48%) as an interim solution. To date, 65 % of Rwandan households have access to electricity. These includes 47.2% of households connected to the national grid whereas 17.8% are connected to off-grid systems. To guide investments in electrification and achieve the access targets within the framework defined by the NST1 and ESSP, EDCL/REG has developed a 7-year Electricity Access Development Plan deduced from the National ('NEP 2018-2024') subject to revision periodically according to electrification status in the country.

According to Rwanda's NST-1 target, LPG use must increase from 6% in 2020 to approximately 40% of the population in 2024. To make it a reality, the Government has set the Plan that considers three action options:

- To develop new policies to improve LPG access and direct public institutions to transition to LPG from Biomass use and implement Full Implementing the Branded Cylinder Recirculation Model (BCRM) plan.
- Mobilize industry and financial sector to expand LPG cylinder inventories and distribution networks.
- High plus requiring urban residential and institutional users to switch to LPG and prohibiting biomass supply and use for cooking in the urban markets through awareness campaigns.

Electricity for cooking, while included among the potential alternatives to traditional fuels in the Rwandan policies, has received reduced attention to date, highlighting a gap in cooking sector considering the country is aiming for universal electrification. Despite this, a small number of companies are starting to develop and offer products such as electric pressure cookers or electric hot plates, and developing pilot projects to better understand customer behavior and needs around electric cooking solutions. While upfront costs of electric cooking appliances (from USD 40 to 85) are still in comparative ranges in relation to other clean and modern cooking solutions, the excess electricity generation capacity, the increase of electricity access and electricity supply reliability across the country offer a much more positive prospect for the development of the electric cooking sector. This is particularly relevant if further incentives are set around for the importing, manufacture and purchase of appliances or the use of electricity for cooking.

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6. Local entities responsible for the data publishing on the sectors to characterize social, economic and technological data

(Please fill the google spreadsheet available at https://docs.google.com/spreadsheets/d/1csuhWsKf54bohNwe3C3si72epX5sg2krHNcsupR_P2E/edit?usp=sharing*)*

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

7. Stakeholders

Here put a bullet list identifying the most relevant stakeholders of the solar cooker (including research, SME, industry, local entities and user types) that should be targeted by the project.

- Energy Development Corporation Limited (EDCL)
- Rwanda Energy Group (REG)
- Rwanda Utility Regulation Authority (RURA)
- Ministry of Infrastructure (Mininfra)
- Energy Private Developers (EPD)
- Clean Cooking Companies (CCC)
- Integrated Regional College (IPRCs)
- Rwanda Environment Management Authority (REMA)
- Ministry of Local Government (MINALOC)

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LEAP-RE
Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

Research & Innovation Action

January 2022

Country Characterization Questionnaire

Mozambique

Authors:
Author one (Boaventira Chongo Cuamba)

Author 2 (Alberto Julio Tsamba)

Author three (Ines Macamo Raimundo)

- # Socio-economic background and context

Here write max. 1 page about the current socio-economic characterization of your country, including regional specificities.

Mozambique is located on the south eastern coast of the Indian Ocean, with an area of about 800,000 km^2, and a coastline of about 2,800 km. The country is very rich in natural resources, among which the following stand out: (i) About 5,650,000 ha of arable land, of which only 10% are being used; (ii) Water resources, being that the country is crossed by about 100 hydrographic basins, some originating in Mozambique and others in neighbouring countries, with lakes and ponds in addition to groundwater. Additionally, the country is bathed by the Indian Ocean in an extension of about 2,800 km; (iii) Mineral resources, including heavy sands, granites, precious stones; (iv) Coal and natural gas; (v) Biological diversity, which translates into rich ecosystems; (vi) Renewable energy resources (the country has solar, wind, hydro, geothermal, oceanic, biomass energy, among other forms of renewable energy); and (vii) Forests (the country has extensive areas of native forest).

The total population of the country in 2020 was estimated at 32,163,000 inhabitants [1]. The population density was 39.75 inhabitants per square kilometre and the annual growth was 2.88%. The population living and working in rural areas is around 67%. Mozambique is one of the poorest countries in the world, ranking 181 out of 189 countries (2020) in terms of the human development index [2]. Gross domestic product (GDP) in 2020 was US$450, which is low compared to many other countries in the region, with neighbouring Malawi having a GDP of US$407, Zambia US$981, Tanzania at US$1,090 and Eswatini at US$3,504 [3]. The main diseases that affect the country are malaria, anaemia in children and HIV/AIDS. The average level of schooling is 3.5 years, and the adult literacy rate is 60.7% [4]. The total population with access to potable water is 50.3 (%) [5], and with access to energy from the national electricity grid is 35% [6].

Historically, Mozambique is the country most affected by natural disasters in the Southern African region. Mozambique has recorded a total of 53 disasters in the last 45 years, representing an average of 1.17 disasters per year. These disasters displaced 500,000 people, destroyed infrastructure and had a very negative impact on the national economy. The main disasters faced are of a meteorological nature, mainly droughts, floods, cyclones and storms [7].

The country has comparative advantages in many areas, of which the following stand out, among others (i) Extremely privileged strategic location, as it is the natural way out for most of its landlocked neighbours; (ii) Ecosystems that allow you to have coastal and inland tourism; (iii) Neighbourhood with South Africa, a regional power.

• Energy system background and context

Here write max. 1 page about the energy supply and demand panorama at the national level (include regional specificities if needed). Please include information about available energy purchase models for the consumers (both for electricity and fuels).

Mozambique is rich in both fossil fuel based and renewable energy based resources. Mozambique holds 1,975 million tons (MMst) of proven coal reserves as of 2016, ranking 26th in the world [8]. Mozambique holds 100 trillion cubic feet (Tcf) of proven gas reserves as of 2017, ranking 14th in the world and accounting for about 1% of the world's total natural gas reserves of 6,923 Tcf [9]. As far as renewable energy resources is concerned, solar is the most abundant one, with 23,000 GW, hydro with 18 GW, wind with 4.5 GW, and biomass with 2 GW [10].

Mozambique's energy balance in 2019, was constituted by 85% of hydroelectric energy, 14% of natural gas and 1% of solar energy [11]. However, over the last decade, Mozambique has started to actively develop its large reserves of coal, natural gas and hydropower. Once developed, Mozambique can become a major player in regional and global energy markets.

Over the last two decades, Mozambique's energy balance already shows a considerable expansion of the energy sector, unprecedented in the country's history. Since 2000, on average and by approximation, energy production has increased by 6% a year, imports by 10%, exports by 20% and final consumption by 4% [11]. This expansion is largely driven by developments in the natural gas and electricity markets. Despite the emerging production and use of modern forms of energy, traditional biomass energy services (firewood and charcoal) still dominate Mozambique's energy balance: it currently represents more than 60% of final energy consumption. About 95% of the total energy needs of families are still met with firewood and charcoal. In urban areas, charcoal quickly became the predominant fuel, accounting for approximately 50% of all energy consumption expenditures. Currently, households are responsible for around 60% of total energy consumption, followed by the transport sector (30%) and industry (8%). .

In recent years there have been initiatives to promote programs to increase, the access to energy services in areas not covered by the national electricity grid, in line with the Gobal Agenda 2030. Significant efforts to develop regulatory instruments for the energy sector have been taking place. practices.

• Use of energy for cooking

Here write max. 10 lines about the current situation regarding use of energy for cooking in your country, including regional differences.

Energy for household cooking accounts for the major fraction of household energy demand in Mozambique. In Mozambique, biomass is the main source of household energy [12]. The most common source of household energy for cooking is biomass. Indeed, Urban households are heavily dependent on biomass, with charcoal being the most used biomass fuel, either exclusively or in combination with other cooking fuels such as firewood, LPG and/or electricity. In the purely rural settlements, the most common source of energy for household cooking is firewood. Special circumstances may result in the adoption of livestock manure, crop residues, agricultural wastes and forest residues as cooking fuels. The Mozambican main cities were found to charcoal-reliant as follows: Maputo and Matola-87%, Beira-85% and Nampula-92%, used either exclusively or in combination with LPG, Electricity or Firewood. Maputo town had also another energy source: ethanol [12].

• Use of clean cooking solutions

Here write max. 10 lines about the current use of clean cooking in your country and perspectives for the future, including regional differences. At least, both thermal and electricity based solar cookers should be addressed.

There had been efforts to shift from unsafe cooking fuels and devices to cleaner and efficient cooking fuels and devices. These included ethanol stoves, improved cook stoves and good cook practices. Indeed, ethanol cook stoves had been widely spread in Maputo by Ethanol and Cooking Fuel Project (CleanStar, Lda) [13]. Apart from this initiative, different projects introduced cleaner and more efficient charcoal/firewood cook stoves in Maputo funded by different organisations. Therefore, cleaner cooking solutions are fairly known in urban households. However, for different reasons, low acceptance has been achieved in the rural area. As an example, in Maputo urban households, 96.12% use charcoal for cooking with around 30% using only charcoal. The remaining households combine charcoal with LPG (32.8%), electricity (22,9%), ethanol (17%) or firewood (12%) [12]. The rest of the country is more reliant on biomass fuels than Maputo and has fewer modern fuels alternatives available.

• Future orientations

Here write max. 10 lines about ideas for future development (5 to 10 years) of the energy sector in your country, including supply and demand sides.

For future cleaner and efficient cooking solutions, at household level, there's a hope that, in Maputo Metropolitan area, natural gas will be the most probable solution. However, in the other towns, the spread of cleaner fuels is less probable to take place. Additionally, there's a need to perform pre-study on socio-economic factors influencing the choice of fuels and cooking devices. This should include the retrieval of past experiences and full characterisation of the different cultural and behavioural habits according to different socio-cultural backgrounds found in the urban and periurban areas. For rural communities, improved cooking stoves are most unlikely to succeed unless appropriate measures are undertaken in partnership with sociologist scientists. Indeed, every solution implemented so far, had advantages and disadvantages from the economic point of view as well as from the socio-cultural perspective. These aspects demand confirmation and must be addressed while designing future cooking solutions to these communities. In fact, in the past, a program on improved cook stove showed the advantage of a participatory design of customized improved cook stoves in a rural community near the Maputo City.

• Local entities responsible for the data publishing on the sectors to characterize social, economic and technological data

(Please fill the google spreadsheet available at https://docs.google.com/spreadsheets/d/1csuhWsKf54bohNwe3C3si72epX5sg2krHNcsupR_P2E/edit?usp=sharing*)*

• Stakeholders

Here put a bullet list identifying the most relevant stakeholders of the solar cooker (including research, SME, industry, local entities and user types) that should be targeted by the project.

- Universities: UEM and UP-Maputo
- Research institutions: CPE-UEM and Faculty of Engineering-UEM
- Non-governmental organisations: Clean Star; Improved Cook Stoves Project
- Private sector;
- Ministry of Mineral Resources and Energy;
- Cooperation partners: GIZ

• References

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