

Modelling Cooking Energy Demand for E-Cooking Transition

By

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DECLARATION AND APPROVAL

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the dissertation contains no material previously published or written by another person except where due reference is made in the dissertation itself. No part of this thesis may be reproduced without the permission of the author and Strathmore University.

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DEDICATION

To my family for support and loving grandmother Mrs. Petronalla Ang'awa for her unwavering faith in me. To all my friends for the amazing and wonderful support all through that will never be forgotten. I extend my heartfelt gratitude to the REED TEA/LP scholarship for making my dream possible.

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ABSTRACT

As per estimates, 92% of rural households still use a form of traditional biomass as their preferred cooking fuel. Children especially those under 5 years, suffer from respiratory infections due to the solid fuel combustion. Kenyan women as well as young children are especially exposed to indoor air pollution, which is connected with more than 15,000 unnecessary deaths annually. The Kenyan government and other non-governmental agencies have been on the forefront to promote adoption of electric cooking through various policies and set targets. Considering population expansion in the rural areas and greater electrification percentages, the expectation is that electric energy consumption would increase. This study employs the LEAP modelling tool to forecast rural residential cooking energy demand from 2020 to 2040. Results indicate that traditional biomass, continues to dominate cooking practices, contributing to indoor air pollution. However, alternative scenarios demonstrate the potential for accelerated shifts toward cleaner cooking technologies. Analysis of household surveys reveals a prevalent reliance on traditional biomass fuels such as fuelwood and charcoal, with minimal usage of electric cooking technologies. The LEAP modelling exercise simulates three scenarios: Business As Usual (BAU), Moderate Accelerated Shift (MAS), and High Accelerated Shift (HAS). Under the BAU scenario, traditional cooking methods persist, resulting in a steady increase in total energy demand, reaching 1,937.98 million Gigajoules by 2040. In contrast, the MAS scenario projects a moderate shift towards cleaner technologies, with total energy demand reaching 1,681.9 million Gigajoules by 2040. Notably, the HAS scenario envisions a proactive transition, with rapid adoption of electric cooking and other advanced technologies. This scenario leads to a significant reduction in traditional cooking methods, resulting in a 17% decrease in total energy demand by 2040. The findings highlight the importance of targeted interventions to promote the adoption of electric cooking and other clean energy technologies in rural Kenya.

Keywords: LEAP model; clean energy; electric cooking fuel; sustainability; scenario analysis; electricity; fuel switching;

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DEFINITION OF TERMS

Greenhouse Gas Emissions: Any type of gas capable of retaining heat in the Earth's atmosphere, thus contributing to the greenhouse effect and global warming (Bakun et al., 2015).

Clean energy cooking technologies: Cooking systems characterized by their low or almost non-existent pollution output when contrasted with conventional technologies (Rosenthal et al., 2018).

ABBREVIATIONS/ACRONYMS

AEPC	Alternative Energy Promotion Centre
CCAK	Clean Cooking Association of Kenya
CETs	Clean energy technologies
EPC	Electric pressure cooker
EPRA	Energy and Petroleum Regulatory Authority
GHG	Greenhouse Gas
HAP	Household Air Pollution
IEA	International Energy Agency
KNBS	Kenya National Bureau of Statistics Kenya
KPLC	Kenya Power and Lighting Company
LEAP	Low Emissions Analysis Platform
LMCP	Last Mile Connectivity Program
MECS	Modern Energy Cooking Services
MoE	Ministry of Energy
MTP	Medium Term Plan
NDC	Nationally Determined Contribution
NEA	Nepal Electricity Authority
SDG	Sustainable Development Goals
SE4All	Sustainable Energy for All
SSA	Sub Saharan Africa
TED	Technology and Environmental Database

WHO

World Health Organization

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Over 2.5 million rural communities rely on biomass for cooking, which includes animal dung, agricultural waste, and charcoal (IEA, 2006). Energy poverty has an effect on rural Kenyans' growth and well-being yet energy is a necessary condition for social and economic advancement. For the vast majority of rural houses, biomass serves as their main energy source. Uncontrolled tree cutting occurs in rural regions due to an overreliance on unsustainable wood fuel, which is made worse by climate and rainfall variation (Hamid & Blanchard, 2018).

A study by the Clean Cooking Association of Kenya (CCAK) and Ministry of Energy (MoE) revealed that nearly 70 percent of Kenyans use a form of woodstove as their main or secondary cook stove, with a greater proportion of 92 percent in rural families (Clean Cooking Association of Kenya, 2019). The Sustainable Development Goal 7 (SDG7) has a target to guarantee that everyone has access to inexpensive, dependable, sustainable, and contemporary energy by 2030. Cooking is a key entry point for encouraging the use of clean, inexpensive, and sustainable energy (Sarkodie & Adams, 2020). Kenya is determined and has set a target to achieve universal access to modern cooking solutions by 2030, in accordance with SDG 7 and electric cooking is among the solutions (Mugo & Ong, 2022).

Population growth is increasing and biomass users in rural areas is predicted to reach 2.7 billion by 2030 (Twumasi et al., 2020). In order to fast-track electric cooking adoption in the rural area and to ensure that the policies in place are on track, it is important to have a viewpoint of the future cooking energy demand in the rural households. Kenya's government has been supporting the

usage of electric cooking in order to reduce fuelwood demand. Nevertheless, the effects of such initiatives have never been measured from the perspective of the national economy. To address the issues provided by emerging countries' energy systems, Chang et al., (2021) claimed that good energy planning necessitates a good energy model. A successful transition to E-Cooking necessitates a detailed understanding of present cooking energy demand patterns and variables influencing fuel choices. This is where data-driven research comes into play.

This study seeks to fill these information gaps by modelling cooking energy demand using a data-driven methodology. By leveraging large-scale datasets, such as national energy consumption statistics, valuable insights can be gained into the current energy consumption patterns for the rural areas. The findings of this research are expected to provide valuable insights for policymakers, energy planners, and other stakeholders involved in promoting sustainable energy transitions. By understanding the dynamics of cooking energy demand and the factors influencing the shift towards cleaner cooking technologies, targeted interventions can be designed to facilitate a successful E-Cooking transition, leading to positive impacts on public health, environmental conservation, and overall sustainable development

1.2 Problem Statement

Concerns about climate change and the negative environmental effects of traditional cooking methods have spurred policymakers to investigate alternate cooking methods, such as e-cooking, which uses cleaner and more sustainable energy sources. E-cooking policy implementation demands informed decision-making based on credible data on cooking energy usage. The lack of comprehensive and up-to-date data, on the other hand, poses a huge difficulty in formulating

effective policies that address the complicated and various culinary practises around the world (Makonese et al., 2018).

Access to modern energy sources is essential for raising living standards in emerging nations, especially for rural and underprivileged urban families (Lewis & Pattanayak, 2012 ; Hart & Smith, 2013; Shankar et al., 2015; Makonese et al., 2018). Traditional cooking fuel consumption has a substantial impact on indoor air quality, human health, and environmental sustainability (Makonese et al., 2018). In order to design regulations that encourage clean cooking and lessen the dependency on traditional fuels, it is crucial to understand the present cooking fuel types and the factors that influence their choice.

Energy planning in Kenya is a key task that necessitates understanding of the energy requirements in order to ensure optimal resource allocation and utilisation. As the country's population and economic activity develop, the need for energy to cook has become an important factor in creating the country's energy landscape. The availability of data from cooking energy demand modelling is critical for Kenyan e-cooking energy planning. There have been few studies undertaken in Kenya to investigate the energy requirements and implications of establishing universal access to clean cooking fuels and stoves (Dagnachew et al., 2020).

Although electric cooking adoption has been slow in the rural areas due to perceptions and cultural beliefs; increased electrical connectivity in conjunction with aggressive clean cooking targets, opens up a fresh window of opportunity for electric cooking. Considering population growth in the rural areas and increased electrification, electricity energy demand will increase. This emphasises the importance of data analysis on cooking energy usage in informing policy and promoting energy-efficient cooking practises.

There have been studies on modelling the overall energy landscape of Kenya but there are no peer reviewed studies that focus on long term prediction of the cooking energy demand in the rural households. This study therefore seeks to develop a long-term model to predict the expected cooking energy demand in the rural areas over a period of 20 years. The resulting data can then be used by policy makers to influence policy development and energy planning for the rural households in Kenya.

1.3 Research Objectives

1.3.1 General Objective

The general objective of the research is to develop a model to predict the cooking energy demand for rural residential sector that will inform the development of energy plan and policy.

1.3.2 Specific Objectives

- i. To analyze the types of cooking fuels used in the rural households
- ii. To estimate the average cooking energy demand in the rural areas
- iii. To develop a model for prediction of the cooking energy demand of the rural sector
- iv. To validate the developed model

1.4 Research Questions

The research seeks to answer the following questions;

- i. What are the different types of cooking fuels commonly used in rural households?
- ii. What is the average cooking energy demand in the rural areas?

- iii. What factors and variables are integral in the development of a predictive model for cooking energy demand in the rural sector?
- iv. How can the developed model be validated?

1.5 Justification of the Study

This data from the study should be useful to Kenyan government and other stakeholders to plan accordingly and make necessary policy changes to ensure adoption of electric cooking. The results are helpful to the policymakers to establish policies regarding the industry's regulation for the benefit of the households and the local economy. This research is of great worth to the rural households as the developed model is helpful help to fast-track electric cooking adoption. With electric cooking, the women in the rural households would save on the time they use to cook, time that can be used to focus on business. The young girls tasked with the cooking chores can focus their time more on studies. The HAP will reduce and thus respiratory diseases will reduce too.

1.6 Scope of the Study

The study focuses on rural households in Kenya. This research seeks to develop a model which will predict the cooking energy demand in the rural households. Secondary data from government sources and other credible sources were analyzed.

1.7 Limitations of the Study

The study faced a few limitations worth noting. The time for the research was limited. Data to be used in the modeling was a challenge to get, especially where the data was not available online or from government agencies. The area of focus was the rural households. The rural household consumed the major share of biomass energy demand as reported from census data by Kenya National Bureau of Statistics. The studies that had been done focusing on rural areas' cooking

energy demand were limited. This study gave an idea of how the landscape would look in the next 20 years and how to fast-track electric cooking adoption

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

This section examines the current literary works on the subject of study. It incorporates the results of related investigations conducted by other scholars.

2.2 Theoretical Review

Several research efforts have been directed towards household cooking energy sources, a topic that is directly related to cooking energy demand. The energy ladder model serves as a theoretical framework for comprehending the transition of households from traditional, inefficient cooking fuels to modern, cleaner energy sources (van der Kroon et al., 2013; Cheng & Urpelainen, 2014; Bisu et al., 2016; Megbowon et al., 2018). This model posits that as households experience improvements in income and access to resources, they tend to shift away from biomass fuels like firewood and charcoal towards cleaner alternatives, such as liquefied petroleum gas (LPG) and electricity (van der Kroon et al., 2013).

The core concept of the energy ladder model revolves around the idea that as households ascend the socioeconomic ladder, they gain the capacity to afford and access more efficient and cleaner cooking technologies (van der Kroon et al., 2013). This transition is driven by various factors, including income, education, urbanization, and the availability of modern energy infrastructure (van der Kroon et al., 2013; Cheng & Urpelainen, 2014). As households progress up the energy ladder, they not only enhance their cooking energy efficiency but also mitigate indoor air pollution and related health risks.

Nonetheless, it is essential to acknowledge that the energy ladder model has faced criticism and encountered limitations (van der Kroon et al., 2013). Critics argue that the model oversimplifies the intricacies of household energy transitions and neglects cultural, social, and behavioral factors that play a role in fuel choice. Additionally, it assumes a linear progression from one fuel type to another, disregarding the possibility of fuel stacking, in which households simultaneously use multiple fuels for different cooking purposes (van der Kroon et al., 2013).

According to the "energy stacking" model, the transition by families to clean energy is not linear; rather, households simply expand the amount of energy sources used without necessarily discontinuing use of old ones (Bisu et al., 2016). In this case, household energy use habits are influenced by a variety of factors other than income. For instance Habib et al. (2023), conducted a study in India that revealed the prevalence of fuel stacking, where households employ a combination of biomass fuels, LPG, and electricity for cooking. The study also highlighted the complexity of the factors influencing fuel stacking, which can vary depending on the household's socioeconomic status, location, and cultural norms.

Figure 2.1 depicts two models, the energy ladder model , which essentially demonstrates how people with lower incomes stop using traditional biomass fuels and switch to contemporary substitutes as their income rises and the energy stack model which explains that the transition by families to clean energy is not linear; rather, households simply expand the amount of energy sources used without necessarily discontinuing use of old ones (Bisu et al., 2016)

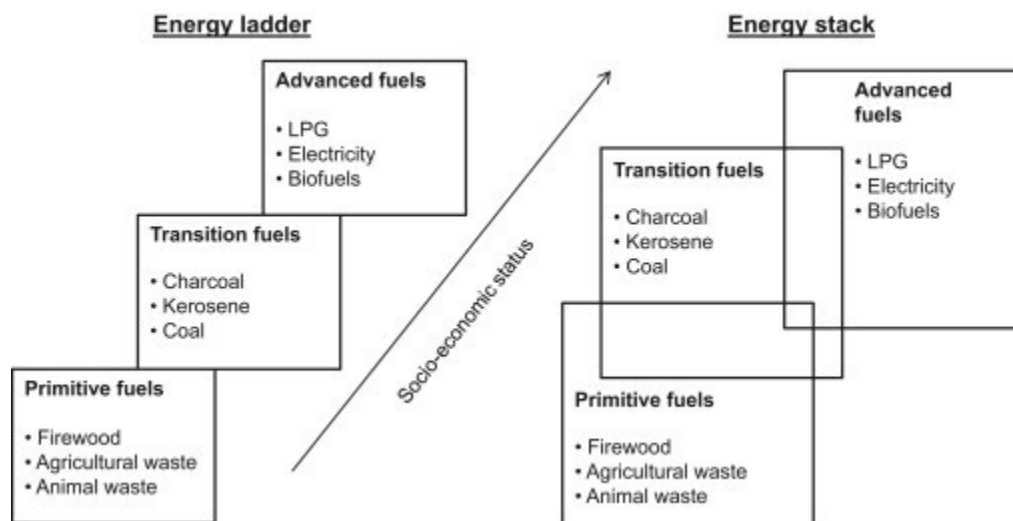


Figure 2.1: Energy ladder and Energy Stack Models

Source: (van der Kroon et al., 2013)

Despite its limitations, the energy ladder model remains a valuable framework for comprehending the factors influencing fuel choice and the potential for transitioning to cleaner cooking fuels. By considering variables such as income, education, and access to modern energy infrastructure, researchers can develop models to predict and analyze cooking energy demand patterns (van der Kroon et al., 2013). These models can then inform policy interventions and strategies aimed at promoting the adoption of cleaner cooking technologies and enhancing energy efficiency in households (van der Kroon et al., 2013);

A connection has been established in numerous research studies between the size of a household, which refers to the number of individuals inhabiting a dwelling, and the utilization of energy (Gatersleben et al., 2002). It is obvious that as home size grows, so does total energy use. It is important to note, however, that there is significant variety in the forms of energy usage. Energy efficiency is determined by the fuel choice used and the features of certain equipment/appliances that consume fuel. In many developing countries, agricultural waste, firewood, and charcoal are

the main sources of domestic energy. Total end-use efficiency is greatly impacted by these devices' poor energy efficiency (Gatersleben et al., 2002; WHO, 2022).

2.3 Empirical Review

In their assessment of the domestic electric cooking demand in Nepal, Bhandari & Pandit (2018) used the Long-range Energy Alternative Planning System (LEAP) modelling tool to evaluate the expected household cooking energy consumption and its effects on the environment and the economy from 2015 until 2035. In order to model Nepal's household cooking industry, the researchers created four scenarios: business as usual (BAU), low growth rate (LGR), medium growth rate (MGR), and high growth rate (HGR). The researchers agreed that cooking energy is a major factor in Nepal's energy requirement. The model's findings indicated that from 2015 to 2030, there would be a growing requirement for electricity and LPG gradually in step with population growth and urbanization. The study also found that, under the Business as Usual (BAU) Scenario, 718 MW of total power would be needed by 2035 to sustain the growing requirement for electricity for cooking. The scenarios used government policies and strategies to anticipate future energy balances based on current trends. If present patterns in LPG demand persisted, official projection data that determine the shape of the sector for the ensuing years would result in a rise in GHG emissions from LPG of 2.1 to 7.5 times the emission level of the base year. The model also demonstrated that, if current trends in LPG consumption hold true, LPG-related GHG emissions would increase by 2.1 to 7.5 times compared to baseline year emission levels. To transition the cooking industry from LPG to electricity by 2035, varying hydropower capacities will be required for different scenarios: 1207 MW for BAU, 734 MW for LGR, 2055 MW for MGR, and 2626 MW for HGR. The entire residential market in Nepal was the subject of the investigation.

Yangka & Diesendorf (2016) used MARKAL as a modelling tool to analyze long-term patterns in Bhutan. This study evaluated the advantages associated with the increased adoption of electric cooking within Bhutan's household sector. It specifically focused on the potential savings in kerosene and firewood usage within the context of Bhutan's long-term energy system development strategy. According to the estimate, home electricity usage would grow by 9.1%, resulting in an average yearly increase of 41 million kWh and an average yearly savings of 55 kl of fuel wood and 1,832 kl of kerosene. The researchers arrived to the conclusion that the rise in power use brought on by electric cooking will add to the peak demand in the system. The entire Bhutanese residential market was also the subject of the investigation.

Debnath et al. (2015) employed a bottom-up approach to forecast the total energy consumption of Bangladeshi rural households from 2010 to 2050. Lowest, highest, and ideal energy demand paths for rural Bangladeshi homes were predicted by combining 4 level scenarios of 4 factors (population, public energy conservation index, GDP electrification index). The entire energy demand was computed by adding the demand for electricity, liquid fuel, and biomass. The following formulae were used to compute these demands:

$$E_{ELEC} = A_{GRID} H F_{PEC} F_{GDP} \sum_{i=1}^n O_i N_i P_i \quad (2.1)$$

$$E_{LF} = (1 - A_{GRID}) H \sum_{i=1}^n O_i N_i P_i \quad (2.2)$$

$$E_{BIO} = H \sum_{i=1}^n O_i N_i P_i \quad (2.3)$$

In this equation, E_{ELEC} , E_{LF} , and E_{BIO} represent electricity, liquid fuel, and biomass demand, respectively. A_{GRID} = Access to utility grid, H = Number of rural homes, F_{PEC} = Public energy conservation factor, F_{GDP} = GDP electrification index, O_i = Operating hours of an appliance, N_i = Number of appliances and P_i = Rated power consumption of an appliance are also denoted. The model forecasted energy consumption using three types of assumptions:

- i. Trajectory: Population, access to utility (A_{GRID}), public energy conservation factor (F_{PEC}), GDP electrification index (F_{GDP}), and choices of luminaire technology were all influenced by trajectory parameters.
- ii. Fixed: These parameters were established using past data. Fixed assumptions were used to establish size of rural home (H), appliance ownership (N_i), appliance operating hours (O_i), and power rating of appliance (P_i).
- iii. Derived: These were derived from the trajectory and the fixed parameters. These parameters anticipated luminaire technology, energy usage per unit, and solar home system (SHS).

The energy demand pathway model showed that energy demand increased significantly. In the event of significant demand, the increase might be three times that of 2010. If the population, GDP, access to utility grid, and energy use consciousness are not kept an eye on and under control, the unmet demand in 2010 could become unsustainable.

Ibitoye (2013) used LEAP to simulate future household sector trends in Nigeria under various scenarios, using 2005 as the base year. In order to support the United Nations' millennium development goals, three growth paths were used in the different scenarios for the demand for energy in Nigerian households: improved electricity supply, improved access to advanced fuels

for cooking, and better living conditions for the overpopulated urban slums. From the analysis, the demand for modern cooking fuels would more than double, resulting in a drop in the usage of fuelwood, while home power needs would increase by 41% over the baseline scenario to fulfill the century targets.

According to Adam et al., (2022), International Energy Agency (IEA) in its attempt to enhance the data processing and long-term energy planning, created an Excel centered model to provide household solid bio-fuels usage, per fuel type and end uses. Focus was on charcoal and firewood for 10 African countries including Kenya, Benin, Senegal, Ethiopia, Ghana, Nigeria, Democratic Republic of Congo (DRC), Rwanda, Uganda and Zambia. The population and the number of households categorized into urban and rural areas are the main demographic parameters that were used to estimate the residential energy consumption of solid biofuels. The prediction model used is a hybrid strategy that combines top-down and bottom-up techniques.

The following nation statistics from IEA datasets on solid biofuel usage for charcoal and firewood, as well as demographics data, are used to calculate average family consumption for charcoal and firewood:

$$Q_{daily} = \frac{E_{solid\ biofuels}}{NH * Pop * NCV_{Solid\ biofuels}} * \frac{1}{365} \quad (2.4)$$

$E_{solid\ biofuel}$ represents total residential electricity supply per fuel type, NH is the number of homes, Pop represents the population and NCV is the Net Calorific Value.

Four scenarios were modelled including;

- i. User-defined option which enables the user to select figures between decades to meet the requirements of the specific exercise or the predicted development for the nation of analysis.
- ii. STEPS Future pathway of the variable by 2050- following the Stated Policies Scenario (STEPS) of the IEA.
- iii. SDS Future pathway of the variable by 2050- following the Sustainable Development Scenario (SDS) of the IEA.
- iv. Linear - The variable's projected path by 2050 is based on a linear forecast using the FORECAST.ETS function in Excel, which derives or forecasts a future value utilizing existing (past) data.

The energy usage per end-uses and fuel type were computed using the following equations;

$$E_{0=} \sum_i \sum_j (NH * \%NH * E_{fuel_{ij}}) \quad (2.5)$$

$$E_{0=} \sum_i \sum_j \sum_k \sum_l (NH * \%SH_i * E_{use_{ijkl}}) \quad (2.6)$$

$$NH = \frac{Pop}{\theta} \quad (2.7)$$

NH is the overall number of homes, SH_i is the percentage of each type of household, and E_{Fuel} is the amount of energy used by each type of household and each fuel (TJ/Household). i refers to the demographic nature of the area (urban or rural), θ is the average household size (person/household), and j the type of solid fuels used (firewood, charcoal, agricultural waste). E_{use} stands for energy use, where k stands for the kind of end-uses (heating, cooling, lighting), and l stands for the different kinds of cooking stoves.

The results from the model shows that firewood would still be a dominant source of cooking fuel in 2015 as shown in Figure 2.2.

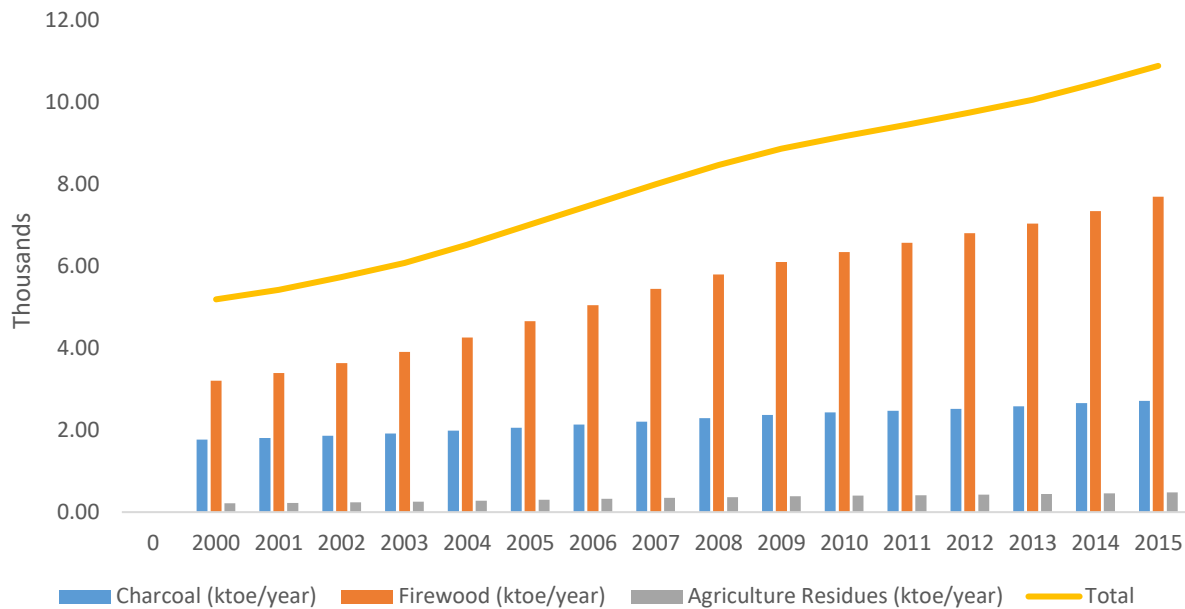


Figure 2.2: Biomass energy demand

Source: (IEA – International Energy Agency, n.d.)

Ambition To Action (Schiefer, 2021) created an excel-based model to provide an understanding of Kenya's specific relationship between domestic cooking alternatives, climate change, associated risks, and related sustainability objectives. Based on the 2019 National Cooking Sector Study, the model used scenario simulation to present different possible development strategies for Kenya's residential cooking industry, assessing their corresponding effect on GHG emissions and people's health, as well as detailed study on fuel use, energy usage, fuel expense, and deforestation. The scenarios modelled were 5 as explained in the Figure 2.3 below;

Scenario	Description	Objective	
BAU	Business-As-Usual Scenario	Based on historical data. Displays a future in which historic trends in the Kenyan residential cooking sector continue in a similar manner.	Present baseline scenario.
NDCU	NDC Update Scenario	Based on expert input from the modelling of Kenya's <i>updated NDC</i> . Assumes that a similar rate of change is maintained post-2030.	Present existing national policies and targets and a realistic development pathway for the residential cooking sector in the short- to medium-term.
IP	Implemented Policies Scenario	Based on policies and targets set for the mid-term (pre-2030) in the <i>2016 SE4All Kenya Action Agenda</i> . Assumes that a similar rate of change is maintained post-2030.	
GF	Gas Focused Scenario	Scenario with a focus on gas as cooking fuel, based on the <i>2020 IEA Africa Case</i> .	Speculative scenarios to analyse enhanced ambition and explore the requirements for decarbonising the residential cooking sector.
NZ	Net Zero Scenario	Scenario with a focus on electricity as cooking fuel, based on regional best practices and top-down assumptions to reach net zero by 2050.	

Figure 2.3: Scenarios used by Ambition To Action

Source: (Schiefer, 2021)

The results from the model by Ambition To Action (Schiefer, 2021) are displayed in Figure 2.4. The overall energy demand exhibits the same pattern as the emission pathways: the lower the energy demand, the greater the fraction of clean fuels and the quicker the transition to enhanced solid biomass cook-stoves. Improvements in solid biomass cook-stoves helped to significantly reduce energy demand, but long-term fuel demand continued due to increase due to population increase. Electricity saves the most energy since it is the most effective technology. As a result, the NZ-S scenario, which is primarily focused on electricity, is the only one that exhibits a continuously declining energy demand over the course of the time series. By contrast, the GF-S scenario, which is primarily focused on gas and biofuels, is unable to keep up with the rising

population and overall energy consumption between 2030 to 2050. The same is observed for the IP-S scenario.

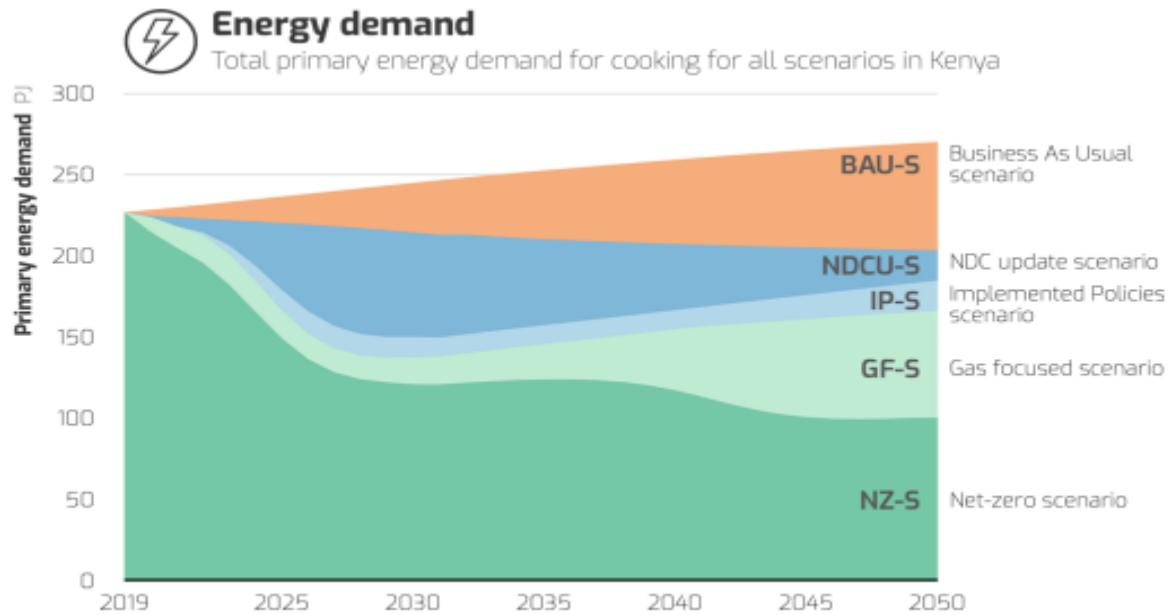


Figure 2.4: Total primary energy demand (PJ) for residential cooking for all scenarios

Source: (Schiefer, 2021)

Figure 2.5 below depicts the GHG emissions (MtCO₂e) paths for all scenarios. The gas focused scenario (GF-S), the net zero scenario (NZ-S), and the implemented policies scenario (IP-S) all share the goal of having full access to modern cooking technologies by 2030, in conformity with SDG 7. The improved efficiency has a major influence on Kenya's overall GHG emissions from the domestic cooking sector. As a result, in all of those scenarios, GHG emissions and fuel demand will be rapidly declining by 2030 (Schiefer, 2021).

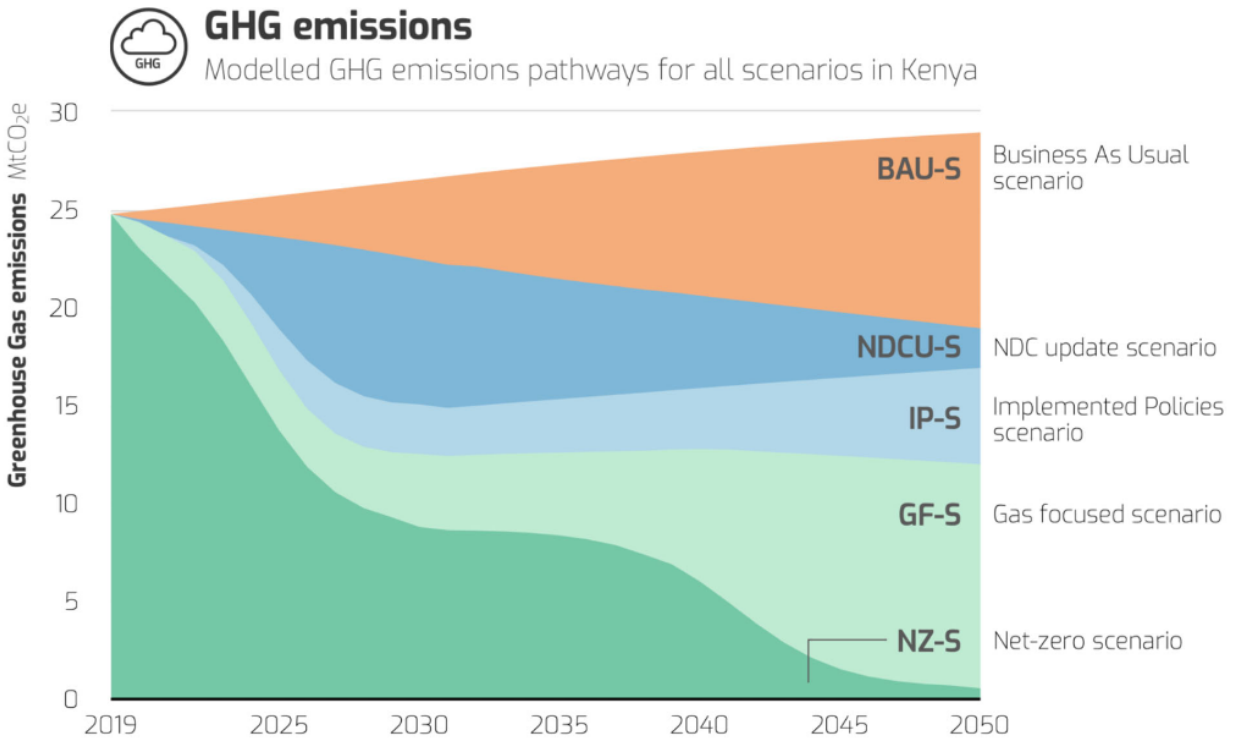


Figure 2.5: Modelled GHG emissions (MtCO_{2e}) pathways for all scenarios.

Source: (Schiefer, 2021).

2.4 Cooking Energy Sources

Energy is a basic living resource as well as an industrial need. The definition of rural residential energy usage often includes cooking, lighting, appliances, and other home requirements. The economy and wellbeing of rural populations are significantly impacted by the use of energy in rural areas. At the moment, over 2.64 billion individuals in developing countries depend primarily on conventional biomass fuels for heating and cooking with 82% residing in rural areas (IEA, 2011). Nearly 400 million people in China, the world's most populous developing country, rely significantly on conventional biomass energy, the most of whom live in rural areas (Wang et al., 2017). Over 70% of energy use is still fuelwood and straw, with only a small portion coming from

high-quality modern energy sources. This system of energy consumption increases CO₂ emissions, which affects the environment and human health (Chen et al., 2006; Venkataraman et al., 2005).

A 2019 report by Kenya Continuous Household Survey Programme (KCHSP) revealed that, firewood remained the most common source of cooking fuel at 84.3% the rural areas. Electricity represented only 0.2% of the households' cooking energy source. Kerosene was used by 2.3% of the rural households while charcoal and Liquefied petroleum gas (LPG) represented 8.9% and 2.5 % respectively (KNBS, 2019b).

Table 2.1: The Percentage of Households by Primary Source of Cooking Fuel

	Firewood	Electricity	LPG	Biogas	Kerosene	Charcoal	Animal dung	Agricultural Crop Residue	Other	Number of households
Rural	84.3	0.3	2.5	0.2	2.3	8.9	0.0	0.3	0.9	6,442,000
Urban	16.1	2.0	27.6	0.2	29.0	21.9	0.1	0.0	2.4	4,972,000
National	54.6	1.0	13.4	0.2	14.0	14.6	0.1	0.2	1.6	11,415,000

Source: Author modified from (KNBS, 2019a)

2.5 Electric Cooking Adoption

2.5.1 Electrification

Kenya has an ever-changing low-carbon, low-cost, and varied energy mix. The generation capacity is a comfortable 2,670 MW, with a peak demand of 1,841 MW. Renewable energy contributes for 65% of total installed capacity and 78% of total electricity generation as of June 2018. Kenya is a global leader in the usage of this low-cost renewable energy resource, accounting for more than 40% of total electricity generation. Vision 2030 scenario projects that power demand will rise from

1,841 MW in 2018 to between 2,633 MW and 3,348 MW over 2018-2022 (Ministry of Energy, 2018)

The Kenyan government established the last mile connectivity program (LMCP) in 2015 hoping to boost household power connections, attaining more than 70% connectivity by 2017 and striving for universal accessibility by 2030. The total rural households connected shot to 61.2% in 2019 compared to 25.1% in 2014 (WHO, 2022). The primary purpose of the LMCP was to promote the social welfare of rural areas and to launch economic activities at the local level in order to develop the country. Even though most of these households were connected, a study conducted by UC Berkeley researchers revealed that LMCP locations consumed less electricity than expected at the time of connection. This insufficient demand indicates a deficiency in social and economic advancement in comparison to what was anticipated at the time of connection. (Lee et al., 2020).

On a critical look, under-consumption of power compromises the existing grid by increasing transmission losses and consequently maintenance costs. Both factors point to uncollected money by the government due to a lack of anticipated economic growth, and under-consumption by the grid supplier, Kenya Power & Lighting Company (KPLC). Okoth (2020), reported that the population of connected rural homes rose by 5.8 percent in 2018/2019 to 1,409,256 as compared to 1,332,209 in 2017/2018. However, income generated decreased by 9.1 percent from KES 11.84 billion to KES 10.77 billion due to low usage by the new clients.

Increased maintenance expenses worsen the problem by converting a potentially profitable investment into a liability for KPLC. In the rural households in Kenya, electric cooking adoption will have a dual impact of increasing electricity consumption while resolving the issues of

pollution. Electric cooking can be regarded as clean on both a household and a national level because Kenya's national grid uses 77% renewable energy (IRENA, 2022) .

2.5.2 The Status of Electric Cooking

Consistent with the 2019 report of Kenya Population and Housing Census (KPHC) by the Kenya National Bureau of Statistics (KNBS), 26.3% of 7,379,282 rural households in Kenya use grid electricity and only 0.4% of that population has embraced electric cooking (KNBS, 2019b). Further to this, the proportion of urban and rural population using electricity to cook stands at 3% and is projected to increase to 18 % and 7 % respectively by 2030 (IEA, 2019).

Through the promotion of electric cooking, Kenya has a good opportunity of linking the clean cooking problem to the nation's rapid advancement in electrification. At the domestic level, there is already a great desire to make use of energy-efficient equipment that are ideal for local dishes and which offer an ideal experience during cooking (Leary, Kalyonge, et al., 2019). Hivos and World Future Council found that electric cooking technologies for instance the slow cooker and the electric pressure cooker (EPC) are cost competitive when compared to other clean cooking technologies (Couture & Jacobs, 2019). However, only 3 percent of households, according to a research, have an electric cooking device. The report attributed the low usage of grid electricity to cook, to a high cost of cooking appliances and consumer perception of electricity prices as being high (Clean Cooking Association of Kenya, 2019).

2.5.3 Benefits of Cooking using Electricity

Traditional 3-stone cooking stoves have a number of negative health effects on its users. Inefficient firewood use has a range of health consequences, as well as major economic and environmental consequences. Asthma, bronchitis, coughing, tuberculosis, and pneumonitis have all been linked

to high levels of indoor pollution caused by the use of firewood. Aside from the disorders stated, exposure can cause a variety of body irritants such as lung swelling, respiratory issues and eye irritation (Vivan et al., 2012).

The consumption of biomass and fuel-based energy sources contributes to indoor pollution, which results in 1.5 million preterm deaths and 1.6 million new born fatalities per year. Furthermore, it is estimated that indoor pollution causes 2.7 percent of all illnesses worldwide (Adepoju et al., 2012; Waweru, 2014). One tactic for reducing indoor pollution is the usage of clean cooking technologies. Traditional cooking stoves used in households consume a lot of fuel due to their high inefficiency. As a result, gathering fuel needs a significant amount of time from household members (Stone et al., 2008). Fuel collection is typically a tough duty that female family members and children must endure. Clean cooking fuels/appliances for instance electric pressure cookers exhibit greater fuel economy and a decreased need for fuel to accomplish a task than conventional stoves. Utilizing these clean cooking fuels and appliances reduces the time spent gathering fuel ((Tigabu, 2014; Kanangire et al., 2016). Cooking heavy foods (eg beans) on EPCs was found to be over 5 times cheaper compared to charcoal, kerosene or LPG in grid connected households. (Leary, Todd, et al., 2019). Heavy foods like dried beans are a major consumer of fuel during cooking as it takes longer to cook, yet they are a staple meal in most households.

2.5.4 Clean Cooking Policy & Initiatives

Senegal is a good example on the importance of progressive government policies towards clean cooking. Senegal, which notably relies on LPG as a cooking fuel, exemplifies how countries can effectively promote LPG over biomass. In the 1970s, the Senegalese government facilitated the widespread use of small LPG cookstoves by eliminating taxes and tariffs on LPG equipment and

introducing subsidies for small cylinders. The objective was to alleviate pressure on forest resources, and by 2006, 75% of urban households were utilizing LPG stoves. However, the removal of subsidies in 2010 due to fiscal constraints led to a sharp decline in LPG consumption, highlighting the sensitivity of households to price fluctuations (Bensch & Peters, 2020).

Brazil's 65-year history with LPG adoption demonstrates the transformative power of government initiatives. Brazil gained widespread adoption of LPG as the primary cooking fuel source through generous subsidies, price controls, and private sector involvement, drastically lowering dependency on wood and charcoal. This transformation coincided with substantial economic growth and urbanisation. Ecuador is also among the countries in Latin America that effectively switched from polluting fuels to LPG for primary cooking fuel in urban areas through effective policies (Puzzolo et al., 2020).

The Sustainable Energy for All (SE4All) Plan served as the foundation for the 2016 Kenya Action Agenda. It offers a long-term outlook for the growth of the energy industry from 2015 to 2030. It explains how Kenya will accomplish the SE4All objectives by 2030, including achieving 100% access to contemporary cooking options and 100% access to electricity. KOSAP, the Kenya Off-Grid Solar Access Project (2017-2023), is a World Bank-funded project that focuses on the electricity supply and cooking sectors. It offers power and clean cooking choices to 14 impoverished communities until 2023. Import duty on cookstoves (2016 – 2020) proposes lowering the import tax for energy-efficient cooktops from from 25% to 10% to encourage the clean cooking appliances, with an on emphasis on energy efficient cooking appliances (eg those using electricity, or other cleaner technologies). Kenya's Vision 2030 aim, as stated in the Medium Term Plan (MTP) III, is to achieve nationwide energy access by 2020, which might increase the

availability of clean cooking options. This objective is completely consistent with SDG 7 (Schiefer, 2021).

In keeping with Kenya's sustainable development objective, the Nationally Determined Contribution (NDC) 2020-2030 aims to reduce GHG emissions by 32% by 2030 through a low carbon and climate resilient growth route that includes the energy sector. Electric cooking adoption should be one of the target to achieve the NDC goal. The National Climate Change Action Plan (NCCAP) for the period of 2018–2022, which sets corresponding goals for the plan's duration, lists the switch to clean cooking as a key climate change action in the energy consumption sector. The NCCAP is based on and takes inspiration from the MTP III, which offers a roadmap for national growth over a similar time period (2018-2022)(Ministry of Energy, 2018).

Other government players in the electric cooking sector are KPLC, who are implementing LMCP, and the Pika na Power programme which seeks to increase electricity consumption through electric cooking. The programme raises awareness and markets electric cooking to KPLC's 7 million customers.

The National Electrification Strategy, which describes the policy agenda, investments, and cooperative environment that can enable Kenya to achieve SDG7 by 2022, is currently the policy document that is closest to electric cooking. With respect to policy actions the Kenyan government added electric cooking to its results-based financing option under the Kenya Off-Grid Solar Access Programme. This incentivised supply chain development for off-grid electric cooking and electric cooking device use in underserved counties (Leary et al., 2022)

2.6 Estimation of Cooking Energy Demand

Cooking is a necessary daily activity that necessitates the use of energy, and the need for cooking energy varies greatly across different locations and societies. Cooking energy demand estimation is critical for building efficient energy systems and promoting sustainable practises. Various procedures and techniques are used to estimate the energy demand for cooking in order to determine the energy requirements for various fuel types.

2.6.1 Methods and Challenges of Estimating Cooking Energy Demand

Cooking energy demand estimation is measuring or calculating the amount of energy required to prepare food for a particular population over time. Surveys, tests, models, and proxies can all be used to do this. Each strategy, however, has advantages and disadvantages, and there is no universally acknowledged or standardized approach.

One of the most difficult aspects of predicting cooking energy consumption is the diversity and complexity of cooking behaviors and preferences across locations, cultures, and households. Cooking involves a variety of aspects, including food type and quantity, cooking device and fuel, cooking method and time, ambient temperature and humidity, size of household and composition, revenue and expenditure, energy availability and accessibility, and cultural and behavioral norms. These parameters might vary greatly within and between countries, making generalization and comparison problematic.

Another problem is converting various energies into a single unit of energy for comparison and aggregation. Physical and chemical features of various energy sources influence their energy content and efficiency. Natural gas, for example, has a larger calorific value than wood, which means it provides more heat per unit mass. Similarly, electric stoves are more efficient than gas

stoves, which means they require less energy to provide the same amount of heat. To compare or aggregate different energies, proper conversion factors must be used to transform them into a common unit of energy (such as megajoules or kilowatt-hours).

For instance, in 2019-2020, the Sustainable Energy for All (SEforALL) programme undertook an integrated energy planning effort for Nigeria. The household cooking intensity (HCI) was calculated as the product of household size and energy needs (MJ) per meal per individual. They assumed that all homes had a three-meal-a-day meal frequency. Based on an average HCI of 1.5 MJ per meal per person and a household size of 4.9 people, they computed the annual per capita cooking energy need as 1,643 MJ. They forecasted the demand for cooking energy under several scenarios of population expansion, urbanisation, and access to contemporary fuels and technology. They discovered that in the business-as-usual scenario, cooking energy demand would rise from 1.3 EJ in 2018 to 2.1 EJ in 2030, and 1.7 EJ in the SEforALL scenario (SEforALL, 2022).

Hager & Morawicki, (2013) examined energy use during cooking in the developed world's residential sector. They estimated the average cooking energy use per capita per year for 25 different countries using data from national statistics, survey responses, experiments, and models. They discovered that the average cooking energy consumption ranged from 190 kWh in Norway to 760 kWh in Canada, with 420 kWh being the global average. They also discovered that, with the exception of Italy and Spain, electric stoves were more common than gas stoves in the majority of countries. They proposed that by enhancing the efficiency of cooking appliances and modifying cooking habits, they could reduce cooking energy use by up to 50%.

2.6.2 Standardization of the Energy Equivalents of Different Types of Cooking Fuels

The three basic kinds of cooking fuels are clean, transitional, and polluting. Electricity, solar energy, and gaseous fuels (such propane, natural gas, and biogas) are examples of clean fuels. Kerosene, ethanol, and processed biomass (in the form of pellets and briquettes) are examples of transitional fuels. Unprocessed biomass (such as wood, plant waste, and dung), charcoal, and coal are examples of polluting fuels. These classifications are based on the WHO categorization of clean, transitional, and polluting fuels and lighting technologies (Malla & Timilsina, 2014).

The physical and chemical characteristics of various types of cooking fuels can affect their energy content and effectiveness. The amount of heat produced by burning a fuel's unit mass or volume is its energy content. Megajoules per kilogramme (MJ/kg) or megajoules per litre (MJ/L) are the most common units of measurement. Efficiency is defined as the ratio of energy input to energy output. Typically, it is stated as a percentage (%).

It is necessary to convert several cooking fuel types into a common unit of energy using the proper conversion factors in order to compare or aggregate them. Conversion factors are numbers that compare the efficiency or energy content of one fuel type to another. They may be obtained from assumptions, theoretical calculations, or empirical measurements. Kilowatt-hours (kWh) are a standard unit of energy that are frequently used for comparison or aggregation. A gadget that uses one kilowatt (1000 watts) of power for one hour utilises one kilowatt-hour of energy. It has a 3.6 megajoule (MJ) equivalent (Finkel, 2023).

2.7 Energy Demand Modelling

Energy system models are essential for planning and comprehending energy transition trajectories.

Due to the increasing complexity of energy systems, energy system models — mathematical

depictions of energy systems – are frequently required to assess the significance of this transition and propose possible avenues (Horschig & Thrän, 2017). Energy modelling professionals and planners have access to a variety of tools for representing energy systems in accordance with various technical and methodological concerns. The information from the models can then assist policy- and decision-makers in their planning processes and policy recommendations (Chang et al., 2021). The majority of energy models can be categorized as top-down macroeconomic models or bottom-up techno-economic models (which include intricate engineering linkages between technological activity and energy use) (Bramstoft et al., 2018; Prina et al., 2020; Chang et al., 2021).

Energy is typically treated at an aggregate sectoral level in top-down models as a derived demand that changes in response to changes in economic output and energy costs via elasticities. Bottom-up models accurately depict the energy industries and technology options, describing both present-day and foreseeable technological possibilities. They are helpful for analyzing specific changes in technology and standards because they are typically written as mathematical programming problems. Price increases and macroeconomic consequences are not easily accounted for by these models (Gargiulo & Gallachóir, 2013). A third group is hybrid models, which blend bottom-up and top-down models using either a soft-link or a hard-link strategy (Deane et al., 2012; (Krook-Riekkola et al., 2017).

Gargiulo & Gallachóir (2013) explained that depending on the model formulation, energy models can also be categorised as simulation models (predicting how prospective energy demand and supply patterns will evolve based on prospective patterns of energy drivers) or optimization models (in which, for example, future energy demand is delivered at the lowest cost). Optimization models

can be further classified based on whether the energy system is optimized (partial equilibrium, which are technologically comprehensive) or whether the optimization occurs on an entire economy (general equilibrium models, in which the energy system is more simply described).

2.7.1 Long Term Energy Demand Modelling

Climate policy is a major application of current long-term energy modelling. Energy is also an important component of climate modelling, considering its importance in terms of both present climate change and future mitigation choices. Systems analysis employs systems principles to assist decision makers in challenges of recognizing, measuring, and controlling a system by modelling energy supply and demand across all sectors at the same time. It seeks to identify various courses of action, together with their risks, costs, and benefits, while taking into account different objectives, restrictions, and resources. Current energy systems are the consequence of multifaceted, country-dependent evolution (Gargiulo & Gallachóir, 2013).

Scenario planning is a valuable strategy for designing and planning long-term electricity infrastructure in order to deal with uncertain power demand and supply. It makes it possible to create a variety of choices tied to various technical and regulatory methods with the intention of effectively capturing the upcoming unpredictability in the energy, economic, and environmental sectors (Blomgren et al., 2011). Long-term energy scenarios often contain many narratives that provide a collection of different contexts for studying various ways of how the future may look like (Weimer-Jehle et al., 2020).

According to Ouedraogo (2017) There are several different types of tools for long-term energy forecasting which can be divided into seven categories (i) **simulation** (BALMOREL, LEAP, RAMSES, WASP) (ii) **investment optimisation tools** (MARKAL/TIMES ,MESSAGE,

RETScreen) (iii) **scenario analysis** (MARKAL/TIMES, LEAP, MESSAGE) (iv) **equilibrium** (PRIMES, MARKAL) (v) **top-down model** (ENPEP-BALANCE, LEAP), (vi) **bottom-up model** (MESSAGE, HOMER, RAMSES, MARKAL/TIMES) (vii) **operation optimisation** (MESSAGE, BALMOREL, RAMSES). In this particular research study, LEAP tool will be used for the modelling.

2.7.2 LEAP Tool

The Low Emissions Analysis Platform (LEAP) tool, formerly known as Long-range Energy Alternatives Planning System, is a commonly used modelling tool for studying energy policy and assessing climate change mitigation measures. The Stockholm Environment Institute modifies it and it has been applied at many various levels including local, state, national, and international levels. LEAP models are holistic modelling tools that can track energy use, output, and resource extraction across all industries. The majority of computations are made at an annual time step in these models, which are created for medium-long-term analysis (20–50 years) (Gargiulo & Gallachóir, 2013).

LEAP tool excels for integrated, scenario-based modelling. As a tool for this project, LEAP stands out as it enables scenario analysis which is the main focus of this project. LEAP system delivers data visualization to users, making it simple for academics and policymakers to interpret the data without the need for a professional explanation. On an interactive visual platform for its use, it can also create scenarios (Heaps, 2020).

2.7.3 LEAP Algorithm

Some of the mathematical procedures used to determine the energy consumption and GHG emissions inside the LEAP model are;

$$ED_{b,s,t} = AL_{b,s,t,y,p} * EI_{b,s,t,n} \quad (2.8)$$

Where ED is the Total Energy Demand, b is demand branch (eg household) s is scenario, t is year and AL is the Activity level disaggregated by the average national GDP growth rate (y) and house hold population (p). Energy intensity per unit of activity is represented by EI.

The overall activity level for a technology is the sum of the activity levels in all branches back up to the originating demand branch.

$$TA_{c,s,t} = A_{c',s,t} * A_{c'',s,t} * A_{c''',s,t} \quad (2.9)$$

Where, A_c is the activity level in a particular branch b and c' is the parent of branch c and c'' is the grandparent.

2.7.4 Scenario Analysis

Predicting future developments involves the examination of scenarios and end-use analyses, taking into account anticipated changes over time. Emerging technologies, which have not previously or currently been employed, can be considered in these strategies. As a result, scenario analysis is a viable and adaptable approach for dealing with demand uncertainties, and it is especially well-suited for estimating energy consumption in developing countries (Nakata et al., 2011).

Scenarios are self-contained narratives that depict future potential growth of an energy system. It takes into account a certain socioeconomic situation as well as a specific policy variables (Amare, 2007). Scenarios serve as valuable tools for exploring a range of "what if" possibilities. These include considering the potential outcomes of transitioning to more energy-efficient appliances

within the system, contemplating the shift of current electricity generation towards greater reliance on renewable sources, and similar hypothetical situations (Heaps, 2020).

It is necessary to take into account a variety of intervention possibilities that have an impact on the future when working with scenario analysis models. The reference scenario, often known as the "Business as Usual" scenario or BAU Scenario, takes future conditions into account in the absence of an intervention such as a change in policy (Heaps, 2020). Policy changes, economic growth, infrastructure improvements, population increase, and other factors must all be taken into account while creating mitigation scenarios. The tools help to create visualizations of a desired future target while taking experts' opinions into account to enable an assessment of potential adjustments required to achieve the envisioned future state (Nakata et al., 2011).

Model-based scenario analysis is a crucial technique for examining the relationships between environmental concerns, development, and residential energy use. On the basis of comparatively straightforward correlations between energy use and income or GDP per capita, the majority of global energy models forecast future residential energy demand (Daioglou et al., 2012)

2.8 Research Gap

There are few or no studies focusing on the long-term cooking energy demand modelling of rural areas in Kenya. This study attempts to add onto the knowledge by using a model to forecast the cooking energy demand on the overall rural landscape in which data can then be used to influence policy development and energy planning. Most of the modelling for rural households has been done in different localities including Bangladesh and Nepal. The IEA model focused majorly on Charcoal and Firewood in the whole household sector, with no mention of electric cooking and how to accelerate electric cooking adoption through policy action. The Ambition for Target model

focused on modelling climate change mitigation using improved cook stoves. The model was used for both rural and urban households. In both studies, the expected increase in electricity demand was not evaluated.

Therefore, using LEAP, this particular research gives a better view in terms of the trends of cooking energy demand in the rural households using different scenarios. It also analyses the implication of the expected increase in electric demand due to electric cooking.

2.9 Conceptual Framework

The focus of this research is to model the future cooking energy demand for the rural residential households. The study follows a systematic approach from data collection to the analysis of results from the modelling tool. The data for the rural population were collected from credible sources.

The independent and dependent variables are as shown in Figure 2.6

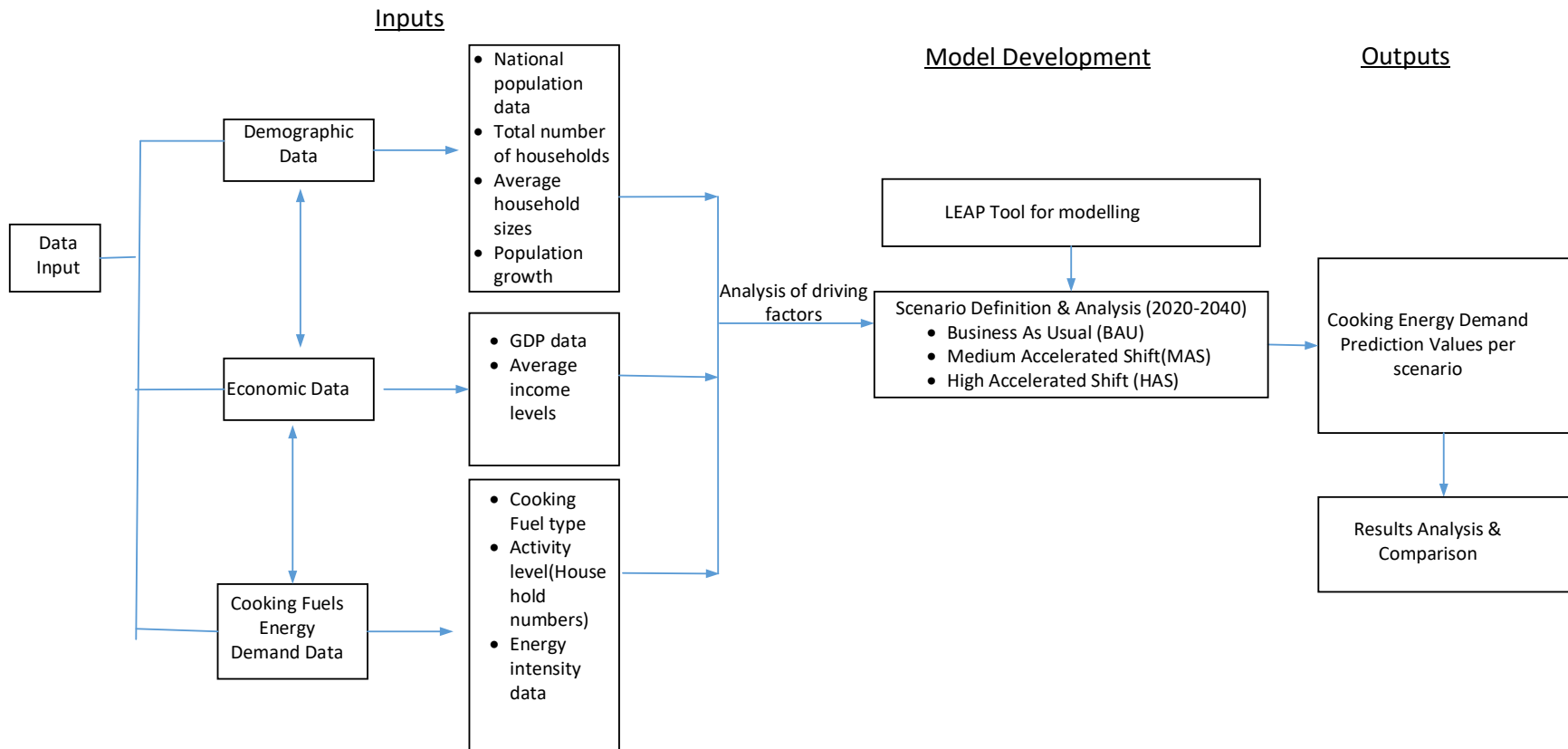


Figure 2.6: Conceptual framework

CHAPTER THREE

3. METHODOLOGY

3.1 Introduction

This chapter describes the methods used for the simulation of the cooking demand for the rural households from 2019 to 2040. The major areas of research are: end use cooking energy demand and analysis for 2019, scenario creation, simulation of the cooking energy demand using LEAP from 2019 to 2040, and a comparative analysis of the scenarios in terms of economic growth rates.

3.2 Research design

The research design has its own procedures and goals, just like any other framework for a study. The purpose of research design is to clearly define a study plan based on independent and dependent variables while accounting for any potential causes and effects that these variables may have. This research adopts experimental research design. The study involved manipulation of variables based on certain assumptions to develop different scenarios. The research relied on desk review of statistical data from secondary sources including the KNBS and ministry of energy. In order to minimize bias during data collection and analysis, each step was standardised. The researcher ensured that the findings are accurate, trustworthy, and broadly applicable.

A comprehensive literature review on Kenya's rural energy sector was used in this study to provide a trustworthy, scientific summary of existing research on the subject. The primary goal of this technique was to discover, evaluate, and summarize all relevant studies in a transparent, repeatable procedure. The researcher identified literature and quantitative data that directly pertain to the research issues under examination. The quantitative data was thoroughly analysed to get full information on the cooking energy demand in the rural households.

3.3 Study Area

The research's study area is the rural area of Kenya, with a particular focus on the rural households across all the counties. According to the 2019 Kenya Population and Housing Census, total population of the rural area was 32,732,596 which is about 70 percent of the estimated national population. A total of 7,432,249 households are in the village according to the 2019 census data (KNBS, 2019b).

3.4 Target Population

In research, a study population refers to the entire group of cases or units that a researcher aims to draw conclusions about. Kothari, (2004) emphasizes the importance of defining the population before collecting samples. It serves as the basis for data collection and allows for statistical inferences to be made from the target population. The target group within this population consists of households in the rural areas of Kenya.

In the context of energy sources, which makes it a suitable study population, a survey conducted by Kenya's Ministry of Energy and Petroleum in 2019 revealed that more than 90% of rural Kenyan households rely on basic wood-burning stoves as their primary cooking method (Clean Cooking Association of Kenya, 2019).

3.5 Sampling Design

According to the Kenya Population and Housing Census of 2019, there are a total of 7,379,282 rural households in Kenya. This study relied on preprocessed data from the Kenya National Bureau of Statistics (KNBS) 2019 and census which covered the entire population. More specific cooking energy demand data was obtained from the Kenya Cooking Sector Study of 2019 by CCAK & Ministry of Energy which used random stratified sampling to select 3,488 households across the

47 sub counties to participate in the survey. Out of 3,488 households, 1,696 were rural households across all sub counties except Nairobi and Mombasa which were characterized as all urban. This study adopted the entire sample size for analysis.

3.6 Data

Secondary sources were used to provide the information for this investigation. The secondary data was acquired through publications produced by governmental and non-governmental organisations, websites, past research, and analysed literature. The primary objective of this research was to gain a thorough understanding of cooking energy demand, the variety of fuels and stoves utilized, and the various factors impacting household energy consumption patterns. To accomplish this, quantitative research techniques was employed to investigate these pivotal variables.

Data on GDP, population, number of households, cooking fuel penetration, and energy intensities of technologies were obtained from various sources including census data.

3.7 Data Collection Instrument

The secondary research tools include government and non-governmental organizations' databases, reports & websites, census data, journals etc. A thorough desk review of existing data from government and non-governmental reports, online resources, prior research, and scholarly articles was done. Population data was collected from census report by Kenya National Bureau of Statistics (KNBS), Economic indicators such as National GDP and GDP growth rate were collected from the World Bank and the reports from National Treasury of Kenya. The other relevant data like types of cooking fuels, household size and energy demand per household were collected from

reports and survey data by the Ministry of Energy, the Clean Cooking Association of Kenya and Modern Energy Cooking Services in association with the Ministry of Energy.

3.8 LEAP Data Requirements

The LEAP model, being a versatile tool for energy system modelling, has varying data requirements depending on the specific analysis you want to conduct. Here is a breakdown of the key data requirements for LEAP:

3.8.1 Demographic Data (Key Assumptions)

National population data, urbanization rates, average household sizes, population growth rate, urbanization growth rates and additional data like population by region, male/female population, and age structure of the population may be needed for specific modelling purposes. These demographic data are filled into the "Key Assumption" section of the data tree in the LEAP model.

3.8.2 Economic Data

GDP data, average income levels, interest rates, inflation rates and other economic data, such as employment/unemployment statistics and investment/national saving rates, can be useful for broader macro-economic analyses or macroeconomic modelling.

3.8.3 General Energy Data

National energy balances with data on energy consumption and production by sector or subsector in the economy. These data are typically sourced from national statistical bodies or energy-related agencies within the country. In cases where national data is unavailable, you can refer to the International Energy Agency (IEA) for published energy statistics. Other relevant data sources

include national energy policies and plans, annual statistical reports, and previously published integrated energy plans or greenhouse gas (GHG) mitigation assessments for the country.

3.8.4 Demand Data

Activity Levels: Activity levels represent the economic activity in various sectors and are a critical factor in LEAP's demand analysis. The choice of data for activity levels depends on the sector. The number of households can be used for the residential sector, while tonnes of chicken production can be used for factory.

Energy Intensity Data: Energy intensity data reflects the energy consumed per unit of activity. For historical data, energy intensity can be calculated as total energy consumption divided by activity level. For future scenarios, LEAP can be used to project energy consumption based on energy intensity and activity level i.e. *total energy consumption = energy intensity x activity level*

These data requirements may vary depending on the complexity and scope of energy modeling project in LEAP.

3.9 Data Calculations

3.9.1 Annual Average Primary Cooking Energy Consumption

Primary and final energy consumption make up the two separate halves of the energy consumption per home. Data typically collected in kilogrammes, litres, or other units per month from the different cooking fuel types were used to calculate the primary energy consumption per household. This data was converted into energy by multiplying it by the Lower Heating Value (LHV) in megajoules per kilogramme or per litre, which was then converted into annual energy intensity.

The efficiency values of the stove or other devices was used to calculate the average annual energy consumption per family by cooking fuel (Heaps, 2020). Data from electric cooking was used as is and was not be converted to other units because electric energy is already expressed in a standardized unit, which is the kilowatt-hour (kWh). Equations used in the calculations are explained below and are modified from (Ejigu, 2016).

3.9.1.1 Household's Primary Yearly Energy Usage

To determine the yearly fuel usage for each sampled family, collected data from households was analyzed to determine annual consumption of different cooking fuels. The fuel's Lower Heating Value, often abbreviated as LHV, was then multiplied by this sum to determine annual energy use.

$$E_{hfs} = \frac{LHV_{fs} \times m_{fs}}{3.6} \quad (3.1)$$

Where:

E_{hfs} : Primary energy usage by households from a fuel source per year (kWh/year)

LHV_{fs} : Cooking fuel's LHV (MJ/kg)

m_{fs} : Quantity cooking fuel usage by mass per year (kg/year)

3.6: Conversion factor from MJ to kWh (1 kWh = 3.6 MJ)

3.9.1.2 Energy Intensity

The energy intensity, is calculated by summation of the energy consumption of the sampled households divided by the sampled households.

$$E_{hfs\cdot avg} = \frac{\sum_1^n E_{hfs\cdot j}}{n} \quad (3.2)$$

Where:

$E_{hfs\cdot avg}$: Average household energy usage (kWh/year)

$E_{hfs\cdot j}$: Primary energy usage of household j (kWh/year)

n: total count of sampled households

3.9.1.3 Energy Usage per Person

The energy consumption per person (per capita) is computed through division of the average energy usage of fuel fs, calculated in (3.2), by the average household size.

$$E_{pp} = \frac{E_{hfs\cdot avg}}{n_{hs}} \quad (3.3)$$

Where:

E_{pp} : Average energy consumption of per person of fuel fs

n_{hs} : Average household size

3.9.1.4 Calculation of Total Energy Consumption per Fuel Type

Each fuel's impact on the overall primary energy usage in rural households is calculated by multiplying the average energy usage for that fuel, as established in (3.2), by the total number of households (N).

$$E_{total\cdot fs} = E_{hfs\cdot avg} \times N \quad (3.4)$$

Where:

$E_{total\cdot fs}$: Overall energy expenditure within the residential sector, with a focus on fuel type fs (kWh/year)

N: Overall count of households in the rural area

fs: Represents a fuel type such as charcoal, LPG, firewood etc.

3.9.1.5 Calculation of the overall energy consumption

To determine the overall energy demand, addition of the total energy usage of specific fuels as shown in equation 3.4 (e.g., charcoal, LPG, firewood, electricity, and so on) are used as indicated in equation (3.5).

$$E_{total.demand} = \sum E_{total.fs} = E_{total.charcoal} + E_{total.LPG} + E_{total.firewood} + \dots \quad (3.5)$$

Where:

$E_{total.demand}$: The total cooking energy demand in the rural households

3.9.2 Average Annual Useful Energy Consumption

The previously calculated metrics, such as average household, per person, and overall consumption of energy, were estimated based on the primary energy use, without taking into account the efficacy of the equipment consuming the fuel. To calculate usable energy consumption, the efficiency of the device, such as a cooker that uses fuel, was considered. Therefore, the results obtained from equations (3.1) to (3.5) for a specific fuel's primary energy consumption were multiplied by the corresponding stove's conversion efficiency, specifically its thermal efficiency.

3.9.2.1 Calculation of Average Household Useful Annual Energy Consumption

The following formula is used;

$$E_{hfsUseful} = \frac{E_{hfs.avg} \times \eta_d}{100} \quad (3.6)$$

Where:

η_d : Device or stove efficiency (%)

$E_{hfsUseful}$: Useful cooking energy consumption of fuel per household (kWh/year)

100: Used for conversion of stove's efficiency to decimal form

3.9.2.2 Calculation of Average Useful Annual Energy Consumption per Person

For per capita energy consumption, the calculation of useful values was performed similarly:

$$E_{ppUseful} = \frac{E_{pp} \times \eta_d}{100} \quad (3.7)$$

Where:

$E_{ppUseful}$: Useful Per-person energy usage derived from fuel source f_s

100: Used for conversion of stove's efficiency to decimal form

3.9.2.3 Calculation of Useful Annual Energy Consumption per Fuel

The overall useful energy consumption were computed as follows:

$$E_{total.fs.Useful} = \frac{E_{total.fs} \times \eta_d}{100} \quad (3.8)$$

Where:

$E_{total.fs.Useful}$: Useful total energy consumption of fuel

100: Used for conversion of stove's efficiency to decimal form

3.9.3 Percentage of Households Consuming Several Fuels

The proportion of households utilizing a specific fuel type is ascertained by dividing the count of households using different fuels by the total number of households. For instance, if Y_j denotes the count of households using a specific fuel, f_j , given n represents the total households count, the percentage of all households will be computed as follows (Heaps, 2020)

$$HH_{share} = \frac{Y_j}{n} \times 100 \quad (3.9)$$

Where:

n: The total count of sample households

HH_{share}: The percentage of fuel type f_s (%)

Y_j : tally of households utilizing specific fuel j

3.10 Statistical Methods and Analysis

Preprocessed data was entered into MS Excel before being analysed and converted into usable units. The factors such as stove type, fuel type, household size and cooking energy demand were then be used to produce statistical measures such as means. The mean value will be used for further analysis and predictions

3.11 Model Formulation

3.11.1 Data Collection and Review

Historical data on cooking energy consumption for the sample population were gathered from secondary sources like the ministry of energy. The dataset used for this purpose consist of several independent variables, including household energy use, population growth, and economic indicators, while the corresponding cooking energy demand values serve as the dependent variable.

3.11.2 Data Preparation

The collected data was imported into Ms Excel for processing. During this phase, the data was thoroughly examined including the data's structure and contents. The data was organized and

cleaned for input into LEAP. This involved formatting data, handling missing values, and converting units to match LEAP requirements. A baseline scenario based on historical data was created to establish a starting point for the model.

3.11.3 Installation of LEAP software

The LEAP software, developed by SEI (Stockholm Environment Institute), will be downloaded and installed. The relevant license for LEAP software will be sought from the website to allow usage.

3.11.4 Scenario Development

Key variables and parameters that will influence cooking energy demand in rural Kenya over the next 20 years were identified. These include factors like population growth, technology adoption rates, and policy changes. Different scenarios that represent different possible futures were developed. These scenarios were input into LEAP, with the relevant parameters and assumptions specified for each scenario.

3.11.5 Model Validation

The model was validated using historical data to ensure that it accurately reflects trends in cooking energy demand in rural Kenya to confirm it was working correctly.

3.11.6 Model Deployment and Prediction

After completing the evaluation process, the model was deployed to make predictions for cooking energy demand for the next 20 years in the rural areas. Simulations were run for each of the scenarios over the 20-year period to estimate cooking energy demand and related factors (e.g., emissions, costs). The results were analyzed to understand the implications of each scenario and to compare them to the baseline scenario. These predictions were presented in the form of graphs and charts.

3.11.7 Sensitivity Analysis

Sensitivity analyses was performed to assess how changes in key assumptions or parameters affect the results to help identify the most influential factors.

3.12 Modelling

For the purpose of scenario analysis in this research, the LEAP model was singled out as the most appropriate tool. LEAP, a comprehensive energy ecosystem modelling tool, is proficient in predicting forthcoming electricity demands, generation patterns, and emissions at various scales, including local, national, regional, and global. LEAP accommodates a wide array of modelling methodologies, encompassing both granular bottom-up end-use accounting and top-down simulations, while seamlessly integrating accounting, simulation, and optimization techniques. The tool allows for the usage of a range of input variables, spanning from greatly disaggregated end-use oriented structure to very aggregate analysis. Households, industry, business, transportation, and agriculture are examples of typical sectors, each of which can be further subdivided into numerous subsectors, specific applications, and various technologies aimed at fuel efficiency.

Population size, economic growth (GDP), strategic government policies on energy efficiency and improvements, final energy demand, fuel consumption by sector, and final energy intensity per devices are the primary components of the LEAP tool in this study. To mimic a specific energy system, data structures in the LEAP system are structured in a hierarchy (tree). The LEAP tree is as shown in **Error! Reference source not found.** below. It can have various end use energy demand branches including the Residential, Industry, Transport, Agriculture etc. The focus of this study is on rural residential sector.

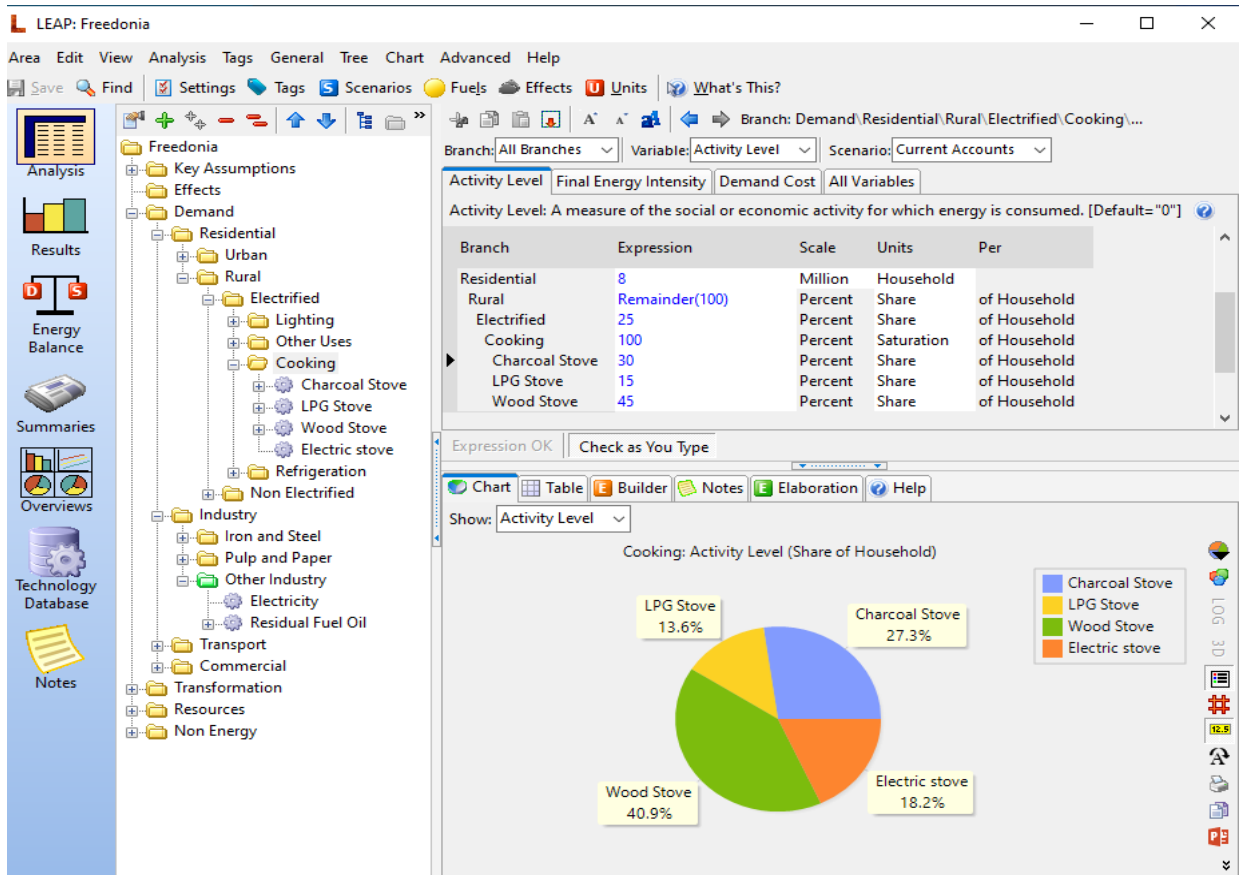


Figure 3.1: A screenshot of the LEAP tool with arbitrary values

LEAP stands out as an excellent choice for this research because it is based on scenario analysis, requires a small initial data input and grants access to a comprehensive Technology and Environmental Database (TED). TED delivers the most current energy technology information and facilitates user-friendly data visualization. This empowers academics and policymakers to evaluate data. As a result, the LEAP tool is the best system for understanding Kenya's rural households long-term energy projections for a sustainable energy future.

3.12.1 Base Year Modelling

The modelling of long-term cooking energy demand in the rural residential sector relies heavily on factors such as population dynamics, economic development, and energy usage patterns as its foundational elements. The census data by KNBS (2019) was used as the baseline to provide the total rural population and the population growth rate. The total rural population in the last census of 2019 by KNBS was 32,732,596 with a growth rate of 2.2% (KNBS, 2019b). The data on energy intensity for each cooking fuel was retrieved from the Kenya Cooking Sector Study done by CCAK (Clean Cooking Association of Kenya, 2019).

3.12.2 Scenario Development

The standard strategy to scenario development focuses on the description of alternative choices based on various assumptions. Then, the quantitative significance of the modelled scenarios was investigated, as are their implications for a country's prospective long-term energy paths. The scenarios depict possible future development trajectories that a "window of opportunity" reveals. In general, developing scenarios can aid in highlighting disputes, identifying discrepancies, knowledge gaps and can serve as a crucial foundation for the creation of strategy and actions.

Scenarios were developed in this study to help construct long-term energy plans for better comprehension of energy consumption and its environmental implications. Long-term energy routes present a collection of additional likely future scenarios that could play out in various ways. This study examined three scenarios: one baseline scenario and two reference scenarios based on the national GDP & population growth rate.

Scenario 1: Business as Usual (BAU) scenario estimates the expected energy flows based on current patterns by leveraging government plans, policies, and formal projections that define the

sector's form over the next decades. It presupposes that present energy and financial policies are followed in general. In other terms, the BAU scenario is a replication of current home energy sector trends, with an annual GDP growth rate of 5.6% (African Development Bank, 2023)

Scenario 2: Medium Accelerated Shift (MAS) is built on baseline data from Kenya's Energy Policy objectives e.g., Vision 2030 where electrification rates in the rural areas will increase. The expectation is that certain policy goals and targets established in the reference scenario may not be met. This scenario assumes that, on average, the social and economic sectors will grow. In this instance, many individuals in rural areas are more inclined to switch from traditional biomass fuels to contemporary cooking fuels. Thus, this scenario is characterized by a surge of contemporary cooking fuel thus reducing reliance on traditional biomass fuels.

Scenario 3: High Accelerated Shift (HAS) is based on Sustainable Energy For All (SE4All) and SDG7 whose target is on investing in doubling the amount of renewable energy in the world's energy mix and increasing energy efficiency. This ensures the development of regional resources needed to expand access to electricity and renewable energy sources across the continent. With energy efficient electric appliances and with the right financial policies on acquisition of the appliances, there will be a shift towards electric cooking. This scenario assumes a highly optimistic GDP growth rate of 10%. All significant economic sectors experience growth when the country's GDP is high, and social, political, and economic development will be stable. The demand for cooking energy is considerable in this situation, as will all sector growth rates. It will be projected that over the outlook period, demand for modern cooking fuel e.g. electricity will increase thus reducing overreliance on biomass fuels. This scenario aims to strengthen the country's economy and raise energy demand in the residential sector.

3.13 Research Quality

Most frequently, the phrase "quality research" relates to the scientific approach, which includes all elements of study design, including the evaluation of the match up between techniques and study objectives, topic selection, outcome measurement, and protecting against biasness, non-systematic bias, and inferential mistakes. (Boaz & Ashby, 2003).

3.13.1 Reliability

The accuracy and precision of the measurement, as well as the absence of changes in the results if the research was repeated, are defined as reliability (Collis & Hussey, 2014). A research tool's accuracy and dependability are determined by its consistency and stability in providing those results (Heale & Twycross, 2015). The study is using a secondary data-centric research technique. The quality of the initial data gathering and processing determines how reliable the secondary data is. Thus, the researcher chose reliable sources and using publications that are pertinent to the study's objectives which will help to increase reliability.

3.13.2 Validity

Validity is a critical component of effective research. A piece of research is worthless if it is invalid. Thus, both quantitative and qualitative research require validity (Cohen et al., 2002). A validity check may entail confirming that information is consistent across records, ensuring that no records are missing, and validating the accuracy of calculations and the legitimacy of included values (Zeller et al., 2018). This examination may be performed manually or with the use of software. The researcher ensured that data set is error-free and all standard or planned requirements are upheld by ensuring that all materials utilized to construct the model in this are from credible sites.

3.14 Risks Analysis

A detailed risk analysis was used in this study to detect and handle any potential problems that might occur. To guarantee the accuracy and dependability of the research findings, some of these concerns were acknowledged and were adequately addressed.

The possibility for poor data quality is a major risk. It is acknowledged that the data may have inconsistencies, errors, or missing values that could impair the reliability and accuracy of the research findings. Various data cleaning and preprocessing approaches were used to reduce this danger. These methods include dealing with missing data, eliminating outliers, and assuring data consistency, all of which help to raise the dataset's general quality.

The effectiveness of the created predictive model is another area of concern. The model might not operate at its best, leading to incorrect predictions. Such a danger may result from elements like built-in constraints. To mitigate this risk, the performance of the model was evaluated using a variety of measures.

This study acknowledges the challenge of generalisation. Because of the study's concentration on cooking energy demand in Kenya, the conclusions and findings may not be immediately transferable to other sectors. The research area's specific economic and household characteristics may limit the model's broader application. To address this issue, the research clearly recognised its limits and make recommendations for future research as well as considerations for broader applicability. This strategy ensures that the research outputs are appropriately contextualised, allowing future research to build on this foundation.

3.15 Dissemination and Utilization of Results

The research was disseminated through conference presentations, and research workshop presentation.

3.16 Ethical Consideration

Scientists and researchers have long been thought of as "truth seekers". As a result, the scholarly pursuit concentrates on the generation of new information and understanding. The ideals of trust and responsibility are important to the research enterprise, as information and truth are ideally sought rather than wealth and power (LaFollette, 1994). The researcher strived to avoid bias information during the study period by properly examining of all data obtained for the research purposes. Honesty in data reporting, methods and procedures were observed by ensuring that no data is misinterpreted or fabricated. All these measures were taken into consideration to ensure that all the ethical issues are addressed. This led to correctness of information that has been shown on the thesis. There is no conflict of interest in this research. The data was analysed using the relevant tools and from credible verifiable sources.

CHAPTER FOUR

4. RESULTS

4.1 Introduction

This chapter outlines the key findings obtained through a comprehensive analysis of the collected data. Building on the research objectives and questions outlined in Chapter 1, a presentation and interpretation of the outcomes is done, while shedding light on significant patterns, relationships, and insights. The chapter begins with a presentation of the data, followed by a detailed analysis, offering valuable contributions to the understanding of cooking energy demand modelling.

4.2 Cooking Fuels and Technologies

From the previous studies and surveys by KNBS and CCAK, the most common cooking fuel sources in the rural households are Fuelwood, Charcoal, LPG, Kerosene and Crop Residues as shown in Table 4.1.

Table 4.1: Cooking fuel sources (KNBS, 2006; KNBS, 2016 & Clean Cooking Association of Kenya, 2019)

KIHBS 2005/2006		KIHBS 2015/2016		CCAK 2018/2019	
Fuel	%	Fuel	%	Fuel	%
Firewood	87.7	Firewood	84.3	Firewood	86.0
Charcoal	7.7	Charcoal	8.9	Charcoal	7.0
Gas/ LPG	2.7	LPG	2.5	LPG	6.0
Kerosene	0.7	Kerosene	2.3	Kerosene	0.7
Electricity	0.4	Electricity	0.3	Electricity	0.0
Biomass Residue	0.2	Agricultural Crop Residue	0.3	Crop Residue	
Grass	0.1	Biogas	0.2	Biogas	
Other	0.4	Other	0.9	Other	0.2

From the reports of Kenya Integrated Household Surveys by KNBS in 2005 & 2015 and the Kenya Cooking Sector study done in 2019 by CCAK, the data on cooking fuel technologies as used by the rural households was obtained as shown in table 4.2. The study done by CCAK in 2019 was consistent with the historical data from the KNBS reports, except for ordinary and improved jiko. The difference in the percentages was due to the definitions of improved and ordinary jiko. CCAK grouped the Kenya Ceramic Jiko as an improved jiko, unlike the KNBS survey reports which classified them as ordinary. See figures 4.1 and 4.2.



Figure 4.1: Ordinary Jiko



Figure 4.2: Ceramic Jiko

Table 4.2: Main cooking fuel technologies used in the rural areas by percentage

Main Cooking Fuel Technologies in the Rural Area by Percentage			
	KIHBS 2005/2006	KIHBS 2015/2016	Clean Cooking Study Report 2019
No of households	5,151,105	6,442,000	7,419,542
Technology	%	%	%

Traditional Stone Fire	78	71.7	71
Improved Traditional Stone fire	10.9	12.8	14.9
Ordinary Jiko	4	5.7	0.7
Improved Jiko	3.9	3.7	6.6
Kerosene Stove	2.3	2.2	0.7
Gas Cooker/LPG	0.6	2.4	5.9
Electric Cooker	0.2	0.1	0
Other	0.3	0.9	0.2

Source: Modified from (Clean Cooking Association of Kenya, 2019)

4.3 Cooking Energy Demand

The demand data used for the baseline of this study for cooking fuels for rural households was adapted from the Kenya Cooking Sector study that was done by the Ministry of Energy through CCAK in 2018. It was a comprehensive report that involved data collection across the 47 counties in the country. The sample size was 1,696 households for the rural areas of Kenya. From the report, the following average annual consumption per household was obtained.

Table 4.3: Average Annual Consumption Per Household Per Year

Average Annual Consumption Per Household Per Year	
Energy Sources	kg/yr
Fuelwood	1,362.00
Charcoal	411.00
LPG	47.00
Kerosene	78.00
Crop Residues	421.00
	2,319.00

Fuelwood is the most used at 1,362 kg/yr per rural household followed by charcoal at 411 kg/yr. Biomass plays a big role in the cooking sector in the households. Some other fuels were not included in the CCAK report as they were found to be negligible.

For the sake of the modelling in this study, some other technologies like bioethanol, biogas and electricity have been added because they form a part of the future outlook in the cooking sector.

Table 4.4: Annual Energy consumption per household

Energy Consumption Per Household Per Year							
Fuel Source	Fuel technology	Average consumption per household	% HHs using fuel	% HHs using technology	Fuel Consumption /Technology	% Distribution/ Technology	Energy Consumption /household
		kg	%	%	kg	%	Tonnes
Fuelwood	Traditional Stone Fire	1,783.00	97%	71	1,473.73	63.6%	1.47
	Improved Traditional Stone fire			14.9	309.27	13.3%	0.31
Charcoal	Ordinary Jiko	411.00	42%	0.7	39.41	1.7%	0.04
	Improved Jiko			6.6	371.59	16.0%	0.37
LPG	LPG Cooker	47.00	15%	5.9	47.00	2.0%	0.05
Kerosene	Kerosene Stove	78.00	7%	0.7	78.00	3.4%	0.08
Biogas	Biogas Stove	-	0%	0	-	0.0%	0.00
Electricity	Electric Stove	-	0%	0.2	-	0.0%	0.00
Bioethanol	Bioethanol Stove	-	0%	0	-	0.0%	0.00
		2,319.00		100%	2,319.00	100%	2.32

Source: Modified from (Clean Cooking Association of Kenya, 2019)

Table 4.4 shows the breakdown and calculations for the energy consumption data per household for the baseline period. The average consumption in the initial report was given per fuel type, therefore, a breakdown per fuel technology was necessary for the sake of the modelling. The technology used in cooking converts fuel into energy, as such, conversion factors like the heating value was used in evaluating the energy content of each fuel.

Table 4.5 gives more information for the annual energy consumption per household, per capita and for all the households in GJ and in tonnes. The heating values have been used to convert the

tonnes of energy to Gigajoules. The conversion efficiency per technology is important in calculation of useful energy in the model.

Each household consumes around 40.29 GJ of cooking energy per year, which translates to 299.44 million GJ per year for all the rural households. Energy consumption per capita for the baseline period was calculated and was found to be 8.95 GJ. Fuelwood takes the highest contribution at 5.87GJ per person. Biogas, electricity and bioethanol were assumed to be zero in the 2019 baseline period.

Table 4.5: Annual energy consumption in GJ

Fuel Source	Fuel technology	Energy Consumption /household	Heating Value	Energy Consumption Per household	Energy Consumption for All Households	Energy Consumption per capita	Conversion Efficiency	Energy Demand All Households
		Tonnes	GJ/ton	GJ	Million GJ	GJ	%	kton
Fuelwood	Traditional Stone Fire	1.47	14.8	21.81	162.11	4.85	17%	10,953.09
	Improved Traditional Stone fire	0.31	14.8	4.58	34.02	1.02	19%	2,298.61
Charcoal	Ordinary Jiko	0.04	20.1	0.79	5.89	0.18	20%	292.91
	Improved Jiko	0.37	20.1	7.47	55.51	1.66	35%	2,761.74
LPG	LPG Cooker	0.05	47.3	2.22	16.53	0.49	55%	349.32
Kerosene	Kerosene Stove	0.08	43.8	3.42	25.39	0.76	35%	579.72
Biogas	Biogas Stove	0.00	45.0	-	-	-	55%	-
Electricity	Electric Stove	0.00	-	-	-	-	80%	-
Bioethanol	Bioethanol Stove	0.00	27.0	-	-	-	65%	-
		2.32		40.29	299.44	8.95		17,235.39

Source: Own modifications from (Sanga & Jannuzzi, 2005)

4.4 Results from Modelling and Simulation Using LEAP

This section presents the results of the modelling and simulation exercise conducted using LEAP. To evaluate the performance of the various scenarios considered, following metrics were employed; Business As Usual (BAU), Moderate Accelerated Shift (MAS) and High Accelerated Shift (HAS). By analyzing these metrics, the potential impact of different approaches on the system being studied was assessed. The BAU scenario serves as a baseline, representing the projected outcomes under current trends. The MAS scenario explores the effects of implementing specific mitigation actions, while the HAS scenario examines the potential benefits of a more ambitious strategy.

4.4.1 Business As Usual Scenario

The analysis of rural household cooking energy demand under the BAU scenario presents a comprehensive overview of the evolving landscape of cooking technologies. Population increase acts as a key driver, pushing up demand for cooking energy. As a result, the total energy demand increases steadily over the analyzed period, reaching 1,937.98 Million GJ in 2040 as shown in table 4.6. Traditional 3 Stone Fire remains the dominant cooking technology, contributing significantly to the overall energy demand by over 66% in 2040.

Table 4.6: BAU Scenario- Final Energy Demand in Million Gigajoules

Energy Demand Final Units								
Scenario: Business As Usual Scenario, All Fuels								
Branch: Demand\Rural Household\Cooking								
Units: Million Gigajoules								
Fuel Technology	2020	2025	2030	2035	2040	Total	Mean	
Traditional 3 Stone Fire	193.64	234.74	285.79	298.68	313.78	1,326.63	265.33	
Ordinary Jiko	4.97	4.92	4.85	4.37	3.72	22.83	4.57	
LPG Cooker	6.09	7.37	8.96	17.32	28.21	67.95	13.59	
Kerosene Stove	9.24	5.14	-	-	-	14.39	2.88	
Improved Traditional Stone Fire	39.75	44.13	49.54	50.74	52.01	236.19	47.24	
Improved Jiko	46.56	44.68	42.25	50.36	60.72	244.57	48.91	
Electricity	0.05	0.30	0.63	1.05	1.59	3.62	0.72	
Biogas Cooker	0.03	0.21	0.44	1.59	3.09	5.37	1.07	
Bioethanol Stove	0.25	1.66	3.43	4.72	6.38	16.44	3.29	
Total	300.59	343.17	395.89	428.83	469.50	1,937.98	387.60	

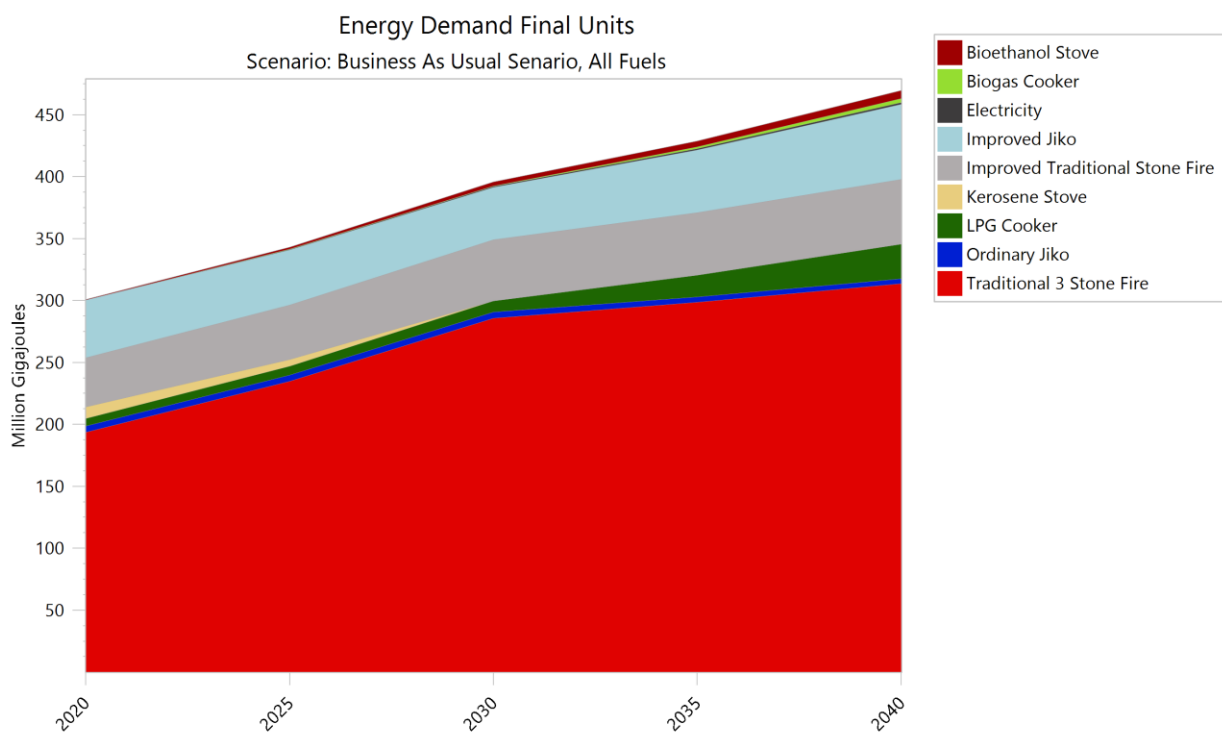


Figure 4.3: Area Graph for BAU final energy demand

Figure 4.3 shows the area graph obtained from the BAU simulation. With the current trends, it can be observed that LPG usage increases over the 20 years modelling period. Electricity as a source of cooking experiences slow growth in the rural households.

4.4.2 Moderate Accelerated Shift Scenario

The Medium Accelerated Shift (MAS) Scenario aims to project the energy demand for cooking in rural households, considering a moderately accelerated transition towards cleaner and more sustainable technologies stemming from the current policies. The analysis covers the period from 2020 to 2040, with a focus on Million Gigajoules as the unit of measurement. As shown in Table 4.7, the total energy demand increases steadily over the years, reaching 1,681.9 Million GJ by 2040.

Table 4.7: MAS final energy demand

Energy Demand Final Units Scenario: Medium Accelerated Shift Scenario, All Fuels Branch: Demand\Rural Household\Cooking Units: Million Gigajoules							
Fuel Technology	2020	2025	2030	2035	2040	Total	Mean
Traditional 3 Stone Fire	187.1	190.7	195.0	200.4	206.3	979.5	195.9
Improved Traditional Stone Fire	39.4	42.1	45.3	42.8	39.1	208.7	41.7
Ordinary Jiko	4.9	4.3	3.6	3.2	2.7	18.7	3.7
Improved Jiko	46.8	46.6	46.2	57.2	71.3	268.1	53.6
LPG Cooker	7.0	13.7	22.0	29.3	38.6	110.7	22.1
Kerosene Stove	9.2	5.1	-	-	-	14.4	2.9
Electricity	0.2	1.6	3.2	4.7	6.6	16.4	3.3
Biogas Cooker	0.7	4.8	9.9	12.3	15.5	43.1	8.6
Bioethanol Stove	0.4	2.4	5.0	6.3	8.0	22.2	4.4
Total	295.8	311.4	330.3	356.2	388.1	1,681.9	336.4

It is observed that despite a slight decrease, traditional 3 stone use maintains its dominance, contributing significantly to the total energy demand; most likely due to cultural practises

accessibility and affordability of the technology to the rural households. The technology will contribute 206.3 Million Gigajoules by 2040, while electric cooking will contribute only 6.6. LPG will be embraced by the rural households for cooking contributing 38.6 Million Gigajoules by 2040. Biogas and Bioethanol are also seen as transition fuels as their growth can be seen from 0.7 and 0.4 Million Gigajoules in 2020 to 15.5 and 8 Million Gigajoules in 2040, respectively.

Figure 4.4 below shows the graphical representation of the fuel technologies over the modelling period. Improved Jiko and Improved stone fire will still be in the picture as primary fuel technologies.

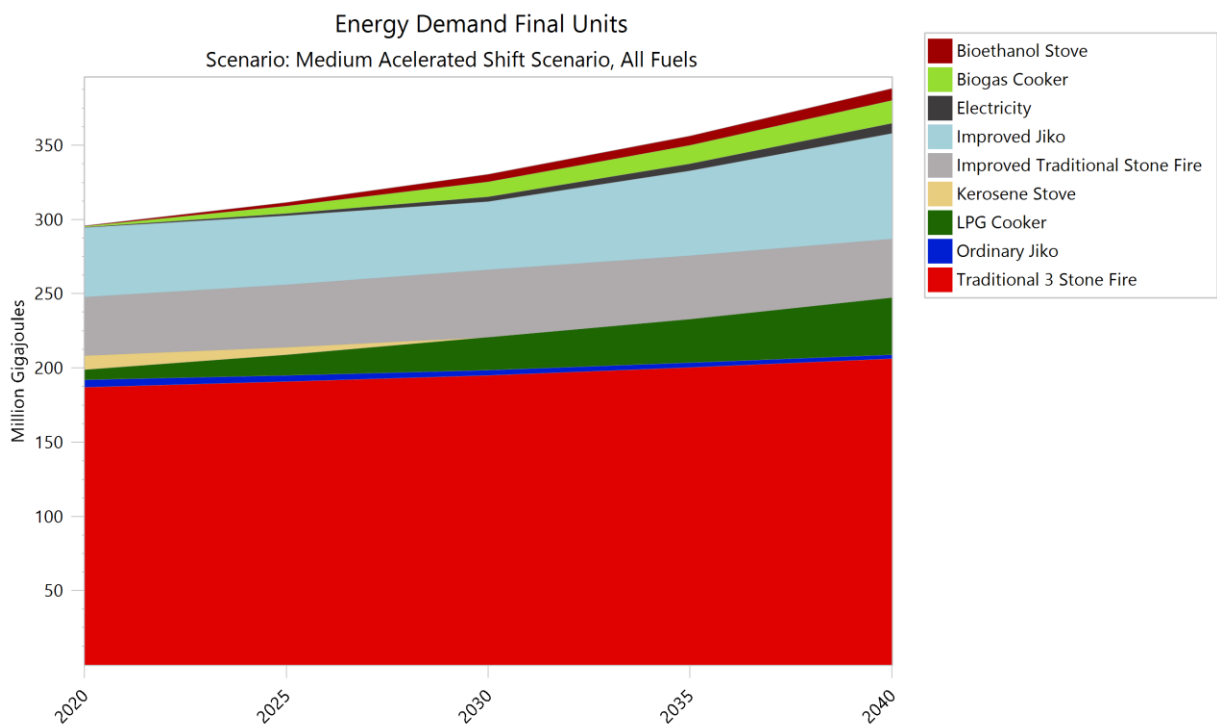


Figure 4.4: Area graph for final energy demand- MAS scenario

Improved Traditional Stone Fire experiences growth until 2030 but sees a decline thereafter. Improved Jiko on the other hand shows consistent growth, indicating a positive response to efforts promoting improved and more efficient cooking technologies.

4.4.3 High Accelerated Shift Scenario

The High Accelerated Shift Scenario for rural household cooking energy demand represents a proactive and ambitious approach towards transitioning from traditional and less sustainable cooking methods to cleaner and more efficient alternatives like electric cooking. This scenario envisions rapid adoption of advanced cooking technologies, emphasizing sustainability, reduced environmental impact, and improved energy efficiency.

Table 4.8: HAS final energy demand

Energy Demand Final Units Scenario: High Accelerated Shift Scenario, All Fuels Branch: Demand\Rural Household\Cooking Units: Million Gigajoules							
Branch	2020	2025	2030	2035	2040	Total	Mean
Traditional 3 Stone Fire	178.8	135.4	80.8	59.6	31.3	485.8	97.2
Improved Traditional Stone Fire	39.6	42.8	46.8	42.4	36.4	207.9	41.6
Ordinary Jiko	4.8	3.7	2.4	1.6	0.5	13.1	2.6
Improved Jiko	45.7	39.2	30.9	26.0	19.4	161.3	32.3
LPG Cooker	8.1	20.8	36.7	48.5	63.8	177.9	35.6
Kerosene Stove	9.2	5.1	-	-	-	14.4	2.9
Electricity	1.1	7.3	15.1	22.4	31.9	77.9	15.6
Biogas Cooker	1.1	7.1	14.7	19.2	25.1	67.2	13.4
Bioethanol Stove	1.2	7.8	16.2	23.0	31.9	80.1	16.0
Total	289.5	269.4	243.7	242.8	240.2	1,285.6	257.1

Table 4.8 shows a summary of the findings from the scenario modelling. The scenario anticipates a substantial and rapid decline in the use of traditional cooking methods. Traditional 3 Stone Fire and Improved Traditional Stone Fire experience a substantial decline from 2020 to 2040, from

178.8 and 39.6 million Gigajoules in 2020 to 31.3 and 36.4 million Gigajoules in 2040 respectively showcasing a successful shift away from traditional cooking practices. LPG Cooker, Biogas Cooker, and Bioethanol Stove are highlighted as key technologies experiencing significant growth. Ordinary Jiko and Kerosene Stove witness a considerable reduction in demand, and Kerosene Stove is eventually phased out by 2030. Electricity emerges as a prominent choice for cooking, showcasing a successful electrification strategy with a growth pattern from 1.1 million Gigajoules in 2020 to 31.9 million Gigajoules in 2040. This means a jump in electric energy consumption from 0.3056 TWh in 2020 to 8.861 TWh by 2040.

The Total Energy Demand witnesses a significant reduction from 289.5 million GJ in 2020 to 240.2 million GJ in 2040. This decrease of 17% underscores the success of the accelerated shift towards cleaner and more efficient cooking methods.

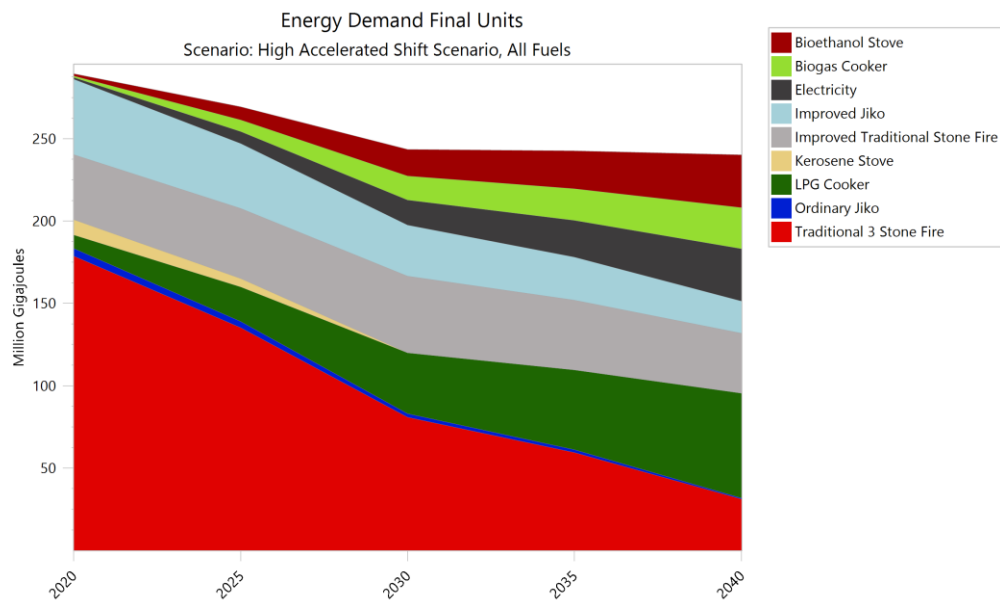


Figure 4.5: Area graph for final energy demand- HAS Scenario

Figure 4.5 shows a graphical presentation of the HAS scenario modelling results. It can be seen that with this ambitious scenario, more energy efficient technologies are preferred for cooking with a bias for LPG, Electricity and Biogas.

In order to benchmark the results of this study against an external perspective, an Excel centered model that was created by the IEA was used to compare results for fuelwood consumption for the BAU scenarios. From the comparison, both models show increase in fuelwood consumption over the period between 2020 and 2040 as depicted in figure 4.6. The IEA model predicts that the rural households cooking energy demand from fuelwood by 2040 would be 315 million GJ while the model from LEAP shows that the fuelwood energy demand would be 365 million GJ. The difference is about 16% which could be attributable to different model structures and assumptions or data inputs used in building the two models.

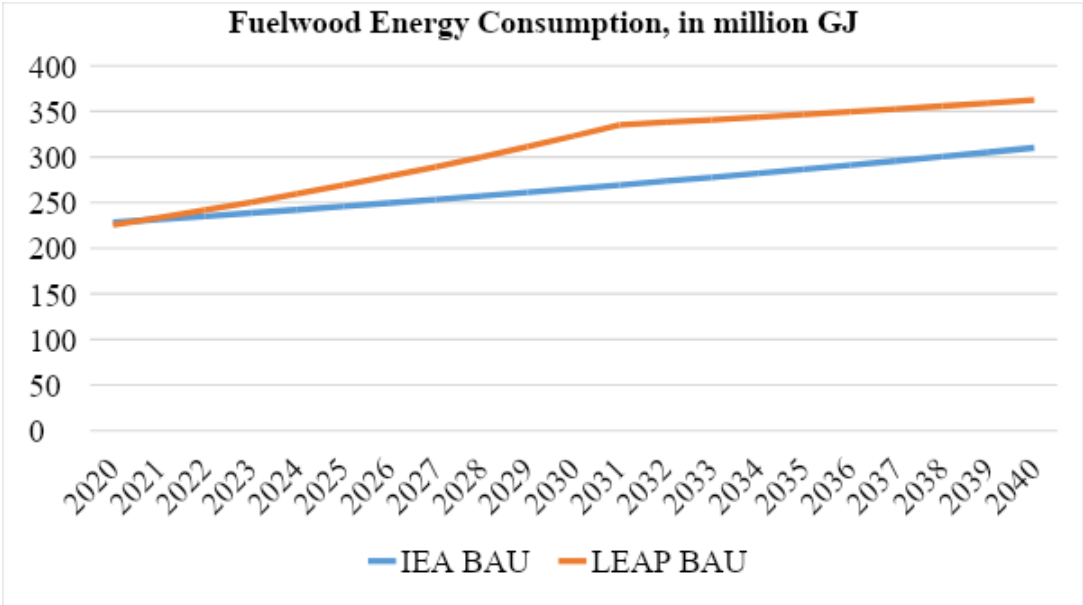


Figure 4.6: Benchmark against IEA model

CHAPTER FIVE

5. DISCUSSION

5.1 Introduction

In this chapter, more insights into the results presented in Chapter 4 are discussed. The findings presented in Chapter 4 shed light on various aspects of cooking energy demand in rural households, aligning with the objectives outlined in Chapter 1. This discussion synthesizes the key results and explores their implications, providing insights into the dynamics of cooking fuel usage, energy demand patterns, and the effectiveness of different scenarios modelled using the LEAP tool.

Cooking accounts for over 80% of domestic energy usage in Kenya (International Energy Agency, 2014). This proportion is even higher in the rural areas as compared to other developing nations, demonstrating the effects of low income and slower rate of development. Many households in the rural areas lack access to essential amenities, and combined with the inefficiency of current cooking methods, cooking emerges as the dominant driver of energy consumption. Many rural households in Kenya rely on inefficient biomass cookstoves for cooking which result in negative health effects and slower development for women and girls, as mentioned in Chapter 1.

5.2 Review of research objectives

As was covered in chapter 2, a number of variables that influence the choice of cooking fuel have been found in the literature that include: socioeconomic factors, cultural and behavioural norms, product-specific features, and external factors. It was also noted that population and household size influence cooking energy demand. As highlighted in theoretical literature in chapter 2, modern cooking technology with improved efficiency become more prevalent as wealth levels rise. With

increasing income levels, households are more likely to purchase more advanced and contemporary cookstoves. In this study, population growth and economic growth were factored in the modelling tool.

5.2.1 Cooking Fuel Usage Patterns

As seen in figure 4.3, the analysis of cooking fuel sources reveals consistent trends over the years, with fuelwood remaining the predominant choice among rural households, followed by charcoal and LPG. These findings corroborate previous studies conducted by the Kenya National Bureau of Statistics (KNBS) and the Clean Cooking Association of Kenya (CCAK). Notably, the data from the CCAK study in 2019 introduces distinctions in fuel technology classifications, highlighting the evolving landscape of cooking practices.

5.2.2 Cooking Energy Demand Estimation

The estimation of average cooking energy demand per household provides valuable insights into the energy consumption patterns in rural areas. Fuelwood emerges as the primary energy source, with significant contributions to overall energy demand. The incorporation of additional technologies such as biogas, bioethanol, and electricity in the modeling reflects a forward-looking approach to address future energy needs and transition towards cleaner fuels. This can be seen from figures 4.3, 4.4 and 4.5 where the 3 technologies incorporated are seen as an influence towards achievement of universal clean cooking. For instance, in BAU scenario, biogas, bioethanol and electricity will contribute about 5.2% of cooking energy demand by 2040, while in MAS, the 3 technologies will contribute up to 16% as shown in tables 4.6 and 4.7 respectively. With ambitious scenario of HAS, the 3 will contribute above 40% of cooking energy demand by 2040.

5.2.3 Model Development and Validation

The development of a predictive model for cooking energy demand in the rural sector represents a crucial step towards understanding and addressing energy challenges effectively. By utilizing data from comprehensive surveys and leveraging conversion factors such as heating values, the model offers a robust framework for estimating energy consumption per household and per capita.

5.2.4 Scenario Analysis Using LEAP

The application of the LEAP tool facilitates scenario analysis to explore different trajectories of energy transition. The Business As Usual (BAU) scenario depicts a continuation of existing trends, with traditional cooking methods dominating the energy landscape. In contrast, the Moderate Accelerated Shift (MAS) and High Accelerated Shift (HAS) scenarios envision accelerated transitions towards cleaner and more sustainable technologies.

Analysis presented in Chapter 4 underscores the limited progress expected in cooking technologies according to the model's predictions under BAU scenario. This slow transition away from biomass is compounded by rapid population growth, significantly hindering efforts to expand access to modern cooking solutions. The model indicates that over 6 million rural households in Kenya rural will still be reliant on biomass for cooking by 2040, highlighting the enduring dominance of traditional cooking fuels. Wood and charcoal are projected to continue representing over 60 % of cooking energy demand in 2040 as shown in figure 4.4. This slow pace of change contrasts with the ambitious targets outlined in various literature sources, including achieving universal access to clean cooking by 2025 and 2030 United Nations' 7th Sustainable Development Goal. The findings emphasize the necessity for decisive and impactful actions to achieve universal access, as relying solely on projected economic development is insufficient.

The MAS scenario explores a moderately accelerated transition towards cleaner and more sustainable cooking technologies, reflecting the implementation of specific mitigation actions and policy interventions. The analysis reveals a gradual increase in total energy demand over the modelling period, albeit at a slower pace compared to the BAU scenario. Notably, LPG emerges as a prominent alternative to traditional fuels, experiencing significant growth in adoption among rural households. Biogas and Bioethanol also witness notable increases in usage, signaling a shift towards renewable energy sources as shown in figure 4.5.

The MAS scenario demonstrates the potential impact of targeted policy interventions and behavior change initiatives in promoting the adoption of cleaner cooking technologies. Investments in infrastructure development and capacity building are essential to enhance access to LPG and other clean fuels, particularly in remote rural areas. Continued support for research and development efforts is critical to advance the affordability, efficiency, and accessibility of renewable energy solutions for cooking.

The HAS scenario represents a proactive and ambitious approach towards transitioning from traditional cooking methods to cleaner and more efficient alternatives. Rapid adoption of advanced cooking technologies, including LPG, electricity, and biogas, characterizes this scenario. Traditional 3 Stone Fire and Improved Traditional Stone Fire experience significant declines in usage, reflecting successful efforts to phase out traditional cooking practices. Electricity emerges as a prominent choice for cooking, showcasing a successful electrification strategy with substantial growth in adoption at 24% by 2040 as shown in table 4.8. The phased-out of kerosene stoves by 2030 marks a decisive shift away from polluting fuels, contributing to improved air quality and health outcomes.

The HAS scenario demonstrates the transformative potential of ambitious policy interventions and technological innovations in driving rapid transitions towards clean cooking. Investments in infrastructure, more energy efficient devices, capacity building, and public awareness campaigns are essential to facilitate the widespread adoption of electric cooking and other clean technologies. Collaboration between government agencies, private sector stakeholders, and civil society organizations is critical to overcome barriers and accelerate progress towards sustainable energy transitions in rural areas. The HAS scenario forecasts a jump of electric energy consumption for cooking from 0.3056 TWh in 2020 to 8.861 TWh by 2040. With the policy initiatives currently in place to ensure access to and use of cleaner cooking fuels by 2030, it is imperative to ensure that the national grid would be able to support this increase in electrical consumption in future.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATIONS

Efficient government policies are pivotal in hastening the transition away from traditional biomass cooking methods. Across the report, numerous instances underscore the significance of governmental interventions in promoting the adoption of improved and contemporary cooking technologies. Sub-Saharan African nations and other developing regions showcase how interventions are often vital to achieving energy access goals.

The outcomes of modelling and simulation conducted using LEAP for the rural areas in Kenya, emphasise how crucial it is to implement proactive interventions and policy measures in order to influence the trajectory of Kenyan rural households' energy demand for cooking. The MAS and HAS scenarios provide a route forward for a future in cooking energy that is cleaner, more sustainable, and resilient, while the BAU scenario emphasises the problems associated with status quo and inertia. Policymakers can improve access to cleaner fuels, accelerate the adoption of advanced technologies, and reduce the negative health, environmental, and socioeconomic effects of traditional cooking methods. By doing so, a more sustainable and healthy future for rural communities can be achieved.

Future Studies

Future research could focus on investigating the carbon emissions associated with cooking fuels and technologies which is paramount for developing sustainable energy strategies. Future studies could delve deeper into quantifying the carbon footprint of various cooking practices. Moreover, exploring the potential synergies between climate mitigation and energy access goals can inform

the development of policies and interventions that prioritize cleaner cooking solutions while minimizing environmental impact.

Secondly, future research could explore how household income levels, expenditure patterns, and access to financial resources influence the adoption of cleaner cooking technologies across different socio-economic strata. By conducting cost-benefit analyses and assessing the affordability and accessibility of alternative fuels and technologies, policymakers can tailor interventions to incentivize the adoption of energy-efficient solutions while addressing affordability constraints and promoting social inclusion.

Lastly, comprehensive studies focusing on both rural and urban areas are needed to capture the full spectrum of cooking energy demand and its socio-economic and environmental implications at the national level. By adopting a whole-country perspective, researchers can identify spatial disparities in energy access, carbon emissions intensity, and socio-economic vulnerability, guiding targeted interventions to address the diverse needs and challenges faced by different communities.

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APPENDICES

APPENDIX A: SIMILARITY REPORT

Sophy-Final V2 28.03.2024.pdf

ORIGINALITY REPORT

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

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APPENDIX B: ETHICAL CLEARANCE LETTER

RHInnO Ethics - SU-ISERC1826/23 - 1 of 1 - Date Issued: 2023-09-26

Strathmore University Institutional Scientific and Ethical Review Committee (SU-ISERC)



Final Decision

This is to certify that the application for ethics clearance submitted by:

Principal Investigator: Ms. Ogalo, Sophy Akinyi

Reference number: SU-ISERC1826/23

For Study: "Modelling Cooking Energy Demand for E-Cooking Transition: A Data-Driven Approach"

Was reviewed and received the following status: "approved"

Reviewer Comments


The SU-ISERC wishes you all the best with this research undertaking.

26 September 2023 15:01:55




APPENDIX C: NACOSTI PERMIT

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION -
REPUBLIC OF KENYA
Ref No: **699865**



NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION.
Date of Issue: **29/September/2023**

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This is to Certify that Ms. Sophy Akinyi Ogalo of Strathmore University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Machakos on the topic: Modelling Cooking Energy Demand for E-Cooking Transition for the period ending : 29/September/2024.

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