National University of Lesotho

Baselining Lesotho's disaggregated energy factors, ratios and intensities for household energy demand forecasting

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Abstract

The approach that is traditionally employed for household energy demand forecasting in many countries, including Lesotho, has primarily focused on two levels of aggregation which are to disaggregate data into rural and urban settlements. This study introduces an approach which is tailored specifically for Lesotho's unique context. It adopts a methodology that utilizes Lesotho's four agro-ecological zones, providing four levels of disaggregation which are the Lowlands, Foothills, Mountains and the Senqu River Valley. Additionally, it incorporates Lesotho's ten administrative districts which are Botha-Bothe, Leribe, Berea, Maseru, Mafeteng, Mohale's Hoek, Quthing, Qacha's Nek, Mokhotlong and Thaba-Tseka. They offer 10 levels of disaggregation in household energy demand consumption patterns.

The adopted approach allows a more comprehensive understanding of how the households energy consumption behavior varies across different zones and districts of the country. The approach provides valuable insights into zone or district specific energy needs and challenges; thus, it will enhance the accuracy of energy demand forecasting thereby informing more effective and targeted energy policies and interventions in Lesotho. The method used to baseline the disaggregated data is the exploratory data analysis (EDA) based on the Household Energy Consumption Survey (HECS) which was conducted in 2017. It uses both graphical and non-graphical techniques to uncover the data behavior, to spot anomalies and to check the trends through the visual and statistical summaries.

The findings of the study, using absolute values, indicate that during summer months, energy intensities per household in zones demonstrate high average intensity on fuel wood (168.4 kg/HH) and animal waste (148.7 kg/HH), and the low average intensity on LPG (6.8 kg/HH), paraffin (21.4 Ltr/HH), and electricity (69.8 kWh/HH). However, during winter months, fuel wood (165.5 kg/HH) and animal waste (147.0 kg/HH) have high intensities, while paraffin (30.8 Ltr/HH), aloe (39.2 kg/HH) and crop waste (62.9 kg/HH) have the lowest intensities. In the districts during summer months, animal waste (155.6 kg/HH) and fuel wood (144.1kg/HH) have the highest average intensities, while LPG (15.5 kg/HH) and paraffin (38.6 Ltr/HH) have the lowest. In winter months, animal waste (157.2 kg/HH) and fuel wood (152.1 Ltr/HH) show high intensities, while aloe (31.1 kg/HH) and LPG (44.1 kg/HH) take the lower energy intensities. Per capita energy consumption in zones during summer months shows shrubs (75.2 kg/cap) and fuel wood (50.2 kg/cap) with high intensities, while LPG (11.1 kg/cap) and paraffin (10.2 Ltr/cap) have the lowest. In winter months, animal waste and fuel wood have the most intensities of 45.6 kg/cap and 50.2 kg/cap respectively. In the districts, animal waste and fuel wood have high intensities of 44.8 kg/cap and 41.9 kg/cap, with the lowest in LPG (4.6 kg/cap) and paraffin (11.9 Ltr/cap) in summer, while in winter, fuel wood (46.9 kg/cap) has the highest and aloe (10.5 kg/cap) has the lowest intensity on average.

Lesotho's energy consumption patterns in agro-ecological zones and administrative districts are mostly influenced by socio-economic and infrastructure gaps, which are apparent in the variation of energy consumption among districts and the reliance on traditional fuels is less urbanized areas. The Lowland zone and the Maseru district dominate most of the energy consumption statistics due to their large populations, better topography, proximity to infrastructure and stronger economic activities. The data delineates that while there is a growing shift towards modern energy sources, significant portion of the population still remain dependent on traditional fuels, particularly in remote areas.

This approach provides critical information for policymakers, enabling them to develop more accurate energy demand forecasts and design targeted interventions. The study's results can guide strategic energy planning to address Lesotho's specific energy needs, promoting energy access and efficiency while transitioning towards cleaner energy sources. The insights gained from this research lay the foundation for future studies to build more sophisticated, localized energy models that better reflect the dynamics of Lesotho.

1. Introduction

1.1. Background

The Sustainable Energy for All (SE4All) initiative of the United Nations (UN) has three objectives under Sustainable Development Goal 7 (SDG7) which are to ensure universal access to affordable, reliable and modern energy services, increase substantially the share of renewable energy in the world's energy mix, and double the rate of global energy efficiency improvement by 2030 [1]. The initiative can be achieved through careful planning to have complete and reliable energy statistics data which depend on accurate predictions of the energy demands and development of baseline conditions for the progress of policy and measurement [2]. To fully understand and control energy consumption trends and to establish a purposeful benchmark against which subsequent comparisons can be made from year to year, the baselining method is normally used to measure energy intensity and other energy use factors at a predetermined level of detail [3].

The population, gross domestic product (GDP) and sectoral changes in the economic profile of a particular country are the key determinants of energy demand modeling and forecasting. Although the amount of economic activity and its structure as measured by GDP along with several sectors and subsectors of the economy, coupled with population, are the most important determinants, the level of economic activity is what primarily drives the need for energy as measured by the energy intensity [4]. Lower energy intensity means less energy consumption per unit of GDP and vice versa. Figure 1 illustrates Lesotho's overall energy intensity from 1980 to 2018 which increased from 0.28 kWh/$ to 0.89 kWh/$ respectively [5].

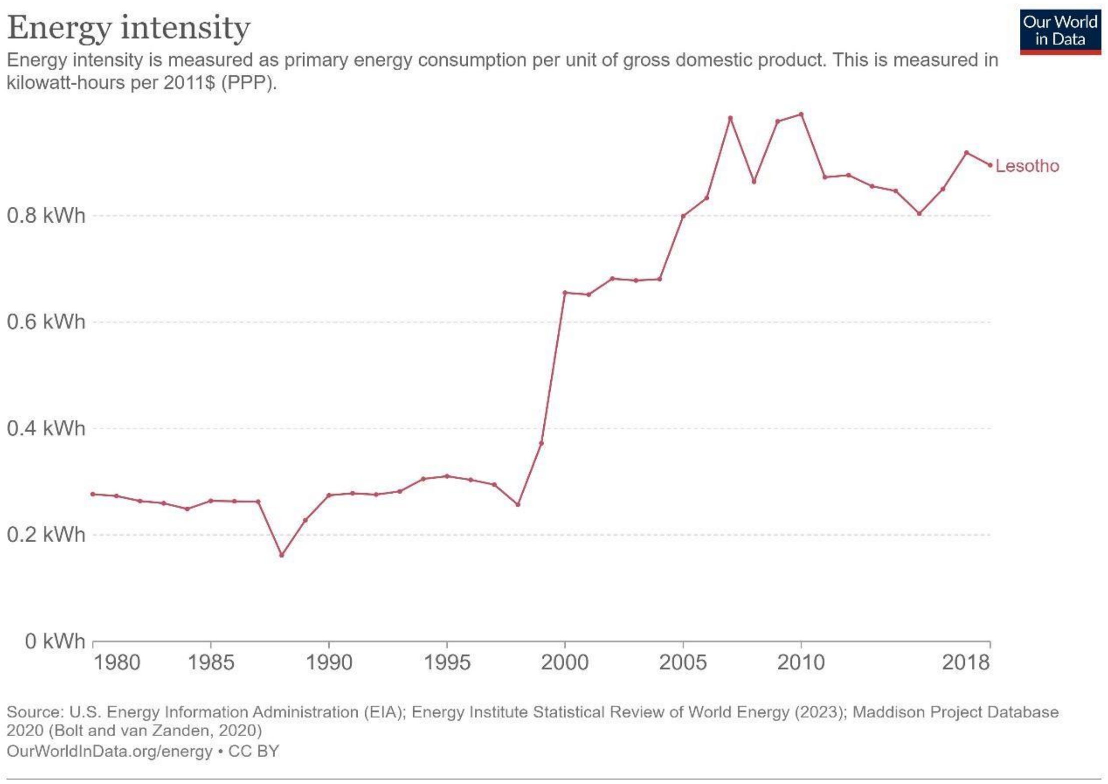

Figure 1: Lesotho energy intensity trend [5]

Energy is necessary for satisfying the demand for energy services, which in turn is necessary to meet economic and social development and to increase the quality of life. As a result, accurate and high-quality energy statistics are important for supplying energy to various users. Moreover, when baselining energy data, factors and ratios (such as energy intensity, energy efficiency, penetrations, etc.) are crucial as they provide clear indications of energy consumption patterns and performance, and also play an important role in the global energy system. Energy efficiency amounts to useful output or service derived from a given amount of energy input. High efficiency implies that less energy is wasted, thus it is recommended that there should be an energy management system as an initial step to implementing energy-saving measures because it allows obtaining an appealing combination of energy efficiency and sustainable development [6].

In the past, the household sector has historically accounted for the majority of the final energy demand of the GDP in developing countries. In Sub-Saharan Africa (SSA), the residential sector accounts for over 70% of the total energy consumption [7]. Baselining the household's energy intensity is a useful metric to be monitored. It measures the amount of energy consumed by households per unit of GDP. It measures how efficiently an average household uses energy to produce a given amount of economic output. Therefore, analyzing the household sector's energy demand makes it easier to identify the changes in household consumption patterns and lifestyles which, in turn, make it easier to guide future energy policies and to respond to new household energy needs [8].

The number of dwellings and their characteristics, including building infrastructure, household size, household income, residential area or location, etc. These are the primary determinants of energy consumption in the household sector [9]. Household choice of energy is also influenced by several factors, including fuel costs, the cost of alternative fuels, the household gender, occupation and size [10]. Different energy forms, such as biomass and other traditional fuels, paraffin, and liquified petroleum gas (LPG), used by households dominate the sources of energy for space heating and cooking in Lesotho, while households connected to the grid mainly use electricity [11]. The households preferred energy forms by the districts of Lesotho, as illustrated in Figure 2, show that in all the districts, electricity is the highly preferred source of energy [7]. Setting up energy usage for each appliance in every residence in a nation would provide a more accurate picture of the country's household energy needs but it is difficult and expensive to collect data at a national level. Hence, survey studies with limited but purposeful samples is widely undertaken for the identification and selection of information-rich cases and for the most effective use of limited resources.

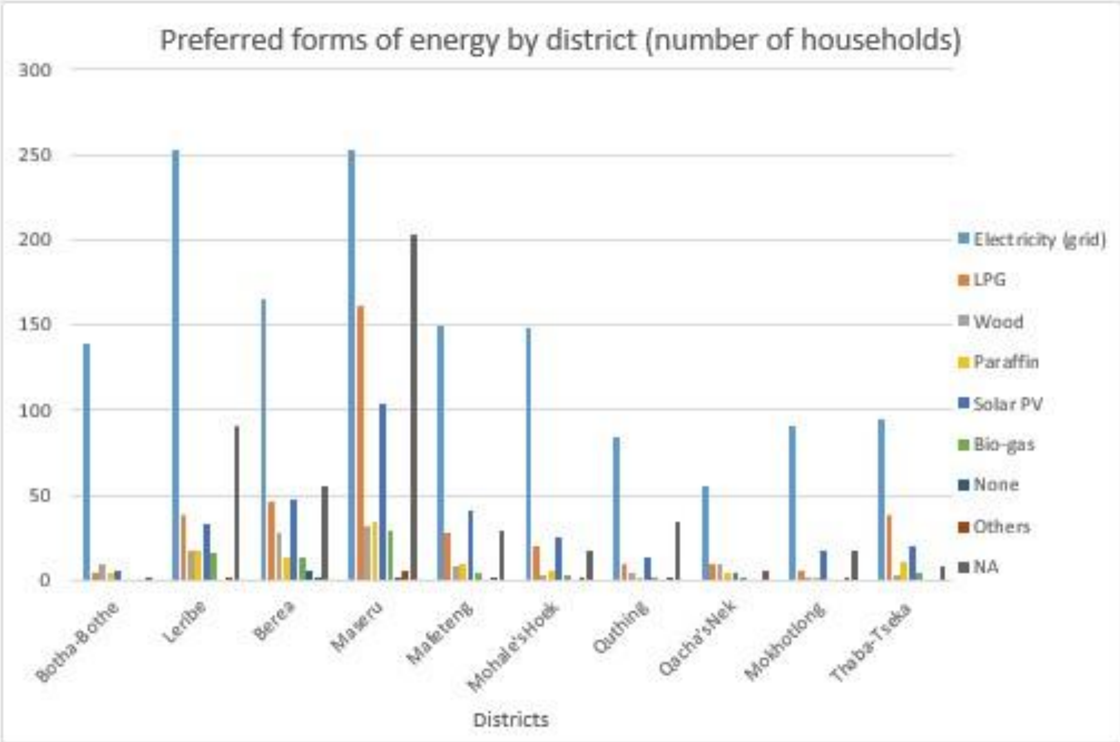

Figure 2: Preferred forms of energy by households in Lesotho [12]

1.2. Problem Statement

Long-term energy planning in developing countries, including the Sub-Saharan Africa (SSA) like Lesotho, is severely hampered by data limitations. The data scarcity and/or poor quality of available data, particularly regarding household energy use and renewable energy resources, and present significant barriers to accurate forecasting [13]. Additionally, existing energy analysis models and methodologies, which are often adapted from developed countries, fail to account for unique socio-economic dynamics, infrastructure limitations and policy contexts of SSA regions [14],[15].

It is usually assumed that the energy systems of developing countries will behave like those of developed regions and that they will follow their historic development trajectories, hence energy forecasting models in developing countries are derived from industrialized countries to discover trends and patterns until more reliable data become available to be used for setting country-specific targets and designing relevant strategies and policies [4,16].

For Lesotho, lack of reliable baseline data or reference year data for key variables such as energy efficiency, intensities, energy demand factors and ratios present a challenge as they are exposed to either overestimating or underestimating energy requirements. Without this foundational data, forecasting household energy demand accurately is difficult, making it challenging to develop strategies for sustainable energy management, efficient infrastructure investment and equitable energy access [15]. This misalignment leads to the application of inappropriate tools and assumptions in energy modeling, which can distort the understanding of local energy systems and hinder the formulation of effective energy policies [15]. Thus, this is an urgent need to develop a country specific energy baselining data and methodologies that are tailored to Lesotho's socio-economic realities, using available data to create reliable baseline for forecasting household energy demand and guiding strategic energy planning.

Lesotho conducted a Household Energy Consumption Survey (HECS) in 2017 through the Bureau of Statistics (BoS) under the Ministry of Development Planning, in tandem with the Department of Energy (DoE). Together they produced a detailed report with comprehensive data to help the government in making informed decisions regarding the household energy sector. A final energy consumption survey by households was undertaken for the winter and summer of 2017, using a sample of around 3,000 households grouped by four agroecological zones and by ten administrative districts. The report deals with the electrification status of the households, specifically looking at access to electricity and the types of energy supply that households have. The survey also focused on energy consumption and use, outlining important parameters such as household size, access to electricity, sources of energy for cooking, space and water heating, lighting and access to solar photovoltaics in the household sector [12]. Despite this commendable effort, the HECS data is yet to be processed to produce critical household energy demand modeling variables for use in energy forecasting.

1.3. Research Questions and Objectives

The current research aims to make use of the existing comprehensive data already available from HECS to the baseline pertinent and sufficiently detailed driving factors for household energy demand in Lesotho that are essential for building energy balances and future energy modeling and to use a statistical analysis to help the country to achieve this goal. The gathered HECS series data was analyzed and understood using exploratory data analysis (EDA). This approach, which emphasizes the graphical representation of the data for pattern extraction and pattern interpretation or analysis, is often used by scientists to develop rich descriptions of the required energy intensities and factors, and to look through spotting anomalies or misleading trends.

The study was guided by the following research questions:

i. What are the average specific energy consumption and penetration levels of the different energy forms (such as traditional fuels, electricity, fossil fuels, solar, etc.) in lighting, cooking, space heating, and water heating?
ii. How much are the variances in terms of household energy consumption reconstruction for the base year using determined factors from ecological zones compared to those from the districts?

The objective of the study was to validate the baseline values from the 2017 HECS disaggregated data for the quantitative modeling variables for Lesotho's household energy factors, ratios, intensities and efficiencies of the four agro-ecological zones (Lowlands, Foothills, Mountains and the Senqu River Valley) and ten administrative districts (Botha-Bothe, Leribe, Berea, Maseru, Mafeteng, Mohale's Hoek, Quthing, Qacha's Nek, Thaba-Tseka and Mokhotlong) and undertake the base year reconstruction for the future households energy demand forecasting using the following steps:

I. The average specific energy consumption and penetration levels of different energy forms such as traditional fuels, electricity, fossil fuels and solar for lighting, cooking, space heating, and water heating.

II. Variances in household energy consumption reconstruction for the base year using the determined factors from ecological zones against to those from districts.

The objectives are in line with the national energy policies because validating baseline values ensures data accuracy which is critical for development of effective energy policies and strategies. They also directly support Sustainable Development Goals 7 and 13 (SDG7 and 13) by ensuring that data used for tracking the progress towards universal access to affordable, reliable and sustainable energy is accurate, and helping to reduce carbon emissions through promotion of clean energy sources.

1.4. Justification

Baselining households' energy intensities, efficiencies, factors and ratios is a consequential step in national energy demand forecasting. The baseline is established based on historical data and trends which provide a solid foundation for demand forecasting and its values. It serves as a reference point that can be used to measure trends and future changes. The research study provides more reliable, adequately disaggregated data for household energy demand modeling and forecasting. Past and current trends in household energy consumption and an understanding of how energy intensities, efficiencies, factors, and ratios are evolving are considered.

The base year data reconstruction will aid the forecasting of future energy scenarios to make plans for energy supply that will accurately ensure energy security, availability and economic growth. The national energy performance, measured by energy consumption and efficiency, can also be compared to international standards to identify areas that require improvement. Policymakers, energy planners and stakeholders can also use reference year data for future forecasts to develop energy policies that strive to reduce energy intensities, increase efficiencies, and support sustainable energy practices. Decisions may also be made regarding infrastructure development, environmental impact assessment and energy management.

1.5. Report Structure

The report is structured from the introduction which outlines the background on baselining household energy demand. The next chapter focuses on the literature review which provides an overview of baselining the household energy demand forecasting, highlighting the factors that influence household energy consumption and discussing the models used for energy demand forecasting. This is followed by a chapter on the description of the methodology implemented in the study and the data used and its disaggregation. The subsequent chapter discusses the results from simulated data, leading to the last chapter on the conclusion from the observed results and recommendations.

2. Literature Review

2.1. Overview of Baselining Household Energy Demand Forecasting

Establishing a baseline for forecasting household energy demand is a pivotal aspect of effective energy management and resource allocation at the national level. Precise forecasting plays a crucial role in enabling policymakers and energy providers to make informed decisions regarding energy consumption, conservation and integration of renewable energy sources [17]. Moreover, baselining the household energy demand provides a solid foundation of historical data and a comprehensive understanding of the factors that influence the intensities and patterns of energy demand [2].

One fundamental step in creating a baseline is the utilization of disaggregated data for forecasting household energy demand. This approach involves the breakdown of the overall energy consumption of households into distinct components corresponding to specific end-uses including lighting, heating, cooling and the appliances used by the households. Within the household sector, various energy sources are employed to satisfy the diverse energy requirements associated with these daily end-uses that lead to a concept of fuel stacking. Table 1 provides an overview of the end-use category and different energy sources used in the household sector. The end-use categories encompass space heating, water heating, cooking, air conditioning and appliances while the energy form include traditional fuels, modern biomass, electricity, district heating, soft solar systems and fossil fuels [18].

Table 1: Energy forms and end-use category for the household sector[18]

Energy forms	End-use category				
	SH	WH	CK	AC	AP
Traditional fuels	X	X	X		
Modern biomass	X	X	X		
Electricity	X	X	X	X	X
District heating	X	X			
Soft solar systems	X	X	X		
Fossil fuels (oil, gas, coal)	X	X	X	X	X
Abbreviations:	SH: space heating AC: air conditioning	WH: water heating AP: appliances	CK: cooking		

Household energy demand and consumption patterns are influenced by various factors, including the socio-economic composition of the household, the level of urbanization, household income and energy demand determinants such as floor space, climatic conditions, and building materials [19]. However, energy consumption concerning socioeconomic and regional factors is different, thus showing no specific household energy consumption pattern. Understanding these influencing factors is of significant importance when establishing benchmarks for intensity, efficiency, factors and ratios in energy demand forecasting. Some of the factors that have a notable impact on energy demand and consumption include the size and composition of the household, the types of appliances and equipment in use, behavioral aspects, level of energy awareness and knowledge within households, energy prices and financial constraints [20].

2.2. Factors that Influence Energy Consumption in the Household Sector

Household energy consumption choices are shaped by a complex interplay of socio-economic factors (including access to electricity and other cleaner sources), cultural norms, and environmental challenges. In most developing countries, the electrification rate is a pressing challenge. In Lesotho, it stands at 52% as of 2022 [21]. Urban areas have access to cleaner sources of energy, while rural households predominantly rely on traditional fuels accounting for 80% of the total energy consumption by the household sector. Furthermore, there are both endogenous and exogenous factors that influence household energy demand. Endogenous factors pertain to the household individual choices of energy sources whereas exogenous factors are not directly related to the households [7].

A hierarchy known as the energy ladder depicted in Figure 3 correlates the rise in a household economic status / income level with the choice of energy type for cooking, space heating and lighting. This concept suggests that as households income increases, there is a likelihood of transitioning from primitive energy sources to cleaner and more modern alternatives [22]. At a very low-income level, households rely on solid fuels for cooking and heating while at a highincome level, they consume electricity which is mostly produced from renewable sources [23]. In line with one case study in Uganda [10], household energy consumption patterns for cooking adhere to the energy ladder model which illustrates that within households, the initial energy choices typically commence with traditional energy sources and gradually advance up the energy ladder to access cleaner sources of energy. Eventually, this progression leads to the adoption of more sophisticated energy sources, including electricity.

Different factors such as literacy, income, local climate and appliance ownership also influence the household energy consumption. Household income emerges as a pivotal factor influencing the uptake of cleaner cooking fuels in urban settings. The middle-income class demonstrates a noteworthy and positive association with the adoption of electricity, LPG and paraffin over traditional fuels across various settlement types (rural, peri-urban and urban areas) in the decision-making process for cooking energy. Households receiving remittances are also more inclined to opt for cleaner energy sources for cooking [22]. One study postulated that households exposed to air conditioning prefer lower heat [24].

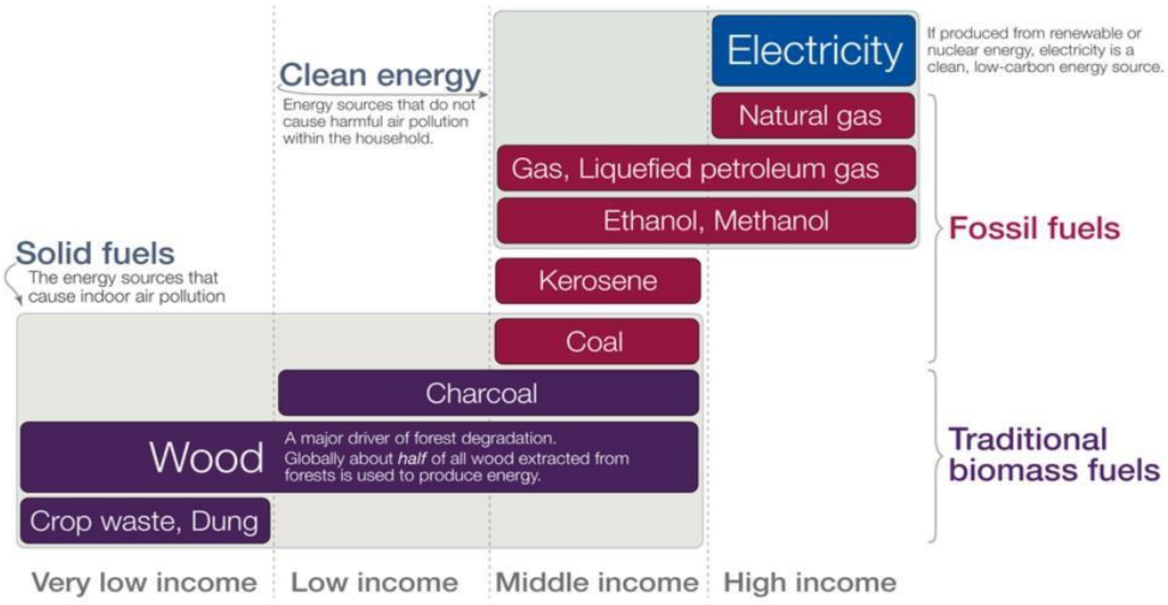

Figure 3: Energy ladder [23]

The household's behavior such as regulating indoor temperatures, selection of ventilation rates, the use of appliances and lighting also significantly contribute to residential electricity consumption. It is indicated that an escalation in household income and average age of the residents may lead to an increased per capita electricity consumption attributed to greater financial capacity for investing in appliances [25]. In addition, the presence of electricity proves to have a positive and statistically significant impact on the preference for electricity for both cooking and water heating. Conversely, larger households exhibit a decreased likelihood of selecting cleaner energy sources over traditional fuels for water heating in comparison to smaller households [22].

Households led by well-educated women have an increased likelihood of transitioning to cleaner energy sources because they are more energy-conscious and are aware of the environmental consequences associated with the use of non-clean energy resources, thereby driving a shift towards cleaner energy alternatives [26]. Statistics reveal a 17% reduction in the use of fossil fuels and an 86% increase in the adoption of clean energy sources [27]. Similarly, education and social factors affect household energy use. Higher levels of household education are associated with an increased likelihood of opting for LPG and electricity as cooking fuels across diverse settlement types [24]. According to [10], There is a need for the implementation of policies and strategies aimed at diminishing the reliance on unsustainable cooking energy sources while advocating for the adoption of alternative options. This can be achieved by directing efforts towards individuals, such as women, who influence household energy consumption decisions.

The types of building materials also influence the type of energy consumed in the households. The households with single detached houses and old-type stories are more likely to choose coal and gas with the probability of 13.2 % and 20.8 % respectively, as a suitable energy form to be consumed in the family[28]. Moreover, building characteristics also have a significant effect on household energy consumption. Dwellings are positively and significantly correlated by size to the household choice of coal [29]. According to [30], the dwelling type, number of bedrooms and appliances used for water heating and cooking have a positive effect on electricity consumption. The dwelling type affects electricity consumption as different house types consume electricity differently. For instance, detached and semi-detached houses consume more electricity than row houses and apartments[30].

Urbanization is another factor that influences residential energy use worldwide, even though the magnitude varies across regions by considering the heterogeneity and stages of urbanization. It is indicated that most countries in Sub-Saharan Africa are at the acceleration stage of urbanization, characterized by rapid population migration to urban areas without the corresponding economic growth. This feature of urbanization leads to a decrease in aggregate consumption. In contrast, urbanization in developing regions in Asia and the Middle East & North Africa, which have been accompanied by booming economies, can increase aggregate residential energy consumption [25].

2.3. Models Used for Long-term Energy Demand Forecasting

A variety of energy demand models are available for use in analyzing energy consumption to establish baselines and forecasts of energy trends. This is particularly crucial in both developed and developing countries, where accurate and efficient energy supply and power system planning are in high demand. Energy consumption models range from long-term forecasting, mid-term forecasting, and short-term forecasting. Short-term forecasting is used for the analysis of network distribution, mid-term forecasting is mostly used for planning the distribution of energy resources and tariffs, while long-term forecasting holds particular significance as it anticipates the outcomes of strategic and substantial decisions, such as the expansion of utility plants which often entail significant investments. This prevents overestimations and underestimations of the nation's future energy demands, thereby mitigating the risk of energy production shortages or the unnecessary construction of electricity generation plants [3].

Figure 4 illustrates some of the long-term energy models that exist and compares each model to the characteristics of the developing countries and their economic characteristics along with their distinctive features. These features encompass the performance of the power sector issues related to the electrification rate and supply shortages, the role of traditional fuels, urbanization trends, the informed economy, structural economic changes, investment decision-making, and other relevant factors [14]. The findings derived from this comparison indicate that specialized large-scale national or global models are intricately crafted, demanding significant expertise for their application. and exhibit limitations in adaptability. Consequently, they tend to be utilized by specific, specialized user groups and remain less accessible. It is challenging to encapsulate rural energy within economic models because end-use models can accommodate them if pertinent to the analysis [31]. However, both the Model for Analysis of Energy Demand (MAED) and Long-range Energy Alternatives Planning System (LEAP) models have a broader versatility, enabling their utilization in a more extensive array of contexts. It is challenging to encapsulate rural energy within economic models although end-use models can accommodate them if they are pertinent to the analysis [31].

Model	Main characteristics of developing country's energy systems and economies										
	Performance of power sector	Supply shortages	Electrification	Traditional bio-fuels	Urban-rural divide/ urbanisation	Informal economy	Structural economic change	Investment decisions	Subsidies	Others features*	*Specification of other features
Global energy environment economy (E3 MG)			(X)				(X)	X	X	X	Emission Trading (ET), limited assessment of renewable energies (RE)
(TARGETS-IMAGE Energy Regional Model) (IMAGE/TIMER)			(X)		X	(X)				X	Clean Development Mechanism (CDM), ET, wide assessment of RE
Long-range Energy Alternatives Planning system (LEAP)	(X)		X	X	X				(X)	X	Indiv. ass. per country, ET, CDM, RE, rural energy programmes
Model for the Analysis of Energy Demand (MAED)	X		X		(x)		X			(X)	limited assessment of RE
Market al location model (MARKA)			X	X	X				(X)	X	ET, CDM, RE
Model for Energy Supply Strategy Alternatives and their General Environmental impact (MESSAGE)			X	X	(X)		X		(X)	X	ET, CDM, RE
Open Source Energy Modeling System (OSeMOSYS)			X					X		X	ET, CDM, RE
Planning of the Electric Power Generating System Programme (PLANELEC)			X					X		X	ET, RE
Prospective Outlook on Long-term Energy Systems (POLES)	(X)		X					X	(X)	X	ET, CDM, RE
PowerPlan	X	X	(X)							X	CDM, RE
International Clean Energy Project Analysis Software (RETScreen)			X	X	X			(X)	(X)	X	ET, CDM, RE, off-grid RE systems
Wien Automatic System Planner (WASP)	(X)	(X)	(X)					X		X	Environmental emission ass.
World Energy Model (WEM)			X	X	X			(X)	(X)	X	Indiv. ass. per country, ET, CDM, RE, focus on energy & poverty

Figure 4: A Comparison of the main characteristics of developing countries energy system and their economies per model [14]

2.3.1 Energy Demand in the LEAP MODEL

The Long-range Energy Alternatives Planning (LEAP) model is a scenario-based modeling tool that adopts a bottom-up approach to monitor energy consumption, providing a coherent perspective on potential advancements in the energy system, including production and resource allocation across various sectors. The LEAP model is also used for energy demand forecasting in the residential sector, as illustrated in Figure 5, where the data was divided into two main subsectors which are the rural and urban areas [16]. The percentage share of electric and nonelectric energy forms by the households was used in the model, containing the categories that include lighting, cooking, refrigeration and other devices. It was discovered that in all sectors, the household sector accounts for the highest share of energy demand. Moreover, household sector consumption can be reduced by rapidly shifting from biomass-based energy consumption to clean-based consumption. This can be achieved through better service reliability and power supply in the rural areas to improve access to electricity [16].

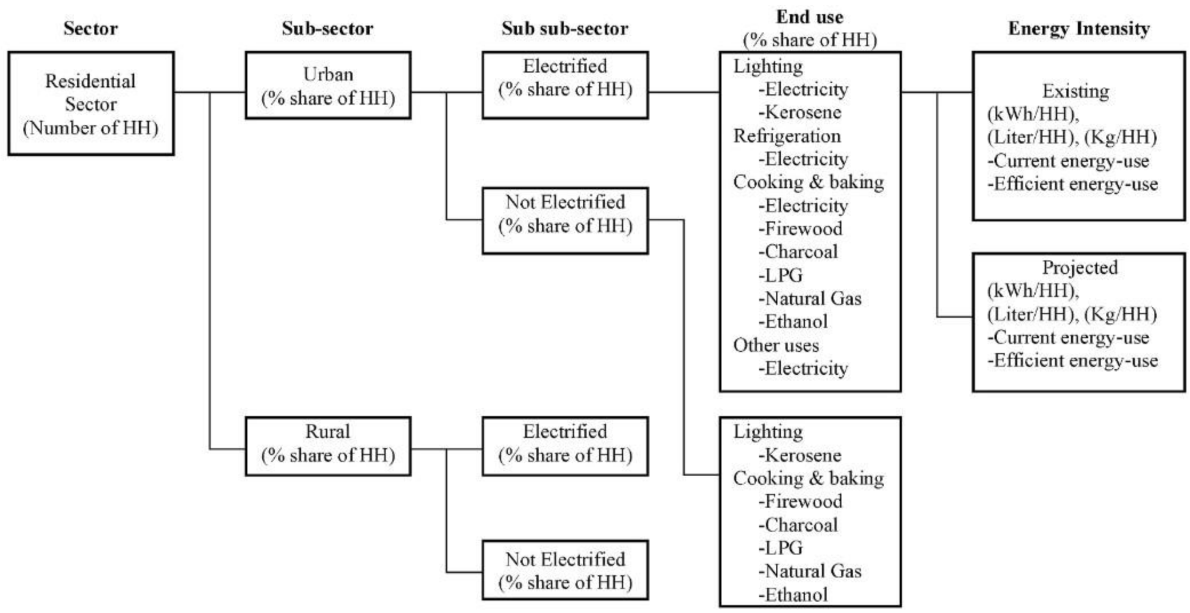

Figure 5: Energy demand tree for the household sector using the LEAP model [16]

As outlined by [32], the LEAP model was applied to predict both energy demand and greenhouse gas emissions in the household sector. It was stated that it is important to note that this model comes with certain limitations, as it is not tailored to a specific energy system. Instead, serves as a framework for constructing diverse energy models, each of which requires its unique structure. However, it shines in its utility projecting energy demand and forecasting greenhouse gas generation [32].

In Colombia, the LEAP model was used to forecast the energy demand in several sectors, including the household sector. The determining factor of household energy demand in the household sector is the number of households in the country (H). The two variables which are national population (P) and number of people per household (PPH) were used to extrapolate the number of households based on the historical data as in H=P/PPH

Equation 1$H = P/PP$H

Equation 1

$$H = P/PPH \qquad \textit{Equation 1}$$

To determine the energy demand in the household sector, the energy demand of domestic appliances for which the number of households using appliances (H_E) was firstly calculated. Energy demand per household was calculated in $HE= H * HCS * Part$ Equation 2.

$$H_E = H * HCS * Part \qquad \textit{Equation 2}$$

Where HCS is the percentage of households that have a certain service and *Part* is the participation of different appliances.

$EHE= DE_E/ H_E$ Equation 3 illustrates the energy consumed per household associated with appliances, EH_E, which is the energy demand for the household appliances (DE_E) divided by the number of households that use the appliances. $EH_E = DE_E / H_E$ *Equation 3*

Energy demand in $DEE(n) = H_n * HCS_n * Part_n * EH_{E(n)}$ Equation 4 is the energy used by each appliance in the household for each year (n)

$$DE_{E(n)} = H_n * HCS_n * Part_n * EH_{E(n)} \quad \textit{Equation 4}$$

The energy demand of all the household appliances corresponding to their use is illustrated in $DEu(n) = \sum DE_{E(n)}$ Equation 5:

$$DE_{u(n)} = \sum DE_{E(n)} \quad \textit{Equation 5}$$

The total demand of the sector (DE) is constructed from the sum of all the energy demands of the uses in $DE_n = \sum DE_{U(n)}$ Equation 6:

$$DE_n = \sum DE_{U(n)} \quad \textit{Equation 6}$$

The Energy Demand Index (*IDE*) is given by the amount of energy consumed per household in $IDE = DE_s / H$ Equation 7:

$$IDE = DE_s / H \quad \textit{Equation 7}$$

DE_s is the household sector energy demand.

2.3.2 Household Energy Demand in TIMES

The Integrated MARKAL-EFOM System (TIMES) modelling framework is also a bottom-up partial equilibrium model that is used for sectorial, local and national energy systems [7]. It was also used in Nigeria for residential energy demand, focusing on the rural and urban households' key drivers for energy demand. The main drivers were identified as population, household number and the size of the households, urbanization, income level, and electrification rate in rural and urban areas. The methodological framework that was employed using TIMES is illustrated in Figure 6. In the residential sector, the end-use functions considered for both rural and urban households were lighting, cooking, water heating, refrigeration, cooling, and miscellaneous electricals [7].

Energy services demand (ESD) of an end-use function was determined by level of activity (A), structure (S) and energy intensity (I), and was calculated as in $ESD = A * S * I$ Equation 8:

$$ESD = A * S * I \quad \text{Equation 8}$$

The useful energy demand (LT_{ESD}) for lighting in rural and urban areas was estimated using $LT_{ESD} = HT_{r,u}(y) * IL_{e.k} * f_{el,nel}$ Equation 9:

$$LT_{ESD} = HT_{r,u}(y) * IL_{e.k} * f_{el,nel} \quad \textit{Equation 9}$$

where $HT_{r,u(y)}$ is the total number of households in a year, $IL_{e.k}$ is the specific energy consumption of electricity or kerosene and $f_{el,nel}$ is the fraction of the electrified or nonelectrified households.

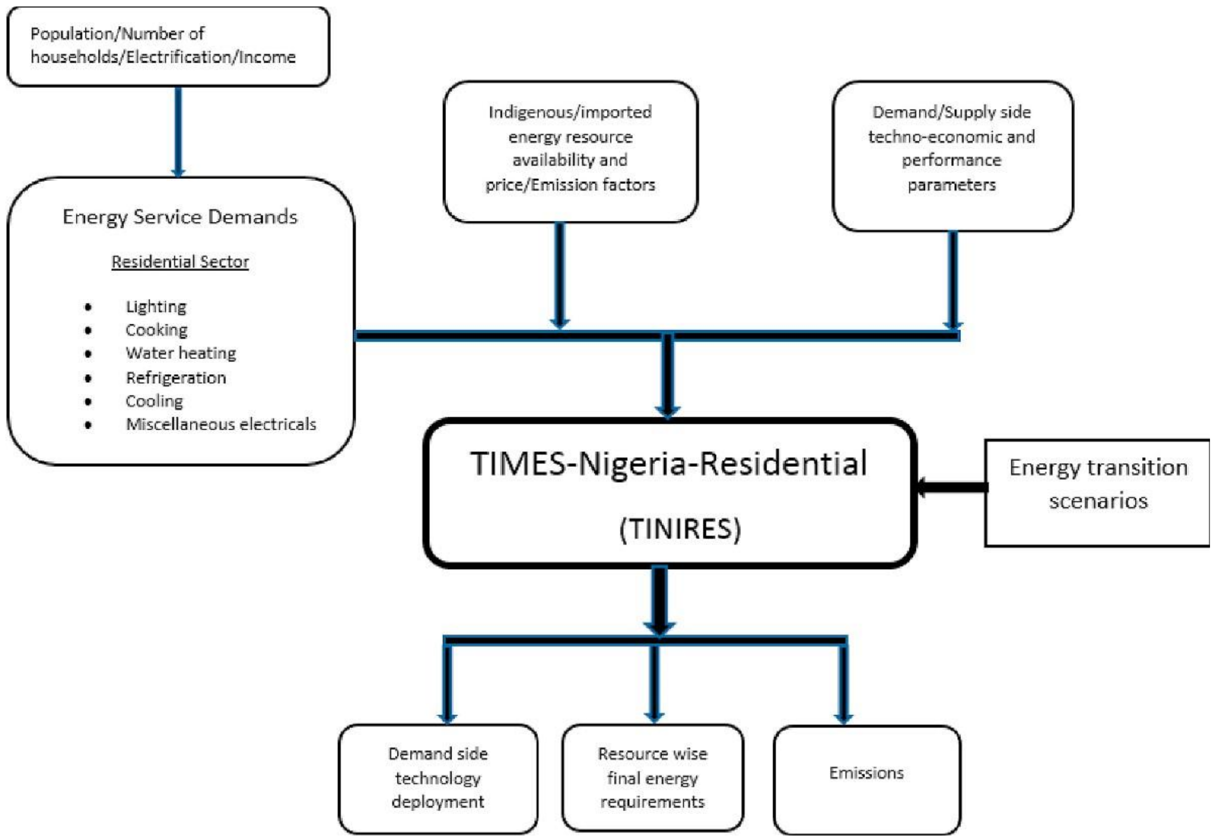

Figure 6: TIMES - Residential energy services methodological framework [7]

The total useful energy demand for cooking (CK_{ESD}) for rural and urban households was estimated in $CKESD = Pop_{r,u(y)} * IC$ Equation 10 as:

$$CK_{ESD} = Pop_{r,u(y)} * IC \qquad \textit{Equation 10}$$

where $Pop_{r,u(y)}$ is the total population in a year (either rural or urban) and IC is the useful energy intensity of cooking.

Useful energy demand for water heating (WH_{ESD}) was estimated by $WH_{ESD} = HT_{r,u}(y) * CW * \theta\Delta * m * 365 * f_{HWT}$ Equation 11:

$$WH_{ESD} = HT_{r,u(y)} * CW * \theta\Delta * m * 365 * f_{HWT}$$ *Equation 11 where* CW is the daily average water demand for bathing per household, $\theta\Delta$ is the temperature change required, m is the specific heat capacity of water, and f_{HWT} is the fraction of households that heat water for bathing.

For refrigeration, cooling and miscellaneous electricals, penetration of appliances was calculated in $AP_{r,u} = \overline{1+e-(k+In^{\alpha}cx1+Elcx2)}$ Equation 12 as:

$$AP_{r,u} = \frac{a}{1+e^{-(k+In_{cx1}+El_{cx2})}} \qquad \textit{Equation 12}$$

$AP_{r,u}$ is the penetration of appliances, a is the saturation of an appliance at a maximum (100%), El_{cx2} and In_{cx1} represents electrification and income rates, k is the coefficient of regressions, $x1, x2$ and k coefficients of regression.

2.3.3 Household Energy Demand in MAED and MARKAL

MAED is a bottom-up and medium to long-term approach model that has flexible attributes to show energy consumption structure [15]. It allows the analysis of different socio-economic development policies for a country, the impacts of technological development and the effect of changes in the lifestyle of society (such as households income increase) [14]. Figure 7 presents the methodological framework utilized for the analysis of energy consumption scenarios in the residential sector, employing the MAED and MARKAL models. The data used in the study was derived from a primary survey, encompassing energy intensity and the parameters essential for the MAED model. The residential sector was categorized into urban and peri-urban segments, with useful energy demand further subdivided into end-uses (space heating, water heating, space cooling, lighting, cooking, and miscellaneous electricity) for both urban and peri-urban areas. Within the MARKAL framework, a similar division into urban and peri-urban segments was applied to the residential sector. This analysis considered various energy resources, technologies and diverse energy scenarios. The findings indicated that urbanization led to an energy transition marked by increased energy demand, particularly in the valleys where population growth contributed to the heightened energy requirements [33].

The equations that are used in MAED for the household sector energy demand the calculations given below for the Urban Household sector but can also be used to calculate useful energy demand for the Rural household sector (with U replaced by R in the notations). The total numbers of dwellings in million are given by $TUDW=UHH = PO* (PURB/100)/CAPUH$ *Equation 13* and $TRDW=RHH=PO * (PRUR/100)/CAPRH$ *Equation 14* as:

$$TUDW = UHH = PO * (PURB/100)/CAPUH \qquad \textit{Equation 13}$$

$$TRDW = RHH = PO * (PRUR/100)/CAPRH \qquad \textit{Equation 14}$$ where UHH or RHH = number of urban or rural households (million), PO = Population, $PURB$ or $PRUR$ = share of urban or population and $CAPUH$ or $CAPRH$ = average household size in urban or rural areas.

The total final energy in household sector is given in $FINHH = FINUH + FINRH = TFHH + MBHH + ELHH + DHHH + SSHH + FFHH$ Equation 15 as:

$$FINHH = FINUH + FINRH = TFHH + MBHH + ELHH + DHHH + SSHH + FFHH \qquad \textit{Equation 15}$$

where $TFHH$ is the total final energy for traditional fuels from urban households ($TFUH$) plus rural households ($TFRH$); $MBHH$ is the total final energy for modern biomass from urban households ($MBUH$) plus rural households ($MBRH$), $ELHH$ is the total final energy for electricity from urban households ($ELUH$) plus rural households ($ELRH$), $DHHH$ is the total final energy for district heating from urban households ($DHUH$) only, $SSHH$ is the total final energy for Soft Solar from urban households ($SSUH$) only and $FFHH$ is the total final energy for fossil fuels from urban households ($FFUH$) plus rural households ($FFRH$) as outlined in detail in the MAED manual [18].

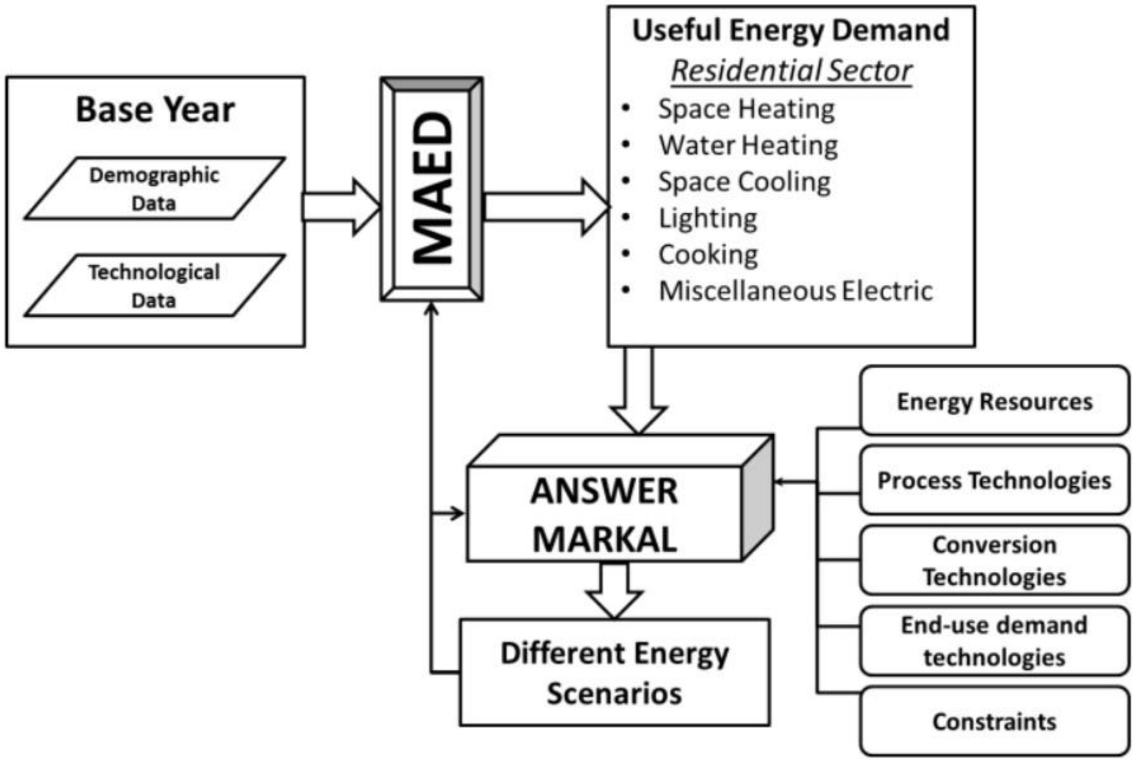

Figure 7: MAED and MARKAL methodological framework [33]

Traditional fuels and modern biomass refer to end-use functions such as space heating (SH), hot water heating (HW) and cooking (CK). Electricity covers specific applications including SH, HW, CK, air conditioning (AC) and electrical appliances and lighting (AP). District Heating mainly concentrates on SH and HW while Soft Solar covers both end-use functions but also include CK. Fossil fuels entail uses such as SH, HW, CK, AC and lighting (LT). The patterns of these energy fuel forms and their end-use functions per ecological zone and administrative districts of Lesotho are going to be examined using the exploratory data analysis approach to assess the potential new insights that may be different from common urban-rural perspective.

2.4. Exploratory Data Analysis

Exploratory data analysis (EDA) is a scientific approach that can be used in data analysis. It is essential in research, serving the purpose of examining the distribution of available data by establishing trends, spotting the outliers and anomalies, maximizing insights into a data set, extracting important variables and clearing an understanding of graphical data presentation. In the early stage of the research after data collection, the data is manipulated to examine its quality without any assumptions. In the study which was conducted in Greece, the EDA is used as a model for building short-term, medium-term and long-term electrical energy demand forecasting [34]. The model can be used in formulating a management policy for the daily operation and maintenance planning as well as expansion.

Utilizing graphical representations leads to gaining some insights by revealing the relationships between the datasets, identifying the outliers, testing assumptions and the facilitating model selection. The EDA process typically begins with problem identification, followed by data manipulation and analysis, data modeling and drawing conclusions based on the results [35]. The approach to EDA varies depending on the available data and the analysis objectives. It can be categorized as a univariate non-graphical, multivariate non-graphical, univariate graphical or a multivariate graphical. Non-graphical methods involve computing summary statistics, whereas graphical techniques encompass a range of visual tools such as histograms, mean plots, standard deviation and probability plots, box plots, residual plots and scatter plots. Univariate graphical EDA focuses on examining individual variables within the dataset, whereas multivariate graphical EDA explores relationships between two or more variables simultaneously [36]. Boxplots are also utilized to convey information about the central tendency, symmetry and the skew of the dataset, as well as to identify the outliers. The rectangular boxes below and above the hinges represents the upper quartile (Q1) and the upper quartile (Q3), as illustrated in Figure 8, and gives the inter-quartile range (IQR = Q3 – Q1). It also entails the median, lower whisker end and upper whisker end. When the whisker is long, it means that the data is less concentrated/ has more variability, and when it is short the data is more concentrated / has less variability [37].

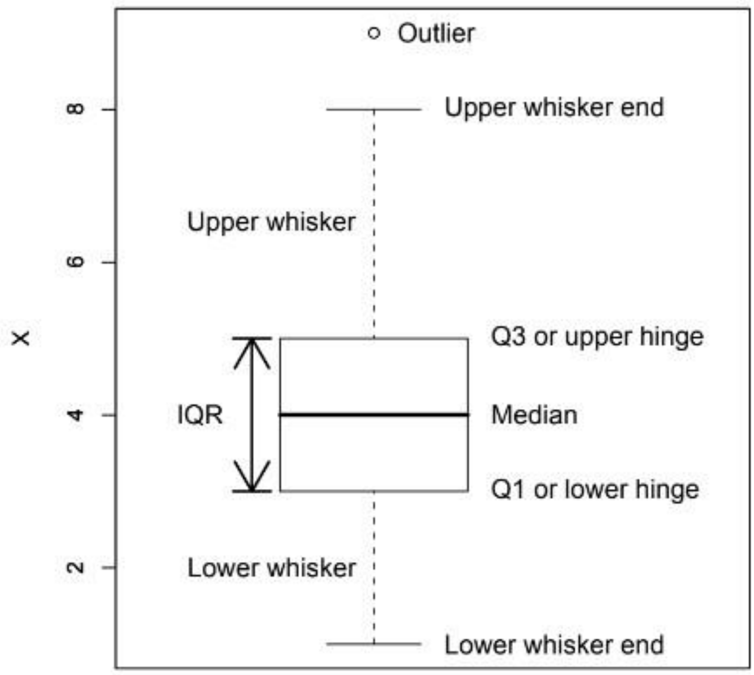

Figure 8: The boxplot [35]

2.5 Synthesis of the study

The majority of research carried out to predict patterns of household energy demand and consumption are at two aggregation levels: rural and urban. As a result, there is a lack of disaggregated data at a more localized level that is consistent with the context of a given nation.

As a result, forecasting becomes more difficult when using universal models because household behaviours and patterns of energy use differ. This result in household preferences, energy awareness, and adoption behaviour being under-explored, particularly in the context of switching from traditional to cleaner energy sources. In addition, the LEAP and MAED models have limitations in the context of developing countries where they are not easily adaptable to areas that rely heavily on traditional fuels. The behavioural dynamics related to energy consumption are also not fully integrated into the forecasting models

Instead of focusing simply on rural and urban settings, the study in the next chapter will provide a more country-specific data disaggregation that takes into account the local variations in behaviour, socioeconomic status, and energy access levels in Lesotho. These variations will be in four agro-ecological zones and ten administrative districts and a deeper understanding of how households make decisions about energy will be possible as a result of this disaggregation. Additionally, it will support the implementation of energy policies and initiatives that will enable the government, district administrators and local councils to accelerate the shift to sustainable energy sources.

3. Methodology

3.1. Overview

Critical factors which have been identified as the key driving parameters in household energy consumption and how they influence the energy demand fluctuations are population / demography, the number of housing units, average size of the households (people per household), income level of the households, energy demand of appliances, percentage of the households with appliances, the electrification rate and access to solar energy. In many previous studies, the analyses of these variables have been done based on urban-rural split.

This study aims to undertake a different approach which is based on Lesotho's four ecological zones and ten administrative districts, as illustrated in Figure 9, based on the HECS 2017 data, which is more disaggregated study and has the opportunity to provide new insights into Lesotho's household energy demand and consumption patterns that are critical for future energy modelling and forecasting.

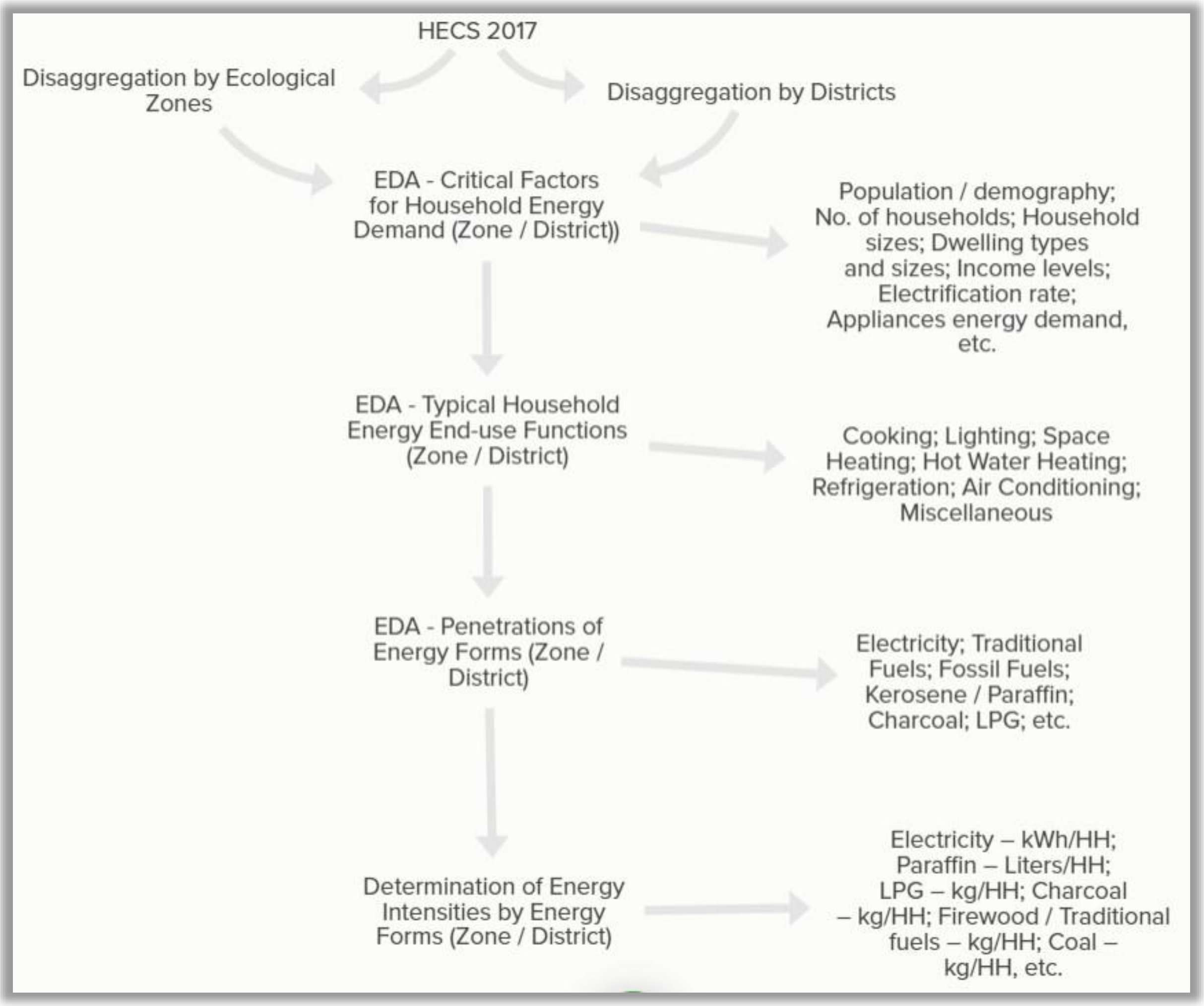

Figure 9: Schematic breakdown of baselining household energy consumption values

The establishment of baseline data usually involves gathering historical data for an extended period to capture seasonal variations and long-term trends. However, due to the challenges of data availability in developing countries including Lesotho, this study only makes use of the 2017 data on household energy consumption. The critical variables, when baselining disaggregated energy intensities, efficiencies, factors, and ratios for household energy demand forecasting, are the demographic statistics, income level, household size, access to electricity, sources of energy for cooking, space and water heating, lighting, access to solar photovoltaics and housing type appliances. Factors of energy intensities help quantify the energy consumption associated with the various activities, applications, and equipment within the household. Therefore, a clear understanding of energy intensities helps with the accurate demand forecasts and the promotion of energy efficiency.

EDA involves the visualization of data to understand the main characteristics of the data set. The use of descriptive statistics involved calculations to describe the data central tendency as well as dispersion and shape of each variable. This included the measures such as mean, median and mode. The univariate analysis, which analysed one feature at a time from the data properties, was presented through histograms, box and whiskers plots.

EDA methodology in data manipulation plays a crucial role in informing future energy modelling and forecasting by uncovering patterns, relationships and insights within the available data set. It will facilitate a deeper understanding of critical factors affecting energy consumption and provide a solid foundation for developing more accurate energy models. Visualization of spatial and demographic trends which shows mapping energy consumption patterns across Lesotho's agro-ecological zones and administrative districts uncover disparities in energy access, consumption and efficiency. Moreover, it displays a clear seasonal energy variation that may recur annually, such as increased energy demand during winter months due to difference factors influencing household energy consumption. EDA also assists in calculating energy intensities for household energy end use functions by analysing energy end use in relation to household critical factors influencing energy consumption. Moreover, it reveals how energy sources consumed in household shifts and affects overall energy demand. More data gaps can be identified which can guide future data collection efforts, ensuring that subsequent studies can build on more comprehensive and reliable data sets, inform surveys and data collection strategies by identifying key variables that needs more granular data.

3.2. Disaggregated Energy Consumption Modelling

Lesotho is organized into ten administrative districts and four agroecological zones as illustrated in Figure 10. The agro-ecological zones are the Lowlands, Foothills, Mountains (or Highlands) and the Senqu River Valley which will be assigned codes Z_1, Z_2, Z_3 and Z_4 respectively to represent each zone during data manipulation. The administrative districts, Botha-Bothe, Leribe, Berea, Maseru, Mafeteng, Mohale's Hoek, Quthing, Qacha's Nek, Mokhotlong and Thaba-Tseka, were assigned codes D_1 to D_{10} respectively during data manipulation.

Figure 10: Lesotho districts and agroecological zones [38]

This study used modified household energy demand equations, based on the main end-use categories established in the literature disaggregated on Lesotho's ecological zones (Zi, i = 1 – 4) and administrative districts (Dx, x= 1-10). The total final energy for household sector in terms of ecological zones or administrative districts is given by $FINHH = \sum_{i=1}^{4} FINHH_{Zi} = \sum^{k}_{x=A} FINHH_{Dx}$ Equation 16, which is composed of end-use categories of traditional fuels ($TFHH$), modern biomass ($MBHH$), electricity ($ELHH$), soft solar ($SSHH$) and fossil fuels ($FFHH$), with the exclusion of district heating, for each zone or district in $FINHH_{Zi,Dx} = TFHH_{Zi,Dx} + MBHH_{Zi,Dx} + ELHH_{Zi,Dx} + SSHH_{Zi,Dx} + FFHH_{Zi,Dx}$ Equation 17:

$$FINHH = \sum_{i=1}^{4} FINHH_{Zi} = \sum^{k}_{x=A} FINHH_{Dx} \qquad \textit{Equation 16}$$

Where;

$$FINHH_{Zi,Dx} = TFHH_{Zi,Dx} + MBHH_{Zi,Dx} + ELHH_{Zi,Dx} + SSHH_{Zi,Dx} + FFHH_{Zi,Dx} \qquad \textit{Equation 17}$$

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$$NDW_{Zi,Dx} = (PO * \left(\frac{Z_i, D_x}{100}\right))_P / CAP_{Zi,Dx} \qquad \textit{Equation 18}$$

t where PO = Population, P_{Z_i,D_x} is share of population for each zone or district and CAP_{Z_i,D_x} is
o average household size in each zone or district. t a
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The energy consumption from traditional fuels $TFHH_{Z_i,D_x}$ mainly consists of space heating (SH), hot water heating (HW) and cooking (CK) as given in $TFHH_{(c)Z_i,D_x} = TFHHSH_{Z_i,D_x} + TFHHHW_{Z_i,D_x} + TFHHCK_{Z_i,D_x}$

Equation 19:

$$TFHH_{(c)Z_i,D_x} = TFHHSH_{Z_i,D_x} + TFHHHW_{Z_i,D_x} + TFHHCK_{Z_i,D_x}$$

Equation 19

NB: The subscript (c) is for the energy consumption.

Similarly, the energy consumption from modern biomass, $MBHH_{Z_i,D_x}$, and from soft solar, $SSHH_{Z_i,D_x}$, mainly consist of space heating (SH), hot water heating (HW) and cooking (CK), as given in $MBHH(c)Z_i, D_x = MBHHSH_{Z_i,D_x} + MBHHHW_{Z_i,D_x} + MBHHCK_{Z_i,D_x}$

Equation 20 and $SSHH_{Z_i,D_x} = SSHHSH_{Z_i,D_x} + SSHHHW_{Z_i,D_x} + SSHHCK_{Z_i,D_x}$

Equation 21 as:

$$MBHH_{(c)Z_i,D_x} = MBHHSH_{Z_i,D_x} + MBHHHW_{Z_i,D_x} + MBHHCK_{Z_i,D_x}$$ *Equation 20*

$$SSHH_{Z_i,D_x} = SSHHSH_{Z_i,D_x} + SSHHHW_{Z_i,D_x} + SSHHCK_{Z_i,D_x}$$ *Equation 21*

The household energy consumption from electricity, $ELHH_{Z_i,D_x}$ covers space heating (SH), hot water heating (HW), cooking (CK), air conditioning (AC) together with electrical appliances (AP) and lighting (SH), as shown in $ELHH_{(C)Z_i,D_x} = ELHHSH_{Z_i,D_x} + ELHHHW_{Z_i,D_x} + ELHHCK_{Z_i,D_x} + ELHHAC_{Z_i,D_x} + ELHHAP_{Z_i,D_x} + ELHHLT_{Z_i,D_x}$

Equation 22 as:

$$ELHH_{(C)Z_i,D_x} = ELHHSH_{Z_i,D_x} + ELHHHW_{Z_i,D_x} + ELHHCK_{Z_i,D_x} + ELHHAC_{Z_i,D_x} + ELHHAP_{Z_i,D_x} + ELHHLT_{Z_i,D_x}$$ *Equation 22*

Lastly, the household energy consumption from fossil fuels, $FFHH_{Z_i,D_x}$, includes space heating (SH), hot water heating (HW), cooking (CK), air conditioning (AC) and lighting (LT), as shown in $FFHH_{Z_i,D_x} = FFHHSH_{Z_i,D_x} + FFHHHW_{Z_i,D_x} + FFHHCK_{Z_i,D_x} +$

$FFHHAC_{Zi,Dx} + FFHHLT_{Zi,Dx}$ Equation 23 as:

$$FFHH_{Zi,Dx} = FFHHSH_{Zi,Dx} + FFHHHW_{Zi,Dx} + FFHHCK_{Zi,Dx} + FFHHAC_{Zi,Dx} + FFHHLT_{Zi,Dx} \qquad \textit{Equation 23}$$

3.3. Household Energy Demand for Different End-use Categories

3.3.1 Space Heating (SH)

The useful household energy demand in space heating ($HHSH_{(UE)Zi,Dx}$) includes dwellings by type, fraction of dwellings in area where heating is required and specific heat loss rate by dwelling type as shown in $HHSH_{(UE)Zi,Dx} = NDW_{Zi,Dx} * (DWSH\_\_\_\_100_{Zi,Dx}) * \{(DWF100_{Zi,Dx}) * DWS_{Zi,Dx} * (FAREAH_{Zi,Dx})/100) * SHL_{Zi,Dx}\} * DD_{Zi,Dx} * 24$ Equation 24:

$$HHSH_{(UE)Zi,Dx} = NDW_{Zi,Dx} * \left(\frac{DWSH_{Z_i,D_x}}{100}\right) * \left\{\left(\frac{DWF_{Z_i,D_x}}{100}\right) * DWS_{Zi,Dx} * (FAREAH_{Zi,Dx})/100) * SHL_{Zi,Dx}\right\} * DD_{Zi,Dx} * 24 \qquad \textit{Equation 24}$$

where $DWSH_{Zi,Dx}$ is the fraction of the dwellings in areas where space heating is required, $DWF_{Zi,Dx}$ is the fraction of dwellings per type of zone or district, $DWS_{Zi,Dx}$ is the average size of the dwellings by type of zone or district (sqm/dw (floor area)), $FAREAH_{Zi,Dx}$ is the fraction of floor area that is actually heated in households by dwelling type; $SHL_{Zi,Dx}$ is the specific heat loss rate by dwelling type (Wh/sqm/degree Celsius/hour), $DD_{Zi,Dx}$ is the degree days for type of dwellings.

3.3.2 Hot Water (HW)

Useful household energy demand for water heating ($HHHW_{(UE)Zi,Dx}$) includes the number of dwellings for hot water, household size and specific energy consumption for water heating which is shown in $HHHW_{(UE)Zi,Dx} = NDWHW_{Zi,Dx} * CAP_{Zi,Dx} * (\frac{DWHW_{Zi,Dx}}{100}) * SECDHW_{Zi,Dx}$

Equation 25 as:

$$HHHW_{(UE)Zi,Dx} = NDWHW_{Zi,Dx} * CAP_{Zi,Dx} * \left(\frac{DWHW_{Z_i,D_x}}{100}\right) * SECDHW_{Zi,Dx} \qquad \textit{Equation 25}$$

where $HHHW_{(UE)Zi,Dx}$ is the useful energy demand for water heating by district or zone (Gwa); $NDWHW_{Zi,Dx}$ is the number of dwellings for hot water heating in zone or district, $CAP_{Zi,Dx}$ is average household size in district or zone, $DWHW_{Zi,Dx}$ is the share of zone or district dwellings with hot water facilities (%) and $SECDHW_{Zi,Dx}$ is the specific energy consumption for water heating per person in zone or district dwellings (useful energy) (kWh/pers/yr.), which is relative to the total number of dwellings in zone or district.

3.3.3 Cooking (CK)

Useful household energy demand for cooking in the household sector ($HHCK_{(UE)Z_i,D_x}$) includes the number of dwellings for cooking and specific energy consumption for cooking which is shown in $HHCK_{(UE)Z_i,D_x} = NDWCK_{Z_i,D_x} * SECCK_{Z_i,D_x}$ Equation 26 as:

$$HHCK_{(UE)Z_i,D_x} = NDWCK_{Z_i,D_x} * SECCK_{Z_i,D_x} \qquad \textit{Equation 26}$$

where $HHCK_{Z_i,D_x}$ is useful energy demand for cooking, $NDWCK_{Z_i,D_x}$is the number of dwellings for cooking $SECCK_{Z_i,D_x}$ is the specific energy consumption for cooking in zone or district dwellings (in useful energy terms) (kWh/dw/yr).

3.3.4 Air Conditioning (AC)

Useful household energy demand for air conditioning in the household sector ($HHAC_{(UE)Z_i,D_x}$)includes the fraction of dwellings per type, share of zone or district in air conditioning by dwelling type and fraction of floor area to be air conditioned which is shown in $HHAC_{(UE)Z_i,D_x} = NDW_{Z_i,D_x} * \left(\frac{DWF_{Z_i,D_x}}{100}\right) * \{\left(\frac{DWAC_{Z_i,D_x}}{100}\right) * DWAC_{Z_i,D_x} * (FAFEAC_{Z_i,D_x})/100\}$

Equation 27 as:

$$HHAC_{(UE)Z_i,D_x} = NDW_{Z_i,D_x} \left(\frac{DWF_{Z_i,D_x}}{100}\right) * \{\left(\frac{DWAC_{Z_i,D_x}}{100}\right) ** DWAC_{Z_i,D_x} * (FAFEAC_{Z_i,D_x})/100\} \qquad \textit{Equation 27}$$

where $HHAC_{(UE)Z_i,D_x}$is useful energy demand for air conditioning in zone or district dwellings of type, $DWF_{Z_i,D_x}$is the fraction of zone or district dwellings per type (%). Relative to the total number of zone or district dwellings situated in the areas where space heating is required, $DWAC_{Z_i,D_x}$is share of zone or district dwellings with air conditioning, by dwelling type and $FAFEAC_{Z_i,D_x}$is the fraction of floor area that is actually air conditioned in zone or district, by dwelling type relative to the average dwelling size.

3.3.5 Specific Electricity Uses (Appliances) (AP)

Electricity consumption for specific uses in electrified zones or districts ($ELPAP_{Z_i,D_x}$) includes the fraction of dwellings, electricity penetration for appliances in zone and districts and specific electricity consumption (final energy) per zone or district dwellings for electric appliances as shown in $ELPAP_{Z_i,D_x} = NDW_{Z_i,D_x} \left(\frac{ELP_{Z_i,D_x}}{100}\right) ** ELAPDW_{Z_i,D_x}$

Equation 28:

$$ELPAP_{Z_i,D_x} = NDW_{Z_i,D_x} \left(\frac{ELP_{Z_i,D_x}}{100}\right) ** ELAPDW_{Z_i,D_x} \qquad \textit{Equation 28}$$

where ELPAP$_{Z_i,D_x}$ is electricity penetration (%) for appliances in zones or districts and can be defined as fraction of total zone or district dwellings that are electrified, $ELAPDW_{Zi,Dx}$ is specific electricity consumption (final energy) per zone or district dwelling for electric appliances (other end-uses than space and water heating, cooking and air conditioning), and $ELP_{Zi,Dx}$ is the electricity penetration per zone or district.

3.3.6 Fossil Fuels for Lighting in Non-electrified Dwellings (LT)

Fossil fuel consumption for lighting and non-electric appliances in non-electrified zones or districts is defined by fraction of total zone or district that uses fossil fuels, traction of electricity penetration and specific fossil fuel consumption per zone or district dwelling for lighting and non-electric appliances as given in $FFLTZ_i, D_x = NDW_{Zi,Dx} * \left(\frac{Z_i,D_x}{100}\right)^{1-ELP} * FFLTDW_{Zi,Dx}$

Equation 29:

$$FFLT_{Zi,Dx} = NDW_{Zi,Dx} \left(\frac{Z_i,D_x}{100}\right)^{1-ELP} ** FFLTDW_{Zi,Dx} \qquad \textit{Equation 29}$$

where FFLT$_{Zi,Dx}$ is fossil fuel consumption for lighting and non-electric appliances (for example, refrigerators using natural gas) in non-electrified zone or district dwellings (Gwa); $FFLTDW_{Zi,Dx}$ is the specific fossil fuel consumption (final energy) per zone or district dwelling for lighting and non-electric appliances (other end-uses than space and water heating, cooking and air conditioning).

The sum or sub-total of useful energy demand for space heating, hot water heating, cooking, air conditioning, electricity penetrations and fossil fuels consumption for a given zone or district is given by $USZ_i, D_x = HHSH_{(UE)Zi,Dx} + HHHW_{(UE)Zi,Dx} + HHCK_{(UE)Zi,Dx} + HHAC_{(UE)Zi,Dx} + ELPAP_{Zi,Dx} + FFLT_{Zi,Dx}$ Equation 30:

$$US_{Zi,Dx} = HHSH_{(UE)Zi,Dx} + HHHW_{(UE)Zi,Dx} + HHCK_{(UE)Zi,Dx} + HHAC_{(UE)Zi,Dx} + ELPAP_{Zi,Dx} + FFLT_{Zi,Dx} \qquad \textit{Equation 30}$$

The energy consumed per household and per capita associated with each energy form or enduse function, is determined by making use of Equation 3 for each energy form or end-use function based on the demography of each zone or each district from the HECS 2017 data.

3.4. HECS 2017 Data

The household energy consumption survey (HECS) data of 2017 presents a valuable rare resource in Lesotho, providing dataset that can be analysed to give useful information to be used for future household energy consumption forecasting. For data collection, the draft pilot questionnaire was developed and piloted in rural and urban setting with a small number of households. The methodology that was employed in this survey included stratification and multi-stage sampling procedure, where the stratification variables used in the sample were districts, settlements and agro-ecological zones. The sampling was done in summer months (September to November) and winter months (April to July), where a total of 2877 households were sampled in winter, and 2684 households were sampled in summer months for the survey.

Several factors that affected HECS data quality are sampling biases as urban areas have better access to electricity, while rural areas rely more on biomass which leads to biases in national energy use. Response biases mainly when discussing the traditional energy sources and accurately recall their energy quantity consumption or frequent use. When using multiple energy sources, households may find it challenging to provide precise information on relative use of each.

4. Results and Discussions

4.1. Overview

This chapter presents the main results of Lesotho's baseline household energy demand critical factors (population, number of households, dwellings sizes, income levels and electrification rate), typical household end-use functions (cooking, lights, etc), penetration of energy forms (electricity, traditional fuels, fossil fuels, paraffin etc), and energy intensities per household and per capita established from the HECS 2017 data, using the EDA approach. The data is disaggregated by Lesotho's unique agro-ecological zones and administrative districts for both summer and winter seasons.

4.2. Critical Factors for Household Energy Demand

4.2.1 Population / Demography

The first critical factor for household energy demand is the population distribution shares in both zones and districts from the 2,684 and 2,887 households surveyed in summer and winter, respectively. The household population distribution percentage shares for the summer and winter surveys are respectively depicted in the 3D bar charts in Figure 11 and Figure 12. In zones, the Lowlands had the highest demographic share (62.4% in summer and 67.2% in winter) of people surveyed while the Foothills had the lowest share (at 7.1% in summer and 7.2% in winter surveys). In the districts, the population shares surveyed in summer months is high in Maseru, Leribe and Berea at 25.6%, 18.4% and 12.4% respectively, and lowest in Qacha's Nek at 3.7%, while in winter is the highest in Maseru, Leribe and Berea by 28.2%, 15.6% and 13.3% respectively, and lowest in Qacha's Nek by 3.1%. According to [39], households move from poor areas of their countries to more developed cities increasing the internal migration due to several factors like job opportunities and infrastructure in developing countries, which is proven in both zones and districts where most population is in Lowlands and Maseru, Leribe and Berea.

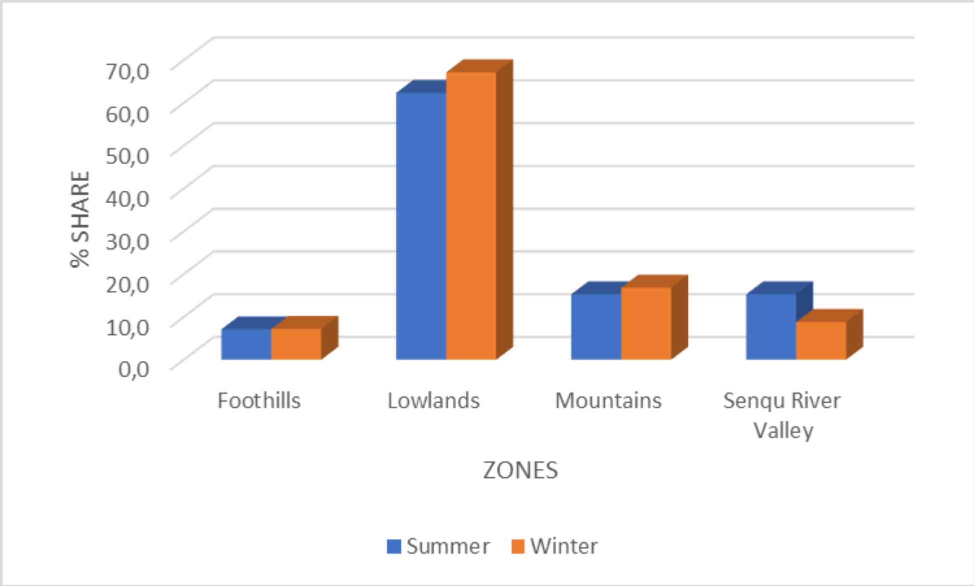


Figure 11: Household population distribution in zones

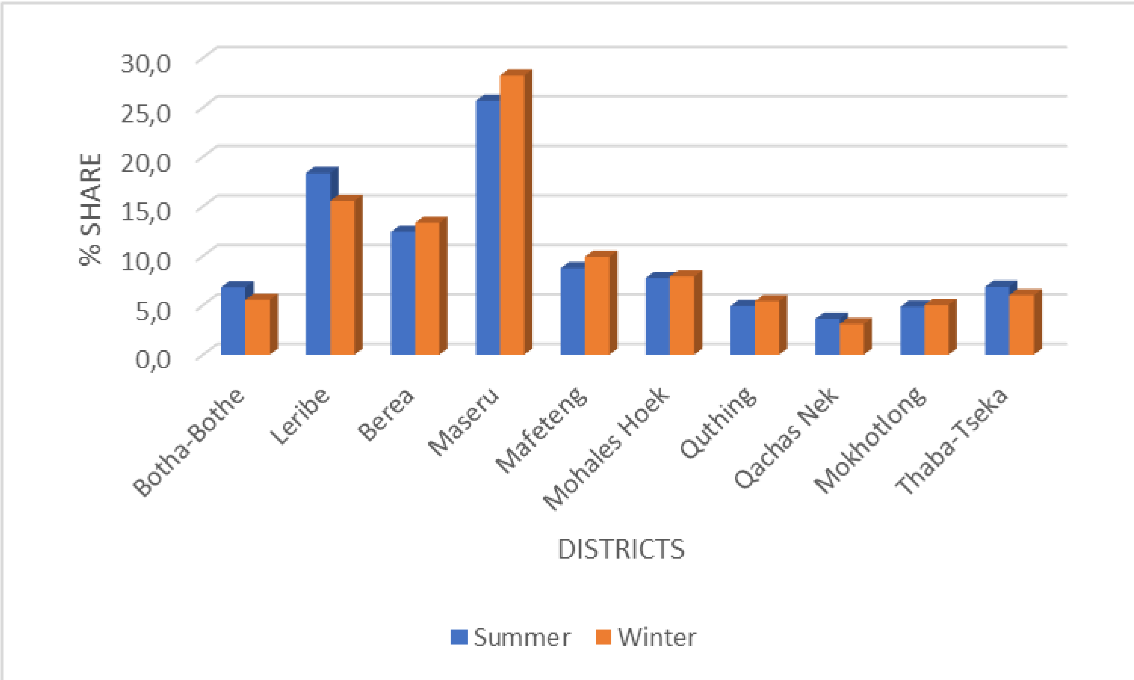


Figure 12: Household population distributed in districts

Variation in zones and districts populations is affected by employment opportunities which indicate that metropolitan areas (such as Maseru, Leribe and Berea, which are also located in the Lowlands zone) have more job opportunities and attract more people. Outside the Lowlands, infrastructure development is relatively less. This causes challenges in attracting the same level of population density and economic growth in other zones or districts. Urbanization and transportation are also other factors, whereby people are looking for better transportation networks, better housing, utilities and services, and thus migrate from the Foothills and the Senqu River Valley to the Lowlands. These demographic distributions give a generalized glimpse of how the disaggregated household energy consumption is expected to unfold for

Lesotho's four ecological zones and ten administrative districts, as more population usually translates to more energy consumption.

4.2.2 Household Sizes (People per Household)

The second critical factor for household energy consumption is illustrated in this subsection. The 3D bar chart illustration of household sizes in Figure 13 shows the data for ecological zones presented as a number of members in the household from 1 member up to 6 and more members as well as the percentage share of each ecological zone. The Lowlands have the highest percentage shares for 1 member and 2 members household sizes and will likely lead to the highest energy demand compared to other zones. The category of 6 or members appears to be the highest in all zones, especially the Foothills, Mountains and Senqu River Valley. The factors contributing to more members in one household are social and cultural, as households rely on traditional family structures such as the extended family that include multiple generations living together. The birth rate in areas outside the Lowlands is often high due to limited access to health care services and lack of female education and family planning.

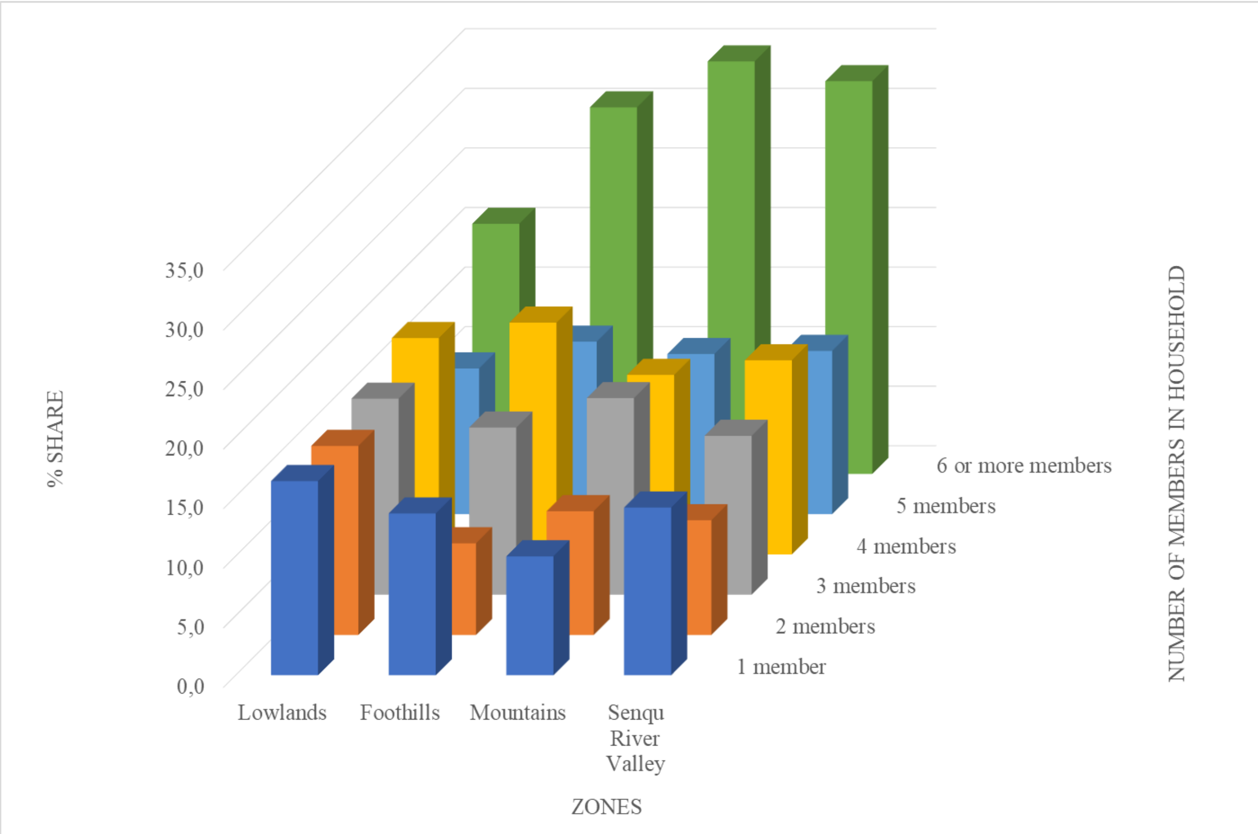


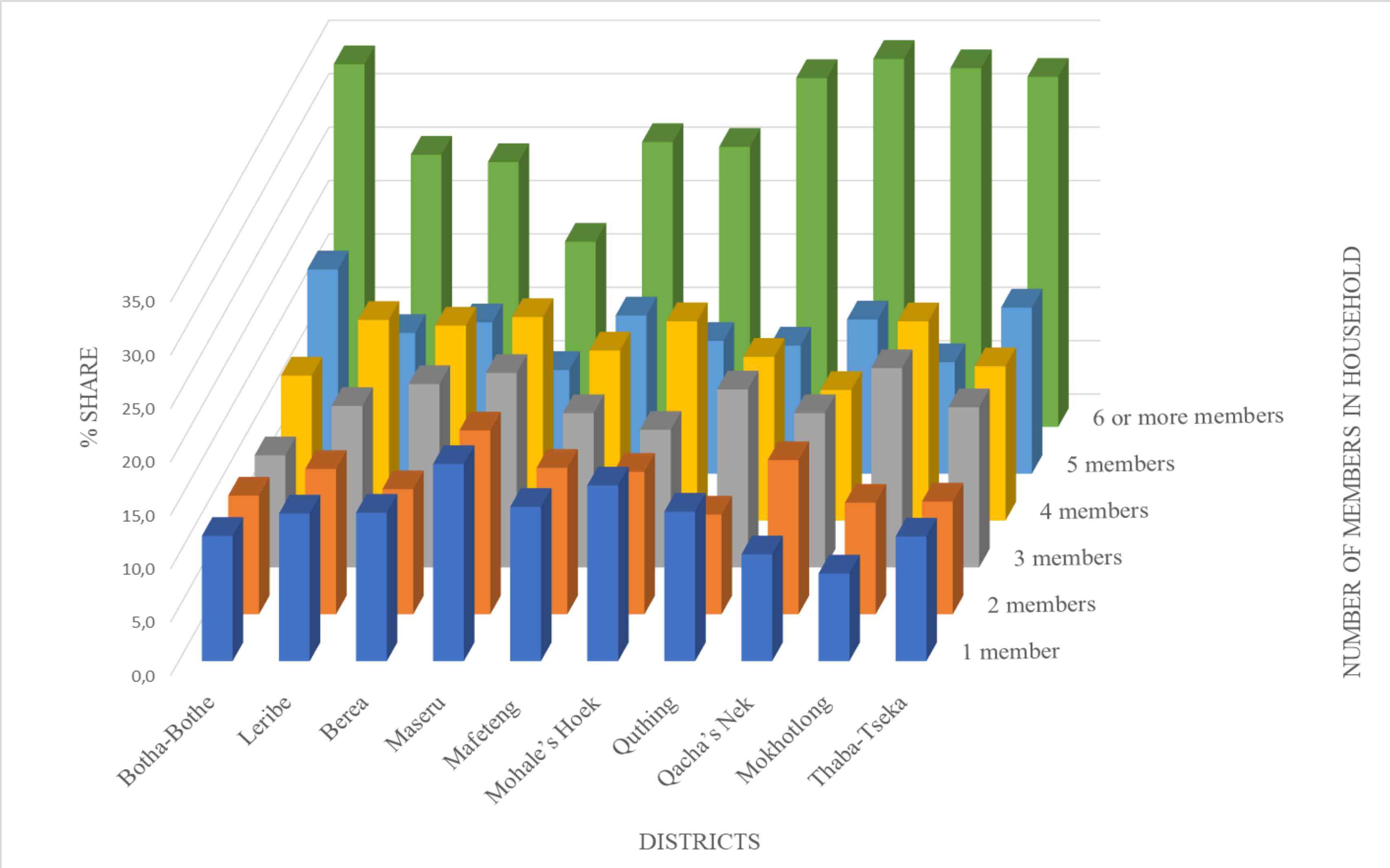
Figure 13: Household sizes in zones

Figure 14 illustrates the percentage shares of household sizes in administrative districts using 3D bar charts. Maseru district is more dominating from one member per household to four members per household, hence its household energy demand will be expected to be higher than in other districts. This can be due to the fact that people migrate to cities to improve their livelihoods by seeking jobs, better education and healthcare. For the districts mostly in the

Mountains (Botha-Bothe, Quthing, Qacha's Nek, Mokhotlong and Thaba Tseka), 6 or more members households are prevalent. The difference in number of household members in households per district can be due to the fact that most people living in metropolitan areas (such as Maseru, Leribe, Berea, Mafeteng, and Mohale's Hoek) live modern lifestyles that favour smaller household sizes which are influenced by urban living trends. Most young adults live in smaller households that accommodate one or two members.

The household sizes spread analysis for zones is illustrated in Figure 15. It shows that the Foothills, Mountains and Senqu River Valley have wide data spread, while the Lowlands have a narrow IQR with closer whiskers. This means that the share of members per household in the Lowlands does not vary greatly between the categories, while it is spread is a bit wider for Foothills, Mountains and Senqu River Valley.

Figure 16 illustrates the spread analysis of household sizes in the districts. Maseru district is portraying a distinct pattern with the narrowest IQR and very short upper whisker and no lower whisker. This demonstrates a relatively low spread or variation of household sizes' shares in the district. However, Quthing, Botha-Buthe and Mokhotlong districts have relatively larger IQRs, with shorter lower whiskers but longer upper whiskers. There are outliers detected in Maseru, Mafeteng, Qacha's Nek and Thaba-Tseka.



% SHARE
35,0
30,0
25,0
20,0
15,0
10,0
5,0
0,0
6 or more members
5 members
4 members
3 members
2 members
1 member
NUMBER OF MEMBERS IN HOUSEHOLD
Botha-Bothe
Leribe
Berea
Maseru
Mafeteng
Mohale's Hoek
Quthing
Qacha's Nek
Mokhotlong
Thaba-Tseka
DISTRICTS

Figure 14: Household sizes in districts

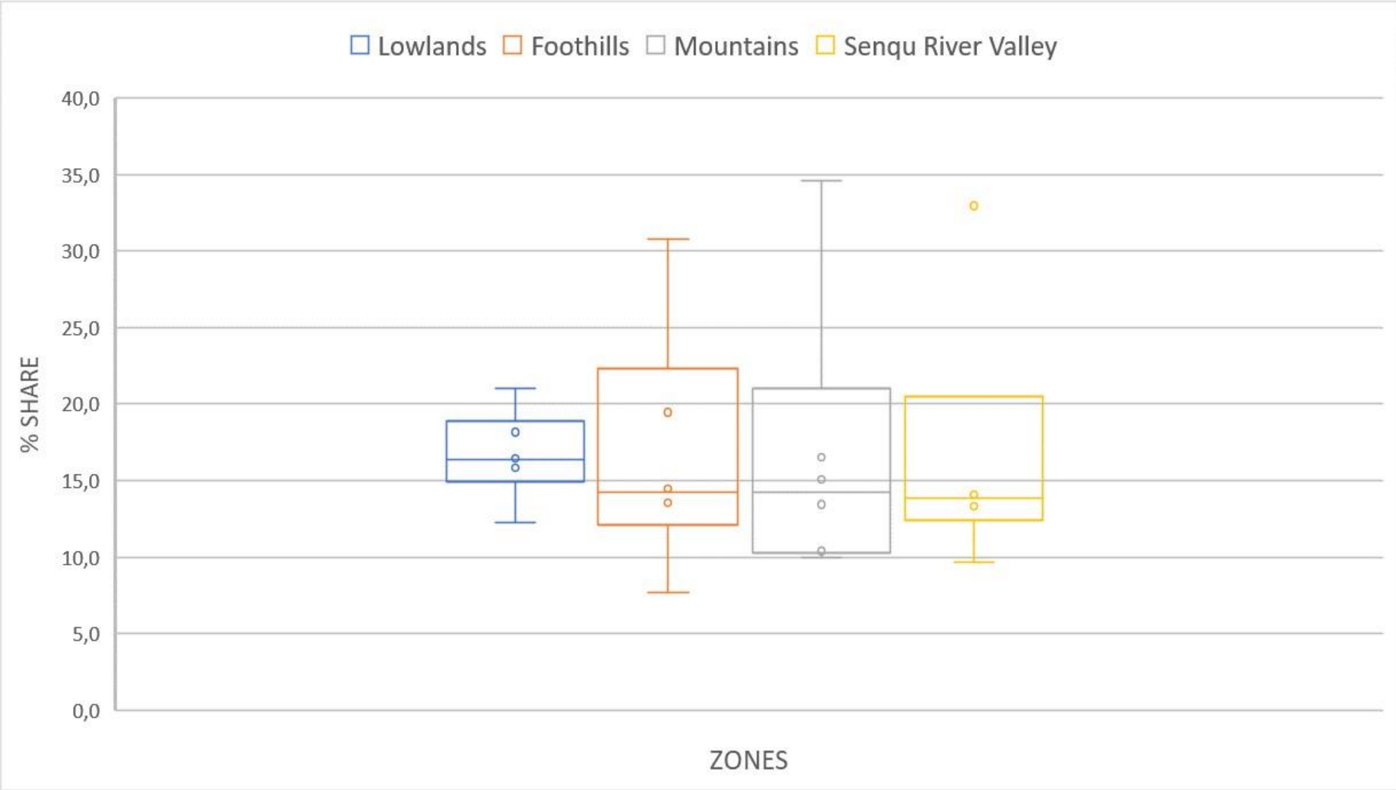


Figure 15: Spread analysis of household sizes in zones

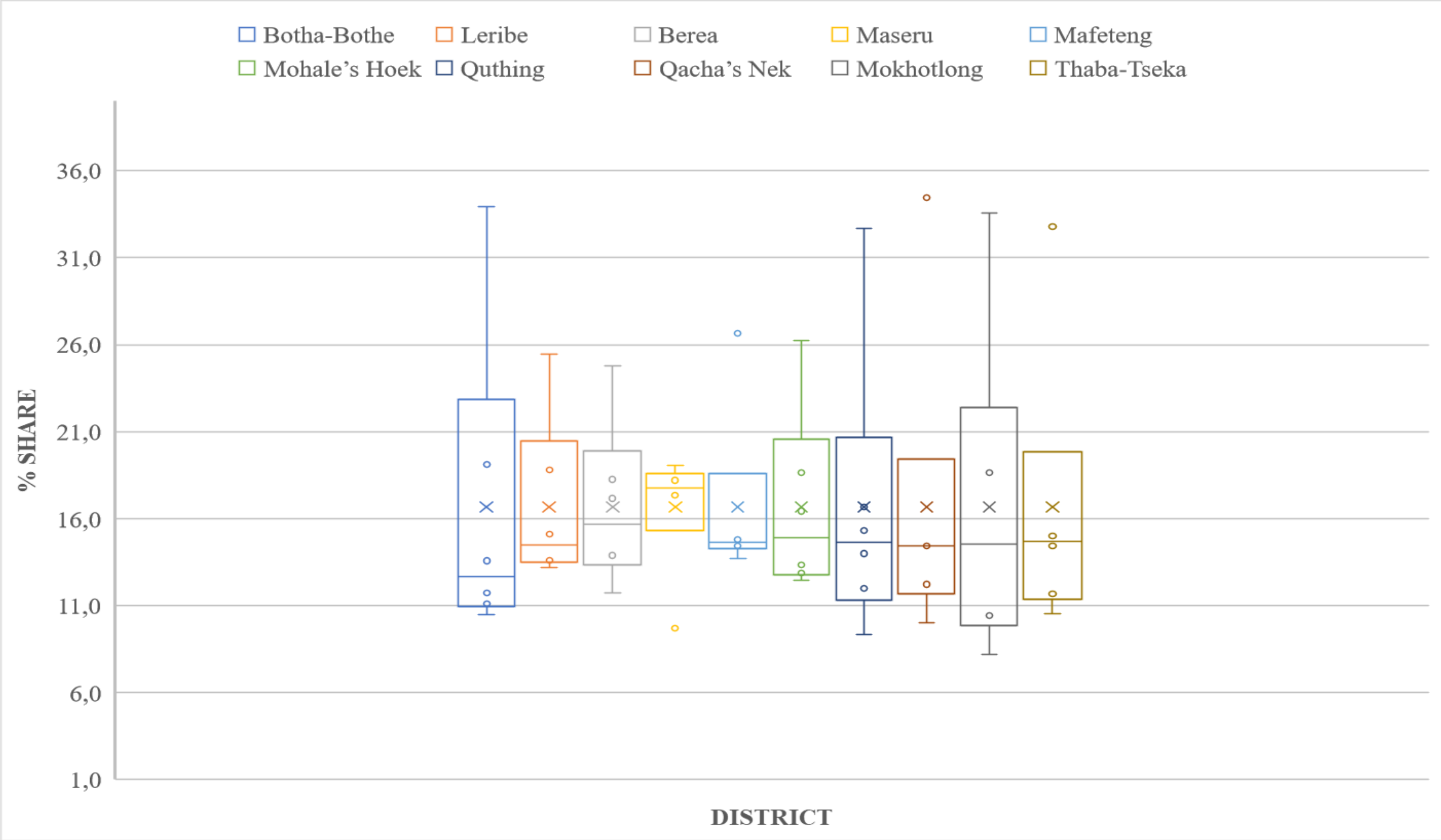


Figure 16: Spread analysis of household size in districts

4.2.3 Household Area (Dwelling Size)

This subsection considers the next critical factor for household energy demand in the form of household area or dwelling size in square meters (sqm). It is mostly dependent on the dwelling type. This can be influenced by rapid development of cities or towns and most households in these places earn more income, as it is illustrated in the next subsection. Figure 17 illustrates the household areas in zones. The household area ranges from 0-10 sqm to 150+ sqm, demonstrating a relatively uniform pattern among all the zones with fewer households in the smallest category, followed by a steep jump to the next category of 10 – 20 sqm and a generally monotonic decrease in shares from there onwards. Figure 18 illustrates that there is a relatively wider variation in household area for the administrative districts, though there is still a general pattern of fewer smaller houses, and higher concentration between 10 – 20 sqm and 40 – 50 sqm.

Figure 19 illustrates the spread analysis of household areas in zones. The data demonstrate relatively larger outliers with much longer upper whiskers in the Foothills and the Mountains, demonstrating slightly more data variability. Figure 20 depicts the spread analysis of household areas in administrative districts. Maseru district has the narrowest IQR and short whiskers and a number of outliers. There is more data variability in Qacha’s Nek district, with the wider IQR and a long upper whisker.

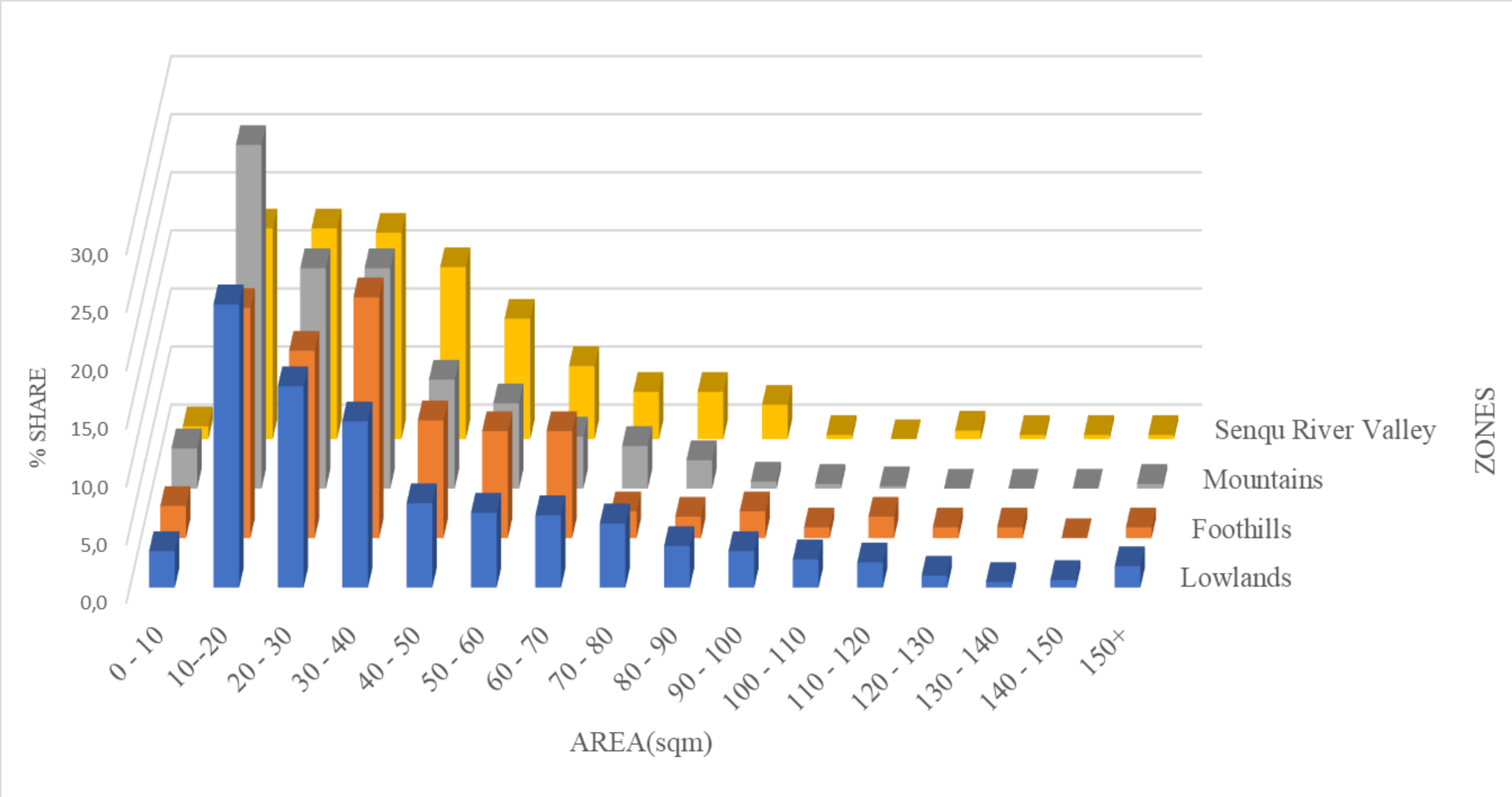

% SHARE
0,0
5,0
10,0
15,0
20,0
25,0
30,0
0 - 10
10--20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100
100 - 110
110 - 120
120 - 130
130 - 140
140 - 150
150+
AREA(sqm)
Senqu River Valley
Mountains
Foothills
Lowlands
ZONES

Figure 17: Household areas in zones

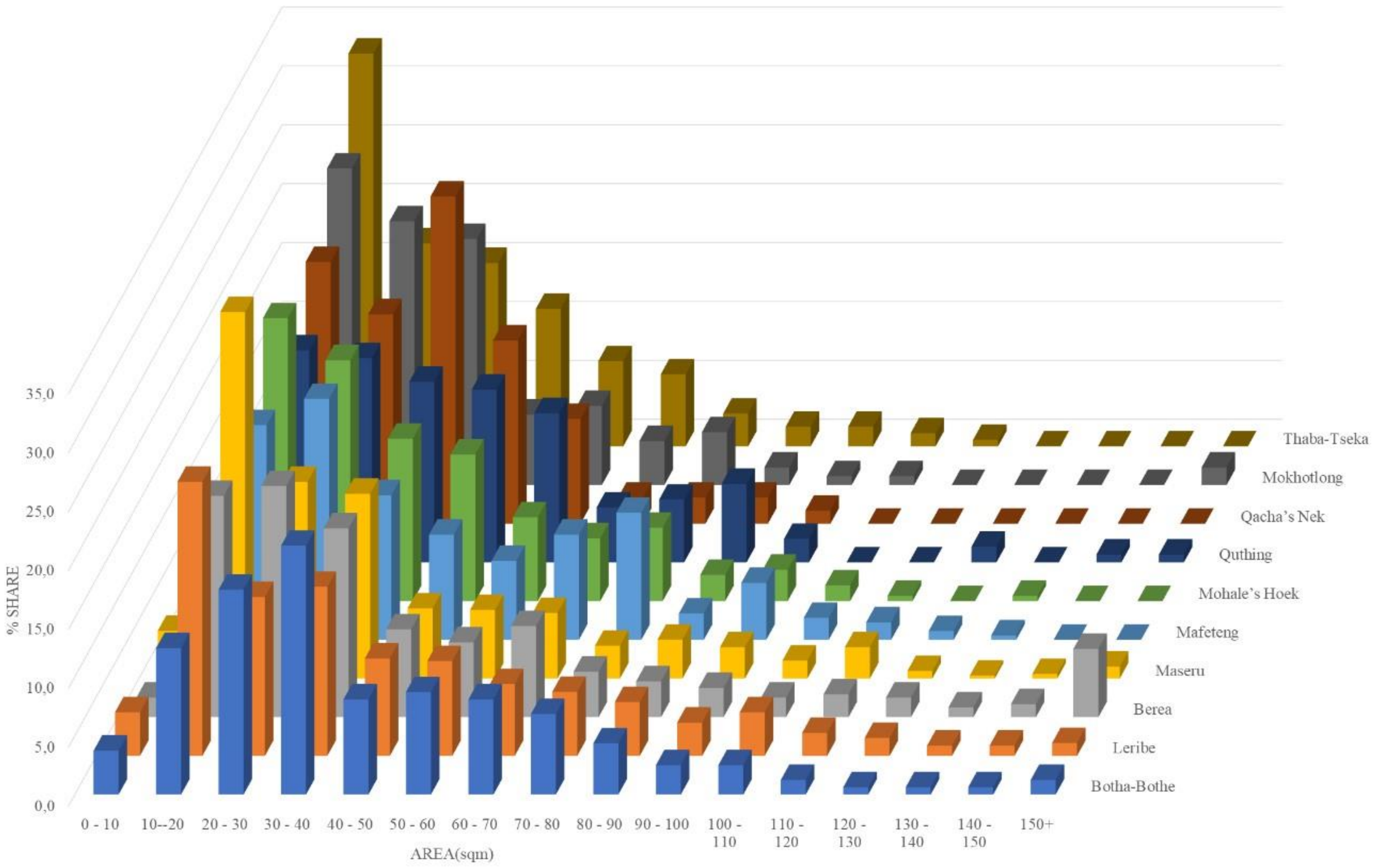


Figure 18: Household areas in districts

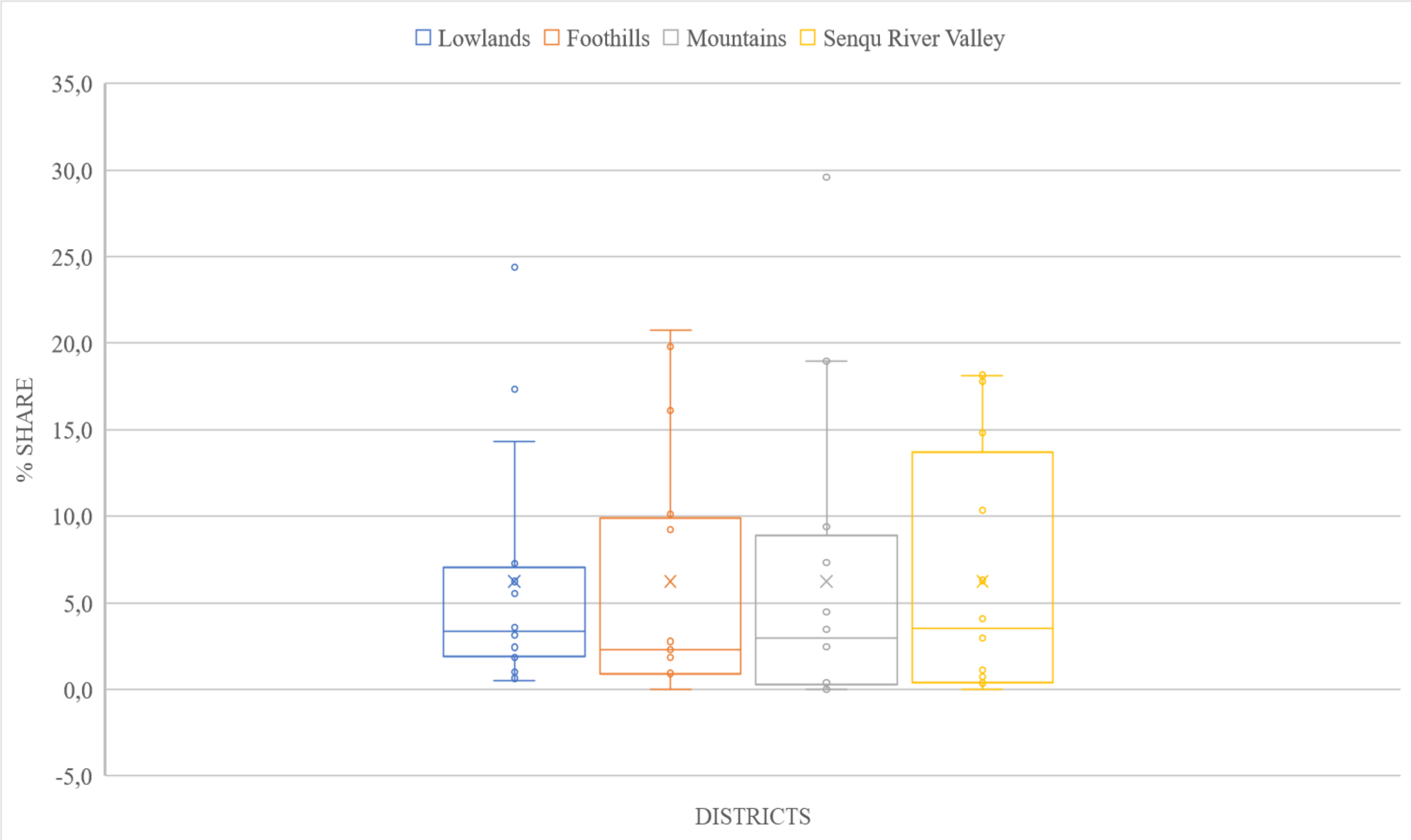


Figure 19: Spread analysis of household areas in zones

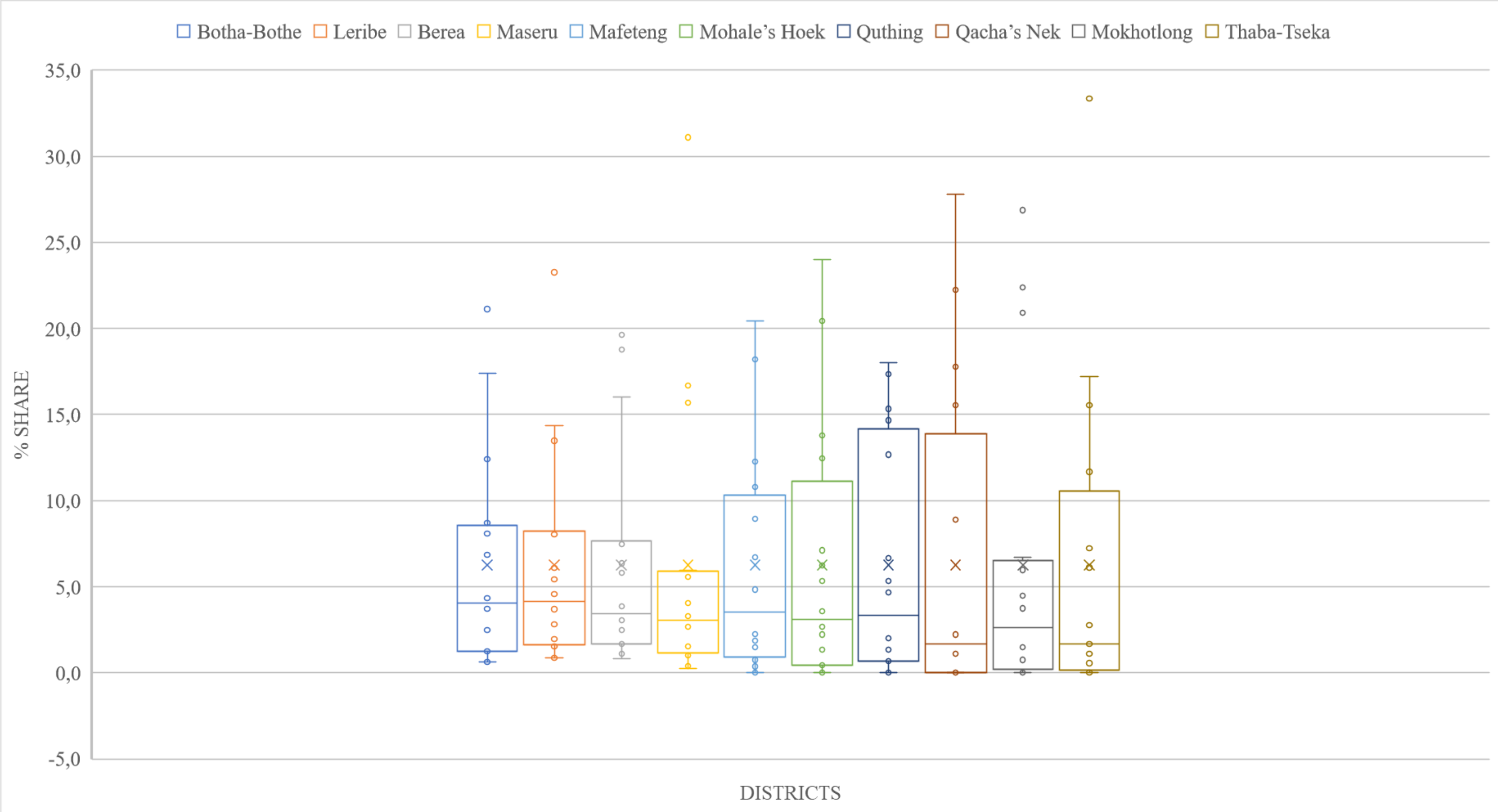


Figure 20: Spread analysis of household areas in districts

4.2.4 Income Levels

Another important factor for driving household energy demand is the income level distribution presented in this subsection. The household income levels are influenced by infrastructure and economic diversification. Zones and districts with different industries facilitate trade, easy mobilization of goods, and ease of technological access, leading to high income levels. For remote zones and districts, most households have low-income levels due to the low density of industries, limited market access and employment rates.

Figure 21 Illustrates the household income levels in Maloti in the zones. There is variation in household income levels across zones. The households in the Lowlands earn more money because of the diversified employment opportunities, infrastructure, and access to the utilities which enhances the business and household activities. The plot in Figure 22 Presents the spread analysis of household income in the zones. The Foothills have the highest median, while the Lowlands have the lowest mean percentage value, with the narrowest IQR, long upper and short lower whiskers. This shows that the household income variation in the Lowlands is of low spread compared to other zones. However, in the Mountains, there is a wide spread of household income level data, with both the longest upper and lower whiskers. Senqu River Valley has the highest IQR, with no lower whisker and short upper whisker.

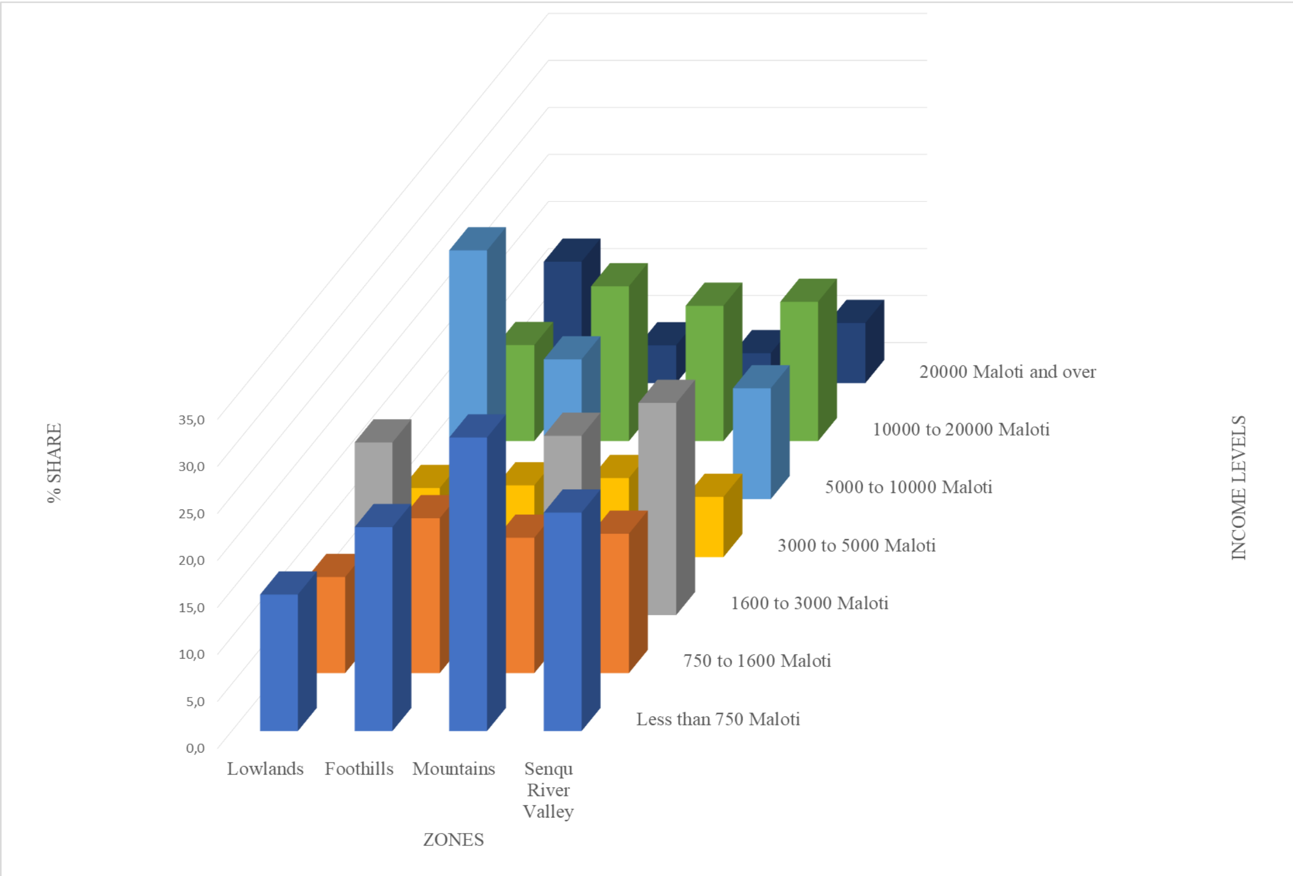


Figure 21: Household income levels in zones

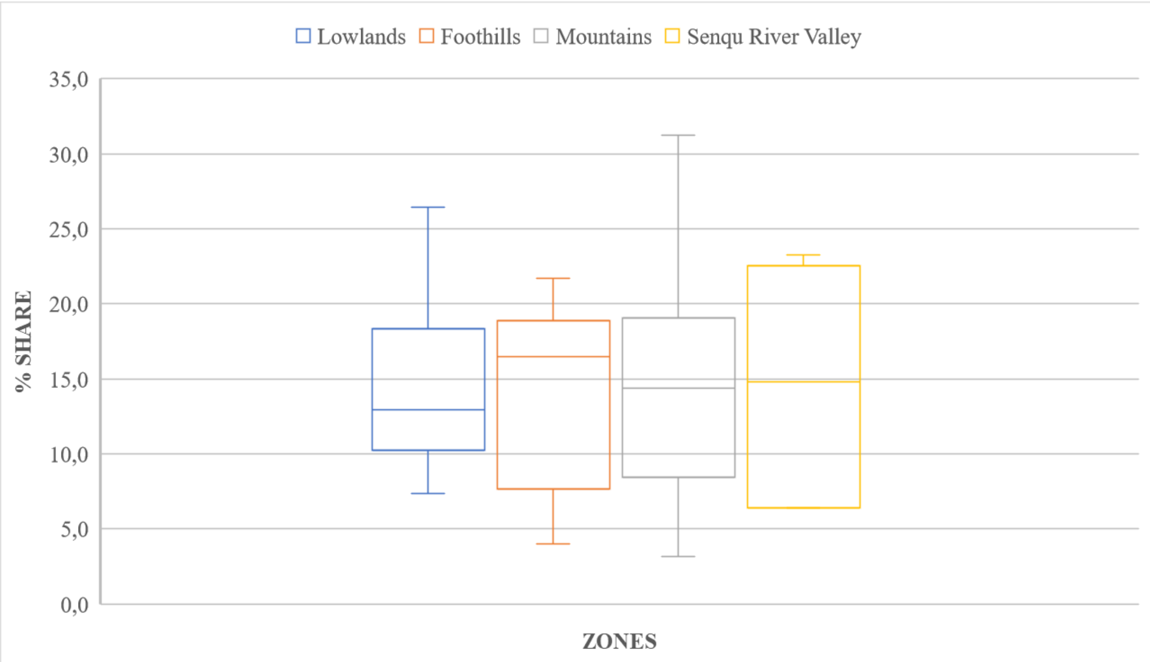


Figure 22: Spread analysis of household income levels in zones

Figure 23 Illustrates the household income levels in the districts. The districts with higher levels of urbanization such as Maseru, Leribe, and Berea have high levels of income due to better access to employment opportunities and services. In the districts such as Mokhotlong and Thaba-Tseka, there are middle to high income levels in households due to the fertile land for agriculture productivity, the mining sectors which increase the employment opportunities, and economic diversification which combines farming with trade and tourism services.

Figure 24 illustrates the spread analysis of the household income in the districts. Maseru district portrays a distinct pattern with the narrower IQR, no upper whisker and long lower whisker, and an outlier. This shows that Maseru demonstrates a low data spread of income levels. Mokhotlong has the widest data spread with both long lower and upper whiskers. Most districts have wider IQR illustrating big variability in terms of household income levels.

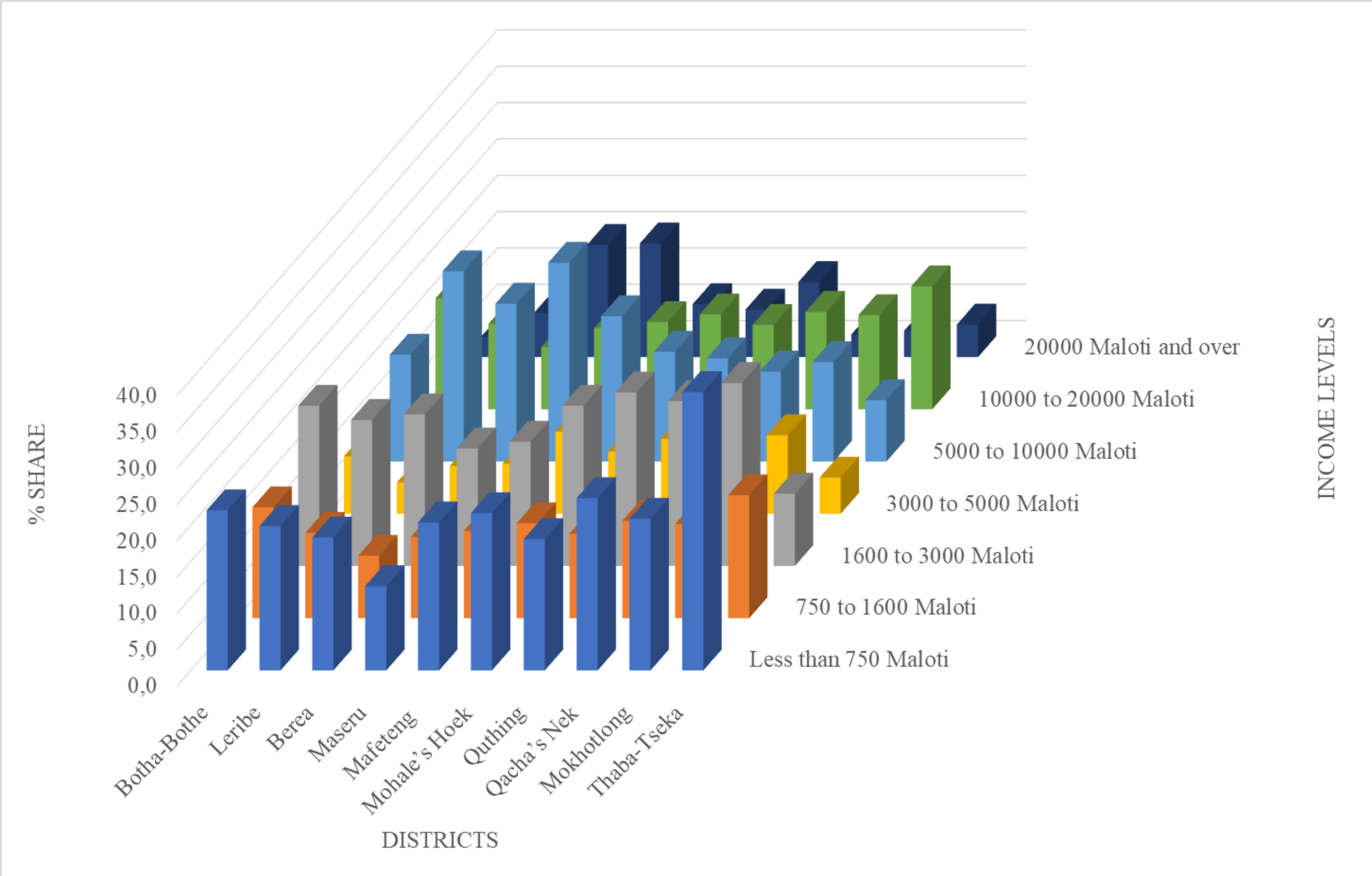
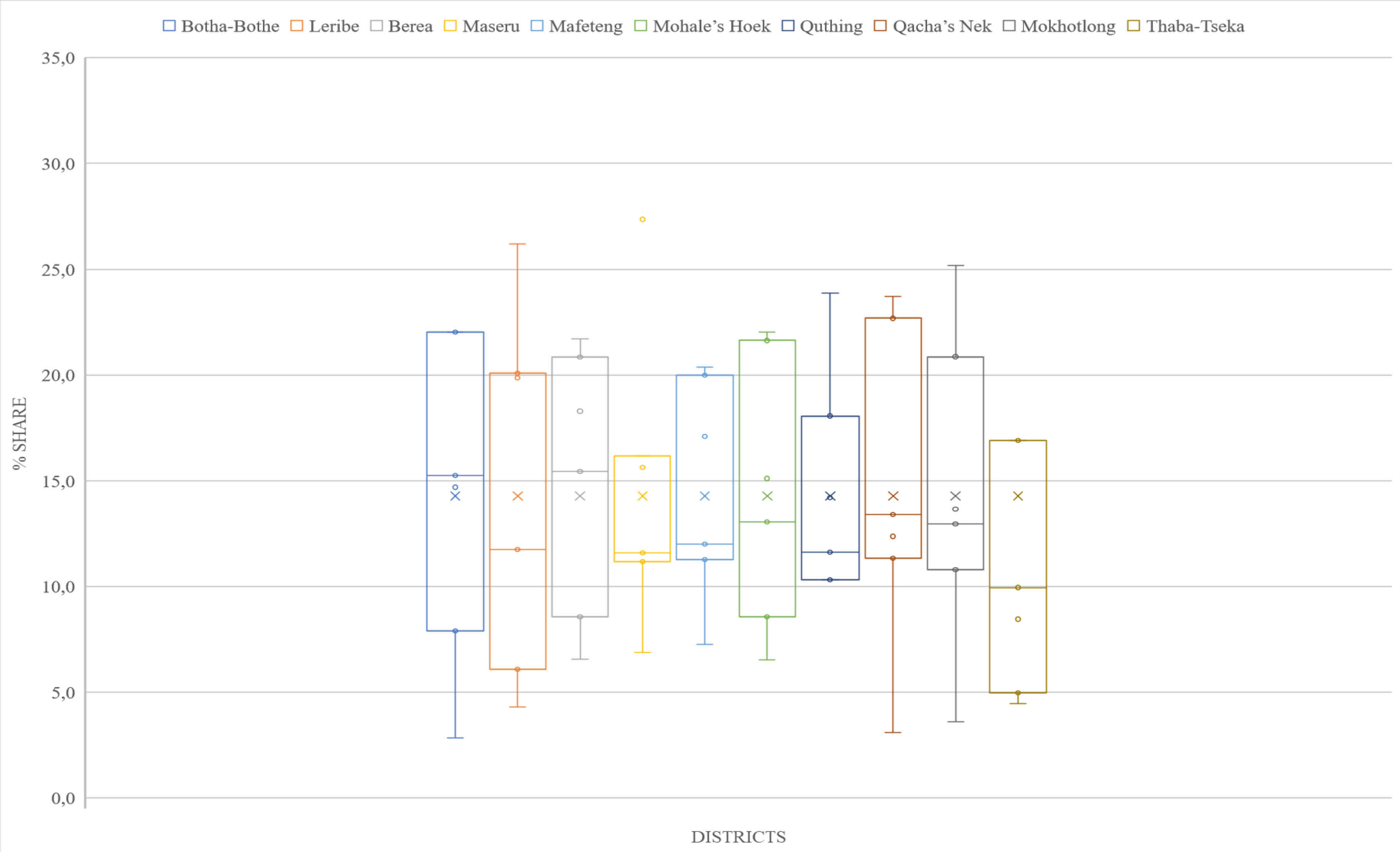


Figure 23: Household income levels in districts



Botha-Bothe
Leribe
Berea
Maseru
Mafeteng
Mohale's Hoek
Quthing
Qacha's Nek
Mokhotlong
Thaba-Tseka
35,0
30,0
25,0
20,0
15,0
10,0
5,0
0,0
% SHARE
DISTRICTS

Figure 24: Spread analysis of household income levels in districts

4.2.5 Electrification Rate

Access to electricity is another factor that drives household energy demand. Figure 25 illustrates the household electrification in the zones. The Lowlands has the most percentage share of electrification compared to other agro-ecological zones. Its electrification rate is higher due to access to the national grid, urbanization and population density while in the Foothills, the terrain is a challenge for grid extension. Other factors that affect the electrification rate may be the difficulty to access remote areas due to sparse population distribution. The low electrification rate in the Foothills and the Mountains is influenced by the mountainous terrain. The Senqu River Valley is also characterized by lower elevation with a diverse topography and riverine landscape which complicates the construction of electric infrastructure and maintenance.

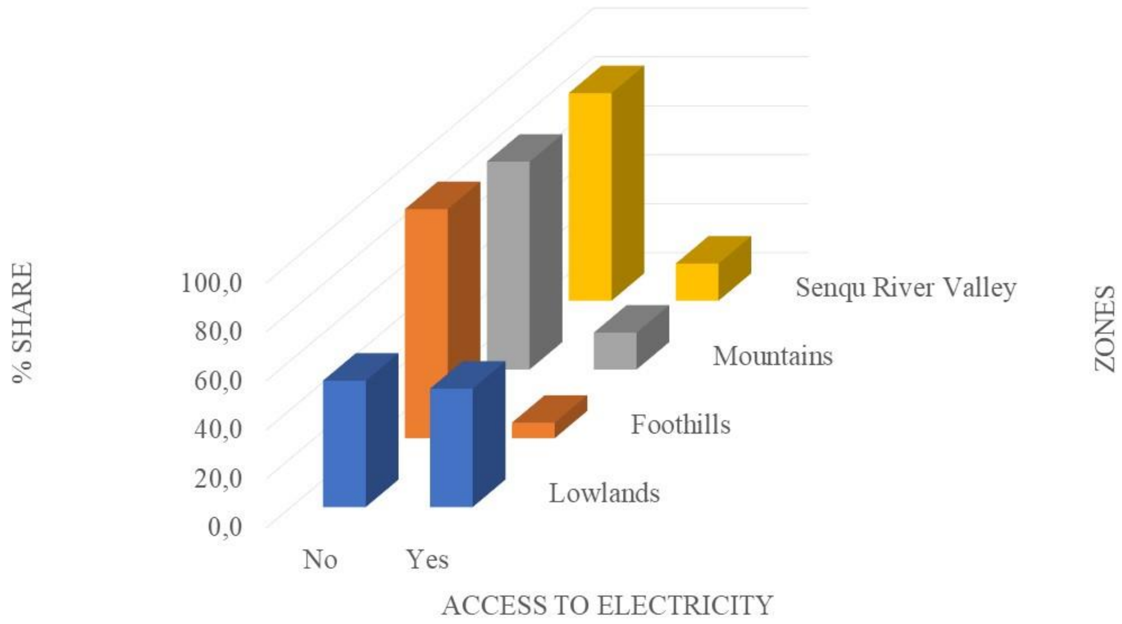


Figure 25: Household electrification rates in zones

Household electrification in the administrative districts is depicted in Figure 26. There is relatively high electrification rate in Berea, Leribe and Maseru because these districts are in the flatter lowlands and closer to the existing national grid infrastructure where grid extension costs are lower. These districts also have more households earning income and therefore, can afford the connection fees and monthly electricity bills. Less populated districts such as Quthing, Qacha's Nek, Mokhotlong and Botha-Bothe have the lowest electrification rates due to low population density which makes per capita cost high for grid expansion while they have high shares of people on low income.

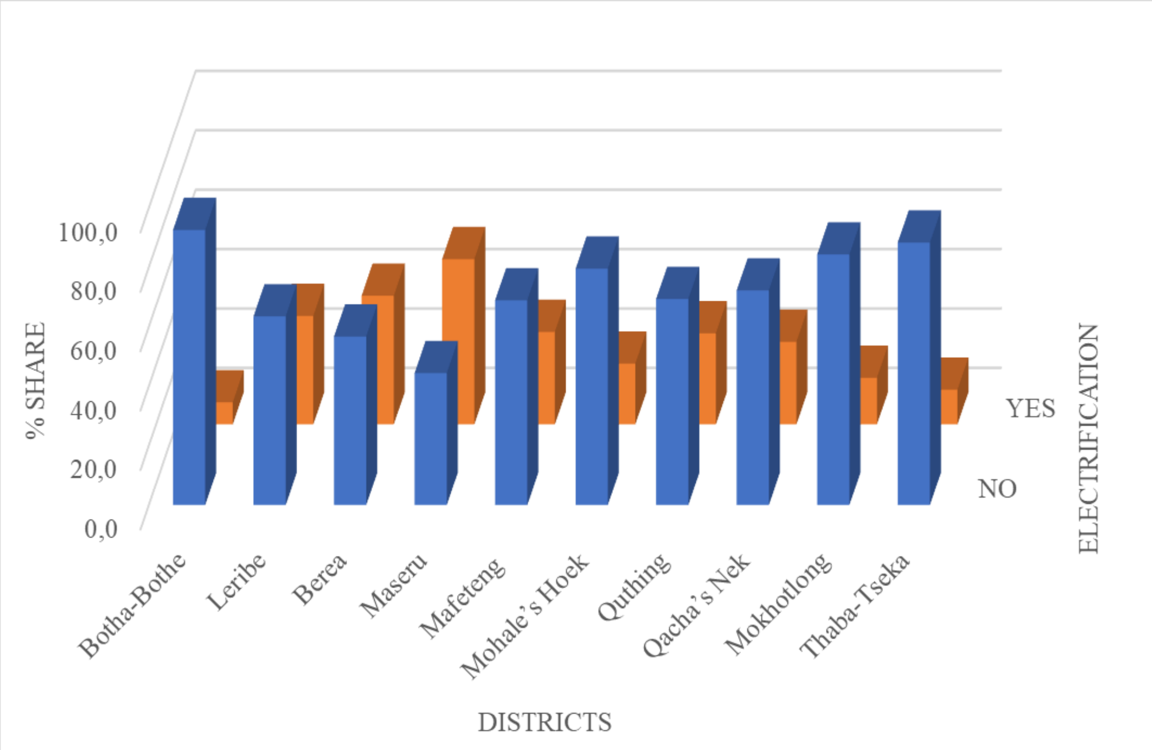


Figure 26: Household electrification rates in districts

4.3 Typical Household Energy End-Use Functions

The household energy end use functions compose of the functions in the household that use energy such as household hot water heating, cooking, lighting, space heating and cooling, refrigeration, air conditioning and miscellaneous.

4.3.1 Energy for Water Heating

Figure 27 and Figure 28 illustrates the percentage share of energy for water heating in households for both summer and winter months by zones. During summer months, Lowlands dominate in share of electricity (91.8%), LPG (84.0%), paraffin (78.5%) and crop waste (77.3%). Foothills consume the least electricity and LPG, with shares of 0.1% and 2.0% respectively, while wood takes a higher percentage share of 18.1%. The Mountains and the Senqu River Valley have a large share of straw/shrubs (60.0%) and other energy sources (27.3%) respectively. In winter months, the Lowlands dominate with a share of electricity (90.1%), LPG (84.7%), paraffin (81.4%), wood (54.6%) and crop waste (59.0%). The least electricity share is in the Foothills and the Senqu River Valley with respective penetrations of 0.2% and 4.4%. Lowlands has a higher share of 75.0% on other energy fuels, which could be fuels like coal, biogas etc. Access to electricity with a share of 48.4% in Lowlands gives households ability to consume more electricity, and more affordable as most of the households are employed, while in Foothills with a least access of 6.4% of electricity, uses more wood as an alternative fuel.

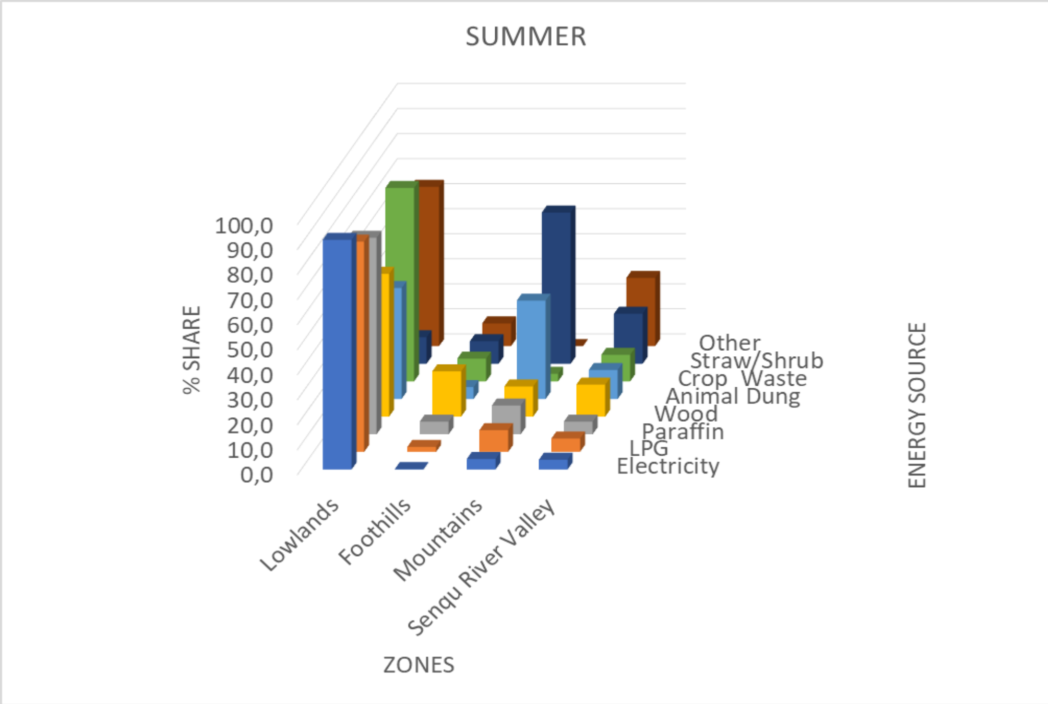


Figure 27: Energy consumption for water heating in zones for summer

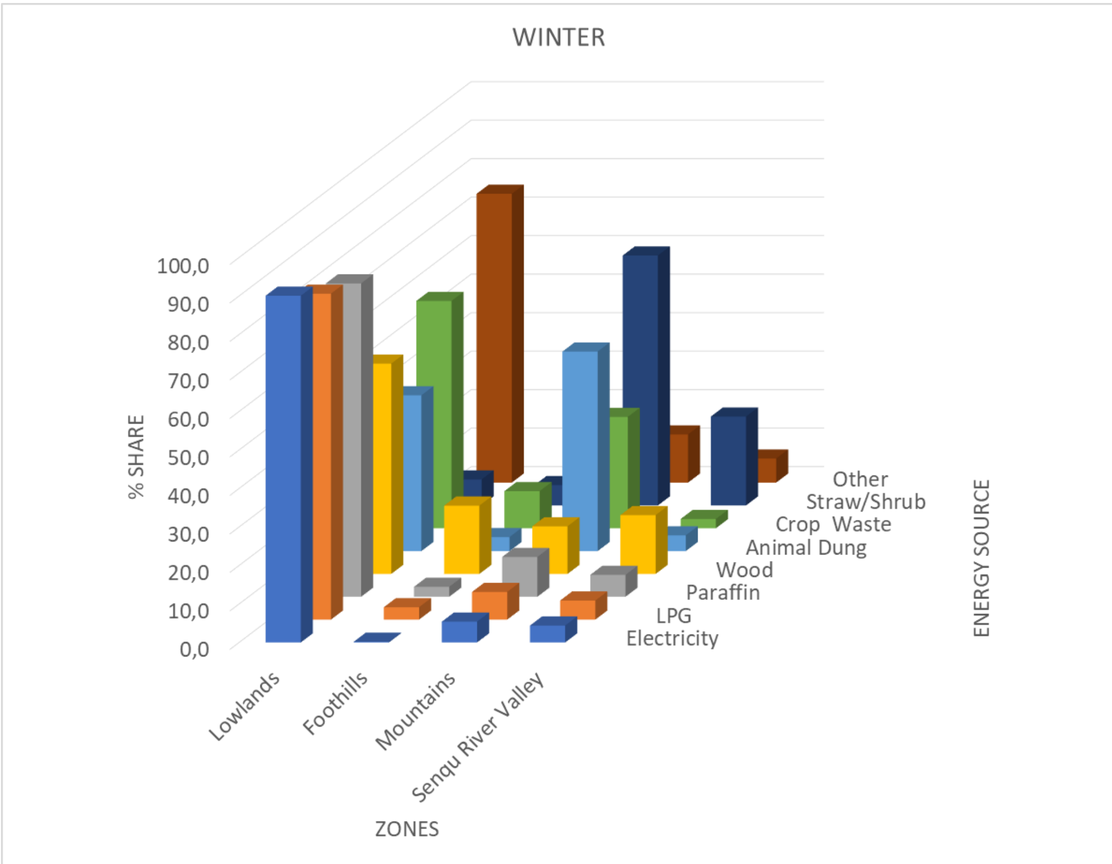


Figure 28: Energy consumption for water heating in zones for winter

Figure 29 and Figure 30 illustrates the energy share of water heating in districts for both summer and winter months. Electricity consumption is highest in Maseru, Berea and Leribe with a share of 46.5%, 17,8% and 14.4% respectively, and lowest in Botha-Bothe with a share of 0.8%.. Mafeteng has a share of 20.3% on animal dung, while Thaba-Tseka has a high share of 22.4% on straw/shrub consumption for water heating. Paraffin (33.3%), LPG (37.2%) and wood (20.0%) have a high share in Maseru. High reliance on different energy sources in districtcts like Maseru, Leribe and Berea, which are mostly in the Lowlands can be caused by factors such as household income, where there is more variation in income levels in households, thus leading to different energy sources.

In winter months, electricity share for water heating ranges from 2.9% in Qacha's Nek to 30.0% in Maseru. Botha-Bothe has the lowest usage of animal dung (2.7%) and Quthing has a low penetration of straw/shrubs (2.4%). Paraffin is mostly consumed in Maseru (32.8%), with Leribe and Berea taking shares of 11.1% and 11.4% respectively. LPG and wood have a lowest share of 4.0% and 2.8% in Qacha's Nek which can be affected by the least share of population (3.1%) that consumes energy for water heating.

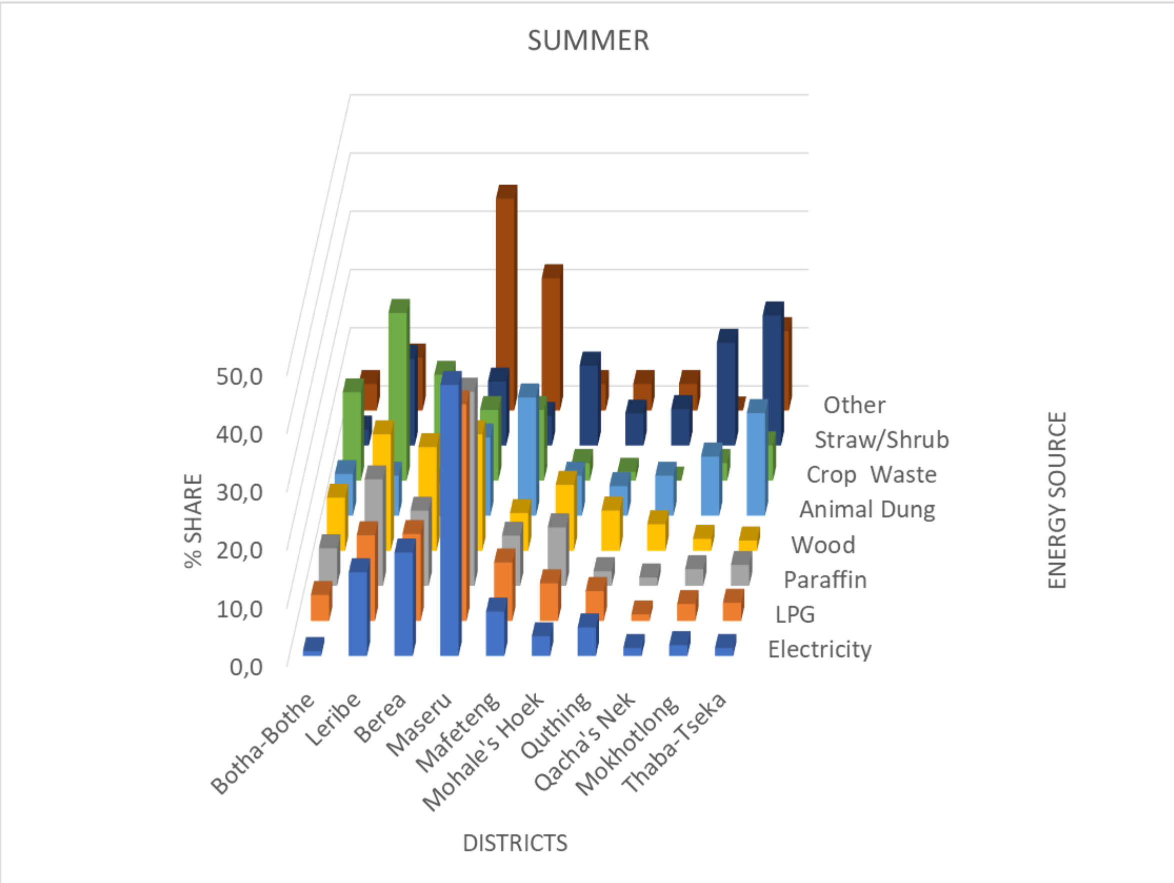


Figure 29: Energy consumption for water heating in districts for summer

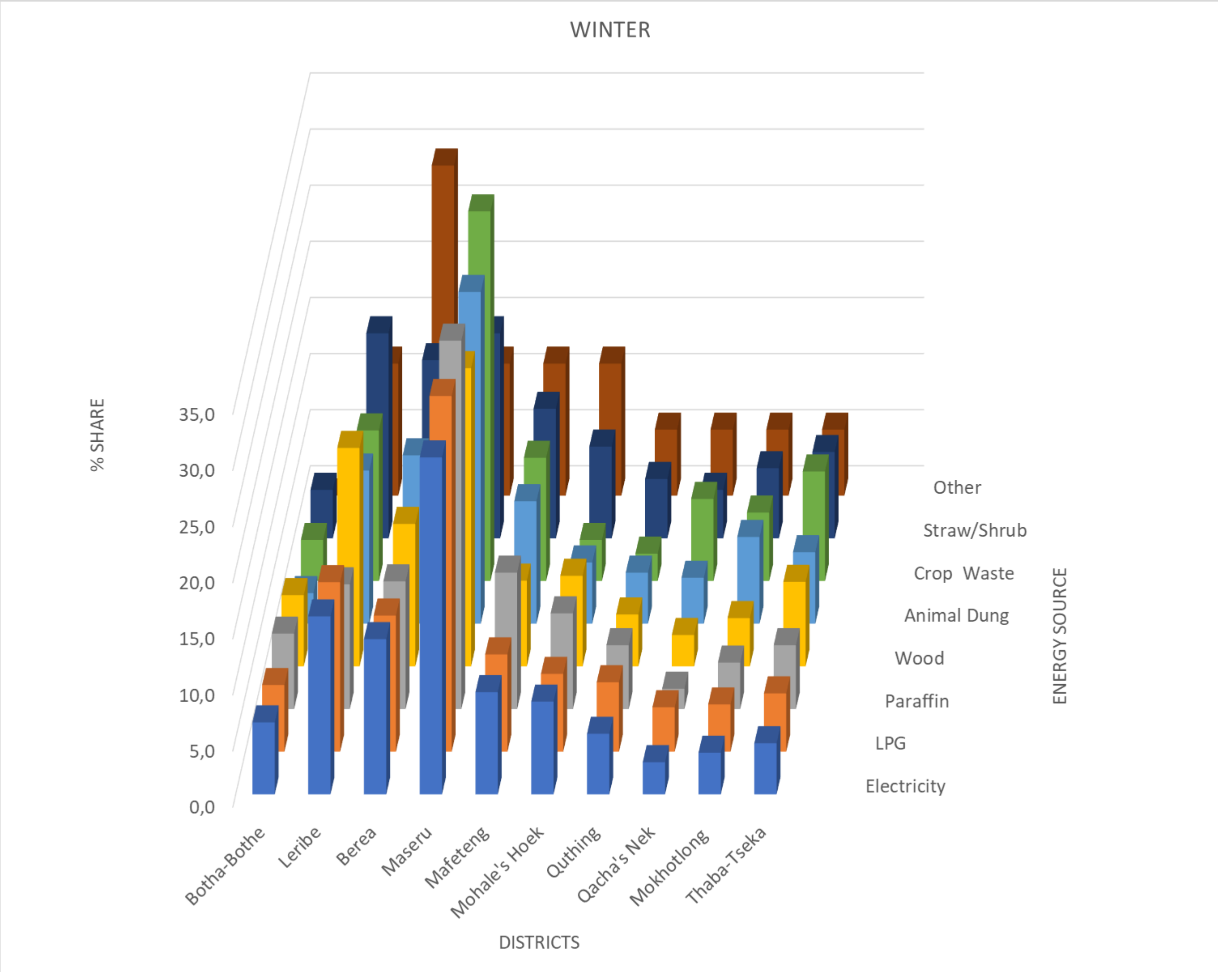


Figure 30: Energy consumption for water heating in districts for winter

4.3.2 Energy for Cooking

Figure 31 and Figure 32 depict the energy percentage shares for household cooking in both summer and winter months by agro-ecological zones. In summer months, straw/shrub has high penetrations of 60.5% and 21.4% in the Mountains and the Senqu River Valley respectively. However, the Lowlands demonstrates a high share in electricity (93.7%), paraffin (83.4%), LPG (81.7%), crop waste (80.0%) and wood (64.8%). There is a least share of electricity (0.4%), LPG (2.3%), paraffin (3.1%) and animal dung (3.4%) in the Foothills. In winter months, the Foothills has no electricity share. Amongst the energy sources, electricity has the highest share of 92.1% in the Lowlands, and LPG has the lowest share of 1.9% in Foothills, with no share of electricity and other fuels in the Foothills and the Mountains respectively. The Lowlands having higher percentage share of clean energy for cooking (Electricity and LPG) shows a positice track towards achieving universal access to modern and clean cooking fuels. However, other zones are in line with [40], which indicates that SSA progress is slow and off track towards access to clean fuels for cooking and technolonigies by 2030. This also apply in districts, where electricity and LPG consumption is high in developed districts. The energy used for household cooking is driven by household income. Households with low income levels rely on solid fuels, whereas high earning households are inline with the energy ladder [41].

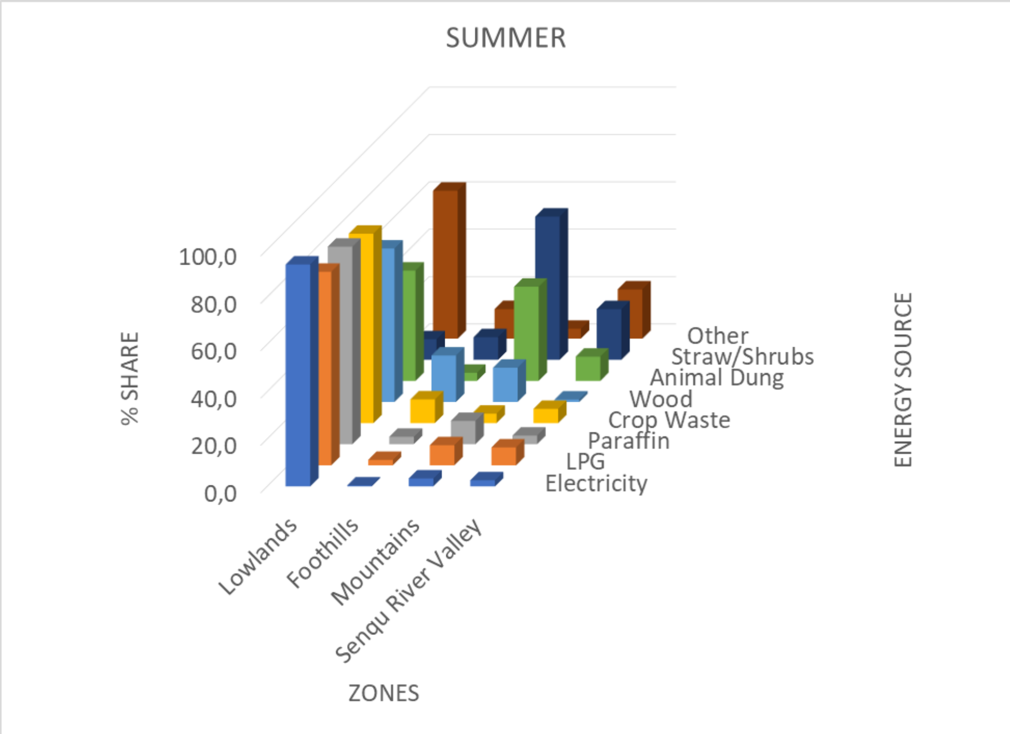


Figure 31: Energy consumption for cooking in zones for summer

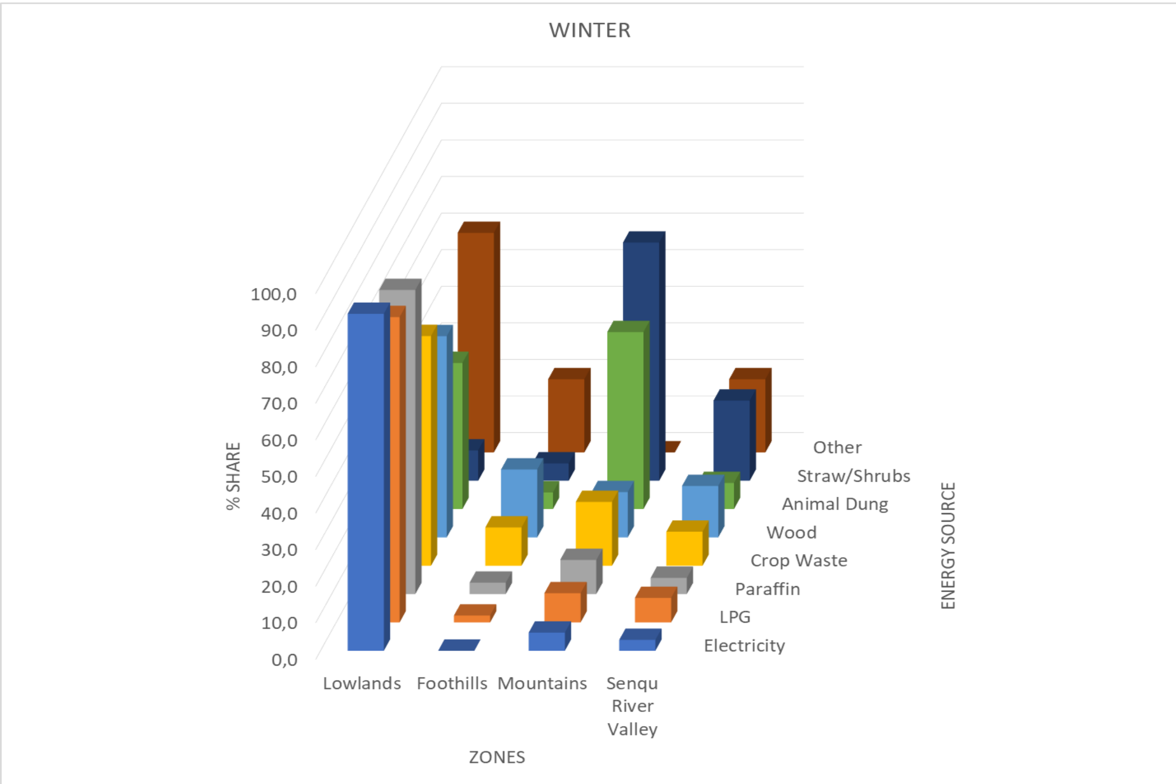


Figure 32: Energy consumption for cooking in zones for winter

Figure 33 and Figure 34 illustrate the energy penetrations for cooking by districts for summer and winter months. In summer months, the electricity share ranges from 0.4% in both Thaba-Tseka and Mokhotlong, to 50.7% in Maseru. Crop waste is mostly consumed in Leribe (44.0%), with no percentage shares in Qacha's Nek and Quthing. Straw/shrub in mostly used, and has a high share of 25.5% in Thaba-Tseka, while Mafeteng has the most share of 23.6% of animal dung. In winter months, the electricity share decreased from 50.7% to 31.4%, LPG from 38.5% to 32.8% and paraffin from 39.4% to 33.3% since the LPG prices increases in winter, and more electricity is used for other end use functions like space heating. However, other alternative fuels' percentage shares for cooking increased, like crop waste (from 8% to 9.3%), wood (from 20.6% to 24.7%), animal dung (from 10.2% to 27.4%) and straw/shrub (from 11.4% to 17.8%). Animal dung, and straws/shrubs are mostly consumed in highlands districts where most population residets, which shows the similar results with [42], which indicates that most population depends on solid biomass fuels for cooking. In rural setting, there is varying climatic conditions which affects the choice of energy sources for cooking, hence rural districts mostly use other sources of energy more than clean sources [42].

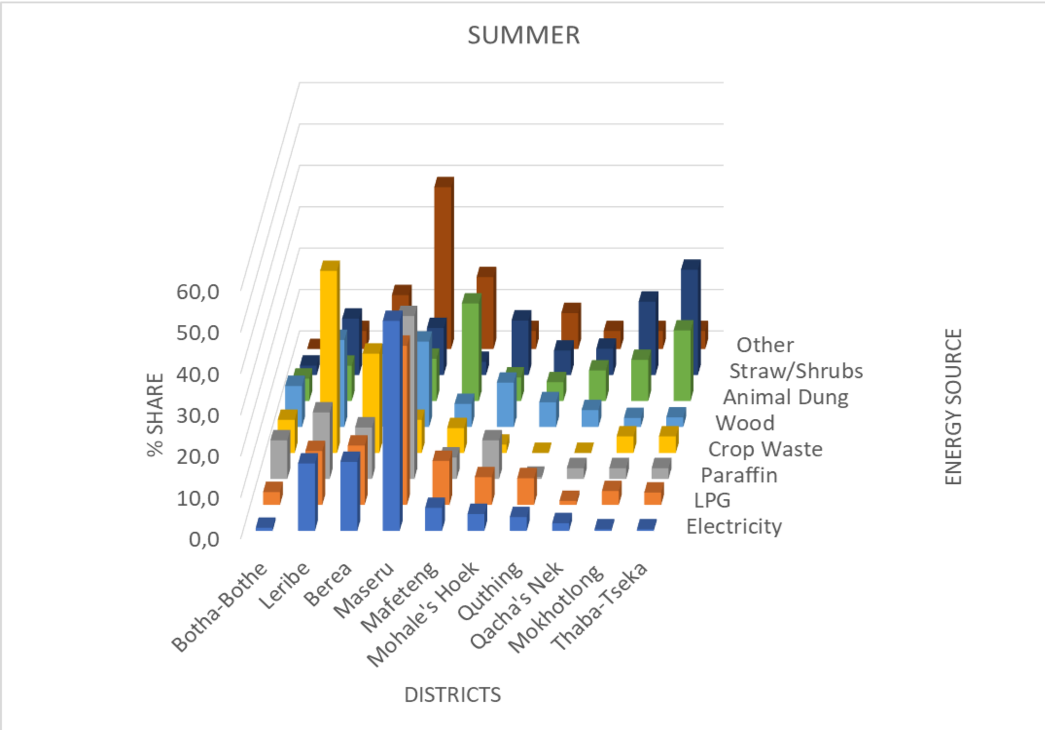


Figure 33: Energy consumption for cooking in districts for summer

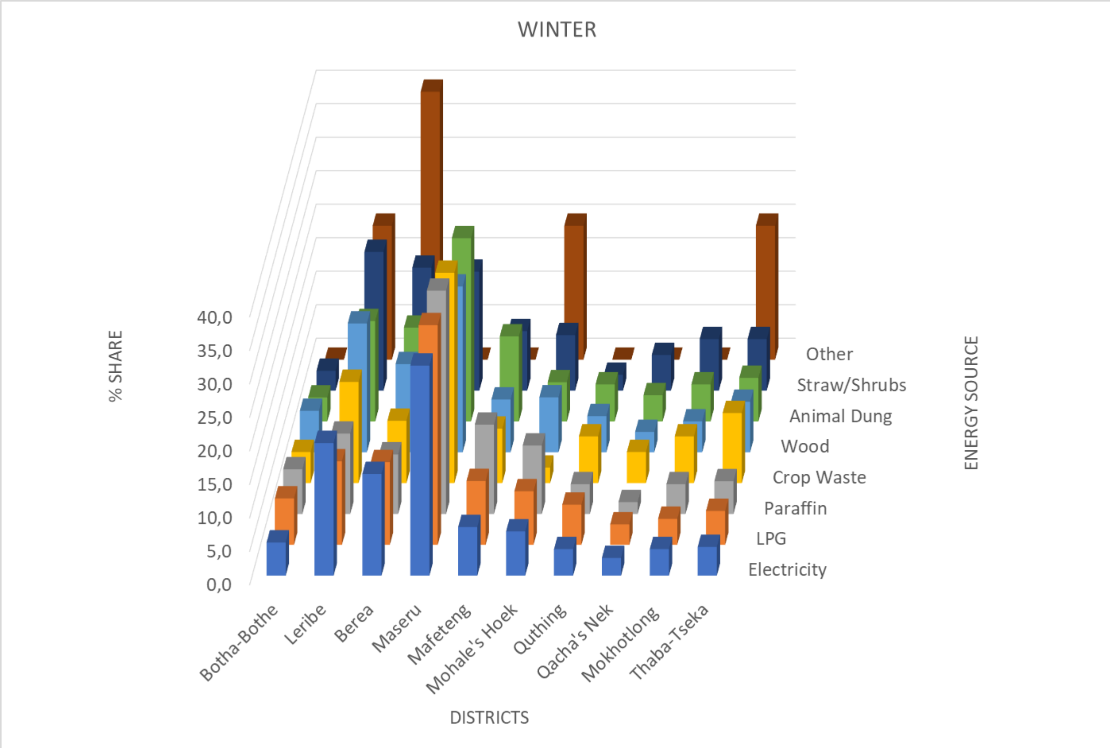


Figure 34: Energy consumption for cooking in districts for winter

4.3.3 Energy for Lighting

Figure 35 and Figure 36 illustrate the energy consumption penetrations for household lighting in zones for summer and winter months. In summer months, Lowlands have a high share in energy sources like candle (70.2%), paraffin (50.4%), solar lantern (34.1%) and grid electricity (39.2%). On rechargeable battery lamps, both Mountains and Lowlands have the same share of 40.0%. Mountains take a second share of 34.2% on grid electricity followed by Senqu River Valley with 21.3%, while the Foothills are the least with 5.4%. This is due to the least electrification rate in the Foothills and the Senqu River Valley, and low-income shares in the household such as 18.9% share at 1600 to 3000 Maloti income. The most energy sources with a high share in candle with 70.2% in the Lowlands and the least share on energy source is rechargeable battery lamp with 5.0% in the Foothills. In winter months, grid electricity has the highest share of 87.8% in the Lowlands, and the least share of 1.3% in the Foothills. Solar electricity has a share of 56.0% in the Lowlands and 32.0% in the Senqu River Valley. Candle is mostly used in Lowlands (49.9%), and paraffin has the highest share in the Foothills (75.0%).

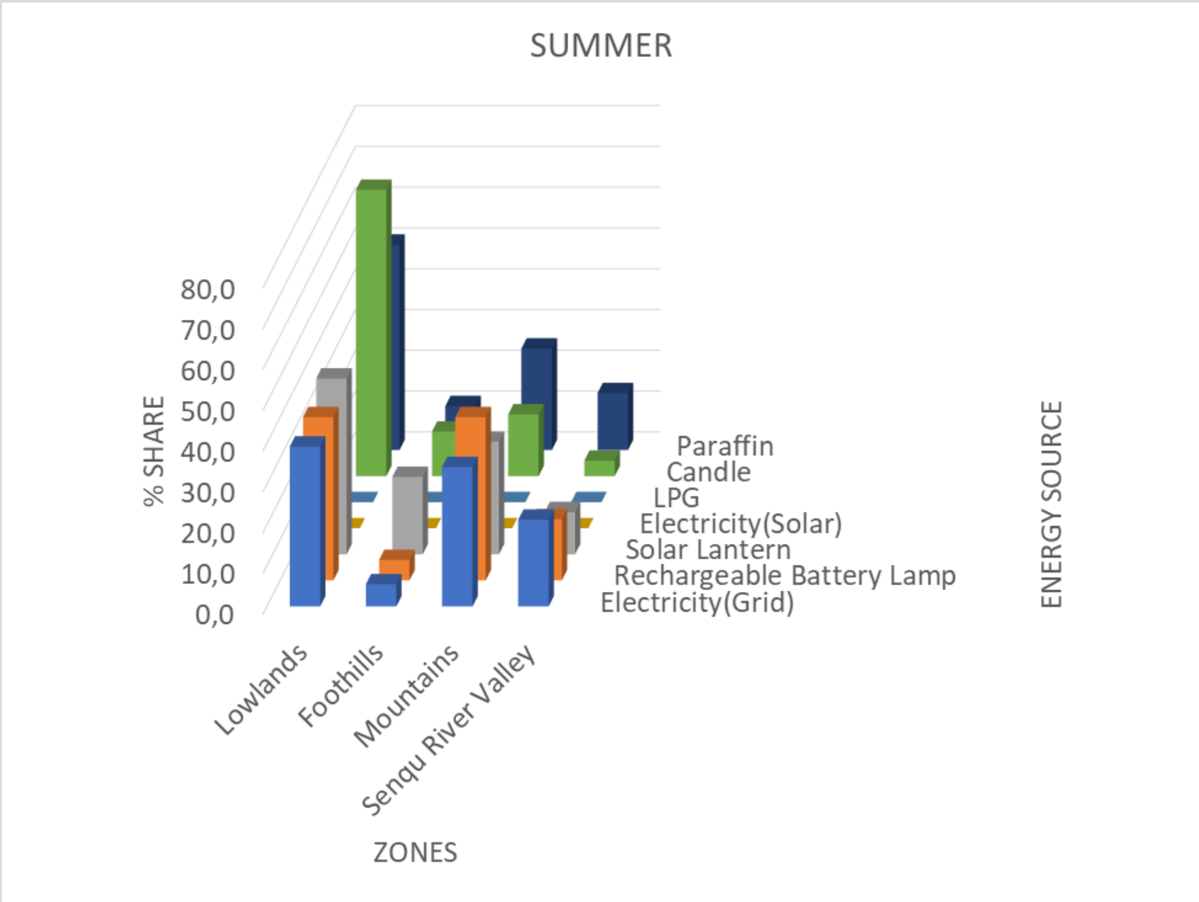


Figure 35: Energy consumption for lighting in zones for summer

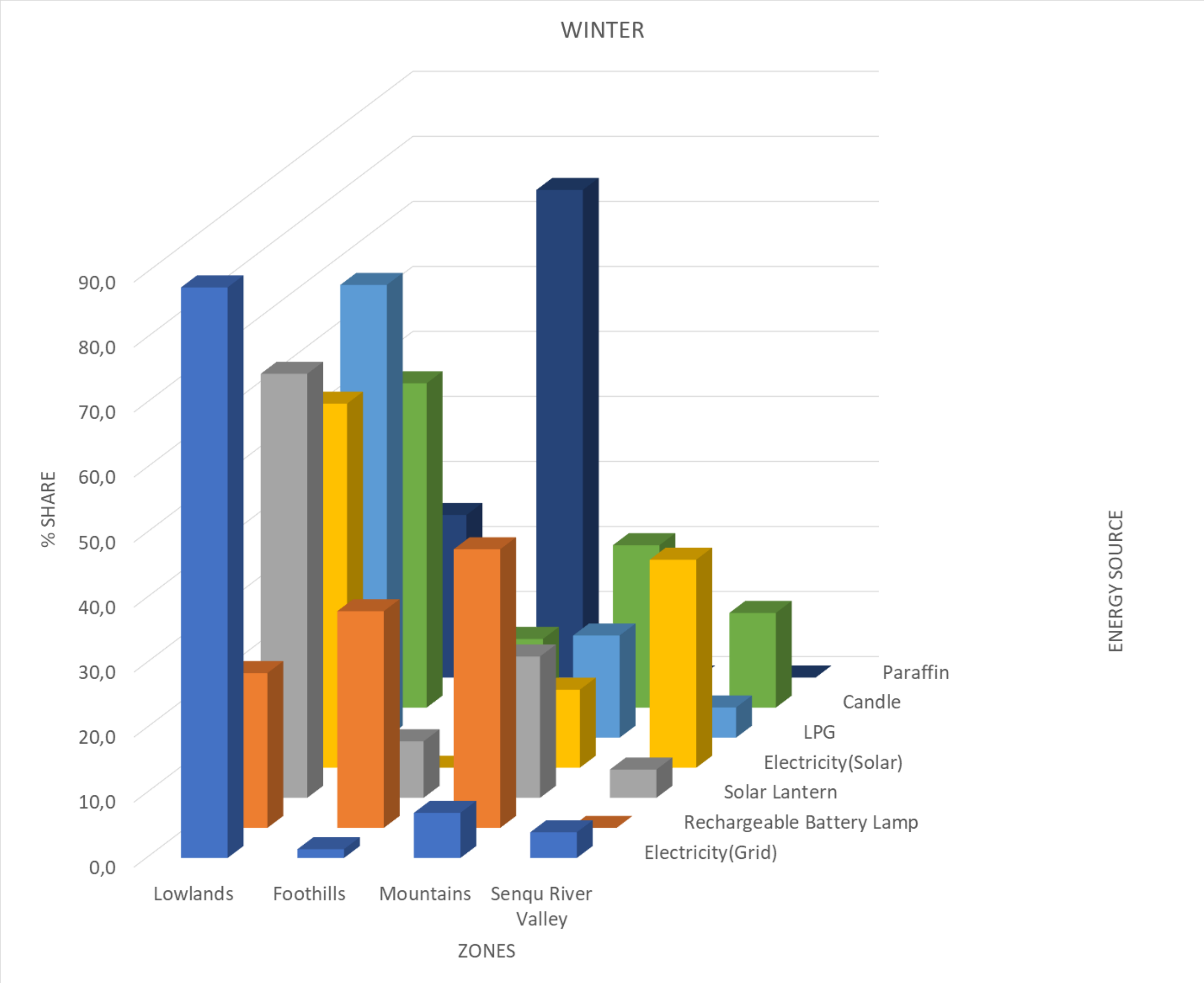


Figure 36: Energy consumption for lighting in zones for winter

Figure 37 and Figure 38 Figure 39illustrate the energy sources penetrations in household lighting in the districts form summer and winter months. In summer months, Maseru has a high share in grid electricity (42.9%), paraffin (20.2%) and rechargeable battery lamps (25.0%). Leribe has the high share of 28.2% in candle and the low share of 10.3% in solar lantern. There is a high percentage share of rechargeable battery lamp in Berea (25.0%) and Thaba-Tseka (20.0%). In winter months, there is high percentage share of paraffin in Mafeteng (40.0%), and 26.7% share in both Maseru and Mohale's Hoek. Grid electricity share ranges from 2.7% in Qacha's Nek to 31.1% in Maseru. According to [42], 50% of the households use Kerosene primarily for lighting, 29% use electricity while other use solar and biogas. This shows that the results found in zones and districts have the same trend, where households use candle, paraffin and electricity for lighting.

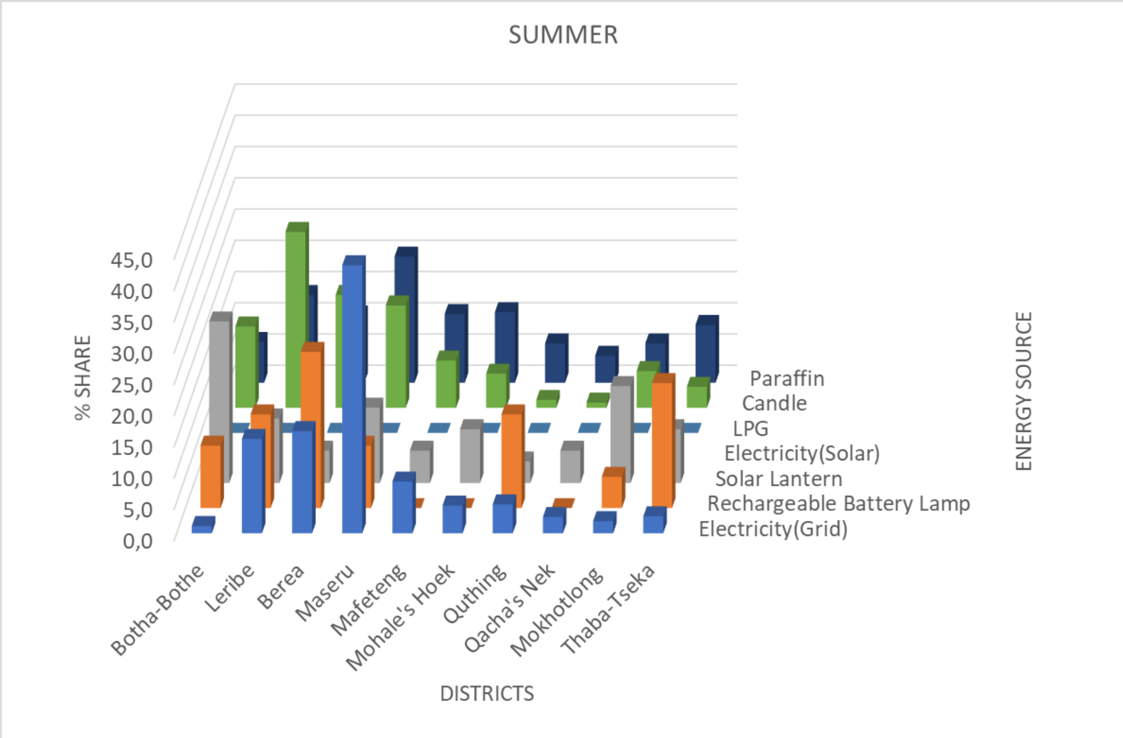


Figure 37: Energy consumption for lighting in districts for summer

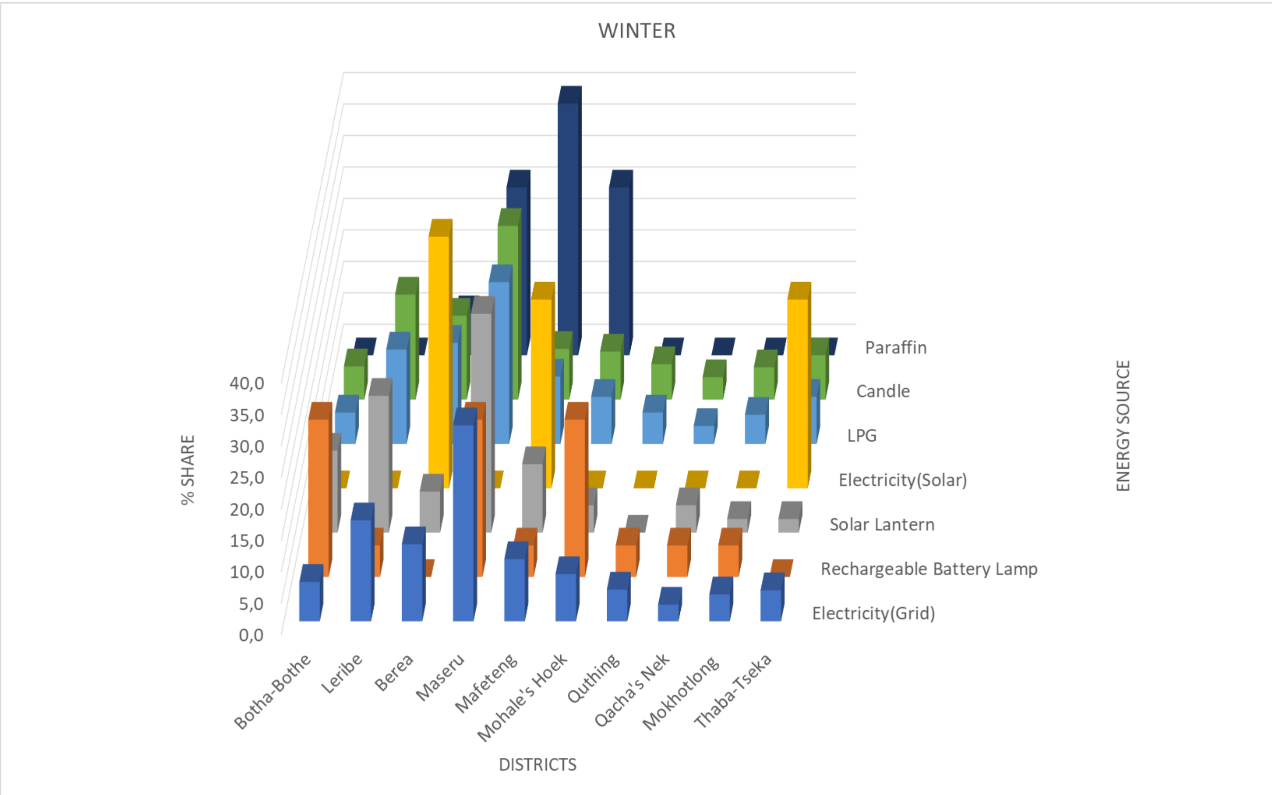


Figure 38: Energy consumption for lighting in districts for winter

4.4 Penetrations of Energy Forms

The penetration of energy forms describes the forms of energy used in the households as the energy sources, showing the overall percentage share of the energy consumed in the household.

4.4.1 Overall Energy Consumption by Energy Sources

Figure 39**Error! Reference source not found.** depicts the percentage share of total energy consumption in zones for summer months. As illustrated, electricity is mostly consumed in the Lowlands, with a share of 89.4%, and the least share in the Foothills with 0.2%. High electricity share in the Lowlands indicates significant access to electricity and infrastructure, which is attributed to higher population density and economic activities. Lowlands also dominate in fuel wood share consumption of 55.9%, while Senqu River Valley has a lower share of 10.2%. Animal waste is mostly consumed in the Mountains (42.8%) and least consumed in the Foothills (4.0%). The lowlands also dominate with a share of LPG (81.9%) and paraffin (77.2%). Crop waste is another energy source taking a higher share in Lowlands (79.1%) and lower share in Foothills (3.4%). Mountains rely heavily on shrubs, likely due to its availability with a share of 61.0%, while Lowlands have a least share of 11.6%. There is 75.1% share of aloe in Lowlands, and none in Mountains due to its scarcity, or the availability of alternative energy sources which are easily accessible.

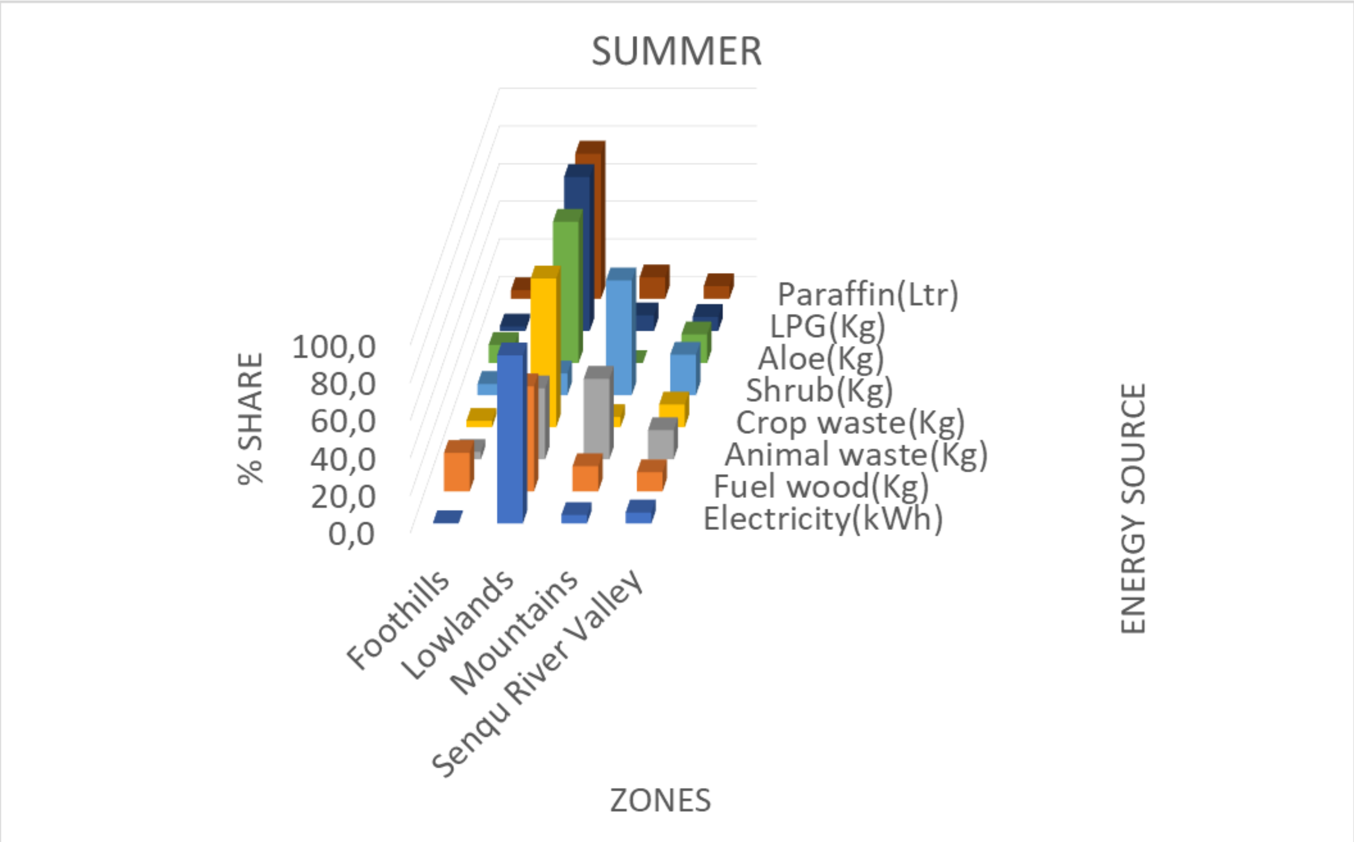


Figure 39: Overall energy consumption by energy source in zones for summer

In winter months as illustrated in Figure 40, electricity consumption in the Lowlands increases significantly, with a share of 92.9%, and a steady lowest consumption share in Foothills of 0.2%, while Mountains and Senqu River Valley consume 4.0% and 2.9% of electricity respectively. Fuel wood consumption in Lowlands decreases to 49.1%, while Senqu River Valley's share increases to 13.9% as compared to summer months (10.2%). Animal waste consumption in Mountains takes a higher share of 49.4%, and Senqu River Valley having a least share of 11.3%. Crop waste is also mostly consumed in the Lowland (54.1%). A share of 59.8% of shrubs takes a high share in the Mountains, followed by 26.3% in Senqu River Valley and 8.5% in Lowlands, and lastly the share of LPG and paraffin in the Lowlands increased to 83.7% and 84.4%. Mountains are characterized by heavy reliance on traditional energy sources, mostly animal waste and shrubs, which reflects the infrastructure being underdeveloped.

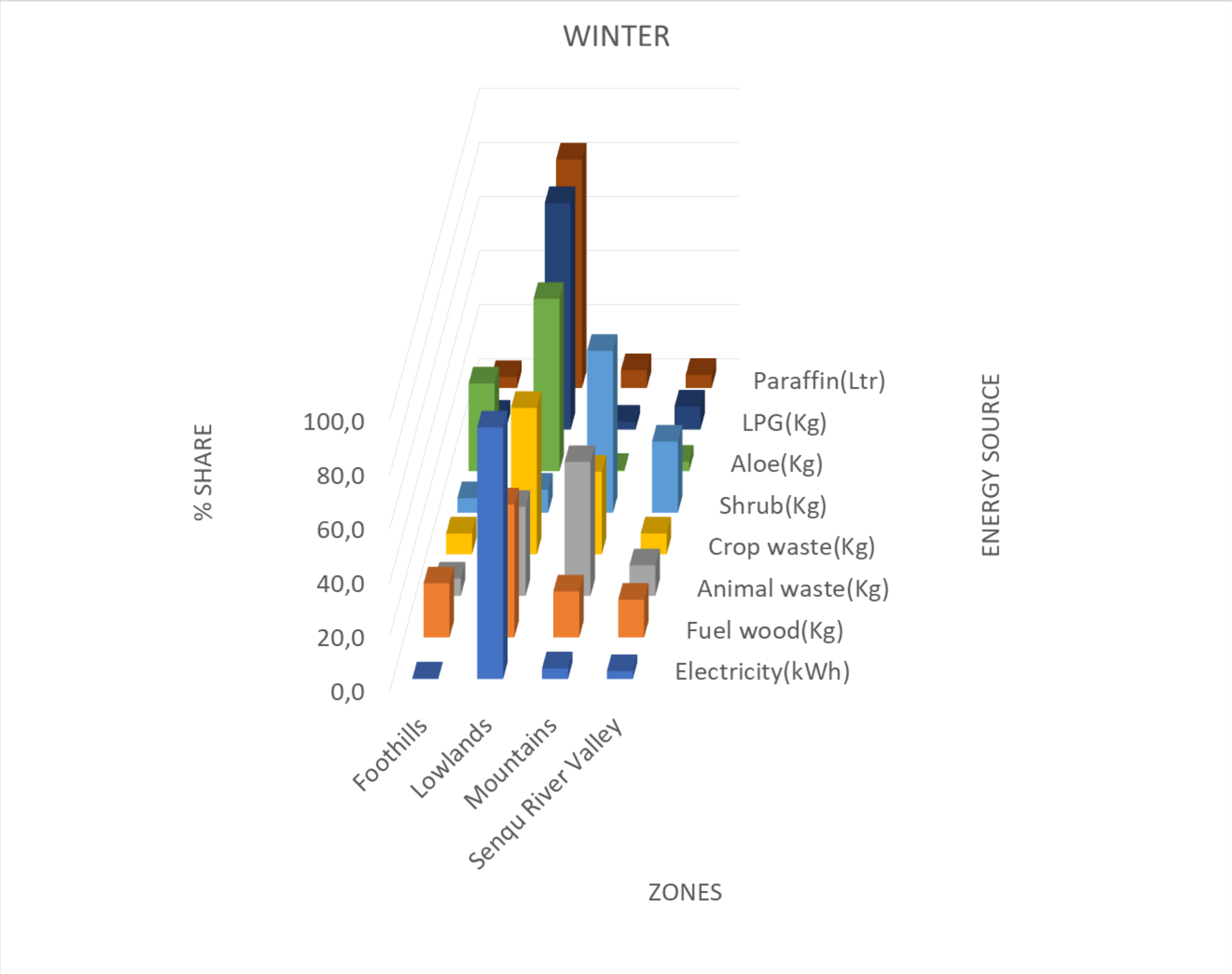


Figure 40: Overall energy consumption by energy source in zones for winter

The penetrations of energy consumption in districts during summer and winter months are illustrated in Figure 41 and Figure 42 respectively. Maseru district takes a higher share of 50.3% of electricity, while the lowest share is in Botha-Bothe with 0.6% which indicates limited access to electricity, with the electrification percentage share of 7.4%. About 20.8% of animal waste is consumed in Mafeteng, and Botha-Bothe has a low share of 4.4%. Crop waste share ranges between 0.4% in Qacha's Nek and 23.9% in Berea. Shrub as another energy source is mostly consumed in Maseru with a highest share of 19.9%, while Mokhotlong, Thaba-Tseka and Qacha's Nek have no records of shrubs which could be due to environmental factors or preferences for other energy sources. Around 72.3% of aloe is consumed by Mafeteng district, while Leribe takes the least share of 0.3%. The dependency of aloe as energy source in Mafeteng is stands out as unique, hinting a specific practice by households or lack of other energy sources. The percentage share of energy consumed in winter months increased as compared to summer months. Electricity share in Maseru increased to 51.3% which shows a strong reliance on electricity compared to other districts. Leribe (18.3%) and Maseru (18.4%) have the highest share of fuel wood usage, which shows that despite electricity, traditional fuels are also mostly consumed. A share of animal waste ranges from 4.5% (Leribe) to 18.9% (Mafeteng). However, Berea has a high share of 22.5% of crop waste consumption, and Mohale's Hoek (2.5%) takes the least share. Despite varying levels of electrification in districts, other traditional fuels like fuel wood, animal waste and shrubs are consumed, mostly in rural areas.

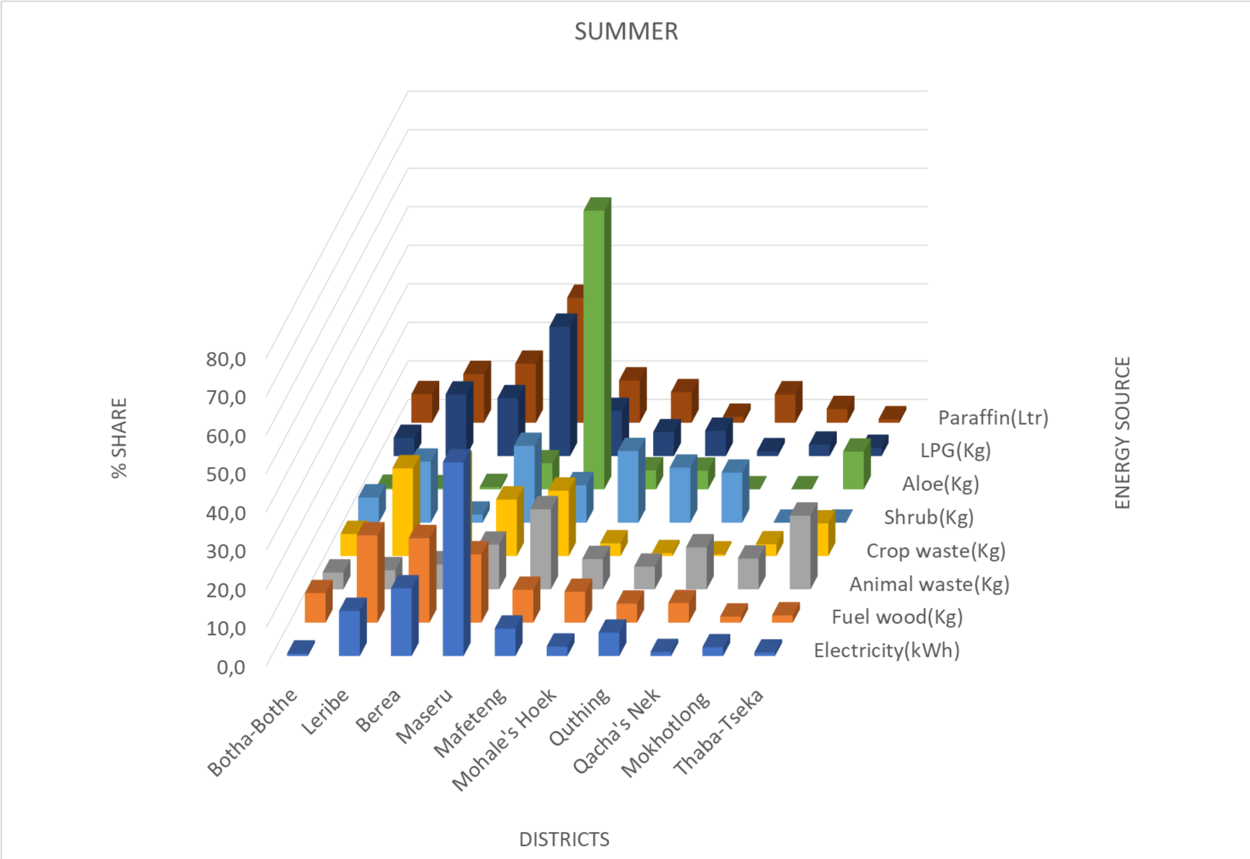


Figure 41: Overall energy consumption by energy source in districts in summer

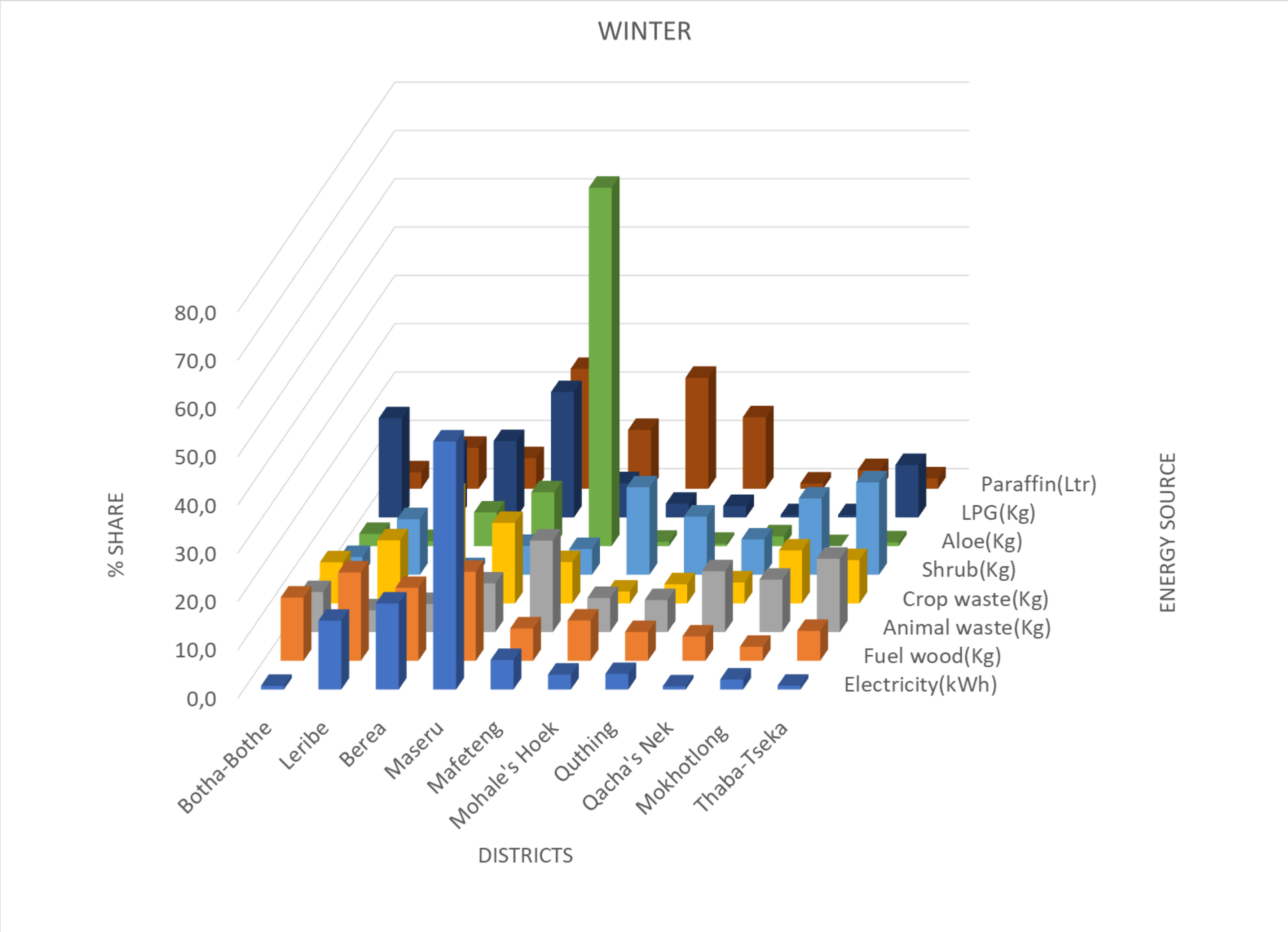


Figure 42: Overall energy consumption by energy source in districts for winter

4.4.2 Energy Forms Preferences

The preference on choice of energy forms is another attribute in household energy consumption. The households which are aware of cleaner sources of energy and have access to electricity have different perspectives compared to non-electrified households. Figure 43 illustrates the preferred energy forms by agro-ecological zones. Across all zones, the Lowlands account for the higher percentage share in all preferred energy forms (electricity, LPG, wood, paraffin, solar PV and biogas) while LPG is the second preferred energy form. The difference in the preferred energy form in zones may be due to the overall demand and peak usage. The Lowlands mostly prefer electricity because they are closer to the national grid, thus making it more reliable during peak demands, while in the Mountains, the Foothills and the Senqu River Valley, electricity preference is due to the households preferring to transition from unclean energy sources.

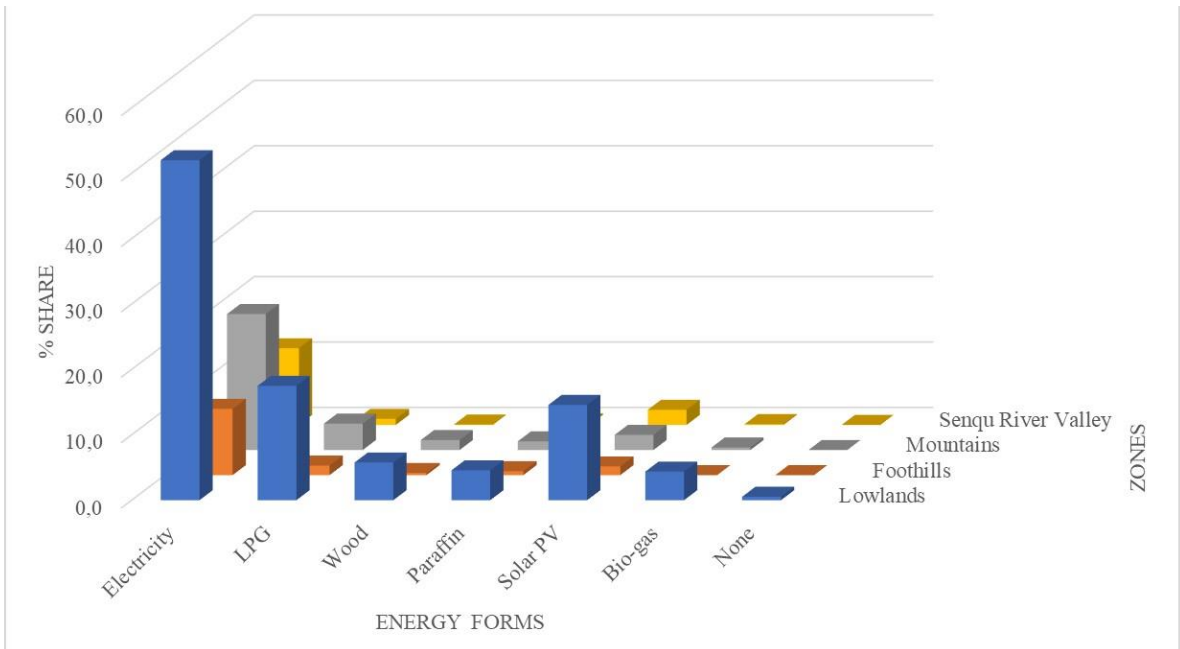


Figure 43: Distribution of preferred energy forms in zones

Figure 44 illustrates the preferred energy forms in the districts presented in 3D bar chat. From the households in each district, electricity is the most preferred energy form. The differences in percentage share of energy form preferences in districts is due to factors like education, environmental awareness and renewable energy potential and cost.

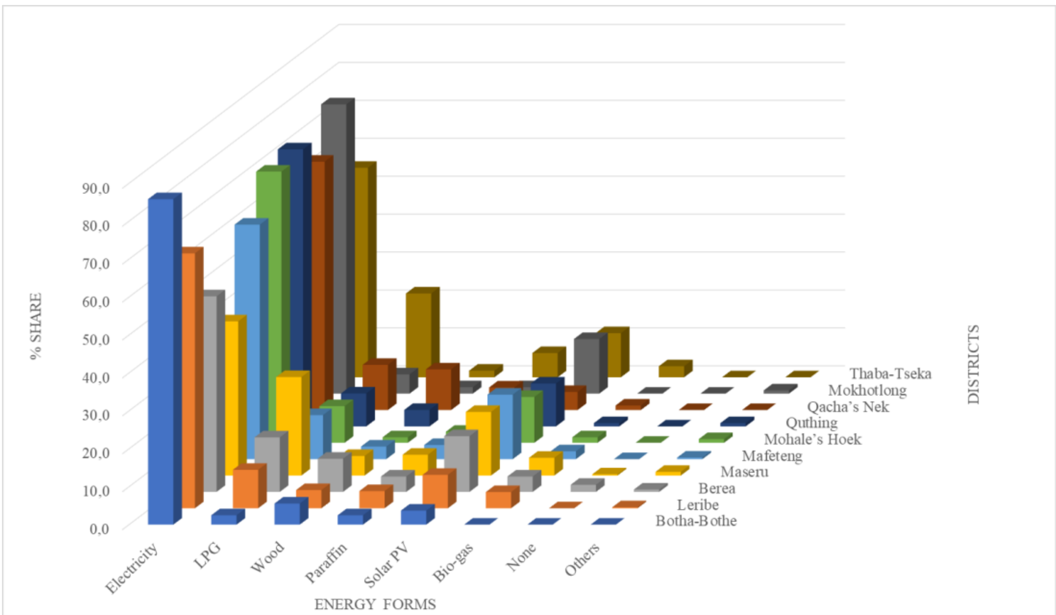


Figure 44: Distribution of preferred energy forms in districts

4.5 Household Energy Intensities

Household energy intensity is referred to as energy consumption which varies significantly in summer and winter months due to differences in heating, cooking and cooling needs of the households. The intensities are categorised in households' total energy consumption of different energy sources, monthly average energy consumption per household (HH) and consumption of energy per capita (Cap) in a month during summer and winter months, for both zones and districts. They are usually measured in kilowatt hour (kWh) for electricity (kWh/HH or kWh/cap), kilograms (kg) for solid fuels (kg/HH or kg/cap), and litres (Ltr) for paraffin (Ltr/HH or Ltr/cap).

4.5.1 Monthly Average Energy Consumption per Household

Figure 45**Error! Reference source not found.** depicts the monthly average energy consumption per household in zones for summer. During summer months, the consumption of electricity per month is highest in Senqu River Valley (122.6 kWh/HH) which might be due to medium household sizes (10.4% at 50-60 sqm) and high-income levels per household which showed that it takes a share of 14.8 % at 10000 to 20000Maloti, the Lowlands consume 87.3 kWh/HH, while the Mountains and the Foothills have lower consumption of 54.5 kWh/HH and 14.9 kWh/HH respectively. Low consumption in the Foothills is possibly due to limited access of electricity, where only 6.4% of the population sampled is electrified, and is the lowest in zones. Fuel wood consumption in a month range from 143.4 kg/HH in Lowlands to 222.9 kg/HH in Foothills. Animal waste consumption is high in Senqu River Valley (189.6 kg/HH), while crop waste consumption ranges from 32.0 kg/HH in Foothills to 114.6 kg/HH. Shrubs and aloe are also consumed in higher quantities, with the lowest consumption of 81.5 kg/HH and 81.1 kg/HH in the Foothills and the Senqu River Valley respectively.

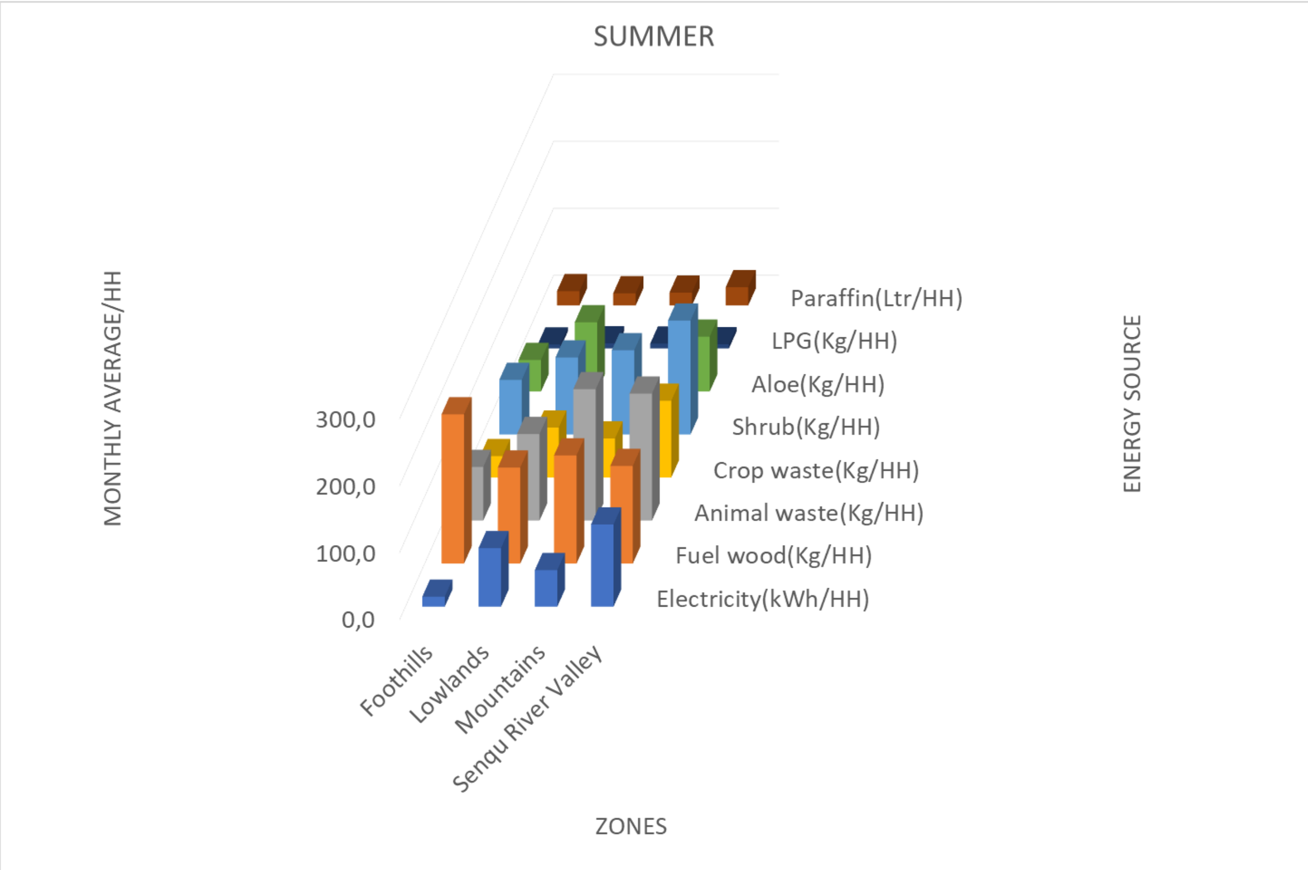


Figure 45: Monthly average energy consumption per household in zones for summer

For household cooking, a typical Lowlands household consumes LPG of 7.6 kg/HH in a month as the highest amount consumed, followed by Mountains with 7.3 kg/HH. The Foothills consumes the least LPG of 6.0 kg/HH. This relates well with the household sizes where 3 or more members in the

Mountains and the Lowlands takes the same share of 16.5%, though there is also less difference in LPG consumption. However, for paraffin consumption for Senqu River Valley (27.1 Ltr/HH) has the highest consumption and the Lowlands (18.1 Ltr/HH) has the lowest in a month. The analysis highlights more dependence on traditional biomass in rural areas (Foothills, Mountains and Senqu River Valley) where there is less access to electricity (6.4%, 15.1% and 15.2% respectively). However, where there is better infrastructure such as in the Lowlands, there is a gradual shift to modern energy sources such as electricity and LPG.

As illustrated in Figure 46 during winter months, the Foothills shows lowest dependence on LPG (33.8.0 kg/HH) and highest on Paraffin (45.0 Ltr/HH), which can be caused by household income as the Foothills has the highest share of 16.5% at 10000 to 20000 Maloti household income level. Lowlands exhibits the highest electricity consumption of 126.8 kWh/HH on average, which reflect better access to electricity (48.4%), but also high use of LPG (199.8 kg/HH) and animal waste (120.0 kg/HH). The Mountains zone is dominated by consumption of animal waste and fuel wood with 193.6 kg/HH and 161.4 kg/HH respectively. The high consumption for animal waste can be caused by high percentage share of household size (34.6%) at 6 or more members. The consumption of shrubs (166.3 kg/HH) and fuel wood (163.3 kg/HH) in Senqu River Valley indicates a balance in winter months. The results reflect a strong reliance on both biomass and modern energy sources to meet the winter energy demands, mostly for cooking, hot water heating and space heating.

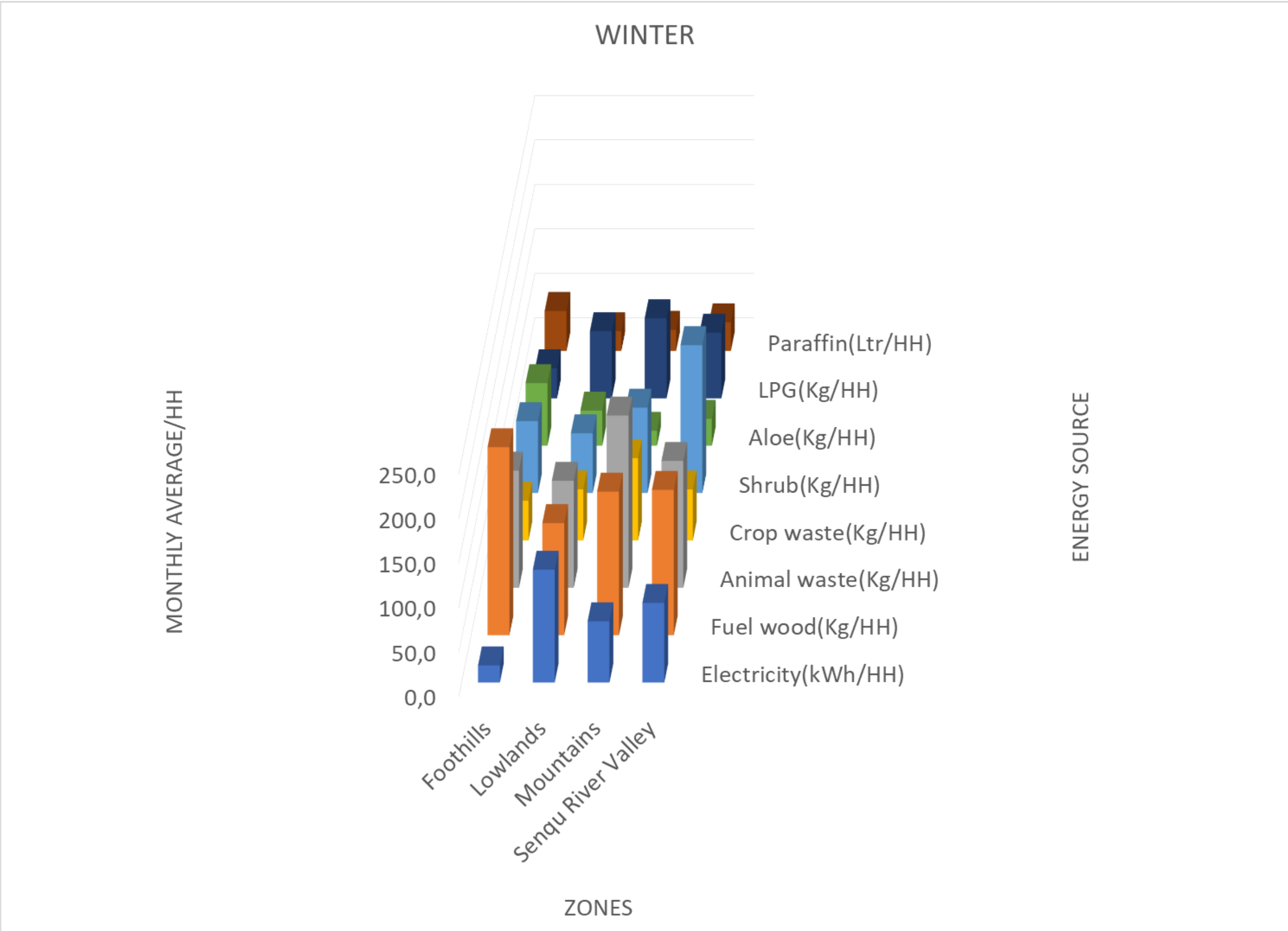


Figure 46: Monthly average energy consumption per household in zones for winter

Figure 47**Error! Reference source not found.** illustrates the monthly average consumption of household energy in summer by districts. There is a diverse energy mix with a notable dependence on traditional and modern energy sources. High electricity consumption is in Maseru and Quthing districts with 97.8 kWh/HH and 113.3 kWh/HH of electricity consumed per month. There is also significant consumption of crop waste (92.8 kg/HH) and shrubs (199.9 kg/HH) in Maseru. Berea follows closely with a high fuel wood consumption (210.0 kg/HH) and moderate electricity (92.6 kWh/HH). Mafeteng district takes a higher share of animal waste with an average of 211.8 kg/HH, while 131.7 kg/HH of crop waste utilization is found in Mokhotlong. Thaba-Tseka relies heavily on animal waste (231.5 kg/HH) with no record on shrub usage and this reflects reliance on biomass fuels as fuel wood which is also consumed is as high as 116 kg/HH. Qacha's Nek consumes more of animal waste (291.8 kg/HH) and lowest consumption of electricity (35.4 kWh/HH) on average.

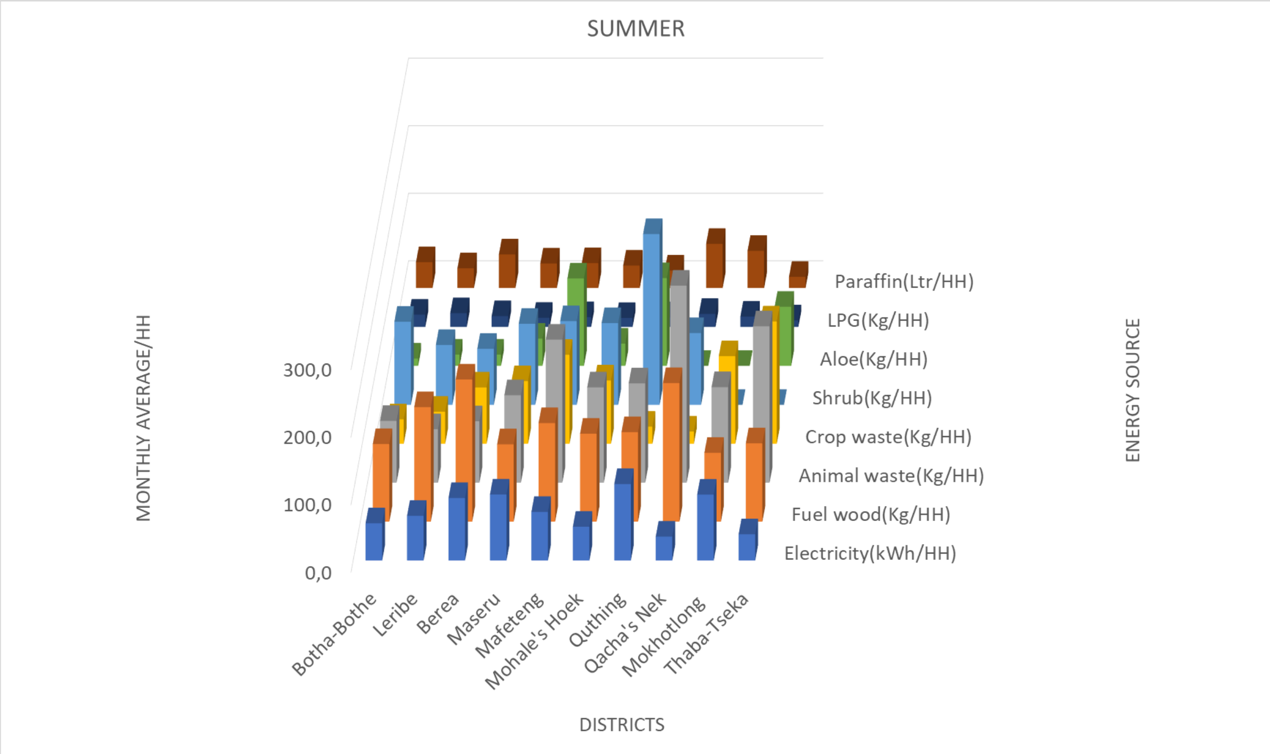


Figure 47: Monthly average energy consumption per household in districts for summer

In winter months as illustrated in Figure 48, monthly household energy consumption across districts has a mix of reliance on traditional and modern energy sources. Maseru and Berea districts lead in electricity consumption, consuming 140.0 kWh/HH monthly. There is also reliance on fuel wood, where Berea consumes 158.0 kg/HH and Maseru consumes 143.5 kg/HH. However, Botha-Bothe and Qacha's Nek are the highest consumers of fuel wood, with 193.5 kg/HH and 233.5 kg/HH of energy consumed per month respectively. Animal waste as a traditional fuel, plays a crucial role in household energy consumption, with Qacha's Nek showing a high reliance of 329.9 kg/HH, and the driving factor could be the household income, where it takes the highest share at 3000-5000 Maloti (11.3%). Leribe and Botha-Bothe demonstrate more balanced energy mixes, with electricity consumption of

104.4 kWh/HH and 78.8 kWh/HH respectively, fuel wood consumption of 140.3 kg/HH and 193.5 kg/HH respectively, and moderate consumption in LPG use, with 48.8 kg/HH and 37.7 kg/HH respectively. Mohale's Hoek and Quthing also exhibit substantial reliance on paraffin where 128.8 Ltr/HH and 173.4 Ltr/HH are consumed for household cooking.

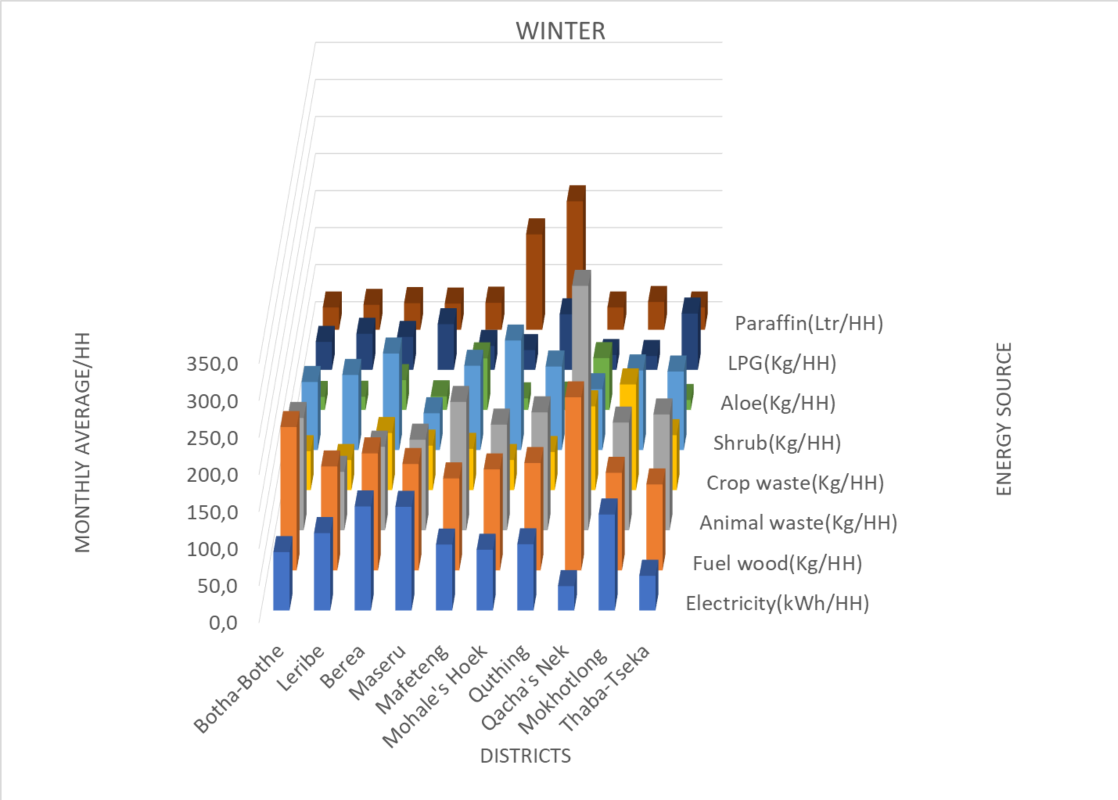


Figure 48: Monthly average energy consumption per household in districts for winter

4.5.2 Monthly Average Energy Consumption per Capita

Figure 49 illustrates the analysis of monthly average energy consumption patterns per capita across zones in summer. The varying energy consumption patterns across energy sources reflect the economic and geographic differences among the zones. During summer months, an individual consumes an average of 60.5 kg/cap of fuel wood in Foothills, 47.1 kg/cap of shrubs and 20.9 kg/cap of animal waste, and only 4.4 kWh/cap of electricity. For household cooking, individuals on average use 9.4 Ltr/cap of paraffin and 15.2 kg/cap of LPG. This shows that most households in Foothills have limited access to electricity and modern energy, thus prefer traditional energy sources. In Lowlands, shrubs have an average of 103.3 kg/cap consumption which indicates high dependence on it as an energy source. On average, fuel wood, animal waste and aloe also have high consumptions of 40.0 kg/cap, 37.4 kg/cap, and 33.6 kg/cap respectively. An individual on average consumes 25.1 kWh/cap of electricity in a month. For cooking, LPG and paraffin consumption is 7.0 kg/cap and 11.1 Ltr/cap respectively. The mixed energy portfolio shows high consumption of electricity and reliance on shrubs, aloe, and animal waste. On average, an individual in the Mountains consumes 61.7 kg/cap of animal waste and 17.7 kWh/cap of electricity.

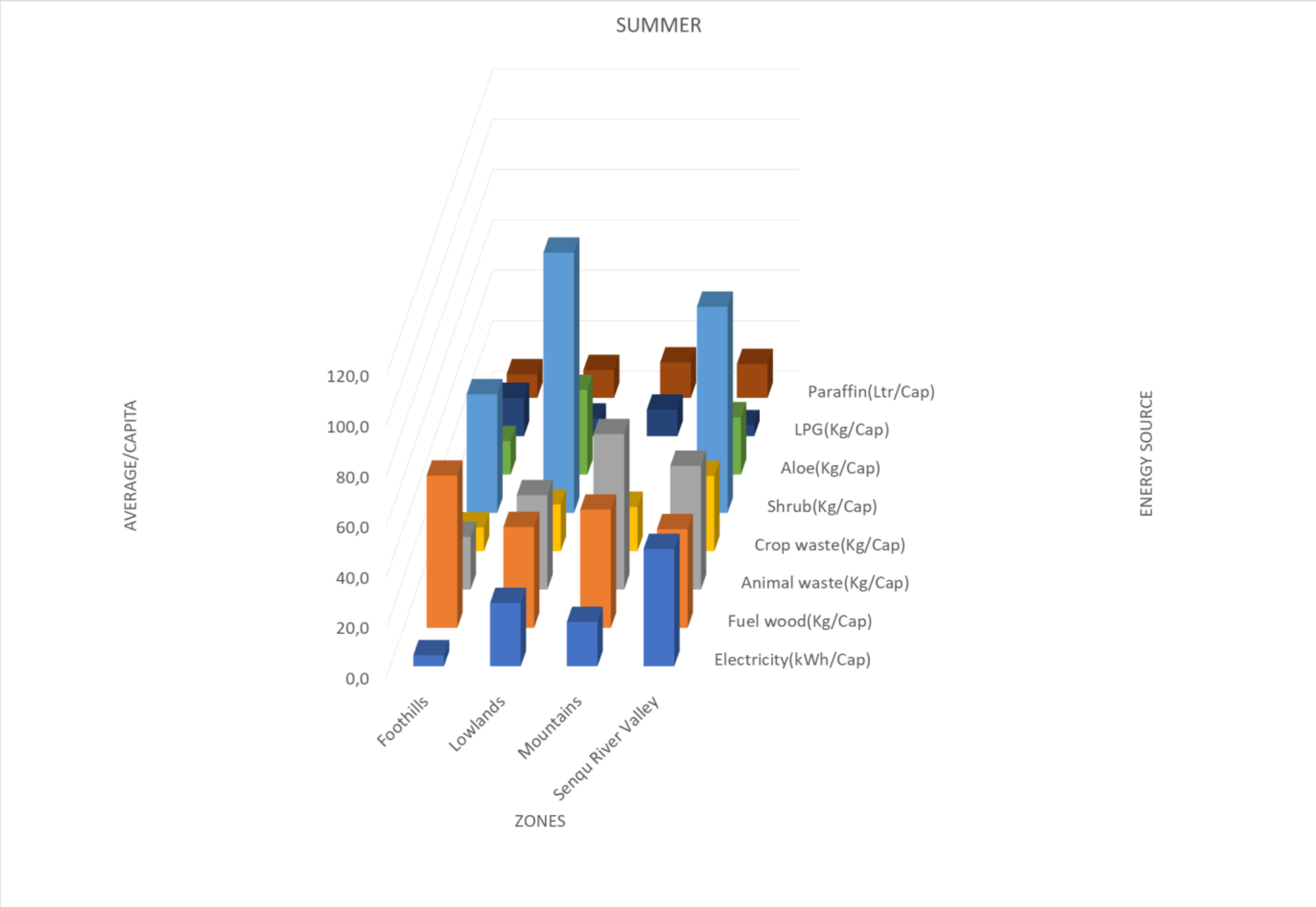


Figure 49: Monthly average energy consumption per capita in zones for summer

In Figure 50 during winter months, average electricity consumption per capita decreases to 28.2 kWh/cap in Senqu River Valley, which can be caused by high percentage share of household size of 33.0% at 6 or more members while having the low population share of 8.8%, which majority earn less than 750 Maloti (23.2%). Most energy sources average consumption increases in winter months, however in the Lowlands, fuel wood, crop waste, shrubs and paraffin consumption decreased from 40.0 kg/cap to 36.3 kg/cap, 37.4 kg/cap to 16.4 kg/cap and 103.3 kg/Cap to 22.8 kg/cap and 11.1 Ltr/cap to 10.6 Ltr/cap respectively. This is because the electricity and LPG consumption increases in winter months showing shift from other energy sources. There is a notably an increase in LPG consumption per capita in all zones, where Senqu River Valley leads with 64.4 kg/cap and Lowlands consumes at least 44.4 kg/cap in a month. Paraffin consumption is lowest in Mountains and Senqu River Valley, where per capita consumes an average of 9.7 Ltr/cap and 7.3 Ltr/cap. The factor contributing to high consumption can possibly be the household income, where the Foothills has the highest share of 16.5% at both 750-1600 Maloti and 10000-20000 Maloti.

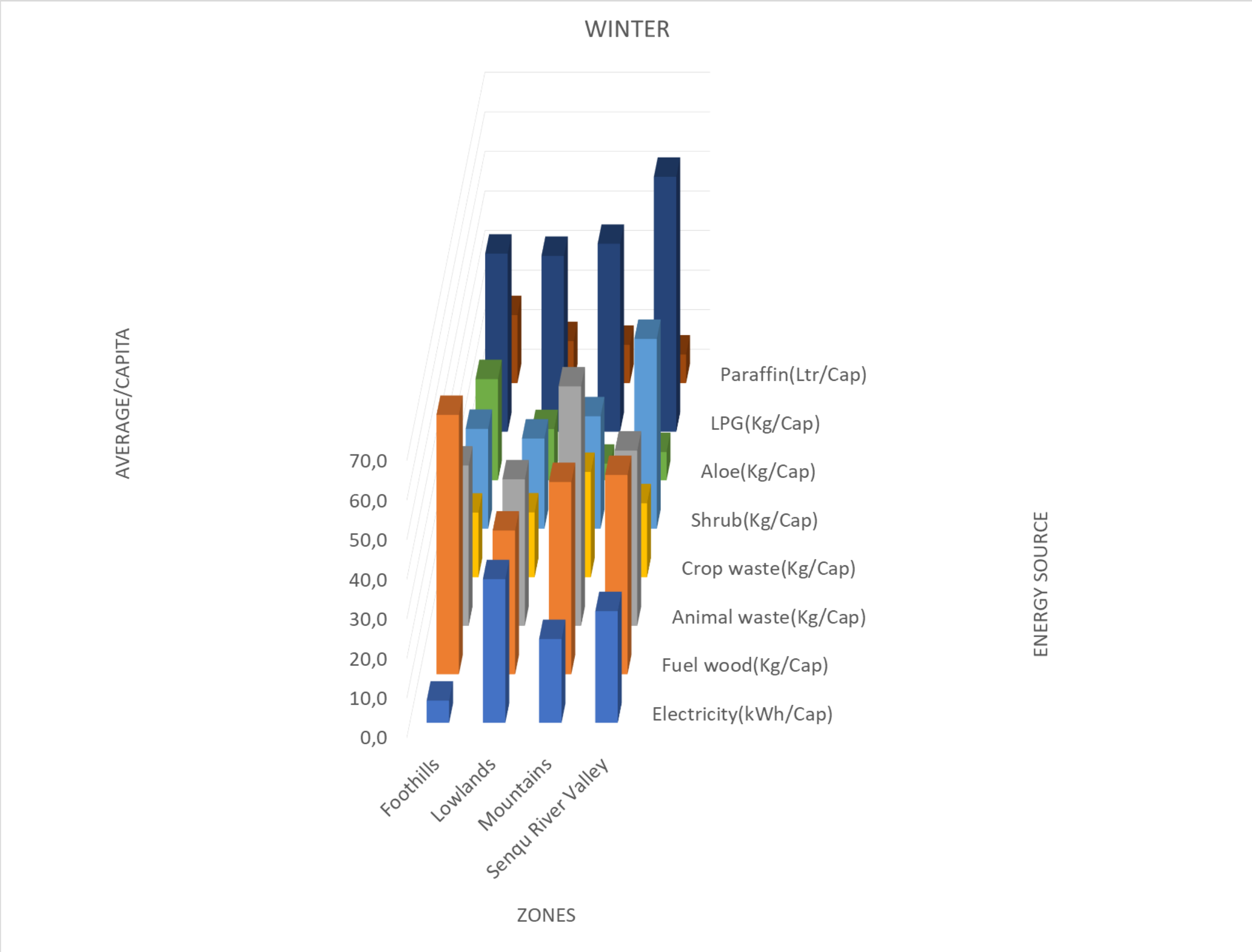


Figure 50: Monthly average energy consumption per capita in zones

Figure 51 illustrates insights into the monthly average energy consumption per capita in districts for summer months. During summer months, electricity consumption per capita is highest in Quthing (35.7 kWh/cap) and Maseru (31.6 kWh/cap), and lowest in Thaba-Tseka (10.0 kWh/cap) and Qacha's Nek (9.1 kWh/cap). The heavy reliance on fuel wood is in Berea where an individual consumes 68.6 kg/cap on average in a month. Botha-Bothe (at 25.0 kg/cap) is the least fuel wood consumer per capita. Animal waste consumption ranges from 19.1 kg/cap in Botha-Bothe to 83.1 kg/cap in Qacha's Nek. Leribe also has a low average animal waste consumption per capita of 20.1 kg/cap. There is no reported consumption of shrubs in Mokhotlong and Thaba-Tseka for the surveyed households, while Quthing as the high consumer, uses 84.3 kg/cap of shrubs. Aloe is mostly consumed in Mafeteng, with an average of 35.3 kg/cap in a month. For household cooking, LPG and paraffin consumption are relatively low across all districts, with the highest LPG consumption in Qacha's Nek at 6.0 kg/cap and the least in Thaba-Tseka at 3.4 kg/cap. Paraffin consumption is highest in Qacha's Nek (22.0 Ltr/cap), Mokhotlong (15.6 Ltr/cap), and Berea (15.2 Ltr/cap).

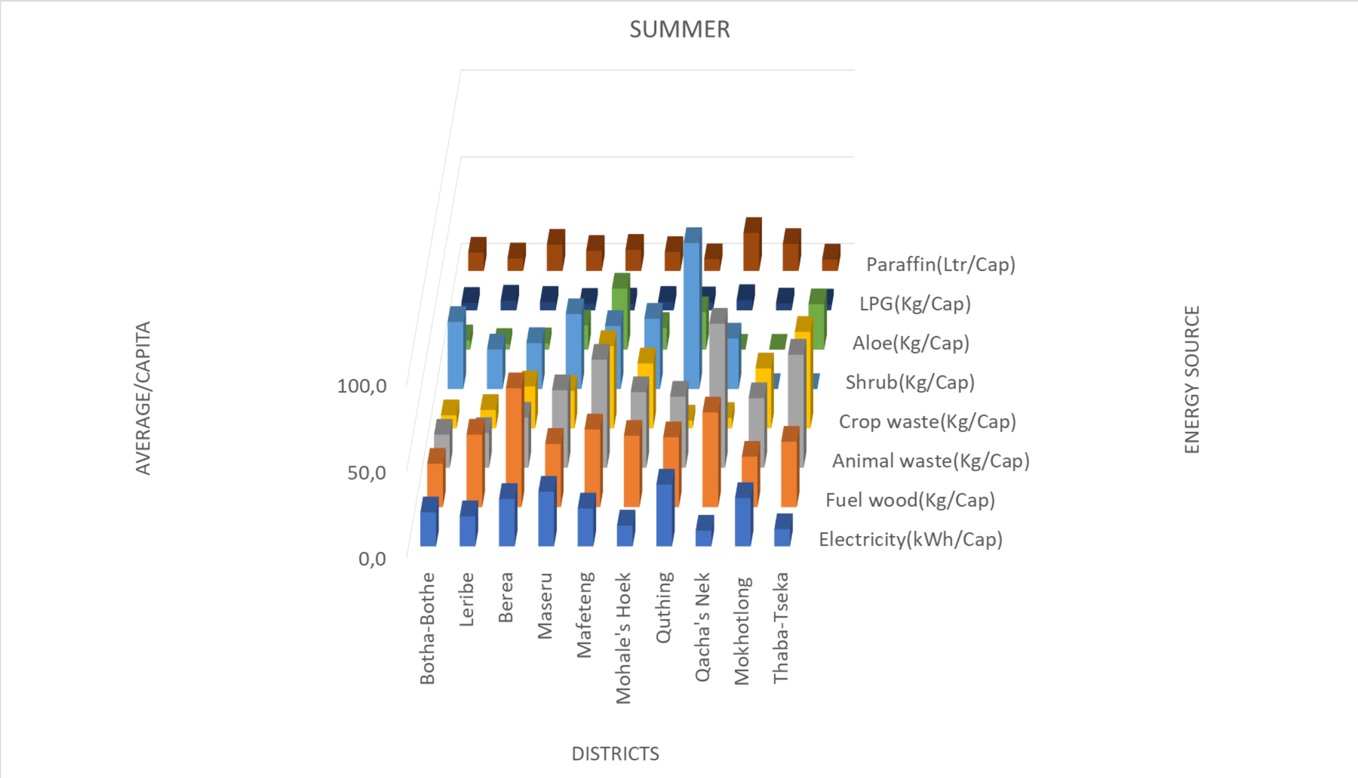


Figure 51: Monthly average energy consumption per capita in districts for summer

Figure 52 illustrates the district's monthly average energy consumption per capita in winter months, there is high electricity consumption per capita in Maseru (42.0 kWh/cap) and Leribe (33.3 kWh/cap), and the lowest consumption per capita in Qacha's Nek (10.9 kWh/cap) and Thaba-Tseka (16.4 kWh/cap). Reliance on fuel wood increases mostly in districts located in the mountains, where Qacha's Nek and Botha-Bothe dominate with 72.6 kg/cap and 58.6 kg/cap. Animal waste consumption ranges from 19.2 kg/cap in Leribe to 104.4 kg/cap in Qacha's Nek. Crop waste is mostly consumed in Mokhotlong and least consumed in Leribe, where an individual consumes 44.4 kg/cap and 11.7 kg/cap respectively. Around 46.2 kg/cap of shrubs is consumed mostly in Mohale's Hoek district, followed by Mafeteng with 37.9 kg/cap. However, the shrub is least consumed in Maseru per month where only 14.4 kg/cap is consumed. There is a high reliance on aloe in Qacha's Nek (35.0 kg/cap) and the least reliance on Mohale's Hoek (0.3 kg/cap). Individual average LPG consumption per month for cooking ranges from 7.5 kg/cap in Mokholtong to 75.0 kg/cap in Quthing. Paraffin is mostly consumed in Quthing and Mohale's Hoek where an average individual can consume up to 60.9 Ltr/cap and 57.5 Ltr/cap respectively in a month. Household income could be the main factor contributing to Quthing relying more on LPG and paraffin, as it has the share of 23.9% of the households earning 1600-3000 Maloti and 10.3% of the population earning 20000 Maloti and more.

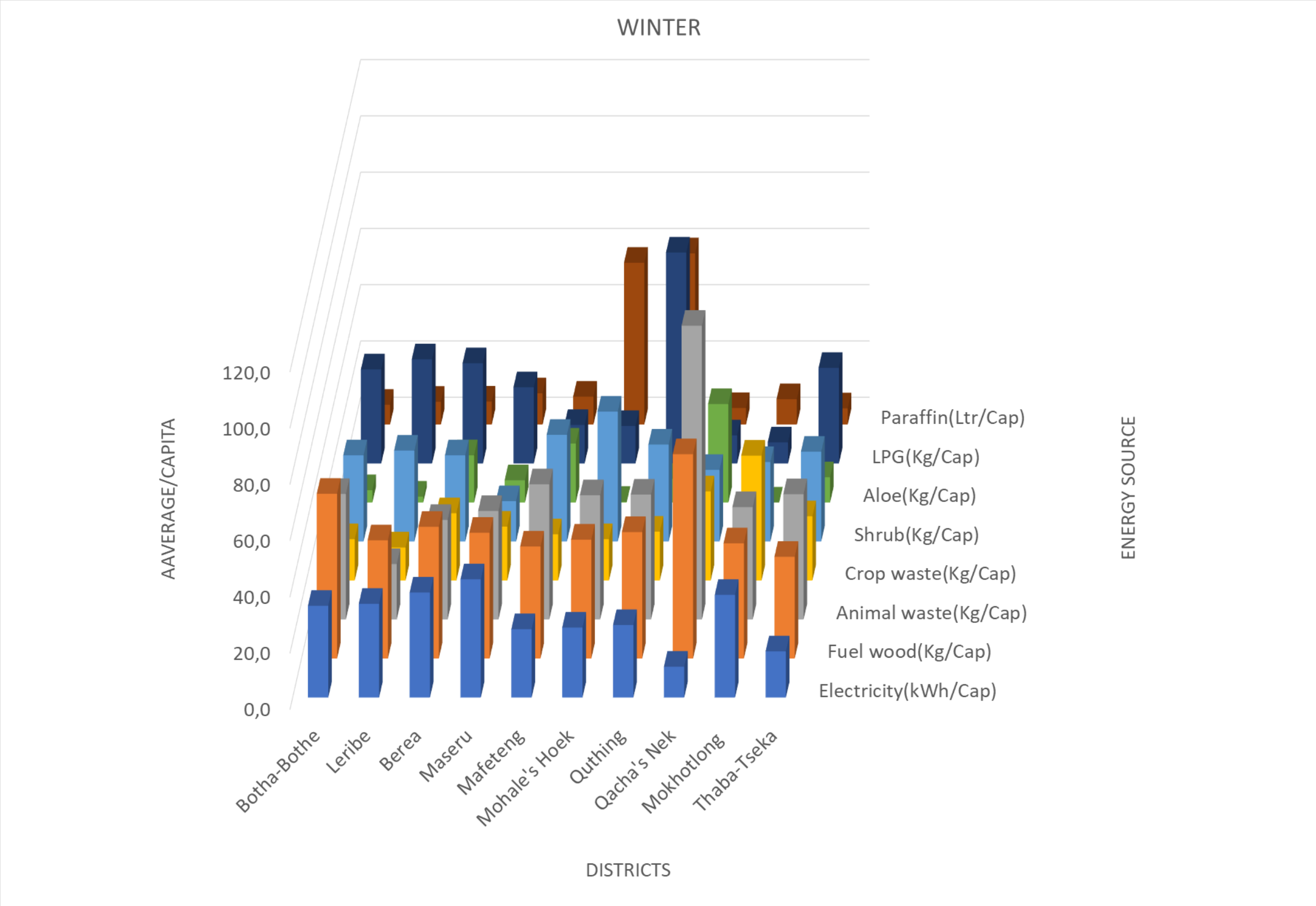


Figure 52: Monthly average energy consumption per capita in districts for winter

5 Conclusions and Recommendations

5.1 Conclusions

The household energy consumption analysis of the disaggregated HECS 2017 data in zones and districts concerns Lesotho's demography, household sizes (people per household), household area (dwelling size), household income levels, electrification rate, energy consumption penetrations, energy forms preferences, as well as determination of energy intensities by energy forms. These factors provide a comprehensive understanding of the living conditions and energy consumption patterns in both Lesotho's zones and districts. The observed variations were influenced by several socio-economic and geographical aspects which offer valuable insights on household energy demand patterns for policy-making, development strategies, and baseline values for future energy demand forecasting.

Population distributions across zones and districts indicate a significant concentration in the Lowlands with the highest share of 67.2% and the lowest share in the Foothills by 7.2% for summer months. In winter months, the Lowlands (62.4%) have a high share, and the Foothills account for the lowest percentage share of 7.1%. In the districts, the population share in summer months ranges Qacha's Nek (3.7%) to Maseru (25.6%), while in winter months, Maseru, Leribe, and Berea have a high share of 28.2%, 15.6%, and 13.3% respectively. Household sizes in zones is dominated by Lowlands in small household sizes which may be due to socioeconomic factors. However, the Mountains have the highest share of household size at 6 or more members per household. In districts, Maseru has a high percentage share at small household sizes, while in the districts such as Mokhotlong, Thaba-Tseka, and Qacha's Nek, has the larger households.

The household area in the zones is dominated by the Lowlands which take up the highest share of large household area. The households demonstrate a relatively uniform pattern among the zones with low shares in larger dwellings of 100 sqm or higher, especially in the Mountains. In the districts, there is also variation in the household sizes, though there is still a general pattern of fewer smaller houses. The households in the Lowlands earn more money and income variation of low spread compared to other zones, while the Mountains have a wide spread of household income level. Districts like Maseru, Berea, and Leribe have high income levels due to urbanization. The electrification rate is high in the Lowlands and lowest in the Foothills. This is influenced by steep slopes and the high cost on grid extension in the Foothills. The districts located in Lowlands (Berea, Maseru and Leribe) have high electrification share due to being closer to the national grid and cheaper installation cost, while those with low population density and low income have low access to electricity.

For household energy consumption for cooking in zones for summer months, Lowlands has the highest share of 93.7 % of electricity and the lowest share of 1.1% of wood in Senqu River Valley. The Mountains has the highest share of straw/shrub (60.5%). In winter months, electricity share decreased to 92.1% in Lowlands, while LPG (83.5%), paraffin (83.1%) and wood (55.0%) has the most share. The Foothills has no recorded share of electricity, and least share of LPG (1.9%). In districts during summer months, Maseru has a highest share of 50.7% of electricity, 39.4% share of paraffin and 38.5% share of LPG. Mokhotlong and Thaba-Tseka both have the lowest share of electricity (0.4%), and straw/shrub share of 17.7 % and 25.5% respectively. In winter months, Leribe and Maseru has the highest share of straw/shrub of 20.7% and 18.3% respectively.

In zones, energy share for water heating in summer months ranges from 0.1% of electricity in Foothills to 91.8% share of electricity in Lowlands. LPG is the second most consumed with a highest share of 84.0% in Lowlands and lowest share of Foothills (2.0%). Mountains and Senqu River Valley has the share of 12.1 % and 12.8% of wood respectively. In the districts during summer months, there is more variation in energy shares with Mafeteng having the highest share of animal dung (20.3 %). In winter months energy shares range from 2.7% of animal dung in Botha-Bothe to 32.8% of paraffin in Maseru. Other energy sources for cooking have the share of 11.8% in both Maseru, Mafeteng and Mohale's Hoek, with Berea taking the highest share of 29.4%.

For household lighting in zones during summer months, the Mountains and the Lowlands have the same share of rechargeable battery lamp (40.0%). Lowlands has the highest share of candle (70.2%) and paraffin (50.4%). In winter months, Lowlands has the highest share of 87.8% and the Foothills with the low share of 1.3% for electricity grid consumption. The foothills have the highest share of paraffin (75.0%), with the Mountains and Senqu River Valley having no share. In districts, Botha-Bothe has the highest share of solar lantern (25.9%) and the lowest share of electricity (1.2%). Most electricity is consumed in Maseru (42,9%) in summer months. In winter months, paraffin has a share of 40.0% in Mafeteng district, while Maseru takes a high share of 31.1% in grid electricity.

The percentage share of total energy consumption across zones in summer months reveals a distinct pattern, where the Lowlands leads in most energy sources like electricity (89.4%), LPG

(81.9%) and paraffin (77.2%). In winter months, Lowlands also dominates in electricity share, LPG and paraffin with 92.9%, 83.7% and 84.4% respectively. When comparing the total energy percentage shares between summer and winter months in districts, Maseru remains dominants in electricity consumption in both summer and winter months with a share of 50.3% and 51.3% respectively. Paraffin consumption decreases from 32.4% in summer months to 24.8% in winter months which indicates a shift to other energy sources. Overall, there is a noticeable increase in electricity consumption in districts located in Lowlands in winter seasons. The results show that areas located in urban setting have a high share of electricity, LPG and paraffin and the similar view is shared by [26], and indicates that larger households located in remote areas are less likely to consume cleaner fuels.

The monthly energy consumption in households across zones shows distinct patterns between summer and winter months. The variation in monthly average energy consumption highlights energy accessibility, income levels and seasonal energy demands. In summer months, Senqu River Valley consumes more electricity (122.6kWh/HH), this is likely due to highlighted larger household sizes and high-income levels, whereas Foothills consume least electricity (14.9 kWh/HH), and 222.9 kg/HH of fuel wood as an alternative energy source in Foothills is consumed more. Lowlands consume more electricity (126.8 kWh/HH), while Foothills show moderate reliance on LPG (33.8 kg/HH) and paraffin (45.0 Ltr/HH) for cooking. The Lowlands evince a significant shift towards modern energy sources due to better access and affordability. The monthly electricity consumption in the Foothills indicates low energy consumption which is below the lifeline tariff (30 kWh) by consuming only 14.9 kWh/HH in both summer and winter months. There is a diverse energy mix across districts, where in summer months, Quthing, Maseru and Mokhotlong districts lead in electricity consumption at 113.3 kWh/HH, 97.8 kWh/HH and 97.7 kWh/HH respectively. In districts during summer months, electricity consumption increases in most districts, with Quthing consumption decreasing to 25.8 kWh/cap. The LPG consumption ranges from 9.8 kg/HH in Thaba-Tseka to 20.4 kg/HH in Leribe, while the paraffin consumption ranges from 16.6 Ltr/HH in Thaba-Tseka to 65.3 Ltr/HH in Qacha’s Nek. Enhancing energy efficiency and implementing technologies in households can reduce electricity consumption thus reducing greenhouse gas emissions. These savings are achieved by minimizing the amount of electricity needed in households for enduse functions. When these measures are applied, they can contribute to significant reduction of energy consumption [43].

In winter months, middle income level districts like Quthing consume more LPG (75.0 kg/HH) and paraffin (173.4 Ltr/HH) for household cooking. This is in line with [20], which also indicated that middle class is positive and more significant to choose electricity, LPG and paraffin over traditional fuels for cooking. Moreover, energy consumption per capita shows a decrease in reliance to traditional fuels, but a noticeable increase in consumption of LPG and slight increase in paraffin in winter season. The results share a similar findings with [44], which indicated that the shares of biomass and kerosene (paraffin) have been decreasing with increasing urbanization in total per-capita household energy use (an emerging important driver of household energy demand), and these energy sources are replaced by LPG and electricity.

The analysis of household energy consumption across ecological zones and administrative districts of Lesotho provides insights into specific energy consumption patterns and penetration of different energy forms like Lowlands having access and high consumption share of electricity compared to other energy sources, while the Senqu River Valley and the Mountains rely heavily on traditional fuels due to geographical challenges. Low electricity access in remote areas suggests that improvements should be made to extend national grid and improve electrification rate in Foothills and Mountains, thus promoting clean energy use.

The variances in energy consumption in summer and winter months reflects disparities in household income level, household size and alternative energy sources access. This shows the importance of tailored energy policies that account for differences by considering the unique needs and challenges faced by zones and districts during Lesotho's energy planning.

The detailed consumption of traditional fuels as an example indicates potential for energy efficiency improvements, where introducing more efficient cookstoves and promoting energy saving practices in household could reduce the consumption of traditional fuels. For sustainability and transition to clean energy, the gradual shift towards modern energy forms indicates a positive trend towards clean energy. Lesotho should capitalize this by incentivising the adoption to renewable energy technologies in both rural and urban areas.

5.2 Recommendations

Based on the above study findings, to improve the household living conditions, access to energy and energy efficiency in Lesotho, the infrastructure and services must be improved in the rural areas of Lesotho (Mountains, Foothills and Senqu River Valley) to reduce the population densities in the metropolitan areas. The government can aim to improve the infrastructure in the Foothills and the Senqu River Valley where it is difficult to make a living due to the difficult terrain by investing in infrastructure projects to improve accessibility. Given low electrification rates in Foothills and Mountains and remote areas in each district, future research should examine the role of renewable energy such as evaluating the feasibility, cost effectiveness and potential impacts of decentralised renewable energy solutions. Also improve the use of renewable energy solutions, and promoted renewable energy technologies in areas where grid extension is a challenge. Government should focus on subsidies and public-private partnerships to reduce the cost of grid extension.

More focus on income-based programs like implementing agricultural projects in areas with fertile soils such as the Senqu River Valley to promote agricultural productivity and improve the standards of living and income for the households which will enhance energy affordability.

The patterns of energy consumption and other factors that affect energy consumption in the household are different in the zones and districts. Therefore, development of inclusive policies that addresses the needs of different zones and districts, depending on their unique characteristics and challenges can significantly provide their specific solutions to their needs. More households may be engaged in future surveys for more precise household energy consumption data and the shaping of productive uses of energy (PUE) programmes. To ensure that researchers, energy planners and the government make informed decisions based on precise data, it may be crucial in future to maintain disaggregated information consistency in household energy consumption survey across all the zones and districts, especially in the various energy forms. This consistency should be applied to all factors that contribute to energy consumption in the household sector to enable the determination of energy intensities and efficiencies which were not undertaken in this study as the data on energy forms was not disaggregated. This may enable an accurate forecast trends and meaningful conclusions.

Strategies that reflect true energy needs and consumption patterns of different zones and districts in the country may be developed.

In future to enhance data quality, longitudinal data collection on household energy consumption should be prioritized to capture the patterns over years, including seasonal variations, economic changes and technological adoption. Development of an updated comprehensive energy database which includes disaggregated data by zones and districts for Lesotho's energy consumption which includes more detailed information on energy sources would be a more valuable tool for policy makers and researchers. Moreover, household energy consumption patterns are influenced by socio-economic factors such as household income, size and urbanization. Models that account incorporation of these variables should be adopted to improve accuracy.

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