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SteamBioAfrica

Innovative Large-Scale Production of Affordable Clean Burning Solid Biofuel and Water in Southern Africa: transforming bush encroachment from a problem into a secure and sustainable energy source.

Deliverables: D9.1. Baseline report and analysis on local market and consumer profiles (Month 9)

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RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

HISTORY OF CHANGES

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1.0	6 June 2022	Section 8	Submitted
2.0	7 June 2022	Various	Inclusion of introduction, Ethics and Security and tables for figures in Tables and abbreviations
3.0	7 June 2022	Cover page	Inclusion EU logo with proper acknowledgement
3.0	02 April 2023	Summary	Inclusion of **Legal disclosure (**Disclaimer) in the section acknowledgements

ABBREVIATIONS

AFDB	African Development Bank
BWP	Botswana Pula
BITRI	Botswana Institute for Technology Research and Innovation
CSIR	Council for Scientific and Industrial Research
DMR	Department of Mineral Resources
FBE	Free Basic Electricity
GDP	Gross Domestic Product
GOB	Government of Botswana
GWh	Gigawatt hours
IRP	Integrated Resource Plan
IRENA	International Renewable Energy Agency
IPP's	Independent Power Producers
kWh	Kilowatt Hours
LPG	Liquefied Paraffin Gas
LSD	Least Significant Difference
MW	Megawatt
MMEWR,	Ministry of Minerals Affairs Energy and Water
MWh	Megawatt Hours
N$	Namibian Dollar
NUST	Namibia University of Science and Technology
N-BiG	Namibia Biomass Industry Group (
PV	Photovoltaics
RE	Renewable Energy
RET's	Renewable Energy Technologies
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
RISDP	Regional Indicative Strategic Development Plan
SAS	Statistical Analysis System
SADC	Southern African Development Community
SAPP	Southern African Power Pool
SDG	Sustainable Development Goals
UN	United Nations
WHO	World Health Organisation
WP	Work Package
WB	World Bank
ZAR	South African Rand

ABSTRACT

Most households in developing countries do not have access to clean cooking and heating energy, owing to inadequate access to energy grid, old and inefficient energy infrastructure, remoteness of most of the rural areas that are off grid, including lack of capacity for these developed countries to invest in renewable and sustainable energy sources. These communities often resort to the use of fuelwood to cook under open fire conditions. Through Super-Heated Steam (SHS) technology there is potential to harvest and convert bush encroachment into safe and sustainable renewable energy that would provide cooking and heating energy to the benefit of these unconnected households and those who cannot afford other energy sources.

This report presents the results of the baseline market assessment for solid biofuel produced through Super-heated Steam (SHS) process from bush and other woody biomass in the domestic household sector. The survey identifies factors that could influence consumer behaviour and market acceptance of this fuel in Botswana, Namibia, and South Africa across rural, urban, and peri-urban areas.

Survey questionnaires were administered to one hundred and ninety-eight (198) household in urban, peri urban and rural areas of Botswana, Namibia, and South Africa to collect socio economic characteristics and energy consumption patterns of these households, with a view to identify factors that influence energy consumption. This information will be used to develop energy consumer profiles in these countries.

The results show that communities in the study areas use a mix of energy sources, and that they would be interested in trying out proposed solid biofuel energy source as long as they are efficient, affordable, and environmentally friendly. The respondents were however not prepared to pay for participation in the trial for the proposed new biofuel.

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1 OVERVIEW

1.1 Introduction

This report is deliverable 9.1 'Baseline report and analysis on local market and consumer profiles' under Work Package 9 (WP9) of the SteambioAfrica project. It provides an analysis of the socio-economic characteristics of household energy consumption in Botswana, Namibia and South Africa, to create an understanding of consumption preferences and potential for biofuel use.

Energy is an important driver of economic development, and improved quality of life (World Bank, 2019). However, access to these important energy sources is not universal (Muhammad Imran 2016). While sub–Saharan Africa has abundant energy resources, it has not been able to meet the growing energy demands of its growing populations. The inability of the region to meet its energy demand is due to lack of technical capacity to exploit the abundant resources fully (United Nations (UN 2015; African Development Bank (AFDB, 2017). Nevertheless, energy production and accessibility vary across the region (AFDB 2017) and is not meeting consumption requirements of its nations.

At 181kWh per annum, energy consumption in Sub Saharan Africa is the lowest in the world for instance, 6,500kWh in Europe and 13000kWh in United states of America. Energy shortages and associated bottlenecks such as inadequate grid infrastructure, ageing electricity generating plants and energy loses and planned load shedding undermine economic growth, employment creation, investment, and quality of life (AFDB, 2017). These inadequacies have resulted in great economic losses for the commercial and industrial sectors in most African countries, for example, South Africa reports that planned power cuts in 2021 were expected to reduce the 2021 GDP growth 3% points and cost the country approximately 350,000 jobs, while in Tanzania and Ghana 15% in the value of sales is expected to be lost due to power outages (The Conversation, 2022; AFDB 2017). The World Energy Trilemma Index, (2020) places Africa in the lower half of the global energy rankings. With rankings scores for Botswana, Namibia and South Africa being as per Table 1. World Energy Trilemma Index ranks energy performance of countries on the three dimensions; namely security, affordability**,** and equity and makes recommendations on policy improvement to facilitate increased access(https://trilemma.worldenergy.org).

Table 1. Energy trilemma rankings for Botswana, Namibia, and South Africa

Country	Score	Security	Equity	Sustainability	Population	Area / sq. km
Botswana	59.2	98	79	68	2.3 million	566.7k
Namibia	58.3	95	90	23	2.5 million	822.3k
South Africa	62.1	73	69	83	56.7 million	1213.1k

While commercial and industrial users in developing countries may offset some of the negative impacts of energy insecurity through secondary backup supply such as diesel generators, poor rural households in developing nations such as South Africa, Namibia, and Botswana struggle to meet their everyday basic energy demands for heating and cooking. This struggle is especially insurmountable for the poor rural households who live far away from secure and reliable grid connection. Regional access to grid-based electricity within Southern African Development Community (SADC) was reported to be 48% overall, with urban areas connection rate at 75% while rural areas were at a paltry 25% overall. Electricity access in the three member states in question is reported as follows: South Africa at 86% nationally (urban areas 93% while rural areas stood at 68%), Botswana at 61% nationally, 78% urban and 37% rural and Namibia at 56% nationally (urban 77%, rural 29% (REN21, 2018). In these poorer and rural communities, where electricity is not an option, households rely mostly on firewood to make open fires for cooking and space heating. The use of open fires for cooking and heating is associated with a myriad of health problems across Africa (World Health Organisation (WHO), 2015; Cédric Philibert, 2022; Onyinyechi et. al. 2020). The African Development Bank (2017) notes that this lack of access to energy shows up as hundreds of deaths annually among those who use open fires, putting pressure on limited hospital resources, compromising educational attainment, and driving up the cost of doing business. WHO 2018) estimated an annual mortality of more than half a million people in sub–Saharan Africa, comprising mostly of women, children and the elderly associated with indoor air pollution from the use of fuel wood for cooking. Lack of clean energy for cooking and heating also affects school performance, as children either go to school hungry or they spent more time searching for fuel wood rather than studying (Pallavi et. al 2021).

The exploitation of renewable energy resources offers great opportunity for developing countries to meet the energy deficits of their people, especially those in the rural areas without compromising environmental or human health. Increased access to clean renewable energy is therefore a move towards improving quality of life, saving lives and a leap towards inclusive growth as it creates opportunities for women, youths, and children both in urban and rural areas. The negative impacts of energy insecurity and the unsustainability of fossil fuels to generate energy have brought to the forefront the untapped potential of available renewable energy resources within the SADC region and the world at large. Since 2015 the SADC region has seen an increase in the number and quality of its renewable energy and energy efficiency policies, demonstrating a growing commitment to renewable energy and energy efficiency. This commitment is demonstrated by the growth and investment in renewable energy projects, programmes, and policies. across the SADC countries, as demonstrated in the SADC Regional Infrastructure Development Master Plan (2012), SADC Regional Infrastructure Development Master Plan 2012, SADC Energy Sector Plan (2012), SADC Protocol on Energy 1996,

Regional Indicative Strategic Development Plan (RISDP) (2001). While these commitments are good in terms of bringing the renewable energy debate to the table, the scale and speed at which energy is provided has not been demonstrable of the intentions. The slow progress has been due for the most part to insufficient innovations and appropriate financing for these bankable projects, appropriate policy and regulatory environments, pricing incentives and coordination (AFDB 2017).

The Africa energy outlook (2019) notes that while Africa has the richest solar resources on the planet, it has only installed 5 gigawatts of solar photovoltaics (PV), accounting for less than 1% of global capacity. Shikangalah and Mapani, (2020) observe that bush encroachment responsible for the degradation of land across Southern Africa is a potential biomass resource. Harvesting and processing of this resource can reduce its negative socio ecosystem impacts and provide sustainable energy resources when the right technologies are used.

While renewable energy technologies (RET's) offer great potential for investment and improvement of household energy access to remote rural areas; their value proposition differs. Hydropower plants require massive capital investments, long lead times and have significant environmental impact. Most of Botswana and Namibia is arid deserts that have no hydropower investments, and with limited resources and the region increasingly suffering from regular and prolonged droughts, hydropower is uncertain (especially amid climate change) and unreliable, hence investment into it will not solve the problems associated with coal-based energy sources such as electricity (IRENA and AfDB (2022). Solar and wind are variable and intermittent sources of energy can also be intermittent owing to weather conditions, requiring investments into back up power plants / batteries and technical knowhow. It is also important to note that while lower than those of hydro power, initial investments in solar can also be high although they have been reducing in the last 10 years. However, as a renewable energy source, biomass can provide cooking or heating energy on demand, as opposed to solar where the energy could easily be intermittent.

Renewable energy technologies for processing of biomass through technologies like superheated steam by Steam Bio Africa promise to adapt, and tailor previously tested and readily scalable biofuel production technologies to provide sustainable, affordable, secure, and clean burning biofuel in the region. Renewable energy can also reduce susceptibility to the risks associated with movements in the price of fossil fuels and cross-border supply chains, as experienced during the Covid-19 pandemic and currently due to geopolitics. The EU Horizon 2020 SPIRE PPP Innovation Action SteamBio (Grant Agreement No: 636865) has been identified as an enabling innovative technology that has the

potential to stimulate the harvesting of bush encroachment and converting it into clean sustainable fuel using a processing technology known as superheated steam (SHS) processing. Through this technology the project seeks to resolve social, economic, and environmental problems associated with bush encroachment by transforming the encroachment into a sustainable and secure clean bioenergy source.

1.2 The Market Assessment Baseline Survey

The Steam Bio Africa project seeks to provide an alternative to the current energy sources for domestic households living in off-grid communities in the three countries with the superheated steam processed biofuel. The proposed energy source is set to be transformative. However, introducing an alternative product in the market is more than just promoting its positive traits over and above those of existing products (Bruner and Pomazal, 1988; Ganesan et al., 2011). The decision often is based on a lot more factors than the good aspects of the proposed alternative.

Introduction of a new products, such as the proposed solid biofuels produced under the superheated steam (SHS) technology involves huge amounts of capital investments. Steam Bio Africa commissioned a baseline market assessment study with potential users, both domestic households and what to understand the market it wishes to enter. Investors need to inform themselves of the interests of the intended consumers of the product, beyond just highlighting its positive traits. It is therefore important to understand the product value system of the intended consumer. It is for this reason that under Work Package 9 (WP9) Task 9.1: the project undertook Baseline Survey market research to explore the energy needs of the household consumer market and establish the gaps therein, with a view to exploit any opportunities that the solid biofuel produced on the SHS offers an alternative to existing energy resources for communities off grid.

1.3 Objectives of the Market Assessment Survey

The objective of the baseline survey is to assess the potential market for solid biofuel produced by the SHS process from bush and other woody biomass in the domestic household sector. This survey identifies factors that could influence consumer behaviour and market acceptance of this fuel in Botswana, Namibia, and South Africa across rural, urban, and peri-urban areas.

1.3.1 Specific Objectives

- Assess the domestic households market potential for the SHS biofuel demand, in the three countries (Botswana, Namibia, and South Africa).
- Collect diverse social and economic information from consumer in these countries to understand.
    - Energy-consuming activities: cooking, heating, lighting, production
    - Fuels used / preferred, monthly energy consumption.
    - Buying patterns and habits: preferred channels, informal sources
    - Income levels, and relation to the energy consumption and buying capacity.
    - Social status, informal / formal position in local society (micro-level)
    - Consumer preferences and requirements, fuel quality and quantity
    - Tradition-related lifestyles influencing local energy consumption, outdoor kitchen, indoor kitchen with or without cook stoves.
- Collect socio-economic information which will be disaggregated by gender, age, and location.
- Develop energy consumer profiles indicating patterns along with associated barriers and opportunities.
- Identify effective means and strategies to commercialise biofuel for each consumer group

2 MATERIALS AND METHODS

The overall data collection was coordinated by Botswana Institute for Technology Research and Innovation (BITRI) while Ekasi Energy (Ekasi) was responsible for on the ground data collection in South Africa and Namibia University of Science and Technology (NUST) and Namibia Biomass Industry Group (N-BiG) for Namibia. The survey consisted of a cross-sectional household survey carried out within two weeks in the three countries. Stratified sampling was used to select study areas or localities.

2.1 Ethics and Security

The report was prepared in compliance with the project's ethics standards as stated in Work Package 13 deliverables, specifically regarding protection of personal data and, to obtaining informed consent by survey participants.

2.2 Study Area Profile

The baseline survey was carried in the three Southern Africa countries of Botswana, South Africa, and Namibia (Figure 1) during the month of February 2022. The three countries share borders and have a combined population of over 60.8 million people. These are stable middle-income democracies, with very high-income inequalities as demonstrated by the GINI indices as follows; South Africa 0.632, Botswana 0.605 and Namibia 0.633 (World population review, 2020). In the scoring system 1.0 is “perfect inequality” and 0.0 is “perfect equality” In all three countries unemployment is high in rural areas, especially for youths and for households headed by women (World population review, 2020).

Figure 1. Study Area

Source https://www.alamy.com/stock-photo-southern-africa-region-political-map-southernmost-region-of-african-174771104.html

2.3 Country Energy Profile

2.3.1 Botswana

Energy consumption in the country is mostly dominated by electricity, coal, diesel, liquefied paraffin gas (LPG) and wood. Solar, biogas, and biodiesel constitute a small proportion, of about 1% (GOB, 2021). The country's installed electricity generating capacity stands at 893.3 MW, comprising 600 MW from Morupule B (coal-fired), 132 MW from Morupule A (coal-fired), 90 MW from Orapa power plant (diesel peaking plant), 70 MW from Matshelagabedi power plant (diesel peaking plant), (MMEWR, 2017b) and 1.3 MW from Phakalane solar photovoltaic power plant. These plants together have an operating capacity that can cover peak demand – which is estimated at 610 MW, enough to meet the demands of all areas connected to the grid, and although the country provides subsidized access to electricity, generation deficits often result in shortages and lack of electricity in some areas (Bader, 2017). All these plants have not operated at full capacity since 2018 owing to infrastructure challenges (GOB, 2021) with a reported electric power transmission and distribution losses of 79% (WB Statistics). The inefficient transmission and distribution of electricity affects mostly rural to remote areas. Fuel wood usage has been declining over the years while LPG and electricity consumption has been on the rise (IRENA, 2021; World Bank, 2017a).

The shortfall in electric energy in the country is met through imports from South Africa and Zambia. In 2021, South Africa supplied 65.1% of electricity in Botswana, while the Southern African Power Pool (SAPP) provided 22.1%, and the remaining 7.4 and 5.4% were sourced form Namibia and Cross border electricity markets. The cross-border electricity markets are a system where neighbouring countries within SADC supply electricity to the remote villages of a neighbouring country (Statistics Botswana 2021).

Just over half of Botswana's population (65.3%) had access to electricity, with rural and urban areas standing at 72% and 65.3% respectively. Household energy consumption stands at 31,2 %, the second most consuming sector after commercial sector (33.7%) (Statistics Botswana 2018).

There is a growing trend on the use of LPG in Botswana 70 % of households in urban areas using it for cooking. Despite the growing trend in its use, poor rural households are still not able to afford it and continue to use fuel wood for cooking and heating. A reported 53% of rural households still use firewood for cooking and heating (Statistics Botswana 2021, Danish Energy Management & Esbensen; 2017). Households in rural areas still use fuelwood as a source of energy, accounting for

approximately 43% of the country's primary energy needs and 38% of total overall energy consumption (Department of Energy 2019).

The use of renewable sources of power is low in Botswana. This could be due to the abundance of coal resources, which are estimated at about 212 billion tonnes amounting to 66% of the resources in Africa (GOB, 2021). Therefore, the market for renewable energy is still at infancy and need to be developed. The government emphasis on coal fired production, given the abundant resources, coupled with subsidies on electricity may be hindering investments into renewable energy especially solid biofuels. Nevertheless, the lack of use of charcoal in households except for recreational purposes such as barbeque may imply that the use of LPG and electricity is cultural driven and therefore concerted effort might be needed in marketing an alternative fuel source. Several attempts have been made to introduce energy efficient wood stoves since the mid-eighties, but communities did not take them up (Botswana Biomass Energy Strategy 2009).

2.3.2 Namibia

With no indigenous sources of oil, coal or natural gas, Namibia's total primary energy supply mix is dominated by imports. The sustainable development goal energy indicators (2018) describe the country as energy insecure. According to the Namibian Ministry of Mines and Energy, the country gets its limited energy supplies from petroleum, coal, solar and hydropower and augments the gap in domestic electricity supply with imports (73%) from the region, mainly from South-Africa, Zambia, and Mozambique (2018). The country has an energy installed capacity of 332MW hydro, 120MW coal & 24MW diesel, 70MW Refit programme (Ileka 2019).

The World Bank global electrification database from "Tracking SDG 7 (2020) noted that the population with access to electricity in Namibia was 56.26 %, with access distribution between urban and rural areas at 74.7% and 36. 3% respectively. The Electricity Control Board of Namibia (2017) estimates that on average domestic consumption per household in Namibia has increased with 0.7% from 4.14 MWh per customer in 2015 to 4.17 MWh per customer in 2016. While annual national energy consumption for all sectors combined was between 2018 – 4285 GWh.

According to International Renewable Energy Agency (IRENA 2021) the proportion of electricity generated in the country is as follows; 62% from oil resources, 36%, from renewables and 2% from

coal. The renewable energy mix comprises of 70 % bio energy, 23% hydro and 6% solar energy (IRENA 2021).

The SADC Renewable Energy and Energy Efficiency Status Report (Geoff S. et. Al 2018) states that 79% of the population without access to electricity resides in rural areas, which are usually sparsely populated. These population is usually off grid and does not have access to electrical infrastructure, or the financial capability to access alternative energy sources like solar or bush to electricity energy available to those who can afford. The sparce populations and remoteness of the rural areas without access to electricity presents challenges to potential investments in alternative energy sources, especially renewable bioenergy sources that offer great potential for off-grid populations (EEP S&EA Energy Market Landscape Study, 2017).

To address these problems the country has made its commitments clear through several legislation including the National energy policy (2017) which seeks to enhance access to secure, affordable, accessible and sustainable modern energy to its population. These commitments are further espoused in the National Renewable Energy Policy (NREP, 2017) which targets 70% additional electricity generation from renewable sources by 2030, while the National Integrated Resource Plan (NIRP, 2017 recommends a generation of up to 700 MW of Renewable Energy (RE) mostly from solar PV, wind & biomass.

2.3.3 South Africa

According to Statistical Review of World Energy (2017), South Africa accounts for 30%- 40% of all energy consumed in Africa, the highest in the continent (Eskom, 2019). South Africa has large coal reserves (66.7 billion tons), making it the 5th in the world (DMR, 2016), which explains the domination of the energy resource base by coal. In their analysis Joanne Calitz and Jarrad Wright of Council for Scientific and Industrial Research (CSIR, 2021) estimated that coal energy contributed 83.5% of all energy in South Africa, renewable energy contributed 10.5% while nuclear contributed 5.2% and remaining was form diesel (CSIR analysis, Eskom, 2021). Only 0.1% of the renewable energy is from biofuels (Olusola, et al. 2021). Approximately 95% of the urban population is connected to the grid, while the proportion for rural areas is 92% (Africa Energy Fact sheet, 2021). While most households using electricity are connected directly to the grid, about 3.6% access electricity via alternative means such as neighbour, or an illegal connection (0.4% of households). A very small proportion of households produce their own electricity with solar systems. In 2016, households accounted for 8% of all energy consumed in south Africa. Consumption was spread through an energy mix made up of

72% electricity, 19% renewable energy sources while petroleum and coal accounted for 5% and 4% respectively (South-African-Energy-Sector-Report, 2019).

In addition to the widespread access to electricity by households in South Africa, and the receipt of 50 kW of free electricity by low-income households every month under the Free Basic Electricity (FBE) policy (2003) there is still widespread use of fuelwood and paraffin for cooking and heating (Bohlmann. et al., 2018). This situation could be an indication that electricity is not viewed as a substitute to traditional energy sources but a compliment. However, it could also mean that these households cannot afford electricity beyond what they are offered, raising the need to supplement with energy that is accessible through either free or cheaper sources. These often-poor rural households therefore continue to rely on energy that presents health hazards (Department of Energy South Africa (year), Electrification Backlog, 2017 and Statistics South Africa, 2012).

In to reach complete access to clean energy for its population especially the country's poorest, South Africa continues to make commitments to provide access to cleaner and safer forms of energy to those left out. This is demonstrated through the creation of an environment conducive to facilitating investment into renewable energy sources that includes the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP). The programme seeks to encourages private-sector participation in the electricity industry through availing to them the platform to generate a capacity of 30% power, against Eskom's 70%. This would inject additional power into the electricity system from wind, solar, photovoltaic, concentrated solar power (CSP), biomass and small hydro technologies by independent power producers (IPP's) enabling the country to meet demand (IPPPP An Overview, 2019). The preferred energy mix up to 2030 was developed by the South African Integrated Resource Plan (IRP, 2010; South-African-Energy-Sector-Report.2019).

2.4 Sampling Approach

Enumeration took place in urban, peri urban and rural locations of the study countries. These locations represented different socio economic populations by economic status.

2.4.1 Criteria for selection of households

Once enumerators were in the locations (urban, peri urban, or rural), a random household was selected for questioning, starting from randomly selected first household; enumerators would

systematically select every third household for enumeration. Where enumeration could not commence for any reason, i.e., the person available for questioning is below 18 or is unable to answer the questions, either because they do not typically live in that household or they were just not willing to participate in the survey, the enumerators then moved on to the next household to enumerate and then follow the system of selecting the third household again. The following criteria were used to help select respondents within the selected localities.

2.4.2 Profile of respondent within the household

Once a household was selected for enumeration, the respondents had to satisfy the following profile

1. Should typically be a member of that household
2. Should be 18 years old or above
3. Should be willing to be interviewed.

2.4.3 Sample size

The study focused on a sample size of 60 households in each country with 20 households for each social strata (low, medium, and high-income) for urban, peri urban and rural areas.

2.5 Data Collection

Data collection was undertaken through household surveys using semi structured questionnaires (Appendix 2). The questionnaire employed both open and closed questions to collect data. Thus, obtaining both qualitative and quantitative data. The questionnaire was then pretested in the three countries for further refinement before being administered.

2.6 Data Entry and Analysis

As data entry was coordinated by BITRI and analysis performed by a statistician under BITRI supervision, BITRI researchers and the statistician designed the data capture spreadsheet template used for data collection in the three countries. Each data column (the variables for analysis) in the worksheet was mapped to the corresponding question of the questionnaire. In the case of questions with multiple options, each option had a separate data column to enable all data to be captured (Table 2). The standardized data entry systems and database structures were shared with partners in South Africa and Namibia for data entry.

The raw data from closed-ended questions of the questionnaire were then subjected to frequency analysis (descriptive statistics) and the chi-square test of goodness of fit and of independence using SAS (Statistical Analysis System) version 9.4 (2020) for the categorical variables for each country. The results of the analysis were populated into standardized tables created based on the questionnaire. For age, the ages of respondents were first grouped accordingly e.g., into Youth and Adult categories, and frequency analysis and chi-square tests done on them. The chi-square test excluded all counts shown under Not stated in the tables as these were treated as missing values or non-replies. The quantitative data analyses were conducted on data for each country and then the three combined.

A comparison of genders, and the three location types i.e., urban, peri-urban, and rural for the variables ages of respondents, amount spent, and quantity of biofuel was done using the statistical analysis of variance (ANOVA) and the means separated using the t-test or LSD (Least Significant Difference). Level of significance for all inferences of statistical tests was $\alpha = 0.05$. The p-value and degrees of freedom (df) for each test (if valid) is shown at the bottom of each table. If p-value is less than 0.05 then the classes/categories are significant.

In some of the tables, the minimum and maximum values of the quantity and cost of biofuel were presented instead of averages (means) as there was a lot of variation among data values, and that most respondents did not respond to some of the questions. The mean was deemed as misleading and thus the lowest and highest values were reported in the tables. The range aims at giving one the market profile of the respondents.

3 RESULTS AND DISCUSSIONS

3.1 Response Rate

This chapter shows the results from the market research, it covers the respondents and household socio economic characteristics, sources of energy, energy consumption activities, buying patterns, habits, energy decision making behaviours, preferences, and requirements.

Table 2 reveals that a total of 198 households' interviews were conducted across the three countries, with 99 household interviews conducted in Botswana, 60 in Namibia and 38 in South Africa.

Table 2. Target and actual Sample size, response rate for the Household survey

Country	Target Sample Size	No. of household interviews completed	Household response rate (%)
Botswana	60	99	165.0
Namibia	60	60	100.0
South Africa	60	39	65.0
Total	180	198	110.0

*Response rates above 100% are indicative of the extra interviews conducted in Botswana.

3.2 Respondents' Socio-Economic Characteristics

Table 3 provides a snapshot of the respondent profile; it shows the socio-economic characteristics of respondents for all the three countries combined. A total of 199 (100 in Botswana, 60 in Namibia and 39 in South Africa) households were surveyed, representing 2% of 60.203 million inhabitants of the three countries combined. An almost equal amount of male (48%) and females (50.51%) responded to the questionnaire. The distribution is almost representative of the gender ratio in the three countries which ranges from (94.8 – 97.8%).

There was a good distribution of age groups in the sample size. The respondents sampled depict a mix of education statuses across the study area, ranging from no education to university level. The sample in Botswana had more respondents with a university degree (27.27%, while Namibia had a higher % of respondents with secondary education. These two figures push the education status of respondents to above secondary school.

The sample shows a high percentage of unemployment among respondents (31.31%). A small percentage of respondents derive a living form agriculture (4.04%). While 26.26 % of the total respondents in the three countries had formal employment. The proportion of respondents with formal employment is higher in Botswana (76.9%), followed by South Africa at 13% and Namibia at 9.6%. Total combined household income for households that responded varies greatly from below BWP/ZAR/N$ 1000 (USD10) to a little above BWP/ZAR/N$ 25000 (USD 2500). Most of the respondents were single in all the three countries (63.64%), followed by those in a civil marriage (15.15%) and customary marriage (8.08%). Most of the households interviewed either lived in an urban area or peri urban area (63.64%), with only 36.356% living in rural setting.

Among the sampled population across the three study areas, fifty-five percent of the interviewees affirmed that they were household heads. Botswana had the highest number of head of households responding to the questionnaire. The time of the day or week the households were visited could be a reason why the percentage for head of house is this low. Most heads would have been at their places of employment or business. The 44% respondents who were not head of household, had no direct relationship with the head of household (in southern Africa most people who are left at home during the day, which was the time during which the survey was conducted, are employed house helpers).

Table 3. Respondents Socio Economic Characteristics

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Variable	Sub Variable	Botswana	Namibia	S. Africa
Gender	Male	45	61.7	38.5
	Female	54	38.2	61.5
Age	Under 20	3	8.3	2.6
	20- 30	49.5	25	23.1
	31- 40	29.3	23.3	35.9
	41-50	6.1	8.3	23.1
	50-60	0	10	10.5
	60 +	0	25	5.13
Education Level	None	1.52	0.51	0.00
	Primary	3.54	7.58	0.51
	Secondary	7.58	16.16	7.07
	College	9.60	1.01	1.52
	University	27.27	5.05	1.01
Main Econ Activity	Formal Employment	17.2	6	18
	Informal Employment	18.2	16.7	10.6
	Own business	0	7	2.6
	Farming/Agriculture	21.2	40	43.6
	Unemployed	3	8	7.7
	Other	17.2	6	18
Total Combined Income (USD)	Under 1000	2	23.3	0
	101-500	8.1	15	0
	501 -1000	11.1	26.7	18
	1001- 1500	16.2	8.3	38.5
	2500+	30.3	11.7	18
	Chose not to Answer	32.3	15	23.1
Marital Status	Single	60.6	66.7	66.7
	Civil Marriage	18.2	13.3	10.3
	Customary Marriage	5	11.7	10.3
	Cohabiting	7.1	3.3	7.6
	Other	8.1	5	5.1
Head of Household status	Yes	51.5	55	64.1
	No	47.5	45	35.9
Relationship with head of Household	Husband	51.5	55	64.1
	Wife	33.33	29.29	14.14
	Partner	1.01	0.51	0.51
	Other	0.51	0.00	0.00

Overall, the sample has more respondents between the ages of 20 and 40 (Figure 2). Less than 10% of respondents in the sample are between 18 and 20 years of age. With Botswana having about 52.5% of respondents in the youth ages of 18-30 years while Namibia has the highest proportion (25%) of respondents' above 60 years of age and South Africa has a higher proportion of respondents aged between 41- 50 years.

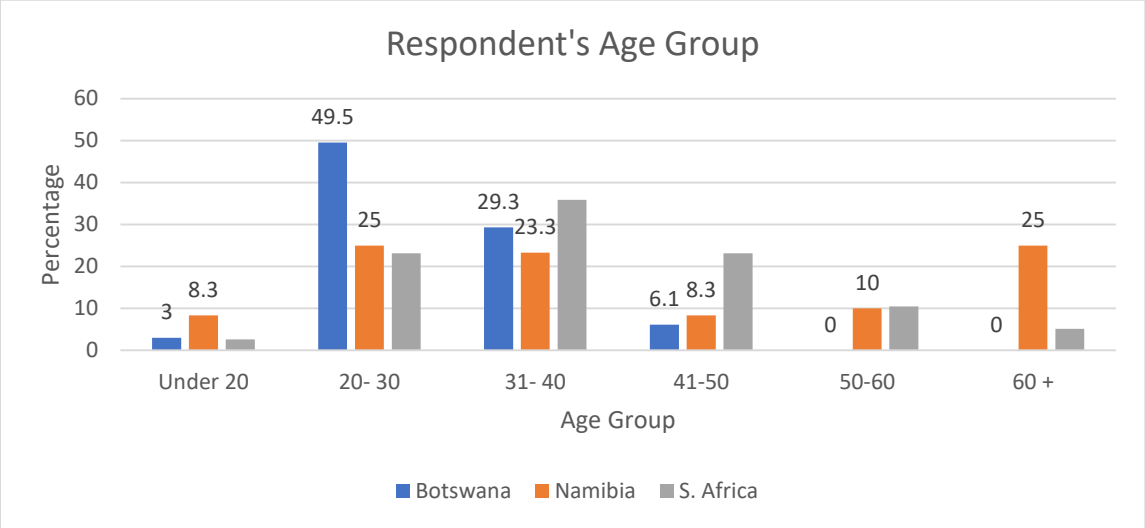


Figure 2. Respondents Age group distribution across the study area

The gender representation of the sampled households is represented in Figure 3. South Africa has more females (61.5%) in the sample, while Namibia has more male (61.7) respondents. Botswana has 54% female respondents. As indicated above the overall gender representation for the study area is (48%) male and (50.51%) females, a distribution that is almost representative of the gender ratio in the three countries which ranges from (94.8 – 97.8%). However, the data shows a marked difference in gender representation within the countries.

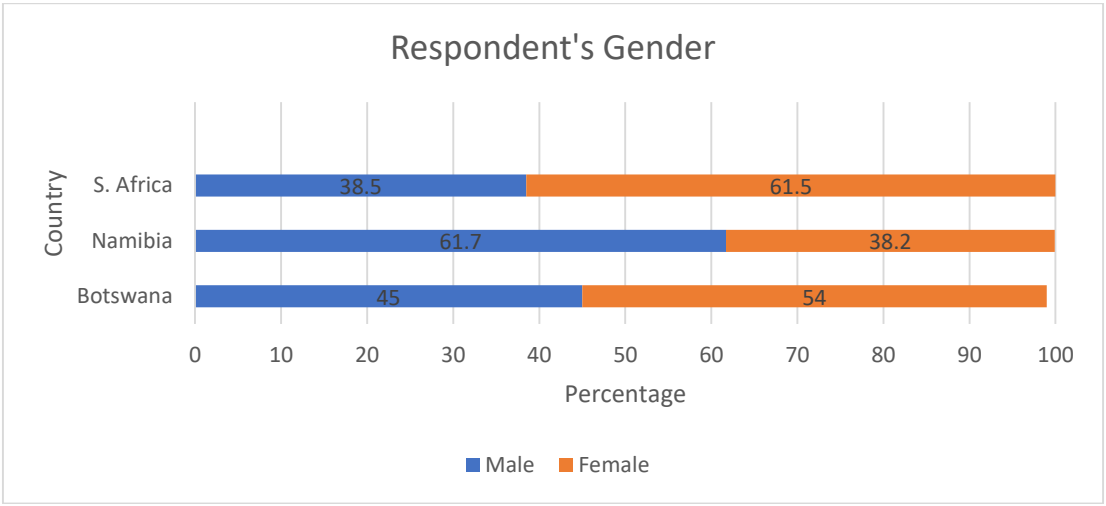


Figure 3. Respondents Gender

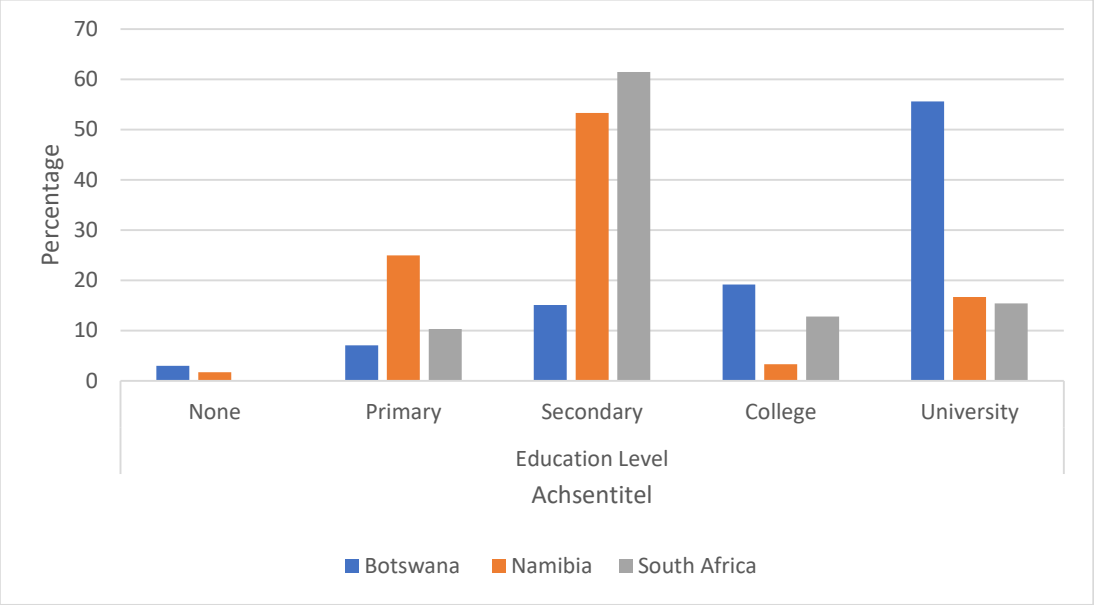


Figure 4. Respondents Education Level

Figure 4. shows that educational level of respondents in the three countries is high, with above 75% of the respondents having attained secondary school and higher. Education is reported to be the second most important factor that determines choice of energy used in the household (Semenya. et. al., 2016). For example (Al-Subaiee 2016) noted that households with university educated respondents prefer electricity to other forms of energy while respondents with lower education status tend to use firewood and biomass-based energy sources. Generally, as education levels rise, income levels may rise, influencing access and affordability of the more modern cleaner energy sources. Education is reported to have the same effect in the move from solid to non-solid biofuels (Chen et al. 2016). There is a difference in the respondents' level of education across the countries, with Botswana having a higher proportion of university educated respondents that the other two countries. As stated above by Al-Subaiee (2016 and Chen et al 2016) it is expected that while generally respondents in the study area would prefer the more cleaner energy sources like electricity and gas, this would be more the case in Botswana than the other Namibia and South Africa.

3.2.1 Economic Activity

Economic status can be used as an indicator of affordability of energy sources. It provides information on the economy of the household, indicating the ease or difficulty with which households could access energy resources. Figure 5 shows percentages of the respondent's employment status/ economic activity.

Overall, the respondents are engaged in several economic activities, such as formal employment, informal employment, own business, and agriculture. However, there is a high proportion of

unemployed respondents. The high unemployment proportion would mean these respondents would find it hard to access modern, clean energy sources like electricity. This would also mean there could be affordability issues in affording the proposed alternative energy source. That the data collected closer to urban areas returned such a high proportion of unemployed respondents, could signal an even higher unemployment in the distant rural areas, where employment opportunities are even lower, owing to very little economic activity besides agriculture. Urban areas generally have higher opportunities for productive employment and higher household incomes than rural areas (ILO, 2008; DEFRA., 2019). Thus, it can be expected that affordability will be lower at the rural areas. The implication for the proposed alternative fuel therefore is that it has to offer lower costs, for it to be affordable.

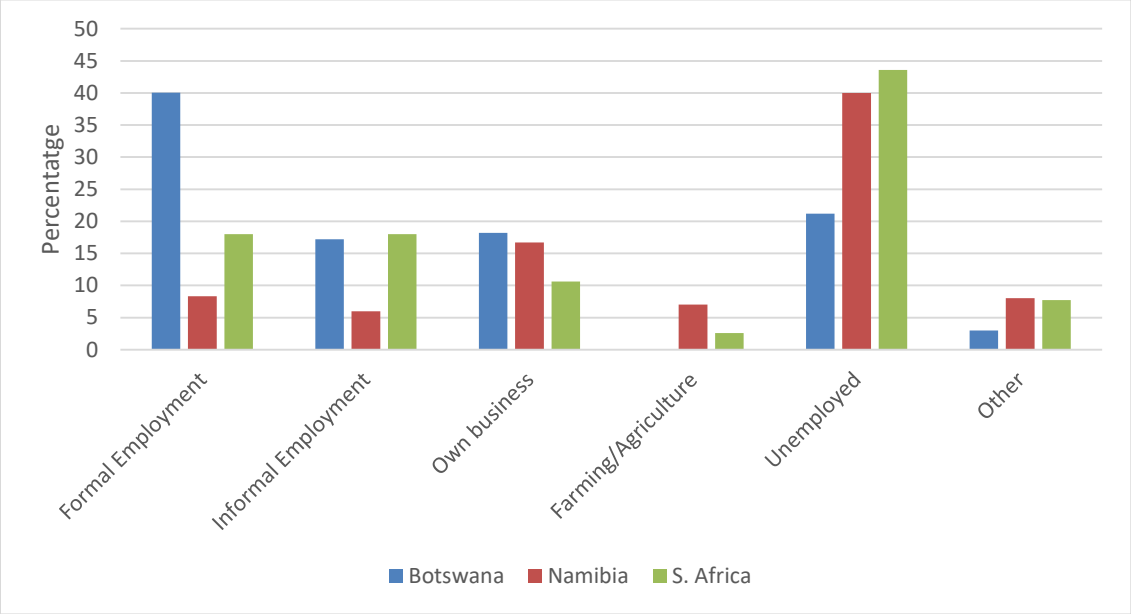


Figure 5. Respondents Main Economic Activity

3.3 Household Characteristics

3.3.1 Household Location

Literature indicates that household characteristics are an important determinant of household energy type, use and consumption. For the most part household energy consumption will vary with varying types and size of houses, varying household sizes and type of facilities available for use (Yohanis, 2012).

Table 4 and Figure 6, show that above 35% of respondents in all the three countries live in urban areas, while between 25%-30% live in a peri urban area. For all the three countries there are more respondents' living in rural areas. While the difference between the proportion of respondents living

in urban and rural areas is not much, it is still enough to signal that there is still a high number of people living in rural areas.

Table 4. Number of respondents in each country and location

	Location			
Country	**Urban**	**Sub-Urban**	**Rural**	**Total**
Botswana	35	25	39	99
Namibia	22	20	18	60
RSA	10	14	15	39
Total	**67**	**59**	**72**	**198**

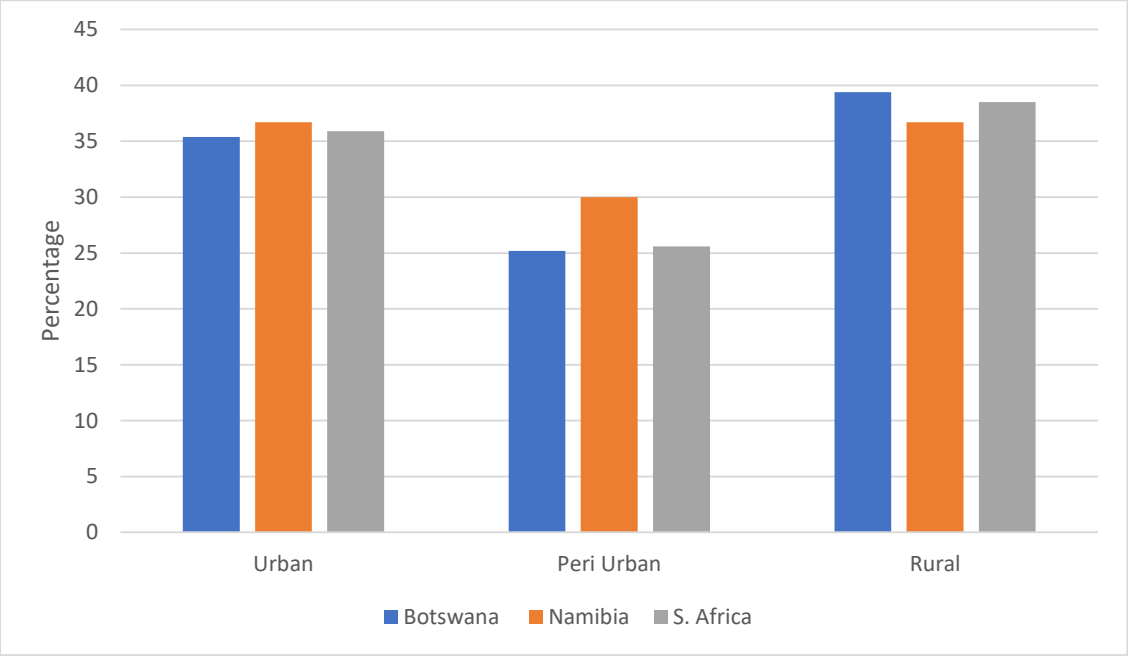


Figure 6. Household Location

3.3.2 Household income

The monthly combined household income of respondents is shown in Figure 7. It shows that most of the household combined income falls below 1500USD. Average combined income is higher for Botswana than the other two countries. This is not surprising as Figure 5 indicated more respondents under formal employment in Botswana than Namibia and South Africa. There are more respondents' household combined income falling above BWP 25000, while South Africa has more households falling in the bracket USD1000-1500. 26.7% of respondents' households in Namibia make a combined income of N$5000 – 10000. Namibia has 23% respondents' household making a combined household income less than USD100. It appears that Namibian' s households in the sample generally

have a lot less combined household income than that of Botswana and south Africa, and this is also reflective of the reported high unemployment rate for Namibia in Figure 5.

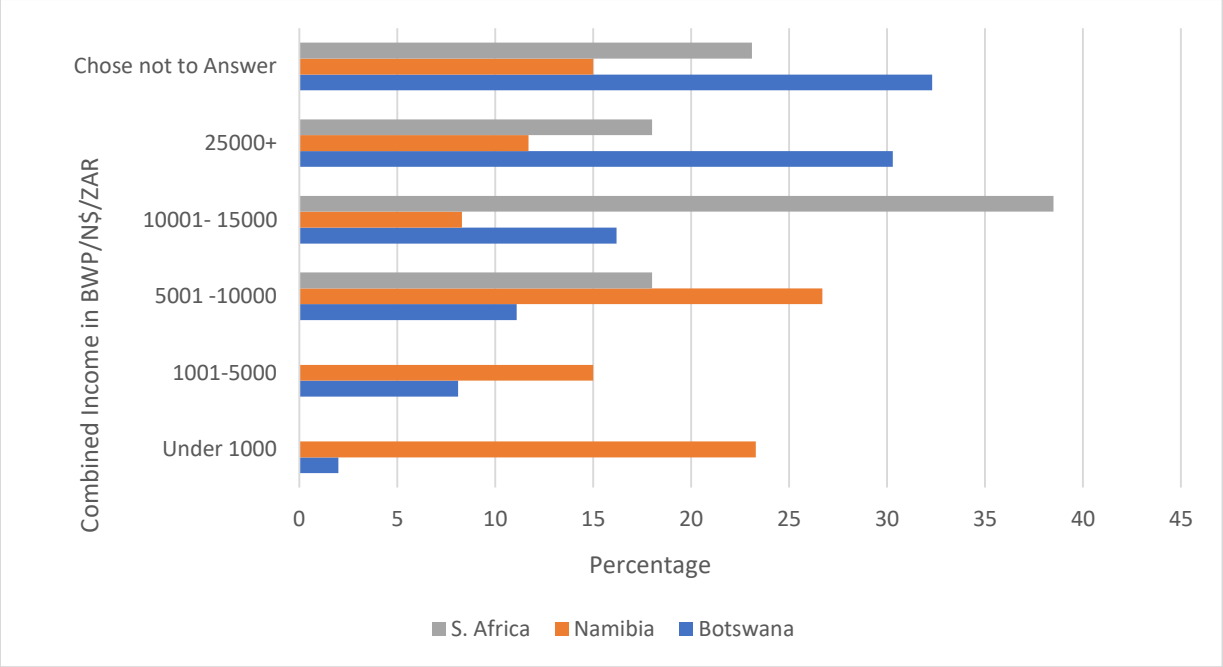


Figure 7. Combined Household Income

3.3.3 Type of housing

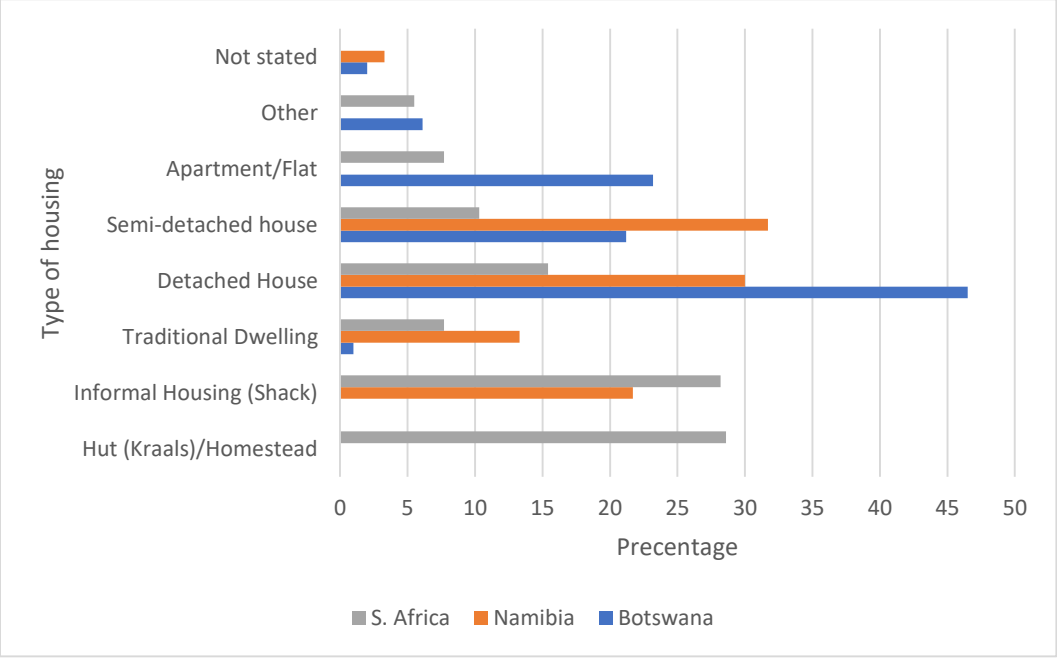


Figure 8. Type of Housing by country

Figure 8 shows types of housing by country. About, 64.5% of respondents in South Africa lived in poorer housing such as traditional dwellings (7.7%), informal housing/shack (28.2%) and Huts/ Kraals

or Homestead (28.6%). Over a third (33.4%) of the houses were of urban and peri urban character detached, semidetached houses and flats).

In Namibia a higher 61.7% of households lived in detached and semidetached housing while 35% lived in informal housing/ shacks and traditional dwellings. Housing types in Botswana were predominantly (90.1%) of modern character, comprising of detached, semidetached houses and flats. A study in South Africa found out that the greatest variation in electricity access was based on household location and house type with households in informal settlements as low as 53% (Stats SA 2012).

3.3.4 Household Size and Number of rooms in the household

Household size is another socio-economic factor that influences household choice of energy. Figure 9 shows that the average number of people living in a household is 6, and the maximum is 11. More than 40% of households surveyed had between 2- 5 persons staying in the household (Figure 9). Less than 10% of households lived only 1 person, while only 1% of household have more than 10 members. The high number of people in the household indicates that families need cooking facilities' that can cater for large number of people.

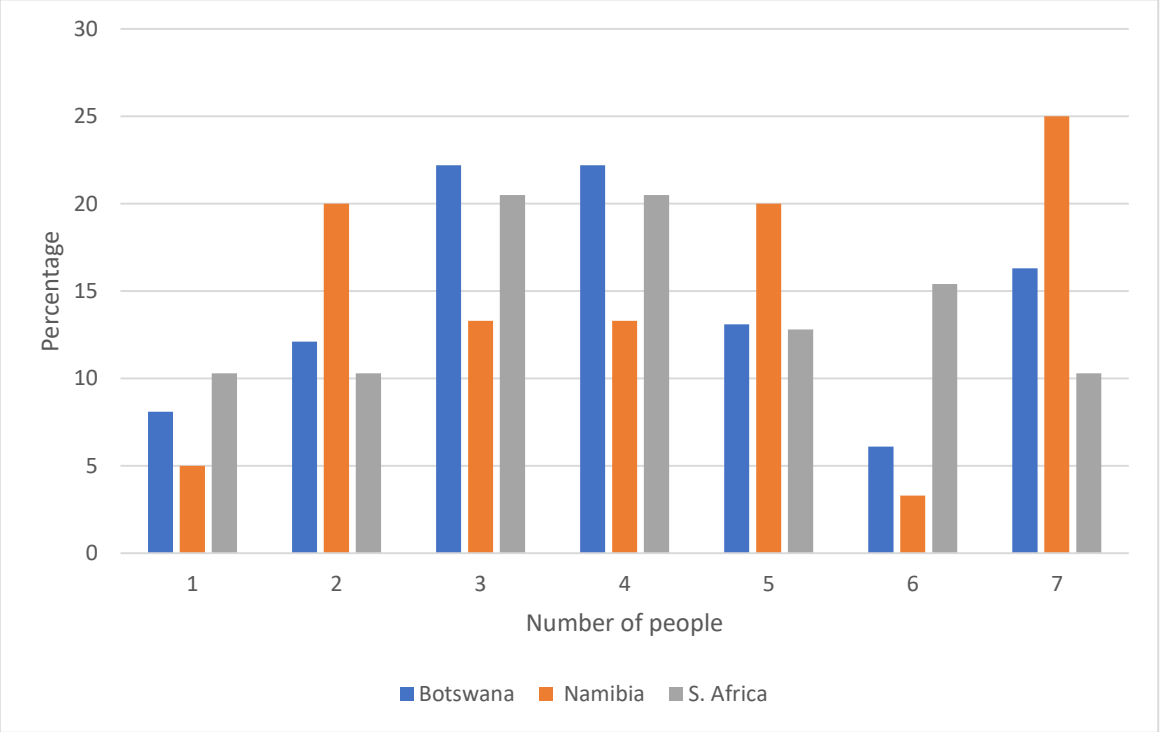


Figure 9. Number of people living in the household

Most of the households had an average of 5 rooms for sleeping, cooking, and living (Figure 10). The number of people living in a household, type of housing (Figure 8), and number of rooms Figure 10 in a household could give an idea on the need for energy in that household. For example, detached

housing spells a separation of houses, meaning more lived space that requires heating energy, the same goes for more rooms. In addition, the higher the number of people in a household the more heating and cooking energy would be required (Kotsila, et.al 2021, Lusambo et al (2016).

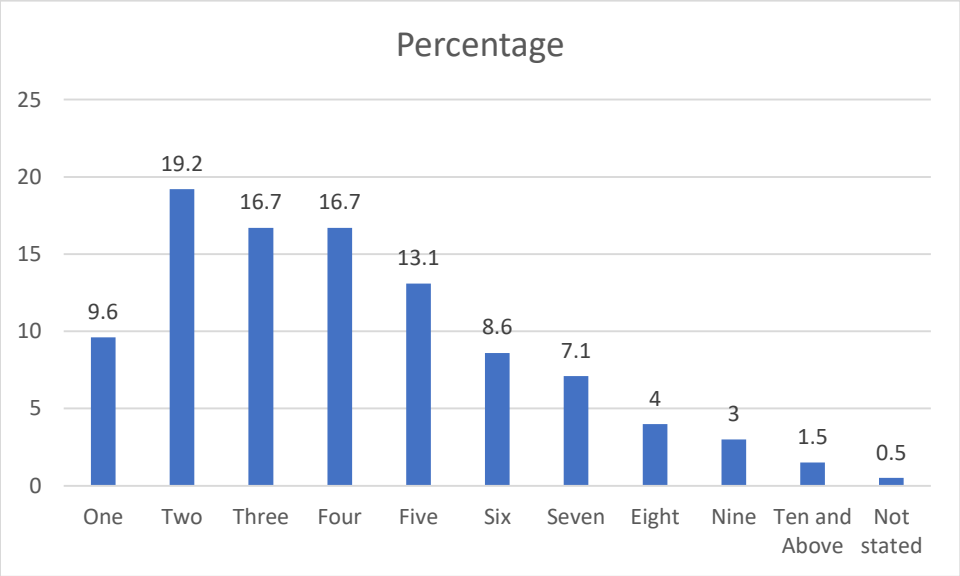


Figure 10. Number of rooms for living

3.3.5 Household Ownership of Dwelling place

Table 5 shows that a majority (76.7%) of households are owned, by the respondents, while 20.7% are living in rented houses. This high proportion of house ownership as opposed to renting is demonstrated again at country level.

Table 5. Ratio of type of Ownership Status by Country

Household Status	Botswana	Namibia	South Africa	Combined %
Rented	15.15	0.51	5.05	20.71
Owned	33.33	29.29	14.14	76.77
other	1.52	0.51	0.51	2.53

3.3.6 Household Water Supply

About 73.23% of the surveyed households had piped water within the house, with Botswana having the largest ratio of households with piped water at 44.44%, Figure 11. A low proportion of households depended on communal standpipe for water. Given that the study areas were within 50 km of urban centres these results are not surprising. About 16.16% of Namibian respondents reported having piped water, while only 1 % had access to a standpipe and 7.7% obtained their water from a communal well or a borehole. Of the three countries South Africa has a smaller proportion of

respondents with access to water piped in the house, as well as access to a standpipe. However South Africa is the only country with the three whose respondents 17.17%) were getting their water from rainwater harvesting.

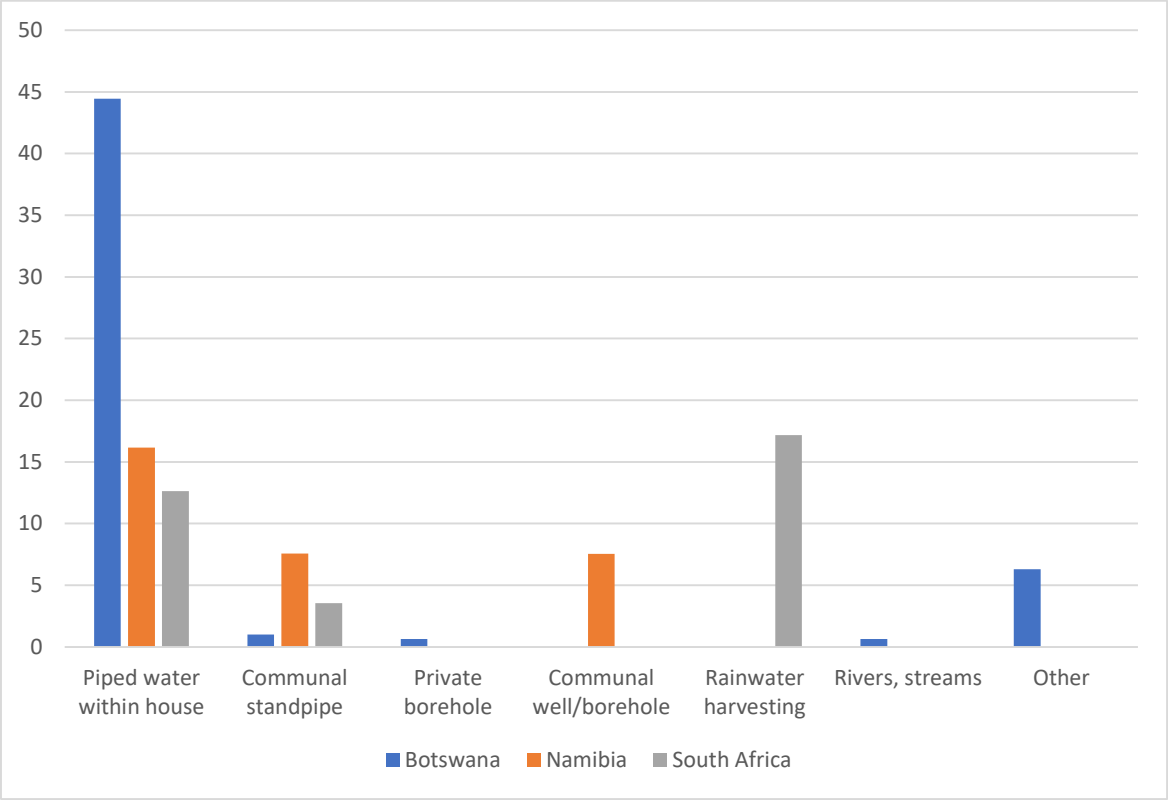


Figure 11. Household Water supply

3.3.7 Ablution facilities

Majority (68.7%, 48.7% and 56%) for Botswana, Namibia and South Africa respectively of households have a toilet flush system followed by latrines (With slab or ventilated improved latrines), which as noted above follows from the fact that the area under study is urbanised.

Table 6. Type of toilet facility for the household

Toilet Facility	Yes		No	
	Botswana	Namibia	South Africa	Combined
Flush (central sewer system)	68.7	48.7	56.7	61.1
Ventilated Improved Pit latrine (VIP)	12.1	23.1	8.3	13.1
Bucket	1.0	5.1	3.3	1.5
Flush (septic tank)	17.2	-	3.3	
Latrine with slab	24.2	-	8.3	
Composting	-		10.0	

Table 7 shows responses from households when asked whether they share toilet facilities with other households or not. Over 70% of the responses indicated that they did not share the facilities. This follows the fact that the area studied has an urban setting.

Table 7. The use of toilet facility (Sharing / or not)

Response	Botswana	Namibia	South Africa
Yes	28.3	6.7	28.2
No	71.7	86.6	71.8
Not stated		6.7	

3.4 Household Cooking Facilities

The study asked respondents to give an account of the cooking facilities in the household. Table 8 indicates that households use a mix of cooking facilities, with 58% of households cooking with electric stoves', 41.9% using gas stoves to cook and 31.8% cooking in the fireplace outside. Fuel wood stoves and fireplace outside are the least used cooking facilities with only 4% and 2% households using them. The use of a mix of cooking facilities may be because different types of food are cooked with different stoves.

There are however differences between the countries in the choice of cooking facilities owned. For example, the most prevalent cooking facility for over 70% of surveyed households in Botswana is LPG stoves, followed by electric stoves (63%). Still a good proportion of households (31.3%) use firewood outside for cooking. In Namibia however, 48.3%households cook their meals in the fireplace outside, while an almost equal proportion (46.7% cook with electric stoves, followed by LPG stoves being used by 15% of households. Like in Botswana, South Africa recorded higher proportion of households using electric stoves (64.1%), the other cooking facilities are not so prevalent with very low proportion of households making use of them. Only 10.3% of households in South Africa use LPG stoves, while less than 8 % use fireplace outside or inside.

Table 8. household cooking facilities

Cooking Facility	Botswana	Namibia	South Africa	Combined %
Electric stove / Electric hot plate	63.6	46.7	64.1	58.6
Fuelwood stove	1.0	11.7	0	4.0
Fireplace outside	31.3	48.3	7.7	31.8
Gas stove	70.7	15.0	10.3	41.9
Fireplace inside	1.0	5.0	0	2.0
Other	0	3.3	5.1	2.0

3.5 Fuels used / preferred and Energy Decisions

To understand what influences household energy choices within the study area the survey sought to establish who makes decisions on the type of energy a household uses. Understanding this is key to develop and target the decision maker as new cleaner energy sources are being promoted. Table 9 captures the energy household decision making responsibilities. In the study areas the data indicates that in 2/3 of households' energy choice decisions are made by a couple together, while in only about a ¼ of the household's energy decisions are made by men. Only 10.6% of households had energy decisions made by dejure female headed households with Botswana showing the highest proportion (41.4%) of households where couples make decisions together, and the highest proportion (34.3%) of de jure female headed households.

Table 9. Household decision making Facility

Definition of leadership	Botswana	Namibia	South Africa	Combined
Couple headed household (2 spouses making decisions about same or different things/spheres)	41.4	31.7	23.1	66.7
Male headed household (man is head and makes all decisions)	15.2	31.7	25.6	25.8
De jure female headed household (woman is head and makes all decisions)	34.3	15.0	30.8	10.6
De facto female headed household (the woman's husband is absent, e.g., due to migration, she makes all decisions)	4.0	18.3	12.8	3.5
Other	5.1	3.3	7.7	5.1

*0.51% Not Stated in Namibia

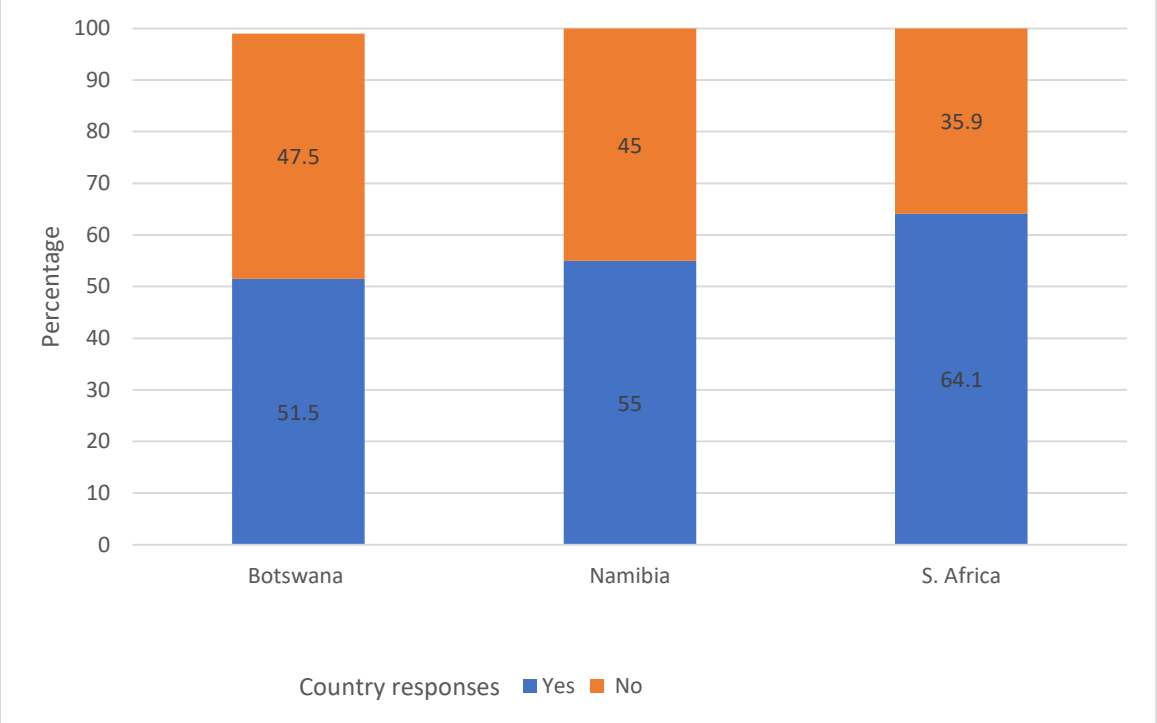


Figure 12. Head of household Status

3.5.1 Sources of Energy Used/ Preferred

Energy sources for households studied consist primarily of electricity (79.8 %), fuel wood (41.41%), Liquefied Petroleum Gas (LPG) for 35.35% of households. Charcoal and other sources are less important energy sources as indicated by a little less than 11% of households who prefer to use them.

Figure 13 shows that almost half (45.96%) of the households in Botswana get their source of energy from electricity, while Namibia has an almost equal proportion of households using electricity (18.18%) and Firewood (19.70%) respectively. LPG is the second most preferred source of energy in Botswana and not as important in Namibia and South Africa. The most preferred source of energy in South Africa is electricity (15.66%). The data also reveals a reliance on multiple energy sources.

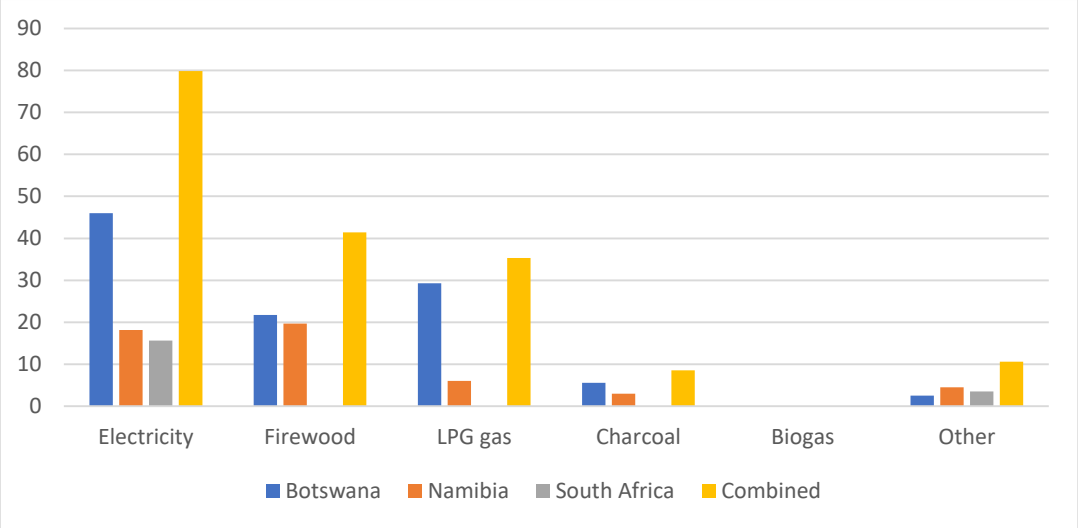


Figure 13. Preferred Household Energy

The high preference and use of electricity and LPG over other sources of energy corresponds to observations by Sunil (2013) that with increasing affluence the use of fuel wood declines, was observed in Botswana (Botswana 2014, UNDP 2012). The three countries under assessment are of middle-income economic level, hence the high proportion of households' preference for electricity is understandable, as it confirms observations by Muazu *et al*; (2020), Prabhakar et.al (2021), Macht *et al*. (2007), Dil et. al, (2017) that as households become affluent and urbanized, they tend to prefer convenient, clean, and often more expensive types of energy like electricity and LPG. These proponents of the energy ladder model, posts that households transition up the energy ladder, as they become more affluent. This affluence can also be attributed to the observed shift from more traditional energy sources of energy to commercial fuels.

However, despite the increasing affluence of households in these countries, we notice that survey data still shows a significant proportion of households depending on fuelwood (41.41%). This is indicative of the vast disparities in development across the study area, where there are still predominantly rural households that do not have access to the grid, hence fuel wood is still an important source of energy for these households. In Botswana, national statistics show that fuelwood is still a significant energy source for 46% of households (Central Statistics Office, 2007).

3.6 Buying Patterns and Habits

3.6.1 Access to Energy

Figure 14 shows the different ways through which households access their energy. More than 50% of the households buy energy from suppliers, i.e., National electricity distributors, and private suppliers for LPG, firewood, and charcoal. A look at the proportion of modes of access shows a high number of respondents in Namibia collect the energy source (wood). The data also shows quite a good proportion of respondents who access their energy source through both means (purchase and collection).

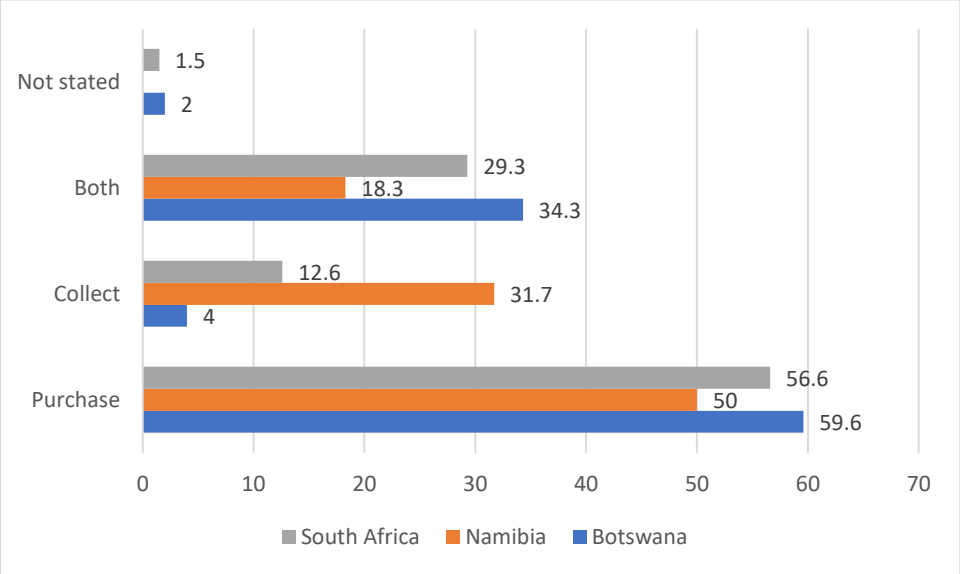


Figure 14. How energy is accessed

3.7 Energy-Consuming Activities: Cooking and Heating

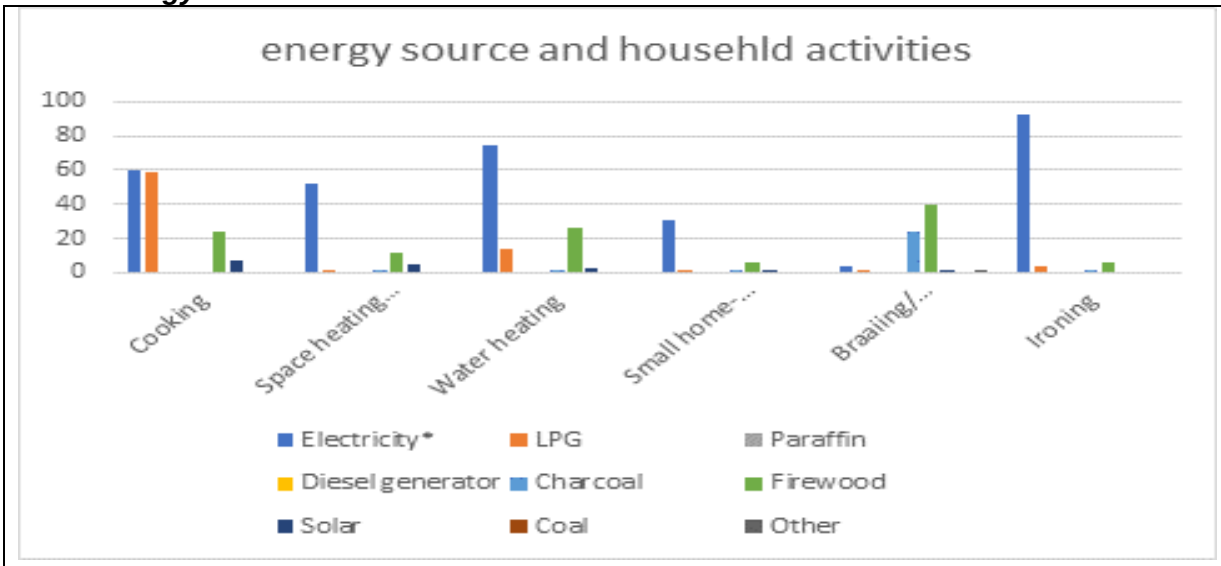
It is important for consumers to be assured that their energy sources will meet the household needs in terms of usability, cost fees and reliability because energy is the most essential in daily household operations (Yonemitsu et.al., 2014).

Table 10. Important factors when choosing energy source

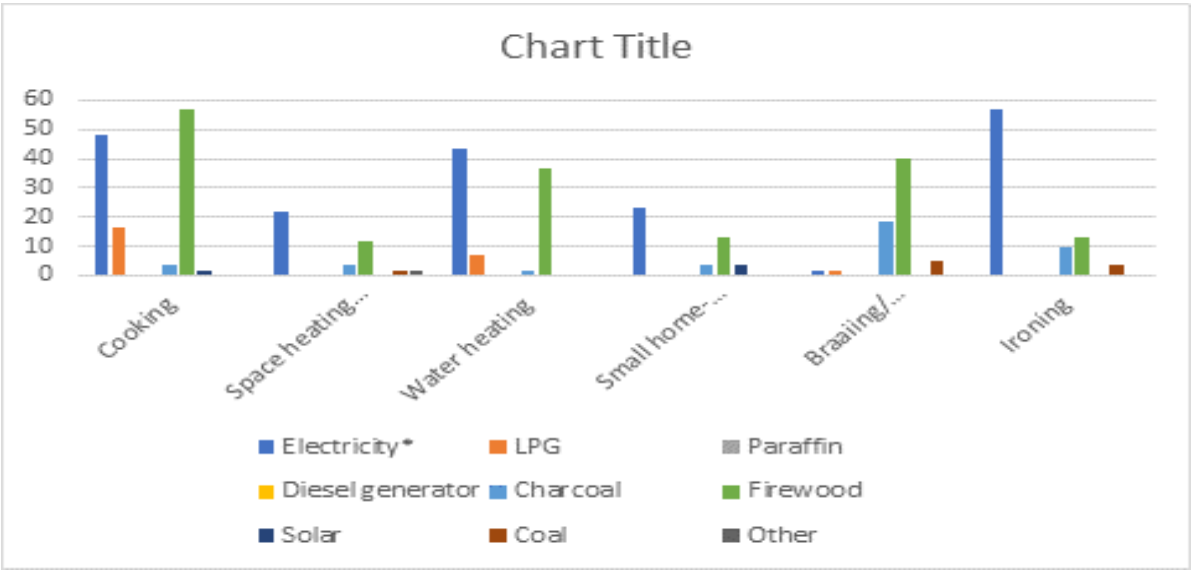
Factors considered important	Botswana			Namibia			RSA		
	Electricity	Firewood	LPG	electricity	Firewood	LPG	electricity	Firewood	LPG
Efficient/cooks fast	25.3	12.1	28.3	16.7	20.0	13.3	30.8	7.7	12.8
Suitable for all-weather	26.3	3.0	24.2	15.0	3.3	6.7	12.8	-	-
Good price	17.2	14.1	14.1	10.0	20.0	-	10.3	7.7	10.3
Reliable Supply	25.3	7.1	8.1	18.3	13.3	1.7	5.1	2.6	5.1
Convenient access to supplier	20.2	6.1	7.1	1.7	1.7	-	7.7	2.6	-
Safe to handle/store	15.2	3.0	3.0	3.3	3.3	1.7	7.7	2.6	5.1

Table 10. presents information on the most important factors respondents consider when deciding on an energy source. There were seven important factors that were considered influential in selection of the type of energy source by respondents, from the list of the factors, the most selected and significant factors were, efficient/cook fast, suitable for all-weather, convenient access, and good price. In Botswana, 65.7% of respondents selected efficient/cook fast as a factor of value. In Namibia, 50% of the respondents selected efficient/cooks fast as the most important factor. South Africa also picked this factor as the most important at 51.3%. The importance of this factor was common in all the three countries with insignificant difference. The part on suitable for all weather was mostly valued in Botswana at 55.5% than in Namibia 20% and South Africa 30%. Traditionally, all countries come from a history of cooking with firewood, which is usually prepared for out in the open, so firewood fuel was a bit inconvenient when it rains, if the wood is wet and if the cooking facilities are out in the open, so respondents would prefer energy fuel that is suitable for all weather. The other factors received the lowest percentage rating. Efficiency is important in an energy source characteristic because all consumers want to maximise their energy usages with minimal cost and save money for the household. Some consumers prefer efficiency characteristic because they are environmentally conscious and do not want to increase carbon footprint.

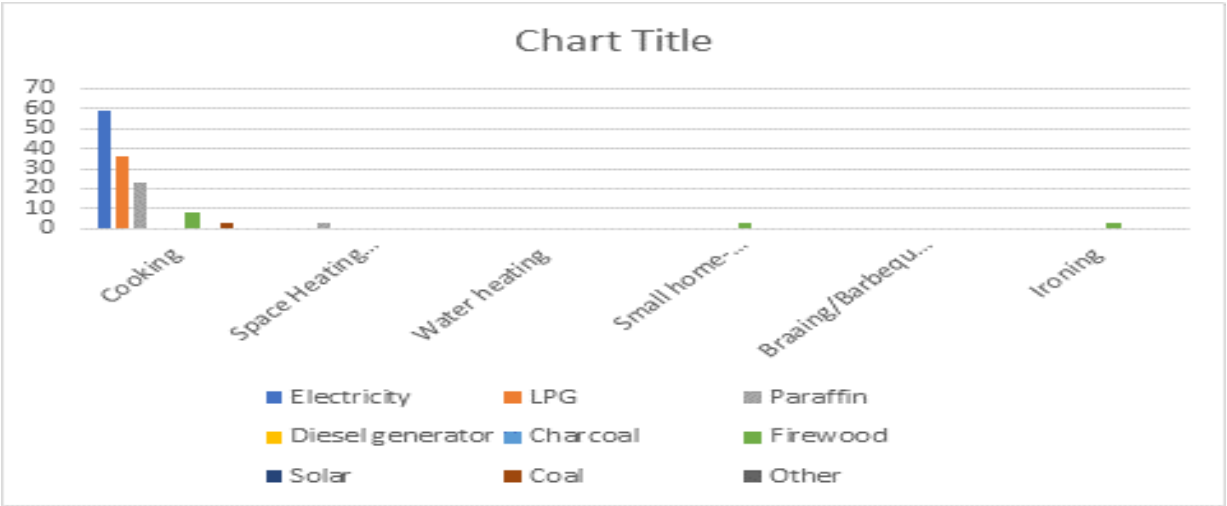
3.7.1 Energy source used for different activities



Botswana



Namibia



South Africa

Figure 15. Energy source used for different activities

Figure 15 represents six listed activities that were regarded as the most considerations for energy use in a household and respondents were asked to link each activity to the energy source used.

In Botswana, electricity was the main source of energy used in cooking especially in urban and peri-urban households. Majority of respondents, 59.6%, used electricity for cooking as compared to other energy sources. LPG was the second main choice for cooking energy, 58.6% of respondents use LPG, which costs between $16.74 and $108.81, depending on the quantity required, which made it cheaper than electricity, even though it was not diversely used like electricity in the household. Firewood was used by 24.2% of respondents in cooking, majority of them were in the rural areas. Wood is generally free and widely/easily accessible in the rural areas.

Electricity was efficient when ironing, the iron would heat up in seconds compared to other energy sources, which are not very competitive in this instance, 92.9 % of respondents noted that they use electricity for ironing. Electricity is the principal fuel used for water heating especially in urban areas, 74.8% said they used electricity for water heating in Botswana, this is with geysers and kettles sometimes urns.

Firewood was also used for water heating 26.3%, compared to other energy sources. This was mainly in rural areas. The heated water was usually used early in the morning and late at night. The reason why water heating with wood was prominent in rural areas was because wood is easily accessible, in the near bush and usually collected by the user, hence don't cost money. Therefore, most used energy source across the basic household activities was electricity followed by LPG and firewood energy, in a descending order.

South Africa, 59.0% respondents of households noted that they use electricity for cooking while 35.9% said they used LPG. Majority of households in South Africa are connect to the grid and have access to electricity, therefore, respondents were from communities familiar with electricity than any other energy fuel, the South African statistics report of 2020 stated that more than 8 in 10households have access to electricity.

In Namibia 48.3% respondents in urban and peri-urban noted that they use electricity for cooking, 56% respondents use wood for cooking. Wood is the main source of energy in rural areas in Namibia, more respondents cooked with wood than electricity as compared to Botswana and South Africa. 48.3% of respondents noted to have a designated fireplace outside, this is a greater percentage compared to that of electric stoves in the country (46.7%). This shows that majority of respondents

were traditional. Still in Namibia, 43.3% of respondents use electricity for water heating, these are mostly in urban areas, while 36.7% use wood for water heating. Electricity is efficient for ironing compared to other energy sources; 56.7% household respondents use electricity for ironing.

The findings on Figure 14 show that majority of the households activities use electricity energy especially for ironing and cooking compared to other energy sources especially compared to bioenergy sources like firewood and charcoal, which scored insignificant percentages. Nevertheless, with the current raise in electricity tariffs this is set to change. Firewood in the list of bioenergy sources is the most preferred, for water-heating and braaiing/barbequing. Fuelwood is easily accessible in rural areas than in urban or peri urban areas, which makes it the most used in those areas. Figure 14 also shows the multi fuel use in households. One household uses up to 3 or more different energy sources for different activities. This is called multiple fuel use, where fuel is not switched or discarded but the household keeps on adding new or different energies according to their needs (Uhunamure, et al, 2017).

3.8 Energy Consumption, Buying Patterns and Habits

Majority of respondents from the 3 countries obtain their energy sources by purchasing them. The data has already stated that a larger percentage of the respondents use electricity. Botswana's electricity is supplied by a state-owned entity called Botswana Power cooperation, Namibia state owned entity called NamPower and South Africa supplied by a state-owned entity called Eskom. Electricity in these countries is then sold by various distributors. LPG as one of the most used sources of energy is sold by different distributors.

Suppliers of main fuel type

Figure 16. Supplier of main fuel type

National service provider

Figure 16 shows a list of suppliers of main fuels used by respondents in the households, where they buy or access their main energy source. In Botswana 25.3% of respondents buy their main energy source from the national service provider, national service provider in Botswana for electricity, is the Botswana Power Cooperation, they are the sole supplier of electricity, even though they have distributors who sell on their behalf.

In Namibia, majority of households do not buy from the national service provider (NamPower). Only 15% of respondents get their source of energy from national supplier, even-though 60% of the respondents answered that they use electricity. This could mean there were some confusions as to what/who is the national supplier during data collection. Namibia like many Southern African countries depend on South Africa for its electricity, 79% of their annual electricity is imported, it produces a small percentage of its own electricity using coal, but the coal is also bought from south Africa. Therefore, the government buys electricity on behalf of her people and sell it to the people as a national supplier, all things equal, it would make sense for all the 60% of respondents to be buying from their national supplier. Respondents from South Africa do not depend on national suppliers because only 7.7% out of the 79.9% who recorded to be using electricity indicated to be buying from national service provider.

Kiosk and supermarket

In Botswana 39.4% respondents buy from kiosks and 60.6% buy from supermarkets, these two suppliers could be producers of a certain used energy source or a distributor on behalf of producers of a preferred energy source. For example, Botswana Power Cooperation has extended its services through supermarkets and kiosks to make sure their energy is easily accessible to the public. LPG suppliers also sell from kiosks and fuel station or company warehouses. Wood fuel and charcoal are also available through these platforms in Botswana, these services cut across from urban areas, peri-urban to rural areas.

Percentages of respondents who buy fuel energy from kiosk (40%) and supermarket (18.3%) in Namibia are low. Namibians are popular for using biomass, 10% collect their own energy source, which is cheaper as well as easily accessible because the electricity charges are inflated and unaffordable (Makonese et al 2017). Botswana households, especially in rural areas indicated that they collect or produce their own energy source. 20.2% of the respondents collect their own energy sources, especially the fuel wood. This percentage also include those who buy other energy sources,

some households would buy electricity and still collect firewood for other energy purposes in the household. Some collect more energy source and sell surplus at a reasonable fee.

3.9 Consumer Preferences and Requirements, Fuel Quality and Quantity

3.9.1 Consumption quantity per month

Consumer preferences and buying capacity is determined by different factors from cultural values, locations, background (education and socialization), income level, and the environmental factors. Zhu et al (2022) using his consumer theory stated that, consumers will spend their money on what they believe will satisfy their needs after assessment and comparing to alternative attributes of a product based on their performance according to their preference. The section was used to gauge the market price per quantity required and supplied. Table 11 shows the recorded household energy consumption and buying patterns per month, of the different households across income levels.

Botswana: Households used a combination of different energy sources at the same time, electricity consumptions was measured to be between 64kw and 937kw per month per household, which was estimated to cost between US$8.37and US$585.90, the figures were based on recall and estimates, the respondents were not requested to show any proof of purchase or payment, these are not the exact figures that the respondents pay, hence the disproportion in consumption and cost. The survey did not explicitly segment household electricity trends, which would have showed explicit consumption patterns. The electricity costs are the same across (urban, peri-urban, and rural areas) in Botswana, they only differ in consumption patterns. The difference depends on the household size and uses of the energy fuel. LPG was measured in kilograms, the smallest quantity bought and used by respondents was 9kg and it costs between US$16.64, and the maximum quantity was 48kg bought at US$108.17. In Botswana, LPG is a serious electricity competitor, it was also used in multi energy house set up, some household used it in emergencies such as when there are electricity power cuts. Unlike electricity, LPG could last a household longer than a month depending on their usage. Some respondents also used coal, quantity between 2kg and 500kg per month, coal produces more energy kilo joule per kilogram. They spend around US$0.42 and US$16.64 per month. Despite these attractive benefits, not many households use coal.

Bioenergy consumption, charcoal was consumed in quantities between 3kg to 20kg per month that costs between US$1.66 and US$8.32 per month in Botswana. Charcoal uses are still upcoming in the country, people still use it more during festivities than on normal household chores. Firewood on the other hand was consumed at 0.5kg to 500kg per month and cost between US$0.083 and US$24.96, wood is easily accessible and most of the time freely available in rural areas. In rural areas

communities don’t need permission from leadership to harvest household wood. Respondents in urban areas bought wood in gas stations and kiosks, supermarket and from independent harvesters, the market is free and regulated by the seller.

In Namibia, electricity consumption per month ranged between 8kWh and 2796kWh, and cost between US$8.32and US$1764.00. The consumption was higher compared to that in Botswana and even cost more per month. LPG quantity used per month was between 5kg and 48kg and cost US$13.31 to US$108.17. This information shows that respondents from Namibia’s electricity expenditure per month was quite significant than other competitive energy sources.

Namibia is reported to be using more bioenergy than other competitive energy sources (Makonese et al 2017). The charcoal consumption per month was between 5kg and 20kg, this is contradictory to popular belief, this is even though the country has large manufacturing plants that produce charcoal in the country. The charcoal monthly household expenditure ranged between US$2.50 and US$24.96. The figure ratings concerning charcoal consumption in Namibia are unexpectedly low. Firewood usage in Namibia consumption ranged between 3kg and 2000kg and cost from US$0.42 to US$342.81 kg per month.

South Africa produces its own electricity and sells to several countries in Southern Africa, a larger percentage of its household are on the grid. Consumption quantity was noted to be between 10.1kWh and 2000kWh with monthly expenditure from US$2.50 to US$41.60. Electricity consumption in South Africa was the lowest in terms of quantity consumed and expenditure per month compared to other 2 countries. LPG quantity used ranged between 5kg and 25kg costing between US$8.32 and US$108.17. Related studies show that household energy needs change over time as their income status change, (Mayomi et al 2021). Social status is linked to several different factors, such as level of education, income, household size, and subsequently energy needs. In this study, households with higher income levels used electricity and LPG for their basic household energy needs, while firewood and charcoal were used for entertainment such as braai/barbeque. Campbell et al. (2003) stated that households with higher income level preferred to use modernized cooking energy fuel sources.

Table 11. Quantity and amount spent on each fuel type

Country	Number of entries	N	Variable	Minimum	Maximum
Botswana					
	99	38	Electricity Quantity used per month	64.0000000kW	937.0000000kW
		86	Electricity Cost per month	$8.32	$582.45
		54	LPG Quantity per month	9.0000000 Kg	48.0000000 Kg
		55	LPG Cost per month	$16.64	$108.17
		10	Charcoal Quantity per month	3.0000000 Kg	20.0000000 Kg
		18	Charcoal Cost per month	$1.66	$8.32
		13	Firewood Quantity per month	0.5000000 Kg	500.0000000 Kg
		22	Firewood Cost per month	$0.083	$24.96
		7	Coal Quantity per month	2.0000000	500.0000000
		4	Coal Cost per month	$0.42	$16.64
Namibia					
	60	38	Electricity Quantity used per month	8.0000000	2796.00
		38	Electricity Cost per month	$8.32	$1764.00
		8	LPG Quantity used per month	5.0000000	48.0000000
		9	LPG Cost per month	$13.31	$108.17
		5	Charcoal Quantity used per month	5.0000000	20.0000000
		4	Charcoal Cost per month	$2.50	$24.96
		17	Firewood Quantity used per month	3.0000000	2000.00
		15	Firewood Cost per month	$0.42	$342.81
		2	Coal Quantity used per month	25.0000000	50.0000000
		2	Coal Cost per month	$16.64	41.60
		2	Paraffin Quantity per month	3.0000000	4.0000000
		2	Paraffin Cost per month	$5.82	$6.66
RSA					
	39		Electricity Quantity per month	10.1000000	2000.00
			Electricity Cost per month	$2.50	$41.60
			LPG Quantity per month	5.0000000	25.0000000
			LPG Cost per month	$8.32	$108.17
			Charcoal Quantity per month	2.0000000	4.0000000
			Charcoal Cost per month	$1.66	$8.32
			Firewood Quantity used per month	1.0000000	100.0000000
			Firewood Cost per month	$12.48	$24.96
			Coal Quantity per used month	10.0000000	10.0000000
			Coal Cost per month	$12.48	12.48
			Paraffin quantity used per month	1.0000000	40.0000000
			Paraffin Cost per month	$1.08	$39.94

3.9.2 Responsibility for Purchase of Household Energy

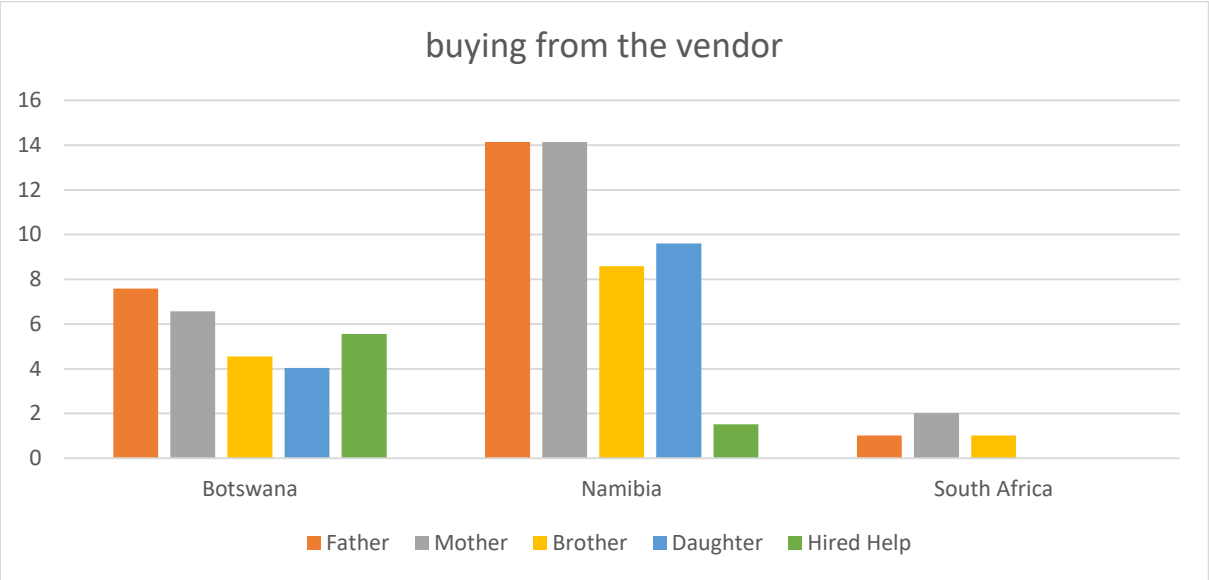


Figure 17. Responsibility for energy purchase

Figure 17 answers to the question, who buys energy source for the household, in Botswana, the whole family including the hired help work almost equally as a team in the household to buy the source of energy and bring it home. In Namibia, the fathers and mothers were more responsible for this task, but other family members assisted in a significant manner. South Africans, only the father, mother and brother bought from the vendor and brought the energy home. The specific people participated in this activity as part of their duties and chores in the household, or because they were responsible enough to transact in this manner depending on the type of energy used, or they had the resources necessary for them to be able to purchase the fuel.

3.9.3 Level of Disatisfaction with Energy source

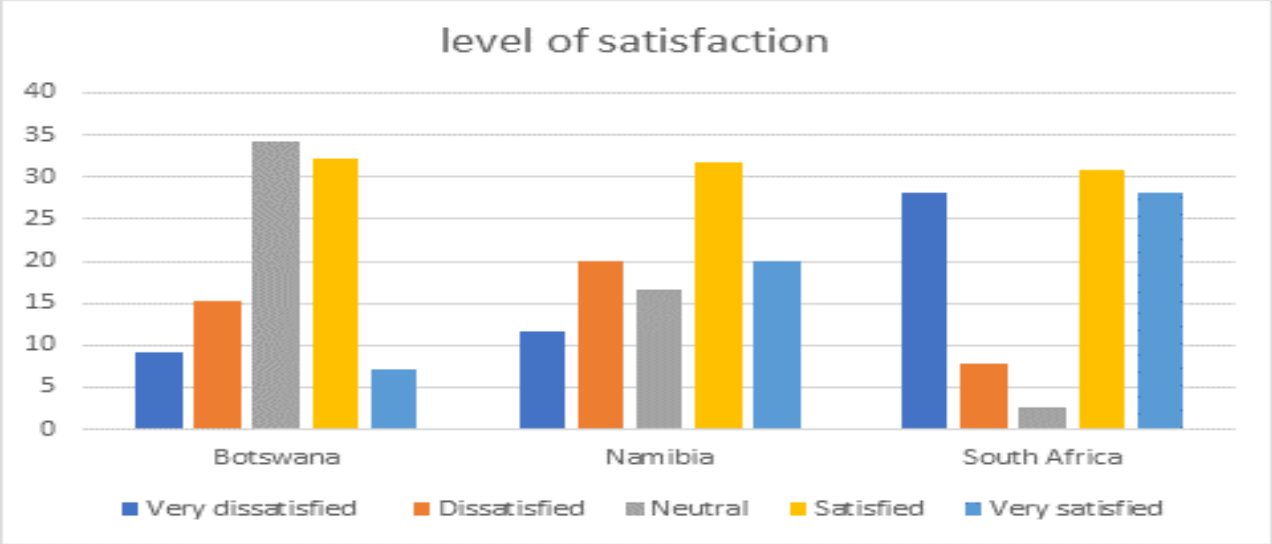


Figure 18. Level of satisfaction with the energy source in the household

Majority of respondents reported that they were neutral and satisfied with their source of energy in Botswana (Figure 18), a small number of the respondents were at the extremes of very satisfied (7.1%) and very dissatisfied (9.1%). Namibian respondents' majority were neutral and satisfied, while they had a significant number of respondents who were very satisfied (20%) they also had those who were very dissatisfied (11.7%). South African respondents mostly were satisfied (30.8%), very dissatisfied (28.2%) and very satisfied (28.2%). Different people need different factors and characteristics from their energy source. Thus, if a certain factor makes one respondent very happy the other respondent could hate the same energy source for the same factor. It is worth noting that the 3 countries combined have a significant number of respondents who are not happy with their energy source.

3.9.4 Reasons for dissatisfaction

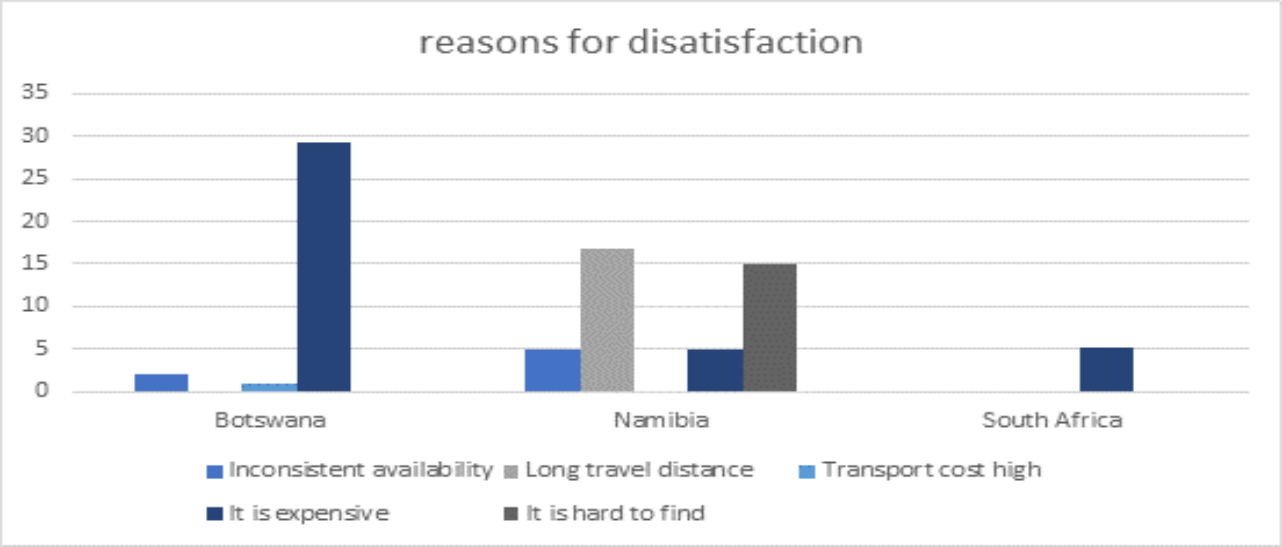


Figure 19. Reasons of dissatisfaction

Figure 19 has a list of factors that caused the respondents to be unhappy with their energy sources. Namibian respondents were also bothered by this factor. Namibians also complained that they had to travel long distances to access their energy source, which has proven to be bothersome on their experience with the source of energy. Botswana respondents complained that the worst factor they experience is that of high costs (29.3%) noted that their sources of energy are expensive, meaning the household budget can barely keep up. Transport costs also add onto the price of the fuel. The inconsistencies in sources of fuel are in most cases results of increased consumption level (Mislimshoeva et al 2014).

3.9.5 Knowledge about Biofules

The sample size had a history of using biofuel products, information collected in this section focused on the general attitude towards biofuel, this included their awareness and interest levels in bioenergy-related information in the three countries. The respondents had an opportunity to share how they received information and how they preferred to receive information on topics of energy, most of them explained that they know about biofuels from their personal experience, and the cultural background in this part of the world inevitably exposes one to certain ways of living as one with the environment. Even though the majority had moved on the energy ladder to more modernized sources of energy, some respondents were not using biofuels because it is not compatible with their current facilities, some said they use it occasionally. The most prominent solid biofuel used was plant material, firewood.

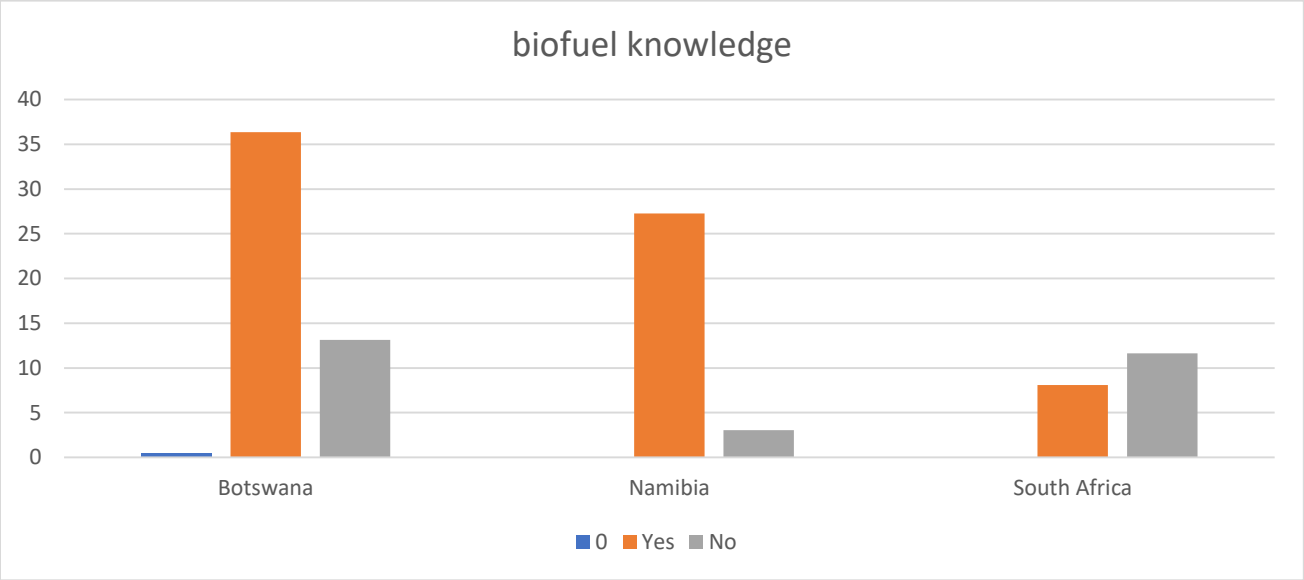


Figure 20. Knowledge about biofuels

Figure 20 shows that biofuel knowledge level of the respondents in the three countries was generally high, majority responded with a yes to the question asking if they have ever heard about biofuel. This survey found out that there is a base they can work from based on their level of understanding of biofuels.

3.9.6 Source of knowledge on Biofuels

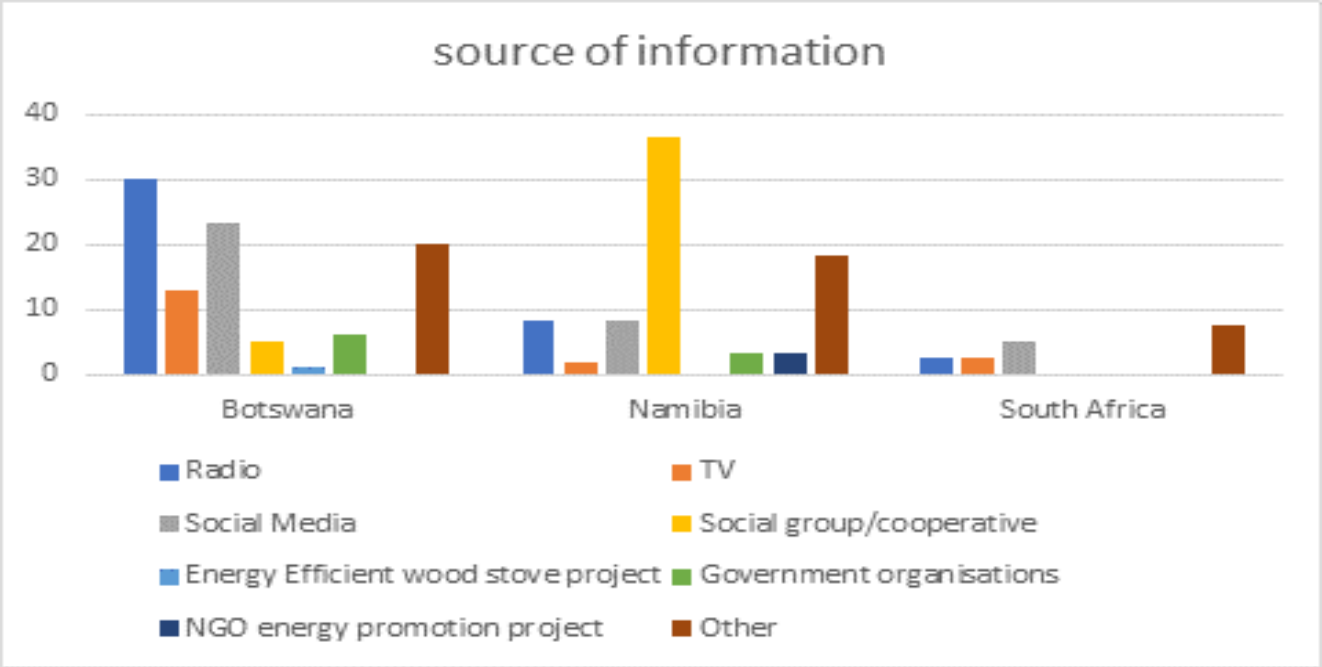


Figure 21. Source of Knowledge on Biofuels

There are global demands for countries to focus on adopting bio energies to reduce the carbon emissions, for consumers to be up to date with information regarding new green energy market, there should some common information platform where they can access information. Figure 20 shows that majority of the respondents did not learn about biofuels from the obvious communication and information platforms as the survey was trying to establish.

The survey provided a list of information platforms that respondents were asked to choose from. The maximum number of respondents per information platform in Botswana was at least 30.3%, and received their information from the radio, Biofuel technology is still upcoming in Botswana, and most people have not realised their value yet. Botswana recently launched biofuel guideline that would be used to guide stakeholder and potential investors about investing in biofuel production in Botswana as a way to pave a communication corridor between policy makers, investors, producers and consumers (Botswana Biofuel guidelines, UNDP 2022).

In Namibia, majority noted that they receive bioenergy information from social group/cooperatives. The government of Namibia avails publications encompassing information about energy, energy projects (new and old projects) on the Ministry of Mines and Energy website, but it seems like it is not reaching the consumers as much as it should. As another way to ensure that the right information reaches the masses, the government through different projects and organizations facilitates conferences that aim to address energy issues.

3.9.7 Experience with the use of biofuels

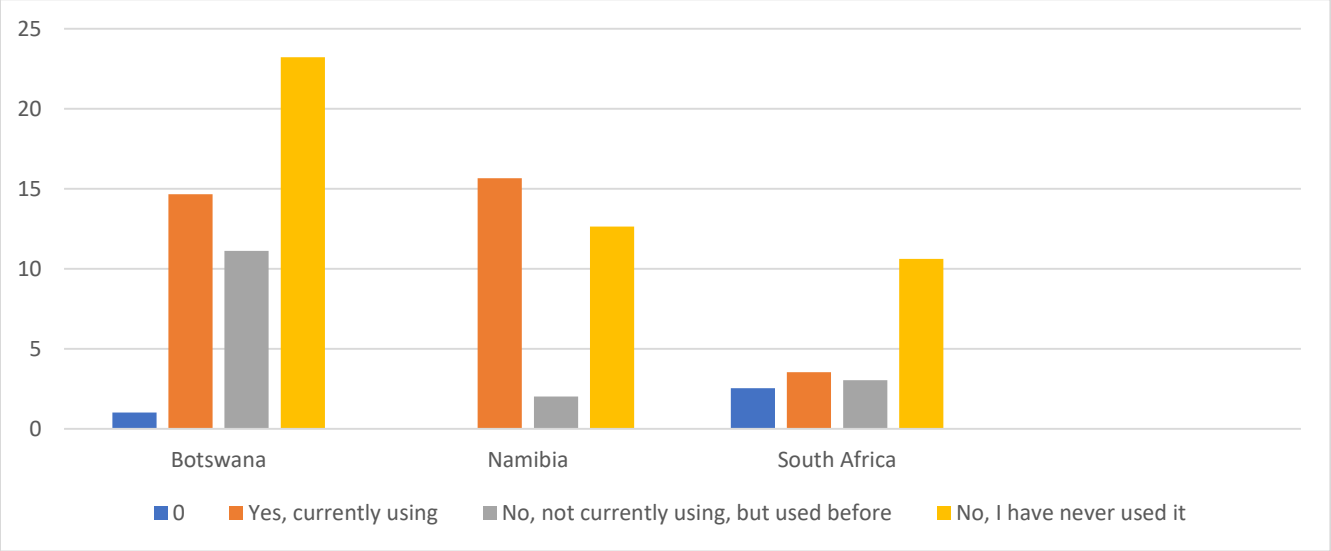


Figure 22. Experience with biofuels

The question was meant to establish the respondent's knowledge and experience on biofuel besides the well-known biofuels of fuelwood, cow dung. Majority of respondents did not understand the question or its intension, hence the answers given. It has been stated that most people confuse the term biofuel to mean some scientific process other than the normal energy we know (Pahl, G. 2008).

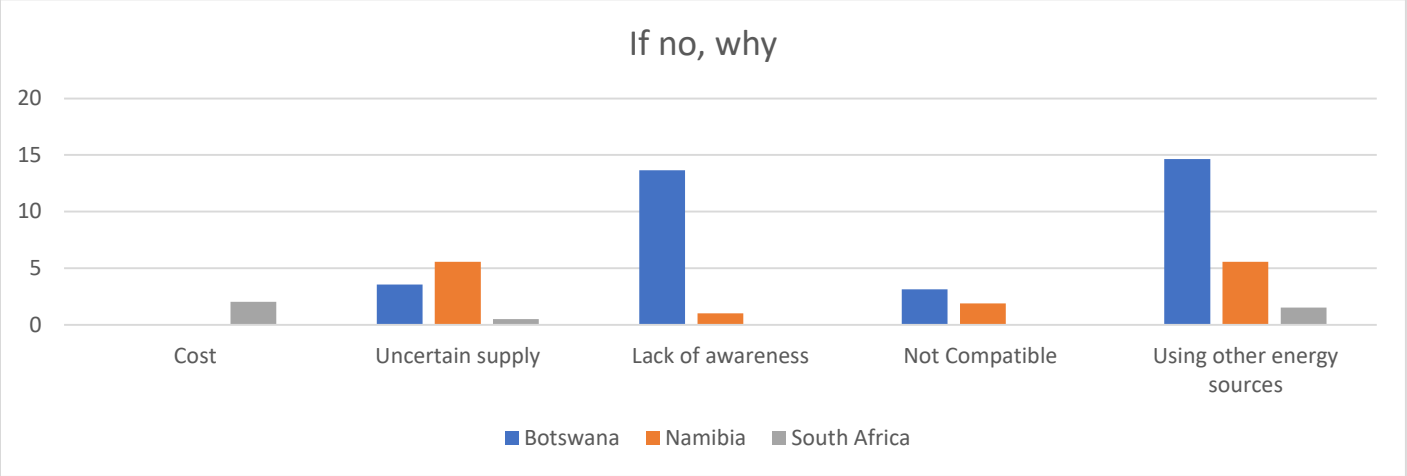


Figure 23. Reasons of lack of experience with biofuel use

Majority of respondents noted that they have never used biofuel because of lack of awareness (Figure 23), which will be interpreted as having misunderstood the question from the numerators. The other significant response was that they do not use it because they use other energy sources. This is quite reasonable explanation because some household facilities do not have allowance or other energy source, are not compatible with the equipment or necessities requirements for the energy.

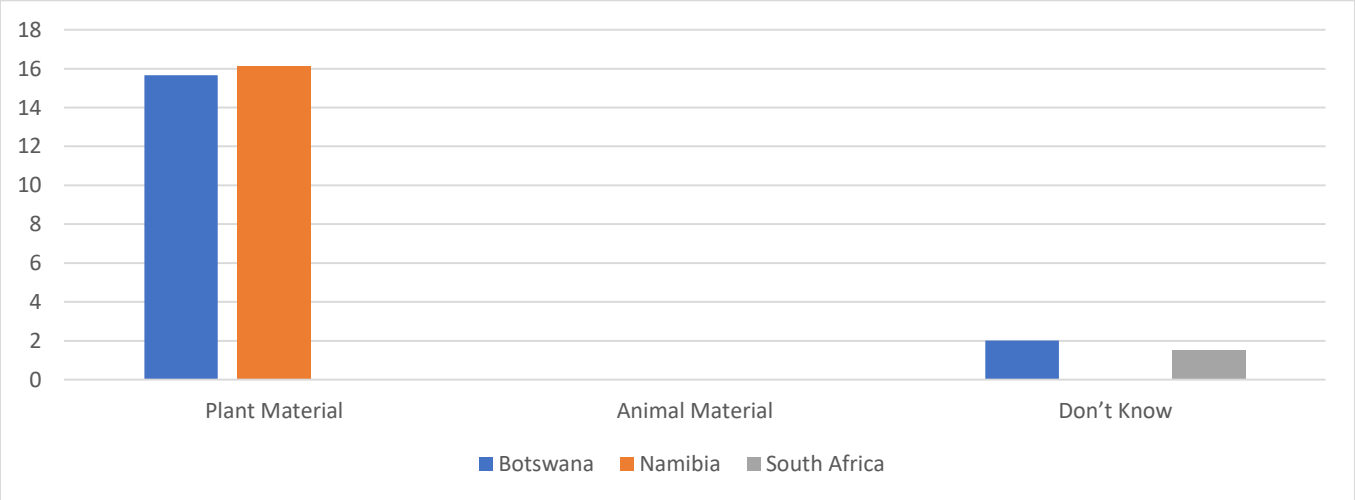


Figure 24. Biofuel material

The survey sought to find out the type of biofuels that the respondents were currently using (Figure 24)

Majority said they were using plant material 15.66%, in Botswana and 16.16% in Namibia. South Africa respondents were insignificant. The plant materials noted here were fuelwood, charcoal, and briquettes.

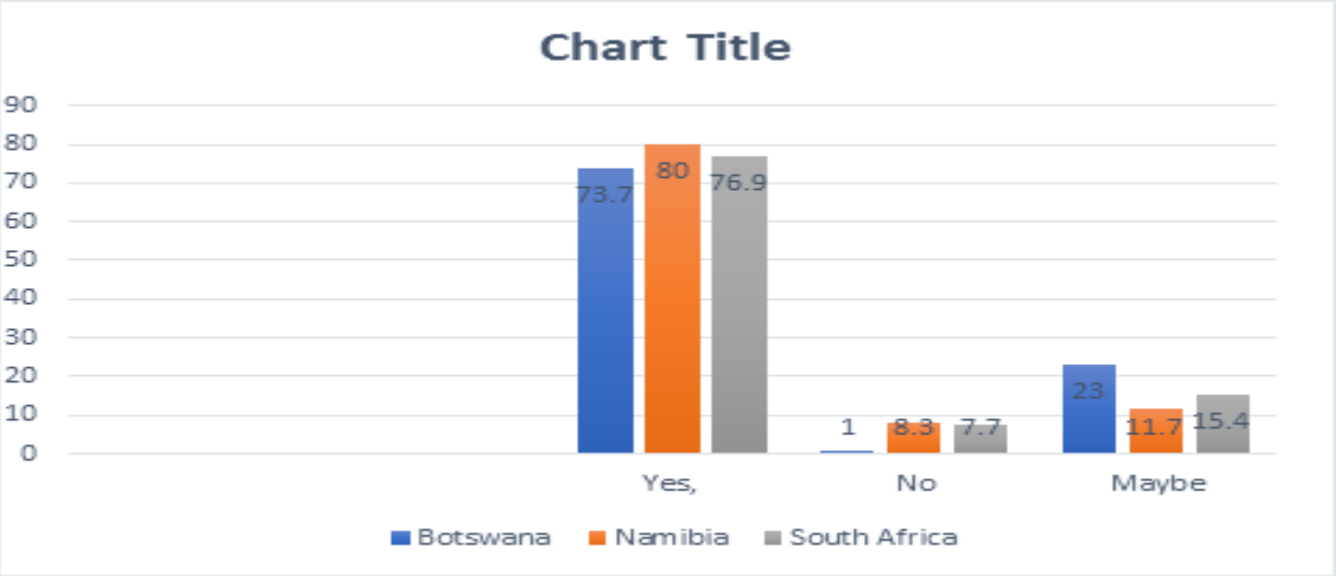


Figure 25. Interest to test solid biofuel

Figure 25 above shows that of respondents who answered the question asking if they would be willing to test the new energy, from Botswana 73.7% showed interest by responding with a yes, Namibia 80.0% respondents said yes, and South Africa only 76.9% said yes, (76.6 % combined from the three countries) would be interested to test the new energy type being promoted. An insignificant number of respondents answered no to being interested to testing out the new product. The respondents were motivated by different factors from their backgrounds, they agreed to being interested in testing the energy source, based on the value that it will bring to their lives, and money was not one of the factors because, the price of the new product was never discussed.

Table 12. Motivation for switching

Considering switching				
	Botswana	**Namibia**	**South Africa**	**Total**
Affordability				
0	1.01	0.00	7.58	8.59
Yes	38.89	14.65	11.62	65.15
No	10.10	15.66	0.51	26.26
Certainty in supply-availability				
0	1.01	0.00	17.68	18.69
Yes	10.61	7.58	1.01	19.19
No	38.38	22.73	1.01	62.12
Low Residues and the waste's potential ash				
0	1.01	0.00	18.69	19.70
Yes	5.56	3.03	0.00	8.59
No	43.43	27.27	0.00	70.71
Not stated	0.00	0.00	1.01	1.01
Environmentally friendliness (provides				
0	1.01	0.00	13.64	14.65
Yes	17.68	5.56	1.52	24.75
No	31.31	24.75	0.00	56.06
Not stated	0.00	0.00	4.55	4.55
Other				

To provide a competitive high value product, it is important to gauge what the target market values and prefers. Table 12 shows that factors that influence the choice of energy source in the household vary according to family values, size of the household, and the need for the energy source. The recorded factors varied between the urban, peri-urban, and rural areas. They also varied across income levels (Affordability), the type of house used should be within range of the supply source (certainty in supply-availability), and the facilities needed by the household compatible with the energy source. Some respondents select fuel energy based on its contribution to the environment, therefore, they required a new biofuel that would be environmentally friendly, which would provide substantial benefits for the climate, their health, and the economy. The factors determined the value the household placed on the energy source, source of energy used for purposes such as cooking, space heating, water heating, small home-based income-generating activity, braaiing/barbequing, and ironing. From the listed options, respondents in Botswana, Namibia and South Africa noted that affordability of the new biofuel would make them consider switching, affordability was regarded in relation to the household's income level and financial commitments, new biofuel should meet the budget means determined by the household income level. The other suggested options scored low percentages, which would be interpreted that they were not so important to the respondents.

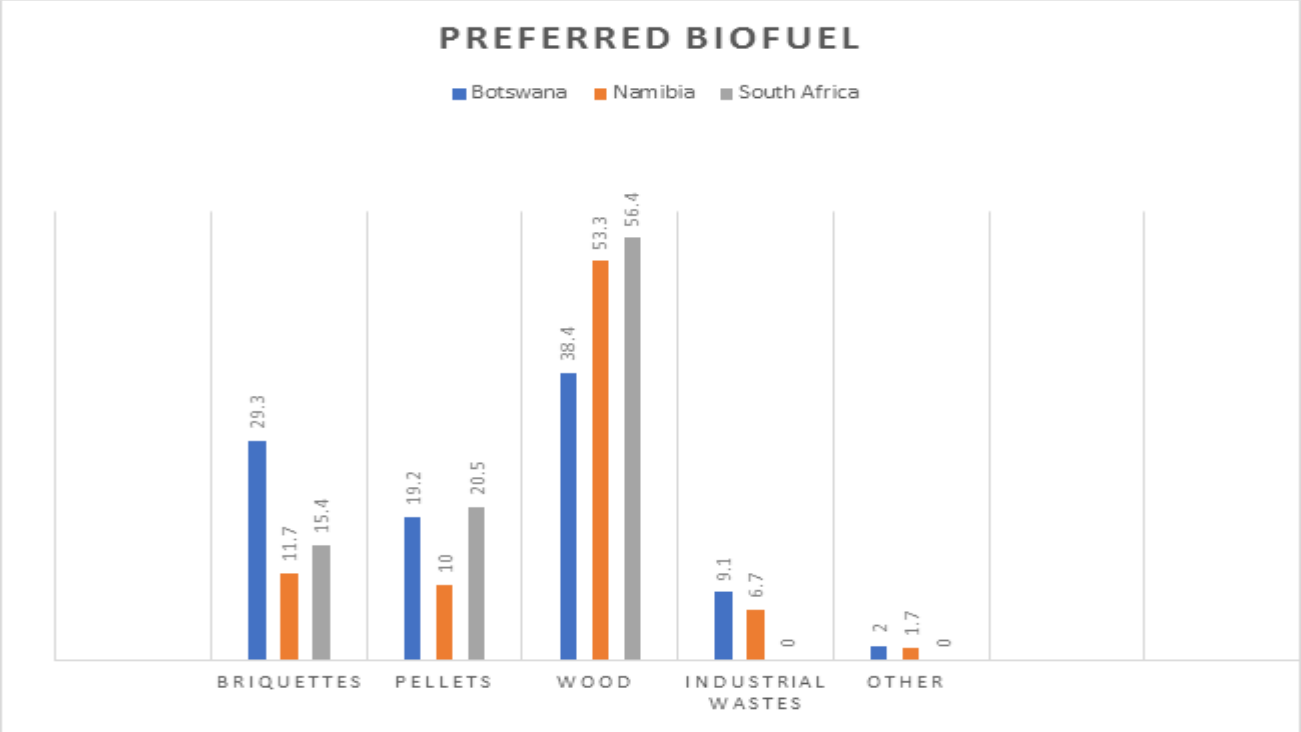


Figure 26. Type of biofuel preferred

To collect information on the kind of biofuel that respondents would prefer, Figure 25, shows results from data analysis for the question asked. Household respondents from Botswana, 38.4% of them picked wood, wood is the main bioenergy source in the lives of Batswana, it is the most affordable/free source of fuel. It is used in cooking, space heating, water heating, therefore, it makes sense for it to be the most preferred. The briquettes and pellets are still making their way up the energy ladder, 29.3% briquettes and pellets by 19.2%, they are usually used during braaiing sessions for recreational purposes. 53.3% of Namibian respondents also preferred wood and 56.4% of South African respondents also selected wood compared to other types of biofuels. Therefore, Majority of respondents noted that they prefer wood to other types of biofuel energy options.

3.9.8 Interest in participation in biofuel testing

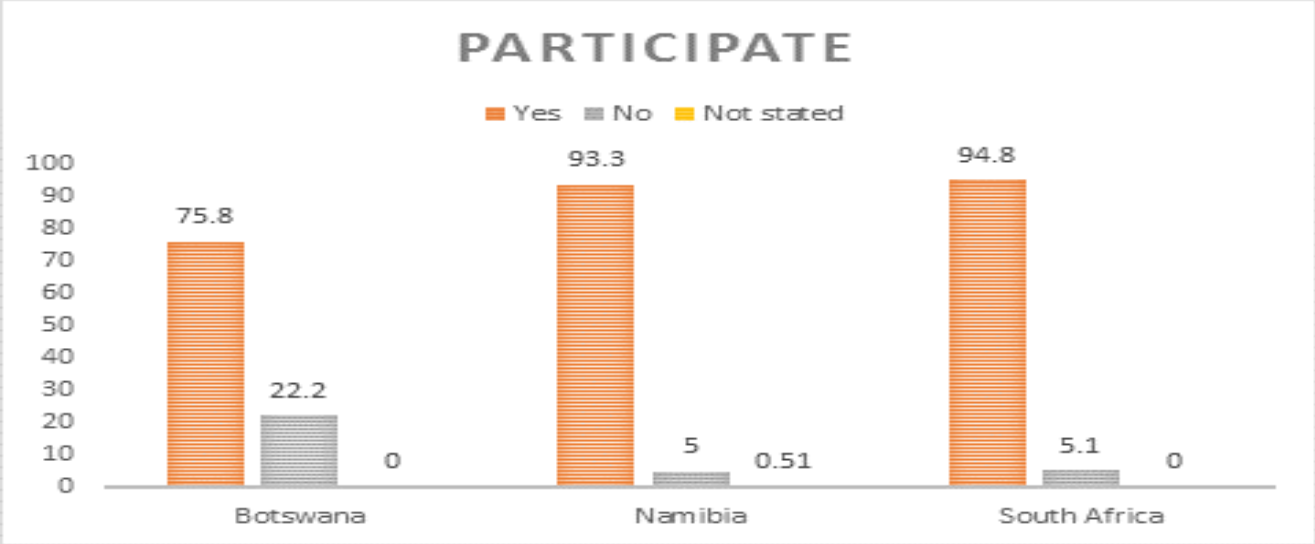


Figure 27. Interest to test biofuel

The ethics of survey requires that respondents give consent to be included in sample trials, the survey had a question that asked the respondents if they would be okay with being contacted to participate in the energy trials. 75.8% respondents in Botswana answered yes to being contacted only 22.2% answered with a no. In Namibia 93.3% of respondents will be interested to participate on the trials. South Africa also had the highest positive response rate from the respondents, 94.8% would like to be contacted to participate in the trials. Most respondents are willing and okay with being contacted to participate.

3.9.8.1 Willingness to pay for participation

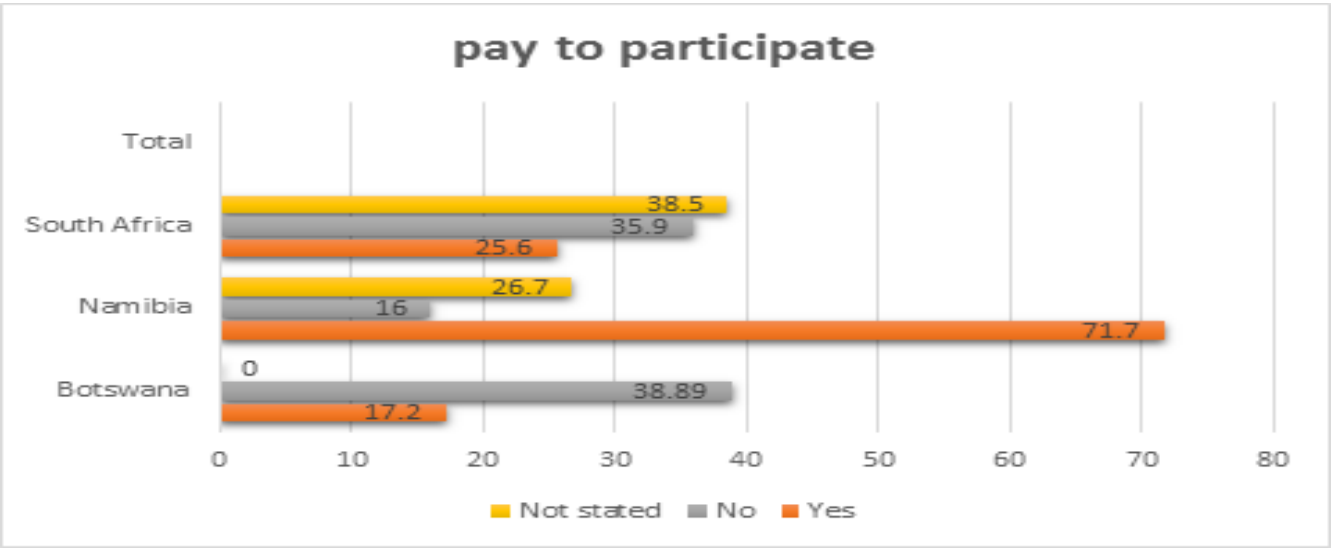


Figure 28. Willingness to pay for participation

Willingness to pay to participate in the new energy trials was measured by using respondents' answers from yes versus no and those who were not sure were recorded as not stated on Figure28 .

Majority of respondents in Namibia 71.7% stated yes, they are willing to pay to participate while in Botswana 17.2% said yes, they are willing to pay to participate in the product trials, but majority (38.89%) said no while 25% of South African respondents were also willing to pay to participate. This shows that majority of respondents from Namibia are willing to pay while respondents from Botswana and South Africa will not want to pay to participate. Whitehead et. al (2007) noted that the respondents' willingness to buy is usually determining by the value in relation to the product and future events of returns that they could possibly benefit from.

4 CONCLUSIONS

The assessment features current energy consumption patterns of households in Botswana, Namibia, and South Africa and establishes factors that influence energy choice at household level. While a high proportion of households prefer to use electricity, there is evidence of use of multiple sources of energy, which gives an idea about lack of security on continued availability of the preferred source of energy, either owing to interruptions or lack of warning on when the energy will finish, such as in the case of LPG. The continued use of energy mix provides potential for introduction of promising sustainable energy sources such as the solid biofuel that will be a product of the SHS technology.

The survey shows that while households are transitioning to more affluent energy sources like LPG and electricity, they continue to use other sources of energy such as fuel wood to meet other needs. The social, health and environmental consequences attached to their production and use of these fuels provide an opportunity for a more friendly and accessible energy source that promises to improve the current energy dilemma.

Respondents were willing to take part in trials for the proposed steam bio biofuel but are not willing to pay to participate in the trials. This then means an effective and worthwhile strategy of facilitating household trials need to be made at no cost to the households. The proposed biofuel should meet the important factors that household consider when selecting energy source for cooking and heating. The energy source should offer more efficiency and also some level of security and convenient while being affordable. The energy must not interfere with established household cooking practices. The proposed energy should not be seen to be regressive or degrading in any manner for it to have a greater likelihood of being accepted and used by households sustainably.

Introduction of the solid biofuel produced using SHS process to select households in the three countries will facilitate further assessment of its appeal and acceptance at household level. The testing should be done in the form of a pilot study with a system of monitoring that allows for capturing useful information to enable market prioritisation and process optimisation

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Appendix 1.

Table 1 characteristics of the study area

Country	Urban	Peri-Urban	Rural
Botswana	**Gaborone:** is the capital and largest city of Botswana with a population of **208,411** (2022 Census). It is the commercial and administrative centre of the country. The capital city is made up of several locations and suburbs; includes low-income areas like Old Naledi and high-income locations like Phakalane, Block 8 and, Phase 2	**Mogoditshane**- is a peri-urban village immediately neighbouring the capital city of Gaborone, it is a hive of economic activity with big city character as well as village appeal. It is a dormitory peri-urban centre characterised by a range of multi residentials properties. With a population of 88 098 (2022) Mogoditshane is currently the most populous village in Botswana.	**Ramotswa**- is a village about 25km Southeast of the capital of Gaborone. It also accommodates a fair share of commuters due to high accommodation costs in the city. The population of Ramotswa is 33 275 (2022 Census) **Metsimotlhabe**: another village 25km Northwest of the capital city of Gaborone, like other villages around the city it also offers cheaper accommodation facilities to people who work in the city. The population of Metsimotlhabe is 11 593(2022 census) **Mmopane** is a village 15 km Northwest of Gaborone. Another Domitory Village with a population of 25 355 (2022 Census)
Namibia	**Windhoek:** is the capital and largest city of Namibia. It is in central Namibia in the Khomas Highland plateau area, almost exactly at the country's geographical center. The population of Windhoek in 2020 was 431,000 which is growing continually due to an influx from all over Namibia. Windhoek is the social, economic, political, and cultural centre of the country. Nearly every Namibian national	**Otjiwarongo** is a town in Namibia, with approximately 90,000 inhabitants in the Otjozondjupa Region of Namibia. It is the district capital of the Otjiwarongo electoral constituency and the capital of Otjozondjupa. Otjiwarongo is situated in central-north Namibia, and it is the biggest business centre for Otjozondjupa Region. Otjiwarongo is located on the B1 road and its links between Windhoek, the Golden Triangle of Otavi, Tsumeb, Grootfontein, and Etosha National Park. It is one of Namibia's fast-	**Ovitoto** is a rural residential area in the Otjozondjupa region in the Omatako constituency. There are about 19 villages with a population of about 3000 inhabitants and one settlement (Okandjira settlement). Basic infrastructures are mainly shacks (corrugated iron). Residents in this community rely on cattle farming.

	enterprise, governmental body, the educational and cultural institution is headquartered there. In many of Windhoek's townships, residents live in shacks. In 2020 the city had a total of 41,900 of these informal housing structures, accommodating close to 100,000 inhabitants. It is made of stratified levels of income: high, middle, and low based on the housing characteristics.	growing towns, with a neat and peaceful quality environment and many excellent facilities, including supermarkets, banks, lodges, and hotels. Some of Namibia's best-known private game farms and nature reserves are in and around the town. There are about 15 schools in Otjiwarongo, three private schools, and twelve public schools. In many Otjiwarongo townships, residents live in shacks. In 2020 the city had a total of 6,251 of these informal housing structures, accommodating more than 50,000 inhabitants.	
South Africa	**Amalinda:** is a predominantly black middle-class township in East London (EL), which is the second biggest industrial centre in the Eastern Cape province of South Africa. Daimler Chrysler's Mercedes Benz manufacturing plant is situated in EL. **Katlehong:** is home to a lower-middle and low-middle class, which is 30 kilometres away from Johannesburg CBD. It falls under Ekurhuleni Municipality	**Rondebult**: is predominantly low-income households. All the houses were built by the SA government after the shacks were replaced through the Rural Development Programme. There is no mortgage or bonded house. About 40% of the population is unemployed. Thokoza and Rondebult are both in Johannesburg. The difference is the fact that Thokoza was never a squatter camp before, the houses were built by the apartheid government. The majority of the population is working class. There are also hostels in the township for male-only residents.	**Pirie Mission** **Pirie Mission** is located at **South Africa**, Dimbaza, Eastern Cape. It is a settlement. **Tokoza** **Thokoza is residential** east of the Johannesburg