ENERGY CHARACTERISTICS OF *PROSOPIS JULIFLORA* WITH BINARY COMBINATION OF MAIZE COBS AND BAGASSE AGRICULTURAL WASTE ON BRIQUETTE PRODUCTION

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Energy Characteristics of *Prosopis juliflora* with Binary Combination of Maize Cobs and Bagasse Agricultural Waste on Briquette Production

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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This thesis has been submitted for examination with our approval as the University Supervisors

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DEDICATION

This study is dedicated to my family and friends for their love and encouragement.

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%	Percent
m^3	Cubic Meter
MPa	MegaPascals
FIn	Future Income
PVn	Present Value
C_n	Costs Incurred
S_n	Savings Made
n	The Project Duration
Σ	Summation
CF	Cash Flow

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ACRONYMS AND ABBREVIATIONS

GCV	Gross Calorific Value
GW	Gigawatts
HCL	Higher Calorific value
IRR	Internal Rate of Return
JKUAT	Jomo Kenyatta University of Agriculture and Technology
Kg	Kilogram
KPLC	Kenya Power and Lighting Company
LCV	Low Calorific Value
LPG	Liquified Petroleum Gas
MJ	Megajoule
MJ/kg	Megajoule per kilogram
mm	Millimetre
MMU	Multimedia University of Kenya
MW	Megawatts
NCV	Net Calorific Value
NPV	Net Present Value
PI	Profitability Index
PV	Present Value

SEAI	Sustainable Energy for All Initiative

ABSTRACT

The demand for energy in Kenya continues to grow despite efforts to increase the country's installed power capacity. There is need to explore clean and sustainable energy sources to meet increasing energy demand. Briquette production is an affordable and environmentally friendly source of energy that uses various feedstocks such as woody biomass, crop residues, municipal, and industrial wastes. The study aimed to investigate the use of *Prosopis juliflora* as a feedstock for briquette production and evaluate the influence of a binary combination of maize cobs and bagasse on the characteristics of the briquettes; this was done by establishing proximate and ultimate energy parameters. Binary combination ratios were done at 25% and 50% of the total sample weights. Proximate analysis results showed that using *Prosopis juliflora* in its pure form for briquette production achieved moisture content of 5.59±0.09%; volatile matter of 77.49±1.98%; ash content of 3.12±0.16%; fixed carbon of 19.39±1.82% and calorific value of 18.99±0.21 MJ/kg. Ultimate elemental composition was 46.26±0.70% carbon, 5.75±0.14% hydrogen, 0.27±0.03% nitrogen and 0.44±0.05% Sulphur; which were all within desirable range for briquette production. Experimental analysis showed that the binary combinations of maize cobs and bagasse increased the calorific value of *Prosopis juliflora* briquettes with 50% *Prosopis juliflora* and 50% Maize cobs fuel combination being the optimal fuel choice for briquette production since it had high calorific value of 19.73±0.05 MJ/kg compared to the other binary combination briquettes. The study's findings revealed a positive Net Present Value of Kshs. 7,863,216 and a higher Internal Rate of Return of 55% compared to a nominal discount rate of 13%; a discounted payback period of 2.07 years and a profitability index of 1.57 indicating that both the technology and biomass material of *Proposopis juliflora* and maize cobs are economically viable for use in producing cheaper and quality briquettes.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Globally, fossil fuels usage are undesirable hence renewable energy topics have been attracting a lot of attention as an ideal alternative (Munga, 2020). Renewable energy has been used across the globe in diverse countries and contexts. Tayar *et al.*, (2022) noted that 176 counties globally have varied policies that seek to improve the production and consumption of renewable energy in their countries. India is estimated to have one of the largest installed sources of renewable energy across the globe. According to Tabassum and Shastry, (2022), India is the third largest producer of renewable energy with 38% (120 GW of 400 GW) of its total installed energy capacity being renewable. China as well is increasingly seeking means of improving its production of clean energy as means of environmental preservation and addressing climate change challenges (Li *et al.*, 2022). In Indonesia, Simionescu *et al.*, (2019) records that the country has plans geared towards improving renewable energy generation to be able to shoot it up to 23% by 2025 and 31% by the year 2050. Within the context of Nigeria, Ugwu *et al.*, (2022) asserts that while it had been expected that the country would achieve a 90% renewable energy by the year 2020; Nigeria stills lags behind at 75% of her energy matrix being renewable; the country alleging that those plans were derailed by the corona virus pandemic challenges (Amulah, 2022). Omenge and Obwoyere, (2020) reiterates that world over, there is a dire need for clean energy; it therefore indicates that renewable energy generating sources should be explored to their entirety.

In Kenya, renewable energy plays a major role in fulfilling the countries' soaring energy needs (Opilli, 2022; Adina, 2021; Munga, 2020). Oluoch *et al.*, (2020) noted that Kenya has been increasing its renewable energy sources with the country having achieved more than 85% (2270 MW of 2651MW) of its energy sources from renewable energy sources in 2020. In this context, Oluoch *et al.*, (2020) noted that Kenya's energy mix in 2020 constituted 18% hydroelectricity, 16% wind energy, 2% biomass, 15% fuel oil, 1% gas energy, 39% geothermal energy, and 9% solar energy.

While this is a notable progress for Kenya, it still falls short of the government's commitment to supply more than 95% of Kenya's energy from renewable energy sources by 2030 (Kiprop *et al.*, 2021). Omenge *et al.*, (2020) further noted that the total installed energy capacity in the country stood at 2339.9 MW in 2020 of which the renewable electricity in terms of wind energy stood at 336 MW, solar energy at 93 MW, and geothermal energy at 663 MW. In this context, Kenya is relatively doing well compared to the other Sub-Saharan Africa countries through its contribution of 4.5% to the Africa's total renewable energy installed capacity and 0.085% of the global renewable energy (Omenge *et al.*, 2020).

Briquette production has also played a role in Kenya's energy mix. According to Omwenga, (2021), briquettes production is a critical source of energy; especially for industrial use; running of boilers as well as cooking in learning institutions. The production of the briquettes in Kenya was first commercialized in the sugar cane dominating region since 2007; as a result of leveraging on easy access of the bagasse as agricultural waste within the region. The briquette utilization was viewed and promoted as clean energy solution compared to the use of charcoal and firewood as sources of energy in industrial, urban and rural homesteads (Chweya, 2020). Briquette production and utilization in Kenya was thus viewed as an alternative to the utilization of firewood and charcoal as a source of energy. Briquette production was also noted to reduce issues of deforestation and leading to compliance to the energy act of 2019 (Omwenga, 2021). The adoption of briquette usage leads to the reduction in charcoal and firewood consumption both in our industries and homesteads. Charcoal and firewood usage is not only unsustainable but contributes to devastating impacts to our environment and the user's health.

This study dwelt on biomass and in particular briquette production as a source of energy. Previous attempts on solving the problem associated with energy for cooking and industrial usage has had limited success as a result of inadequate scientific knowledge on the current level and utilization of modern cooking energy sources among households and industries. This study provides a solution by looking into briquette production as a renewable alternative to reducing if not to eradicate the use of firewood and charcoal in our homesteads and industries. Secondly, the study utilized

Prosopis juliflora (invasive plant) with binary combination of maize cobs and sugarcane bagasse which will not only add value to the invasive plant but provide a useful means to dispose the agricultural waste.

1.2 Statement of the Problem

The use of firewood as a source of energy amongst the rural dwellers, the urban middle class, industrial boilers and utilization in the institutions for cooking has been associated with undesirable outcomes; the use of these non-clean energy sources brings about deforestation, health problems to the users, negative impacts to the environment and are deemed unsustainable. This study sought to evaluate energy characteristics of the *Prosopis juliflora* and also examine the influence of agricultural waste on energy characteristics of the *Prosopis juliflora* with a view of determining there suitability for briquette production. These briquettes will provide an alternative green energy source against use of firewood and charcoal in our households and industries. Secondly it will provide a disposal solution to maize cobs and bagasse agricultural waste and add value to *Prosopis juliflora* as an energy crop, affording the invasive plant a useful means.

1.3 Justification

Firewood and charcoal are considered the two main sources of cooking fuel in most rural and urban areas in Kenya; Statistics from the Ministry of Energy indicate that more than 90% of rural households use firewood for cooking and heating, while more than 80% of urban households use charcoal (Ndegwa *et al*., 2022). Majority of Kenyan industries too continue to utilize firewood in powering their boilers. By adapting the use of briquettes made from *Prosopis juliflora* and agricultural waste binary combination will provide a sustainable and environment friendly energy source compared to use of firewood and charcoal.

1.4 Objectives

1.4.1 Main Objective

The main objective of the study is to evaluate *Prosopis juliflora* energy characteristics with binary combination of maize cobs and bagasse on briquette production.

1.4.2 Specific Objectives

i. To determine the physicochemical characteristics of *Prosopis juliflora* and its binary combinations of maize cobs and bagasse.
ii. To evaluate the fixed carbon and calorific values of *Prosopis juliflora* and the binary combinations.
iii. To establish the desirable binary combination on briquette production of *Prosopis juliflora*
iv. To perform techno-economic analysis of the briquetting process.

1.5 Research Questions

The study was based on the following research questions;

i. What are physicochemical characteristics of the *Prosopis juliflora* and its binary combinations?
ii. What are fixed carbon and calorific values of the *Prosopis juliflora* and its binary combinations?
iii. What is the desirable binary combination on briquette production of *Prosopis juliflora*?
iv. What is the economic viability of briquette production and technology used?

1.6 Significance of the Study

The study is significant in demonstrating the energy characteristics of *Prosopis juliflora* and its combination with the maize cobs and sugarcane bagasse in binary levels. The understanding of these characteristics will establish an alternative source to our country's energy mix while adding value to agricultural waste and the invasive plant.

1.7 Scope of the Study

The study was limited to investigating the physicochemical characteristics of *Prosopis juliflora* as a potential feedstock for briquette production as well as establishing influence of agricultural waste (maize cobs and bagasse) on energy characteristics of the *Prosopis juliflora* on their suitability in briquette production plus choosing the most optimum binary combination based on the resulting energy characteristics.

1.8 Limitations of the Study

This study was firstly inhibited by the inability to readily access *Prosopis juliflora* feedstock which was majorly located at the interior areas of Baringo County due to bad roads. The researcher hired motor cycles and natives who were well conversant with the area's navigation routes. Secondly, acquiring elements such as helium and oxygen used for proximate and ultimate analysis proved difficult during laboratory experiments; this caused delays on the study schedule.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Principles

The theoretical principles examine briquette production and the energy requirements in terms of proximate and ultimate analysis of briquette biomass fuels.

2.1.1 Briquette Production

Briquette production is one of the pathways of generating efficient fuel from biomass materials. According to Marreiro and Junior, (2021), briquette production involves the densification of raw materials into fuel forms that can transform biomass into usable energy. Briquette production is associated with achievement of denser fuel, improved physical and energy properties which enhances homogeneous combustion. Briquette production is then seen as a process of biomass densification that serves to improve physical and chemical properties of biomass hence more efficient energy source (Omwenga, 2021). According to Araújo *et al.*, (2022), a briquette refers to the a biomass that is combustible and that has been compressed for use as fuel. On the other hand, Riyadi *et al.*, (2019) views briquette as block of solid material that is flammable and thus used for fuel. Zhou, (2021) further noted that briquette refers to a solid granular fuel that is a by-product of directly crushing diverse biomass within specific temperature and pressure (Pasymi *et al.*, 2020).

There are diverse context under which briquettes are used; scholars such as Wang and Duan, (2020), Arora *et al*., (2021), and Darban *et al.*, (2019) have noted that briquettes are used to power boiler operations within industries; in this context, briquettes are used in various industries such as bakeries, schools, hospitals, and industries requiring boiler operations; thus making briquettes a potential biomass alternative technology which needs greater attention. As well, briquettes are noted to be utilized in various functions including heating and cooking for both local and urban dwellers (Marreiro *et al*., 2021).

Osei *at al.*, (2020) noted that briquette production from agricultural wastes leads to efficient fuels with low moisture content, high heating values, and desirable density while providing a great means of disposal. According to Marreiro *et al.*, (2021), the second generation biofuels are often utilized in the production of the briquettes. The second generation biofuels are associated with biomass residues from agroforestry sector. This could include leaves and barks for diverse agroforestry products. In this context, various agricultural and agroforestry wastes can be used in the briquette production these may include waste materials, saw dusts, cob husks, and cassava husks amongst others. Osei *et al*., (2020) asserted that the production of the briquettes from agricultural waste leads to the environmental protection, limiting the challenges associated with deforestation and primarily presenting a valuable disposal route.

According to Fikri and Sartika, (2020) briquette refers to a solid that is developed through the process of forming and pressuring it. The briquette is further characterized by low production of smoke upon ignition (Fikri *et al.*, 2020). On the other hand, Patil, (2019) views briquette as a solid block of flammable material that can be used as a source of energy. Petricoski *et al.*, (2020) views the briquettes as biofuels made from compaction of lignocellulosic residues. Bakare *et al.*, (2019) recorded that the major sources of lignocellulosic residues include wood, grass, agricultural residues, and forestry wastes amongst others. Bakare *et al.* (2019) further asserts that on average plant biomass comprises of 23% lignin, 60% cellulose, and 27% hemicelluloses by dry weight making plant biomass a possible candidates to being energy crops.

There are several characteristics of the briquettes that determine their suitability and efficiency as energy sources. These characteristics include mechanical and thermo-chemical indicators, stability, mechanical durability, calorific value, moisture content, volatile matter, ash content, fixed carbon, and briquette density amongst others (Urbanovičová *et al.*, 2022). Within the context of Kenya, several scholars have examined the production and energy efficiencies of briquettes production and use. In this regard, Omwenga, (2021) examined biomass briquette production and the various uses it has, Ng'ang'a, (2021) looked at the production of briquettes from acacia tree, Mokaya *et al.*,(2020), and Chweya (2020) looked at the factors hindering adoption of the briquette as energy source. According to Nunes *et al.*, (2019), high moisture content is not desirable in briquettes production due to crumbling aspects. Isah *et al.*, (2021) further noted the role of the moisture content in the briquette production aspects. In this context, Isah *et al.*, (2021) noted that the moisture content has an impact on the mechanical aberration, density, and the burning efficiency of the briquette. Abdulkareem *et al.*, (2020) further noted that the moisture content impacts on the ignition period, calorific values and the smoke emission of the fuel. In this regard, the low moisture content is deemed important in the briquette production. Oko *et al.*, (2019) asserts that the high moisture content was associated with the decomposition of the biomass leading to its loss of physical and chemical characteristics that makes it ideal as a fuel source. The decreasing of the content moisture also enables the increase of the carbonization of the briquette (Abayomi *et al.*, 2021).

There are several advantages associated with the briquette production. According to Fikri *et al.*, (2018), briquettes are associated with ease of production, high heat value, use of readily available materials as feedstock, and presence of competitiveness over alternative sources of energy. Patil, (2019) notes the importance of briquette as a source of renewable energy; briquettes are noted as alternative sources of energy to fossil-based fuels, charcoal and firewood that are not only unsustainable but also subject to diverse economic fluctuations across the world and add to environmental degradation (Bakare *et al.*, 2019). Other advantages associated with briquettes as sources of energy include cost efficiency, environmentally friendliness, and ease of local production (Styks & Knapczyk, 2021).

2.1.2 Feedstock Binary Combinations

Orhevba *et al.* (2019) indicated that 25% and 50% binary combinations of two various biomass fuels is ideal since it gives results that can be extrapolated to predict other multiple percentage combinations; this is in tandem with Romallosa, (2020) who did use binary combination of 25% and 50% of paper waste to sawdust weighted sample on briquette production. Further, 25% and 50% binary combinations levels for biomass fuels on briquette production have been explored successfully by various scholars which include Shams, (2019) and Sanwal *et al.*, (2020).

2.1.3 *Proposopis juliflora* as an Energy Source

Various feedstocks can be used in the production of briquettes which include but not limited to agricultural residues, forestry waste, and municipal waste and energy crops. *Proposopis juliflora* being a tree plant can as well be predicted to fit well in briquette production; the plant is highly invasive and its eradication methods have borne no fruits (Kumar & Chandrashekar, 2020). Briquette production would not only add value to *Proposopis juliflora* but also provide a better way of eradicating the plant. In this context, the possibility of use of *Proposopis juliflora* as a source of energy through production of briquettes as an environment conservation strategy has been explored by Kumar *et al.* (2020); Feleke and Bekalu, (2020) and Pasiecznik and Fre, (2022) in diverse geographical contexts of interest. The authors considered the high growth rate and the effortless multiplication of the plant; *Prosopis juliflora* high coppicing rate with low demand on its farming input makes it an excellent candidate as an energy crop. *Proposopis juliflora* can contribute tremendously to the dire need of energy to Kenya's growing population.

2.1.4 Bagasse as an Energy Source

Diverse scholars such as Petricoski and Martinez, (2020), Tumuluru, (2020), Nsubuga and Wydra, (2020) have noted the use of sugarcane bagasse in the production of briquettes. In this context, Petricoski *et al.*, (2020) asserts that sugarcane bagasse being a readily available biomass waste generated by sugar industries, they are an excellent energy source. Petricoski *et al.*, (2020) did utilized Sugarcane bagasse to synthesize briquettes while mixing the feedstock with sawdust and achieved a heat value of 17.89 MJ/kg in calorific value which is similar to what can be obtained from pine sawdust and pruning waste; thus deemed substantial. Magalhães and Zied, (2021) noted that the sugarcane bagasse is a by-product in the sugar industry and is treated as an industrial waste; hence making a suitable candidate to be used in production of briquettes as an energy source; thus adding value and contribute to its disposal.

2.1.5 Maize Cobs as an Energy Source

The maize cobs have also been noted as source of briquette production. This has often been in response to the challenges the maize cobs pose during its disposal process. According to Aliyu and Igbetua, (2020), maize cobs forms major agricultural waste which is often discarded after maize shelling. Ojediran and Okonkwo, (2020) noted that the maize cobs based briquettes have been used for cooking in homesteads as well industrial usage. Gutu and Duresa, (2020) note that the use of the maize cobs in briquetting production helps in not only providing a safer means of its disposal but again adding value to the cobs. There are several characteristics associated with the maize cobs that determine their usefulness in briquettes production. Maize cobs are characterized by high lignin content, low water soluble carbohydrates and low protein levels. According to Lavanya *et al.*, (2021) maize cobs refers to the residuals of maize which provide high levels of energy with a notable calorific value of 18.8 MJ/kg; hence making a suitable candidate to be used in production of briquettes as an energy source; thus adding value and contribute to its disposal.

2.1.6 Moisture Content

According to Ifa *et al.*, (2020), the moisture content refers to the ratio of the moisture weight relative to the dry weight of the solid fuel. The moisture content of the briquette has an impact on the burning characteristics of briquettes. In this context, Saeed *et al.*, (2021) noted the moisture content of the briquette had an impact on the quality, durability and burning rate of briquettes. Okot *et al.*, (2020) noted that the briquettes moisture content impacted on their quality; with the increase in the moisture content of briquette reduces the quality of the briquettes. In this context, Aransiola *et al.*, (2019) asserted that low moisture content was associated with high calorific value as no heat is lost while vaporizing any excess moisture in the briquettes during combustion. The briquettes with low moisture content also have low smoke emission and high burning rate which is desirable for any fuel. This was also noted by Anggraeni *et al.*, (2021), affirming that the low moisture content on briquettes led to high combustion and ignitability. Nurek *et al*., (2021) noted that the high moisture content is associated with poor compaction process of the briquette hence impacting on its quality aspects. Ifa *et al.*, (2020) further noted that high moisture content of the briquettes leads to low thermal efficiency, ignition capacity and burning rate of the fuel. The moisture content of the biomass being used in the development of the briquettes is also of critical importance. According to Nurek *et al.*, (2021) the moisture content of the plant materials during the agglomeration period of plant materials has a bearing on the quality of the final briquette products. With a view of enhancing the durability and density, the agglomeration of the plant materials should be undertaken at 8%-12% of the moisture content (Nurek *et al.*, 2021). Moisture content is determined using Equation 1:

$$\%Moisture\ Content = \frac{(W1 - W2)}{W2} \times (100) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 1$$

Where *W1* and *W2* are the weight samples before and after drying, respectively.

2.1.7 Volatile Matter

Volatile matter is a critical component to the briquettes. Volatile matter has been defined as the percentage of products that can be easily vaporized other than moisture during combustion of biomass (Sarakikya, 2020). Variani, (2021) noted that the volatile matter within biomass used in the briquette production is made of carbon, hydrogen, and oxygen. According to Akowuah *et al.*, (2019), volatile matter has an influence on the thermal properties of the solid fuels such as briquettes. Biomass components of briquettes often have high volatile matter of about 70% or more. This leads to high reactivity and high combustion levels. In this context, Variani, (2021) recorded that high volatile matter leads to ease of ignition and high combustion rate. Sarakikya, (2020) asserts that it is expected of biomass fuels to have volatile matter in the ranges of 70% to 80%; this leads to rapid burning and helps in combustion. Volatile matter is determined by using Equation 2:

$$\%Volatile\ Matter = \frac{(W2 - W3)}{W2} \times (100) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 2$$

where *W3* and $W2$ are the weight samples after burning for 10 minutes under 550 ^{o}C and the weight of the dry sample respectively.

2.1.8 Ash Content

Ash content is also a major component of the briquette production in consideration. According to Ikelle *et al.*, (2020), ash content refers to the amount of matter that is left after a complete burning of briquette. Ifa *et al.*, (2020) further asserts that ash content refers to the constituent that is obtained from heating of fuels. Osei *et al.*, (2020) noted that the ash content amount is dependent on the both organic and inorganic matters of biomass; inorganic making up what remains as ash after complete combustion. Sette *et al.*, (2021) asserted that briquettes with high ash content need regular removal of the ashes when used in the process of heating and cooking. The ash content has impact on the use of briquettes due to the clinkering and fouling effect in the combustion chambers. Ullah *et al.*, (2021) explained the impacts on the efficiency of the briquettes through lowering of heating efficacy leading to slagging effect. Ash content below 10% is desirable in most utilities (Sarakikya, 2020). Ash content is calculated using Equation 3:

$$\%Ash\ Content = \frac{W4}{W2} \times (100) \ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 3$$

where *W4* and $W2$ are the weight of ash and the weight of the dry sample respectively.

2.1.9 Fixed Carbon

Fixed Carbon explains the portion of biomass that is left as a residue after volatile matter distils off; after the cumulative sum of volatiles and ash content in the biomass is deducted(Gemeda, 2019). Pruthviraj, (2021) asserts that fixed carbon is the solid combustible residue that remains after the volatiles matter drive off. Therefore, understanding the amount of fixed carbon innate to a biomass feedstock will aid the choosing of combustion equipment, since its forms the part that sustains heat during combustion and a pointer to calorific properties of a biomass fuel. The fixed carbon in biomass material comprises of the elemental carbon plus any other carbonaceous residue formed during combustion process (Gemeda, 2019). A high fixed carbon percentage is associated with higher eating values. However, fixed carbon content gives information of the amount of char formation in the thermochemical conversion process(Nurek *et al.*, 2021). Higher the fixed carbon, the higher the char production in the thermochemical conversion process as a product yields. To find out percentage fixed carbon in a biomass material Equation 4 is used.

$$\%Fixed\ Carbon = 100\% - (\%Volatile\ Matter + \%Ash\ Content) \cdots\cdots\cdots\cdots 4$$

2.1.10 Calorific Value

Calorific value is one of the most important parameter in determining the quality of briquette fuel (Anatasya *et al.*, 2019). According to Deng *et al.*, (2020), calorific value is dependent on the total amount of matter that is combustible. It refers to the maximum amount of heat released on the combustion of a unit mass of briquette to completion. On the other hand, Vijayan *et al.*, (2020) reports that the calorific value refers to the amount of heat that is produced on the burning of a fuel under steady pressure and temperature. Pruthviraj, (2021) further viewed the calorific value as the heat produced on burning a unit quantity of fuel completely in presence of air or oxygen. The calorific value can be divided into the Gross Calorific Value (GCV) and Low Calorific Value (LCV). The GCV is also known as the Higher Calorific Value (HCV). According to Variani, (2021) and Pruthviraj, (2021), the GCV is defined as the as the maximum heat that is produced by completely burning a unit mass of such fuel and the emitted products of such combustion cooled down to room temperature and that above 17 MJ/kg GCV is desirable of biomass fuel. Vijayan *et al.*, (2020) argues that the released water is left to condense and the latent heat used to evaporate water is not included. On the other hand the LCV also known as the Net Calorific Value (NCV) refers to the maximum heat that is produced by completely burning a unit mass of such fuel and the emitted products allowed to escape (Variani, 2021). A Bomb Calorimeter is used to find out the calorific value of a biomass fuel which is measured using Megajoules per kilogram.

2.1.11 Ultimate Analysis

Ultimate analysis involves the determination of chemical elements present in a compound. For this study this involved finding out the percentage composition by weight of Carbon, Hydrogen, Nitrogen and Sulphur. A high Carbon and Hydrogen content in a biomass fuel is an excellent characteristic since it directly translates to high calorific value. This is due to the reason that between carbon and hydrogen, exists a high-energy bonds that releases and increased amount of energy during combustion (TgAzhar, 2020). Nitrogen has no calorific value significance in a biomass fuel; in addition to that, Nitrogen oxide (NO_x) has negative impacts to environment; therefore, low nitrogen content in a biomass fuel is a good characteristic. Low sulphur content in biomass fuel is a desirable characteristic as it leads to low emission of SO_2. SO_2 readily dissolves with water and brings about sulphuric acid; this has corrosive effect to the combustion chambers; also, Sulphur oxides are also responsible releasing significant amount of particulate matter and causing acidic rain (Kunle *et al*., 2021; TgAzhar, 2020).

2.1.12 Raw Materials Utilized for Briquette Production

Prosopis juliflora stem is the major feedstock that has been unutilized in this study. *Proposopis juliflora* is one of the shrubs found in harsh climatic conditions. According to Gemeda, (2019), *Prosopis juliflora* belongs to the family Fabaceae (Leguminosae), subfamily Mimosoideae and genus Prosopis. The shrub originated from South America, the Caribbean, and Central America (Gemeda, 2019). It is now found in the Americas, Africa and Asia. According to Sarmah, (2019), *Proposopis juliflora* is found in Northern south America, Central America, and parts of Africa. Anwar *et al.* (2022) further describe the *Proposopis juliflora* as a local species for Mexico and Australia. Within Africa, Huho and Omar, (2020) notes that *Proposopis juliflora* was first introduced in Senegal, South Africa, and Egypt in the early to late 19th century. In Kenyan context, Huho *et al*., (2020) asserts that the plant was first introduced in Kenyan coast as a means of rehabilitating the quarries that were present there. In 1980s the plant was introduced to Baringo, Tana River, and Turkana areas. Currently, the plant also has infestation in Wajir, Kajiado, Samburu, Isiolo, Taveta, Malindi, Migori, Mandera and Marsabit. The introduction of the plant to various Kenyan regions in the 1980s by the government was to address agroforestry efforts, environmental rehabilitation, ensuring self-sufficiency of fuel wood, and forest conservation from destruction. The plant was also introduced to reduce desertification challenges. It is described as a moderately sized, evergreen and thorny tree. It is described to develop in marshy and waterlogged areas. In most areas, it has been introduced as means of afforestation (Sarmah, 2019). Anwar *et al.*, (2022), Prosopis grows up to 12.5 m tall with a trunk of about 1.2 m in diameter. Elbalola, (2021) noted that the shrub is tolerant to harsh climatic conditions; hence across the globe, *Proposopis juliflora* has been used in afforestation efforts due its various traits. According to Gemeda, (2019) *Proposopis juliflora* is characterized by being tolerant to salt and drought conditions, and is able to thrive in both dry and waterlogged soils. The shrub also grows in poor soil conditions in terms of water and soil fertility aspects (Gemeda, 2019). Due to its various characteristics the shrub was introduced in various countries as means of land rehabilitation efforts, provision of diverse forest products, and provision of fodder (Elbalola, 2021). Apart from the intentional introduction of the shrub, there are also cases of accidental introduction of the shrubs to various geographical locations. However, despite its notable advantages there has been a myriad of challenges associated with the introduction of *Proposopis juliflora*. According to Elbalola, (2021), *Proposopis juliflora* disadvantages include the shrub being an invasive weed, introducing phytotoxicity, lowering soil water table, causes dryness of the soil and has been noted to invade the grazing lands; but the advantages of plant to develop huge seed banks once infestation has taken effect and the high coppicing rate plus its regenerative nature, makes the plant an excellent candidate as an energy crop.

Maize cobs were the other feedstock utilized for briquette production in this study. Maize cobs refers to the residual matter of the maize crop which is lignocellulosic biomass material (Lavanya *et al.*, (2021). On the other hand, Ali *et al.*, (2020) noted that the maize cob refers to the highly fibrous rachis of the female inflorescence of maize ear generated as a major by-product of maize processing. It contains a high amount of energy. Lavanya *et al.*, (2021) asserts that for every tonne of maize shelled about 180 kgs of maize cobs are generated. In the context of composition, Ng'erechi, (2021) notes that 35-40% cellulose, 40-50% hemicellulose and 10-20% lignin. The maize cobs are not easily decomposable and thus lead to environmental degradation (Htun *et al.*, 2022). Bagcal and Baccay, (2019) further notes that the agricultural disposal of the maize cobs is often discarded in landfills and other places within the environment. The maize cobs thus presents an environmental menace given that maize is the largest cultivated grains (Bagcal *et al.*, 2019). However, Maize cobs can be used for the production of fuels. According to Ali *et al.*, (2020) noted that its accessibility, low costs, high fibre, and abrasiveness has led to its use as a briquette fuel amongst other industrial functions.

Sugarcane bagasse was also used for briquette production in this study. According to Ng'erechi, (2021), the sugarcane bagasse refers to the industrial waste produced after juice extraction during sugar production process. On the other hand, Namakula, (2022) characterized the sugarcane bagasse as the fibrous leftover after the crashing of the sugarcane to extract their juice. About one tonne of sugarcane produces 280 Kilograms of bagasse. Bidai, (2020) further notes that as per the composition, the sugarcane bagasse is consist of 45-50% cellulose, 25-35% hemicellulose and 15-25% lignin (Ng'erechi, 2021). According to Bidai, (2020) the sugarcane bagasse when burnt yields 8-10% ash content making a good feedstock to the development of briquette fuels.

2.2 Summary of Related Studies

Different types of briquettes have been used for cooking purposes across the globe. In this context, Ige *et al.*, (2022) noted that rice husk-groundnut shell bio briquettes were being utilized as cooking fuel in Nigeria. Pasymi, and Rahman, (2020) noted that carbonized coal briquette can be used for cooking and heating. In Ghana, Osei *et al.*, (2020) reports that the charcoal briquettes from palm kernel shells have been used for domestic cooking purposes. In Northern Ethiopia, Gebrehiwot *et al.*,(2019) noted that the biomass briquettes from Sawdust and cow dung have been used for domestic cooking and industrial application in the country. Sawdust briquettes has also been used for domestic cooking in Kumasi Ghana, (Agyemang & Opoku, 2021). Briquette has also been used in diverse industries requiring boiler operations and hence higher energy sources. Feleke *et al.*,(2020) examined the characterization of the charcoal briquette using *Oxytenanthera abyssinica, Arundinaria alpina, Acacia melifera and Prosopis juliflora*. The study examined the interaction effect between *Prosopis juliflora* and saw dust which attained the moisture content of 7.95%, between *Prosopis juliflora* and charcoal with moisture content of 6.7%, *Prosopis juliflora* briquette with a moisture content of 6.63%. The study also explored the volatile matter percentage which interaction effect of *Prosopis juliflora* and sawdust stood at 63.05%, *Prosopis juliflora* and charcoal stood at 23.09%, and the *Prosopis juliflora* briquette stood at 20.56%. The study further examined the ash content. The study found that the percentage of ash content on interaction between *Prosopis juliflora* and sawdust stood at 16.66%, between *Prosopis juliflora* and charcoal stood at 5.6%. While the study did revealed significant figures on moisture and volatile content of *Prosopis juliflora* with sawdust briquettes, it failed to explore other important characteristics of biomass briquettes such as ultimate analysis and calorific value.

In India, Chandrasekaran *et al.*, (2021) examined the characterization of *Proposopis juliflora*. The study examined the physico-chemical characteristics of fuel wood using ASTM D1762-84 (2013) standard. In respect to the proximate analysis, the study found that the *Proposopis juliflora* wood had moisture content (12.10 ± 1.74), volatile matter (80.66 ± 2.26), and ash content (1.37 ± 0.34). On the other hand, Ramesh and Somasundaram, (2020) noted that proximate analysis denotes 29.1%, 71.25%, and 5.8 for moisture, volatile, and ash respectively; while the study found out the physical characteristics associated to *Prosopis juliflora* the study did not link the characteristics to briquette production using *Prosopis juliflora.*

In a study undertaken by Okot *et al.*, (2019) that sought to evaluate the briquette production from maize cob and stalk found that maize cob briquettes had high calorific value (17.8 MJ/kg). In another study, Lavanya *et al.*, (2018) undertook a study that examined the physical characteristics of the maize cob briquettes. The maize briquettes were produced by a high pressure briquetting machine at 118 MPa. The study found that the moisture content of the briquette stood at 12.93%. Sulaiman *et al.*, (2019) further noted that maize cob is characterized by volatile matter of 65-80%, and calorific value of 18-19 MJ/kg dependent on maize cobs moisture content and variety.

2.3 Research Gap

The densification of raw materials into briquettes bio-fuel is one of the pathways to converting biomass into useful source of energy. Various scholars have investigated the use of diverse feedstock and technologies in producing briquette fuels and more specifically carbonized briquettes. None of the studies have explored on non-carbonized briquette production using *Prosopis juliflora* and binary combination of maize cobs and bagasse agricultural waste while utilizing piston-type technology which this study extensively dwells on. This study investigated the energy characteristics of the invasive *Prosopis juliflora* and the influence maize cobs and bagasse has to its energy characteristics; this is in quest to have the feedstock utilized as green energy source to offset the increasing demand for charcoal and firewood in order to cap against deforestation and safeguard the degradation of our environment while creating and economical way of disposing the agricultural waste.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Figure 3-1 shows the study area; feedstock materials were collected from Baringo, Kisumu and Trans-Nzoia counties. *Prosopis juliflora* was sourced from Baringo County where the shrub is abundant in nature. Sugarcane bagasse was sourced from Muhoroni Sugar Company located in Kisumu County. While the maize cobs were sourced from the Maize growing areas of Kitale region in Trans-Nzoia County.

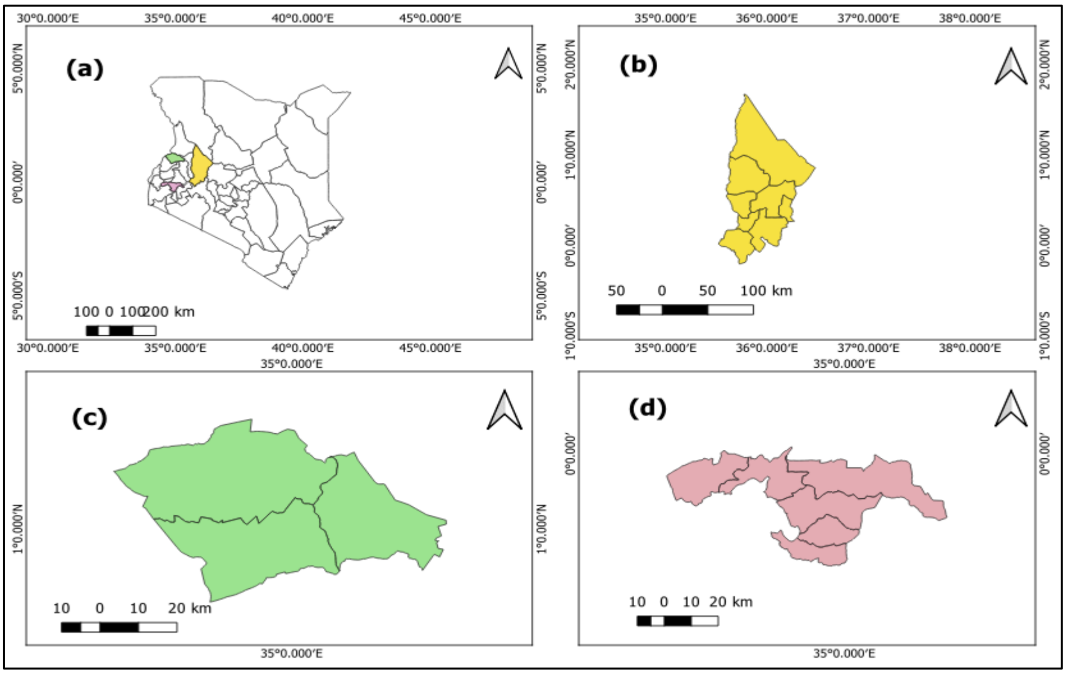

Figure 3.1: Maps of the Geographical Location of the Study Sites: (a) Kenya, (b) Baringo, (c) Trans-Nzoia and (d) Kisumu

3.2 Study Procedures

Figure 3-2, shows the activities that led to achieving briquette production were collection, sorting, size reduction, drying and binary preparation of feedstock was done; after which piston type briquetting machine was used to produce briquettes. The briquettes were then cooled, packed and transported to the laboratory for energy characteristics measurements.

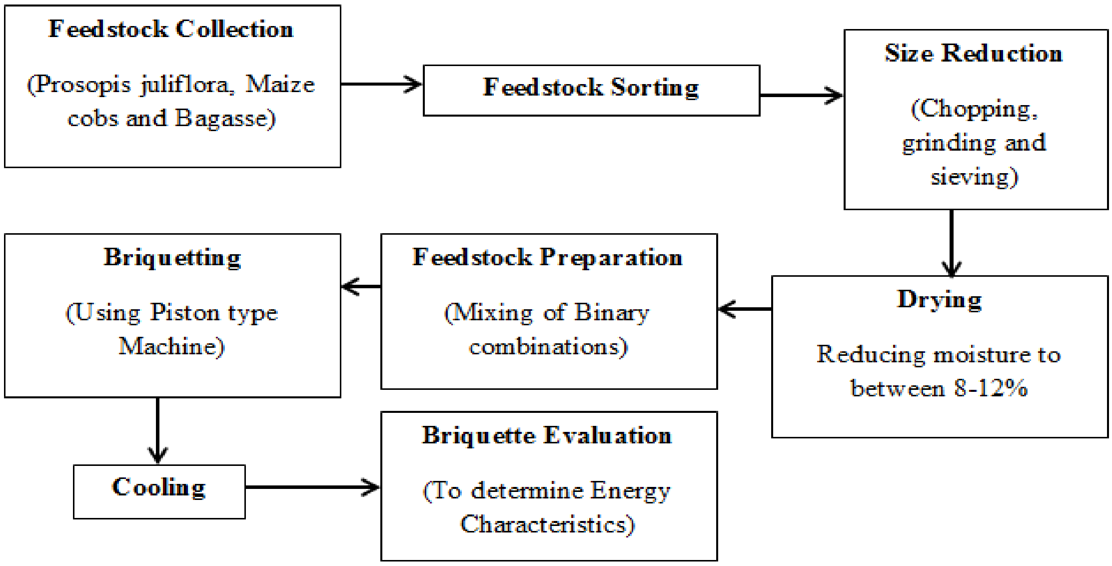

Figure 3.2: Briquetting Process Flowchart

3.2.1 Feedstock Collection

Biomass is a renewable and abundant source of energy that can be harnessed to meet the increasing global demand for energy. In this study, three different types of biomass were collected and evaluated for their potential use in energy production: *Prosopis juliflora* logs, bagasse from Muhoroni Sugar Company, and maize cobs from Kitale. *Prosopis juliflora* is a fast-growing and invasive tree species that has infested many areas in Kenya, including the outskirts of Lake Baringo. *Prosopis juliflora* was picked specifically from Ng'ambo area near Lake Baringo due to *Prosopis juliflora* high density infestation in this area. The logs were collected and transported to a nearby furniture workshop to facilitate chopping and grinding to achieve 2mm of particle size desire by the study. Maize cobs were obtained from maize shelling stores located in Kitale, where they are typically produced during the harvesting and shelling of maize. The selected maize cobs were then transported to nearby miller. Bagasse is a by-product of the sugar production process and is generated after the sugar cane has been milled and the juice extracted. At Muhoroni Sugar Company, the bagasse is primarily used as fuel to the boilers that run the factory. However, some of the bagasse is left as waste either in its loose state or in bales and these were collected for use in the study

3.2.2 Size Reduction on Feedstock

Feedstocks were taken through chopping, grinding and sieving to attain uniform sizes of 2 mm in length which is required to produce briquettes. Furniture saw was used to mill *Prosopis juliflora* logs into sawdust averaging 2 mm particles. Maize cobs and bagasse was taken through a grinding machine which is fitted with an abrasive wheel that resized the maize cobs and bagasse to 2 mm particles. Figure 3-3 shows *Prosopis juliflora* tree which was cut into logs and finally grinded into sawdust; it also shows the collected maize cobs and bagasse feedstock which were grinded using an abrasive wheel machine.

Figure 3.3: Feedstock Used; (a) *Prosopis juliflora* Tree,(b) Prosopis Logs, (c) Prosopis Logs being Grinded, (d)Maize Cobs,(e)Maize Cobs being Grinded and (f) Bagasse Feedstock

3.2.3 Drying of the Feedstock

The feedstock containing high moisture contents than stipulated (below 12% moisture content) for briquetting underwent sun-drying process. All the three feedstock at this point was sundried to reduce moisture to between 8-12% which is the acceptable limits suitable for briquette production.

3.2.4 Feedstock Binary Combinations

As illustrated in Table 3-1 the study had pure *Prosopis juliflora* briquettes produced and subsequently the binary combinations of both maize cobs and bagasse.

Table 3.1: Binary Combination

Biomass Material	Binary combination ratios	Sample % of Binary combination of Maize cobs and Bagasse
P. juliflora	1	0
***P. juliflora* + Maize cobs**	1:1	50
***P. juliflora* + Maize cobs**	3:1	25
***P. juliflora* + Bagasse**	1:1	50
***P. juliflora* + Bagasse**	3:1	25

3.2.5 Briquette Production Setup

Briquetting process was carried out using a piston-type briquetting machine accessed at Ecoline Company, Nakuru County. This machine was chosen due to its ability to generate high pressure, which is critical for pressing the biomass materials into denser briquettes. The machine was set to operate at a pressure of 100 MPa, which resulted in high-density briquettes. Figure 3-4 illustrates a piston type industrial briquetting machine at Ecoline Nakuru briquetting company which utilizes the rotary power of a heavy mechanical flywheel to reciprocate the plunger (piston) and the plunger drives the ram to reciprocate in the forming sleeve to generate a pressing force of 100 MPa which causes lignin to melt and agglomerate the material into briquette; hence there was no binders needed for this study.

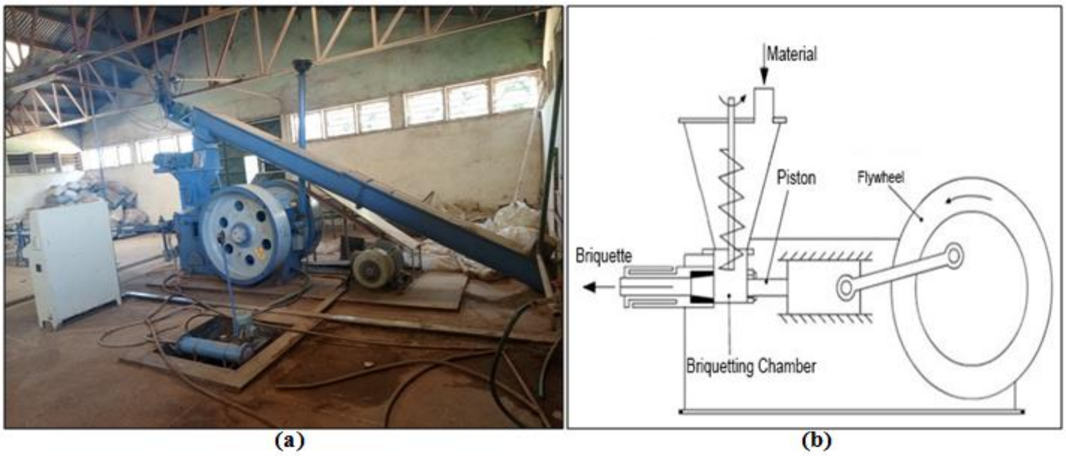

Figure 3 4: Machine Used; (a) Piston-Type Briquetting Machine and (b) Piston-Type Machine Diagram

During the briquetting process, the biomass materials were fed into the machine, which were compressed at 100 MPa which generated both heat and high pressure; heat and high pressure melts lignin inherent to feedstocks hence agglomerating the material to form briquettes therefore binders were not needed for this study. The high pressure generated by the machine resulted in a compaction process that formed the raw materials into solid briquettes. The briquettes were then ejected from the machine and collected for further testing.

The resulting briquettes were of high quality, with a consistent size of 90 mm in diameter. The briquettes were also dense, which indicates that the briquetting process was successful. This can be attributed to the high pressure generated by the piston-type briquetting machine. The use of high pressure during the briquetting process resulted in denser briquettes with higher energy density, which is desirable for fuel applications. Figure 3-5 shows the briquettes produced of *Prosopis juliflora* and the binary combination of bagasse and maize cobs feedstock.

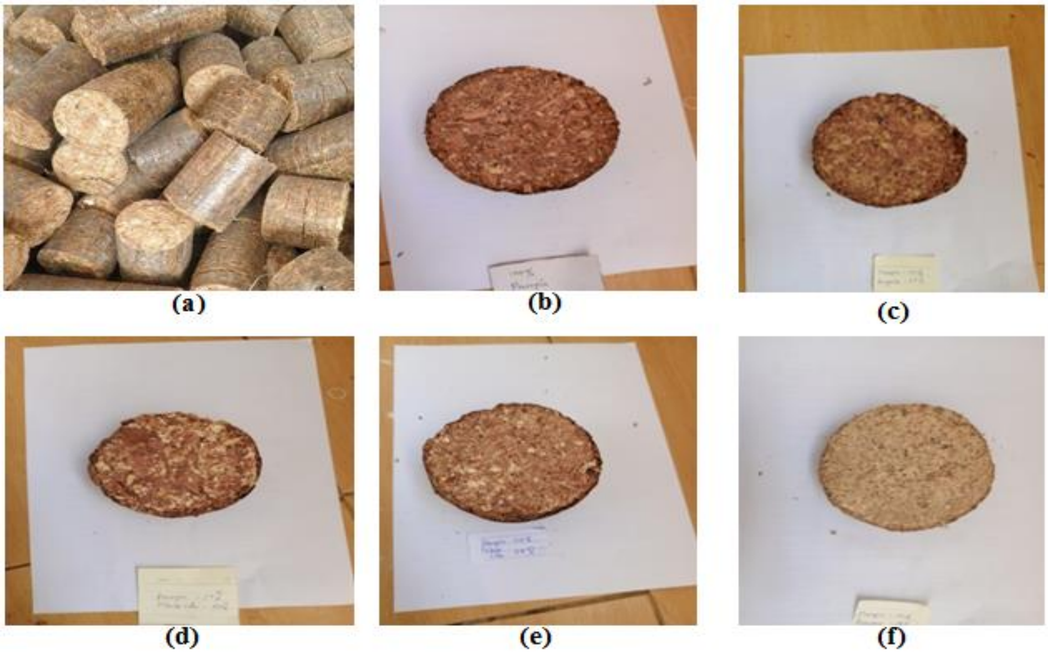

Figure 3.5: Resulting Briquettes; (a) Resulted Briquettes 90mm, (b) 100% Prosopis, (c) 75%Prosopis 25% Bagasse, (d) 50%Prosopis 50%Maize Cobs, (e) 75% Prosopis 25%Maize Cobs and (f) 50%Prosopis 50%Bagasse briquettes

Overall, the briquette development process was successful, and the resulting briquettes showed promising results in terms of their quality and energy potential. The use of a piston-type briquetting machine at high pressure proved to be an effective method of pressing the biomass materials into solid briquettes. The use of locally sourced raw materials and sustainable collection practices also ensured that the environmental impact of the process was minimized. The resulting briquettes have the potential to be a valuable alternative fuel source, providing a sustainable and cost-effective solution to the energy needs of the local community.

3.2.6 Experimental Procedures

After the briquettes were produced and ready they were packed and transported to the laboratory where the briquettes underwent five experiment tests namely; calorific value, moisture content, volatile matter, ash content and fixed carbon to determine their proximate analysis; also, ultimate analysis was done to determine the percentage composition of Carbon, Hydrogen, Nitrogen and Sulphur.

3.2.7 Techno-Economic Analysis

Briquetting process economic analysis was done by first estimating the installation cost taking advantage of Ecoline briquetting plant in Nakuru. Estimates of both operational and maintenance cost ware also carried out. Then the economic viability of the project was computed using assessment criteria tools namely Future Income (FI_n), Present Value (PV_n), net present value (*NPV*), internal rate of return (IRR), amortization time and the profitability index (PI). The future incomes for each year were calculated from the sum of the costs incurred and the savings made; where the costs are taken as negative and the savings positive. The future income of the project was calculated using Equation 5;

$$FI_n = \sum C_n + \sum S_n \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 5$$

whereFI_n, C_n and S_n represents the future income, costs incurred and savings made in year n, respectively. The cost of energy in this case referred to as yearly electricity savings which were calculated considering the small commercial (SC) tariff of the utility (KPLC) including all levies, adjustments and taxes incurred for the supply of the grid power. The PV_n was calculated using the publication of Central Bank of Kenya (CBK) discounting rates as at July 2023 to observe the financial behaviour of the project at inception. The PV_n for year n was evaluated using the future income of a given year and the discounted rates as illustrated in Equation 6;

$$PV_n = \frac{FI_n}{(1+r)^n} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 6$$

where FI_n is the future income for year n, r is the discount rate and n is the time in years. In this project the NPV was calculated using the annual avoided costs of energy resulting from the project (future incomes) since there are no cash flows. The NPV was calculated using Equation 7:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 7$$

where *CF* is cash flow (Kshs), *k* the % annual interest rate, *t* the corresponding year; *n* the project duration. *CF* is also termed as the net annual cost(annual cost minus revenue) (Indrawan et al., 2020). The expression $(1+k)^t$ is the capital recovery factor (CRF) converting present value in a sequence of equivalent annual cash flow over a project period. Observe in Equation 8 that, in the calculation of *IRR* value, the *NPV* was equated to zero because the present value of future cash flows at the project's start is equivalent to the initial investment.

$$0 = NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+IRR)^t} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 8$$

The profitability index (*PI*) also referred to as profit investment ratio, is a measure of the relationship between a project's costs and profits. The *PI* was calculated by dividing the net present value by the initial investmentFI_0. The *PI* was determined according to Equation 9;

$$PI = \frac{NPV}{FI_0} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 9$$

where the variables take the earlier defined meaning (Zeraatpisheh *et al.,* 2018). *PI* is invariably a positive number, with a *PI* less than one indicating a loss-making investment and a *PI* greater than one indicating a profitable investment, and logically, *PI* equals one indicating the lowest acceptable profit for investment (Alrikabi, 2022). The projects pay-back period in this case amortization time, was calculated using a static payment amount (future incomes) and a dynamic amount (present values) to estimate the number of years taken for the breakeven point of the project to be reached. Static and dynamic amortization time was calculated from Equations 10 and 11, respectively:

$$Amortized\ time\ (static) = -\frac{1}{n}\left(\frac{FI_0}{\sum_1^n FI_n}\right) \cdots\cdots\cdots\cdots 10$$

$$Amortized\ time\ (dynamic) = -\frac{1}{n}\left(\frac{FI_0}{\sum_1^n PV_n}\right) \cdots\cdots\cdots 11$$

where the variables carry their initial meaning defined earlier. The viability of the project is determined by the *PI* value and the amortized time (Alrikabi, 2022). In this study, the estimated project lifetime span for the briquetting production system is 7 years which is assumed to be the economic life time.

3.3 Research Instruments

3.3.1 Muffle Furnace

Figure 3-6, shows the Ceramic fibre Faithful Model SGS which was used to determine moisture content, volatile matter and ash content of the biomass briquette samples. It is equipped with a variable temperature controller that is used to set desired temperatures; for this study 105 ^{o}C was set for percentage moisture content and 550 ^{o}C was set for determining percentage volatile matter and ash content.

Figure 3.6: Ceramic Fibre Faithful Model SGS Muffle Furnace Manufacture by FAITHFUL Instrument Co. Ltd-China

3.3.2 Analytical Balance

Figure 3-7 is the Precisa 310M type of analytical balance that was used to measure samples placed in crucibles to determine the weight of the biomass samples of briquettes before and after the Muffle furnace tests; the analytical balance had an accuracy of 1 mg.

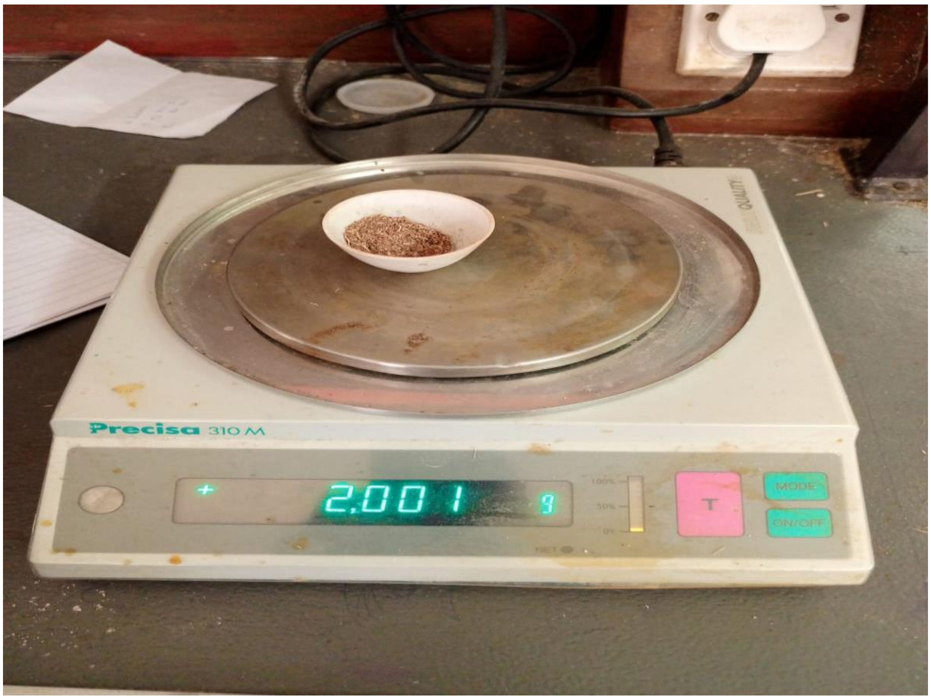

Figure 3.7: Precisa 310M by Precisa Gravimetrics AG-Switzerland, Analytical Balance Measuring Briquette Sample in A Crucible

3.3.3 Desiccator

Figure 3-8 is the desiccator that was used to cool the samples after the muffle furnace tests, and to maintain a dry environment for the samples before and after testing against atmospheric humidity. It contained desiccants which absorbs moisture and maintains a dry environment for the samples.

Figure 3.8: Desiccator Containing Desiccant

3.3.4 Bomb Calorimeter

Figure 3-9 shows e2K combustion calorimeter which was used to measure the calorific values for the respective briquettes samples. The e2K bomb calorimeter had a bomb which was filled with the sample and oxygen, and was then ignited. The heat released during the combustion of the sample was measured and electronically displayed; and this provided an indication of the energy content of the sample.

Figure 3 9: e2K Combustion Calorimeter by Digital Data Systems (Pty) Ltd – South Africa

3.3.5 Porcelain Markers

Graphite porcelain marker was used to label the biomass samples placed in porcelain crucibles during testing. This ensured that the samples were easily identifiable during the testing process.

3.3.6 Crucibles

Porcelain crucible was used to hold the briquette samples during and after experimental testing. Porcelain crucibles are heat-resistant containers that can withstand high temperatures in a Muffle furnace.

The use of these apparatus in the laboratory testing procedures ensured the accuracy and precision of the measurements obtained. The Muffle furnace and the Bomb calorimeter are specialized pieces of equipment designed for high-temperature heating and calorific value measurements, respectively. The analytical balance, desiccator, porcelain markers and crucibles are standard laboratory equipment used for sample preparation and handling. The combination of these apparatus, alongside the adapted testing procedures, ensured that accurate and reliable measurements were obtained for the various characteristics of the biomass sample briquettes.

3.4 Data Collection and Analysis

Data was obtained by experimentally determining the *Prosopis juliflora* and its binary combination briquettes energy characteristics. The parameters measured were the percentage moisture content, volatile mater, ash content, fixed carbon and the briquettes calorific values to determine their proximate analysis; for ultimate analysis, elemental carbon, hydrogen, nitrogen and sulphur was also measured.

3.4.1 Moisture Content (%MC) Calculations

The moisture content was determined by measuring 2 g of sample briquette matter into a crucible and labelled (*W1*). The content was dried in a Muffle furnace at 105 ^{o}C for 2 hours to obtain dry weight which was labelled (*W2*). The crucible and its content were removed from the oven and allowed to cool to room temperature and reweighed. The percentage moisture content was calculated using Equation 12:

$$\%Moisture\ Content = \frac{(W1 - W2)}{W2} \times (100) \ \cdots\cdots\cdots\cdots 12$$

With *W1* and *W2* being the weight samples before and after drying, respectively.

3.4.2 Volatile Matter (%VM) Calculations

Percentage volatile matter was determined by keeping the 2 g of briquette material in crucible with dry weight (*W2*) in the Muffle furnace for 10 minutes at 550 ^{o}C to obtain weight (*W3*) after which the volatile matter in it have escaped. The percentage of Volatile Matter was calculated using Equation 13:

$$\%Volatile\ Matter = \frac{(W2 - W3)}{W2} \times (100) \ \cdots\cdots\cdots\cdots\cdots 13$$

Where *W3* is weight sample after burning for 10 minutes under 550 ^{o}C

3.4.3 Ash Content (%Ash) Calculations

Ash content was determined by putting measured (*W3*) in the crucible and put in the Muffle furnace at 550 ^{o}C for 4 hours. The sample was then cooled in desiccator and weighed after reaching room temperature as *W4*. The percentage Ash Content was calculated using Equation 14:

$$\%Ash\ Content = \frac{W4}{W2} \times (100) \ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 14$$

Where *W4* is the weight of ash.

3.4.4 Fixed carbon (%Fc)

Percentage fixed carbon was calculated by subtracting the sum of % Volatile matter and % Ash content from 100% as shown by Equation 15:

$$\%FC = 100\% - (\%VM + \%Ash\ Content) \cdots\cdots\cdots\cdots 15$$

3.4.5 Calorific Value

To determine the calorific value of briquette samples, a small amount of 0.5 g of every sample mixture was placed in crucibles and inserted into the bomb. A thread was tied through the briquette sample to hold it in place; bomb was then sealed and an oxygen supply was connected to the bomb through a valve. The pressure in the oxygen cylinder was released and increased to 25 atmospheres of pressure. After which the bomb was placed inside the calorimeter and the lid closed. To ignite the sample, an electric circuit was closed which connects the iron fuse wire that surrounds the sample, to the lower end of two electrodes that extended through the base of the bomb. The electric current passing through the fuse wire caused it to heat up and ignite the sample. During the combustion process, the sample and the fuse wire release heat energy, which was absorbed by the calorimeter and given out as a reading by the automatic digital bomb calorimeter.

3.4.6 Ultimate Analysis

Sample weights of 2 g were weighed for every sample and put into a small capsule. The sample was then placed into the Flash 2000 CHNS Elemental Analyzer from Thermo Scientific-United Kingdom. The analyzer is electronically controlled and is equipped with an auto sampler that drops each sample sequentially into a 900 ^{o}C furnace. A small volume of oxygen was introduced to the burner to aid burning the sample and converts the weighted sample into elemental gases. The instrument operates with the basic principle of combusting the sample in a pure oxygen atmosphere, and the resultant gases are automatically measured. Separation column and thermal conductivity detector equipped with the analyzer was used to determine the element concentrations and the digital device gives out the elemental sample gases composition readings.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

The study aimed to evaluate the energy characteristics of *Prosopis juliflora* in combination with agricultural wastes of maize cobs and bagasse for briquette production. The specific objectives were to determine the proximate and ultimate characteristics of *Prosopis juliflora* and its binary combinations, examine the influence of the binary combinations on energy characteristics of *Prosopis juliflora* briquettes, and finally to determine the optimal binary combination for briquette production. The research questions focused on the moisture content, calorific value, volatile matter, ash content, and fixed carbon of *Prosopis juliflora*, as well as the influence of agricultural waste on the energy characteristics of *Prosopis juliflora* and their economic viability on briquette production.

4.2 Proximate Analysis

Proximate analysis results obtained as illustrated in Table 4-1 shows the physical energy characteristics of *Prosopis juliflora* and the binary combination of maize cobs and bagasse.

Table 4.1: Proximate Analysis

	Moisturecontent	**Volatile matter**	**Ash content**	**Fixed carbon**	**Calorific value**
	%MC	**%VM**	**%AC**	**%FC**	**MJ/kg**
***P. juliflora* 100%**	5.59±0.09	77.49±1.98	3.12±0.16	19.39±1.82	18.99±0.21
***P. juliflora* 50% & MAIZE COBS 50%**	5.87±0.02	75.65±1.21	3.24±0.21	21.11±1.42	19.73±0.05
***P. juliflora* 75% &MAIZE COBS 25%**	5.82±0.02	78.46±0.37	2.34±0.01	19.21±0.37	19.27±0.05
***P. juliflora* 50% & BAGASSE 50%**	5.90±0.05	78.05±0.14	4.06±0.08	17.89±0.22	19.14±0.07
***P. juliflora* 75% & BAGASSE 25%**	5.27±0.07	77.81±0.68	2.93±0.29	19.27±0.99	19.07±0.07

The moisture content of biomass fuel is a crucial factor in determining its combustion efficiency and heat output. In this regard, the moisture content of five different biomass fuel combinations was analysed, namely *Prosopis juliflora* 100%, *Prosopis juliflora* 50% & Maize cobs 50%, *Prosopis juliflora* 75% & Maize cobs 25%, *Prosopis juliflora* 50% & Bagasse 50%, and *Prosopis juliflora* 75% & Bagasse 25%.

The moisture content (%MC) of each combination was as follows: *Prosopis juliflora* 100% had a moisture content of 5.59±0.09%; *Prosopis juliflora* 50% & Maize cobs 50% had a moisture content of 5.87±0.02%; *Prosopis juliflora* 75% & Maize cobs 25% had a moisture content of 5.82±0.02%; *Prosopis juliflora* 50% & Bagasse 50% had a moisture content of 5.90±0.05%; and *Prosopis juliflora* 75% & Bagasse 25% had the lowest moisture content of 5.27±0.07%.

Comparing the moisture content of the different binary combinations, it is evident that *Prosopis juliflora* 50% & Bagasse 50% had the highest moisture content, while *Prosopis juliflora* 75% & Bagasse 25% had the lowest. The moisture content of *Prosopis juliflora* 100%, *Prosopis juliflora* 50% & Maize cobs 50%, and *Prosopis juliflora* 75% & Maize cobs 25% fell in between these two extremes.

It is worth noting that higher moisture content in the fuel can lead to incomplete combustion, resulting in reduced heat output and increased emission of pollutants. Therefore, the combination of *Prosopis juliflora* 75% & Bagasse 25% can be considered a better fuel option compared to *Prosopis juliflora* 50% & Bagasse 50% due to its lower moisture content. However, it is important to evaluate other factors such as volatile matter, ash content, fixed carbon, and calorific value before making a final decision on the best fuel combination. The combination of 100% *Prosopis juliflora* had a volatile matter content of 77.49±1.98%. When 50% maize cobs were added to 50% *Prosopis juliflora*, the volatile matter content decreased slightly to 75.65±1.21%. However, when the proportion of *Prosopis juliflora* was increased to 75% and maize cobs reduced to 25%, the volatile matter content increased to 78.46±0.37%. Similarly, it is observed that when 50% bagasse were added to 50% *Prosopis juliflora*, the volatile matter content increased to 78.05±0.14%. But when the proportion of *Prosopis juliflora* was increased to 75% and bagasse reduced to 25%, the volatile matter content decreased slightly to 77.81±0.68%. Overall, the combination of 75% *Prosopis juliflora* and 25% maize cobs had the highest volatile matter content 78.46±0.37%, while the combination of 50% maize cobs and 50% *Prosopis juliflora* had the lowest volatile matter content 75.65±1.21%. The other combinations had intermediate volatile matter contents.

The combination of 100% *Prosopis juliflora* had an ash content of 3.12±0.16%. When 50% maize cobs were mixed with 50% *Prosopis juliflora*, the ash content increased slightly to 3.24±0.21%. However, when the proportion of *Prosopis juliflora* was increased to 75% and maize cobs reduced to 25%, the ash content decreases significantly to 2.34±0.01%. Further, when 50% bagasse was added to 50% *Prosopis juliflora*, the ash content increased further to 4.06±0.08%. But when the proportion of *Prosopis juliflora* is increased to 75% and bagasse reduced to 25%, the ash content decreases to 2.93±0.29%. In comparison, the combination of 50% bagasse and 50% *Prosopis juliflora* had the highest ash content at 4.06±0.08%, while the combination of 75% maize cobs and 25% *Prosopis juliflora* had the lowest ash content at 2.34±0.01%. The other combinations had intermediate ash contents. In summary, the ash content of the mixtures is highly dependent on the proportions of the different types of biomasses and the intrinsic inorganic matter found in the feedstock. It is observed that mixtures with higher proportions of *Prosopis juliflora* tend to have lower ash content, while mixtures with higher proportions of maize cobs or bagasse tend to have higher ash content.

The combination of 100% *Prosopis juliflora* had a fixed carbon content of 19.39±1.82%. When 50% maize cobs were added to 50% *Prosopis juliflora*, the fixed carbon content increased to 21.11±1.42%. However, when the proportion of *Prosopis juliflora* was increased to 75% and maize cobs reduced to 25%, the fixed carbon content decreased to 19.21±0.37%. Similarly, it was evident that when 50% bagasse was added to 50% *Prosopis juliflora*, the fixed carbon content decreased to 17.89±0.22%. But when the proportion of *Prosopis juliflora* was increased to 75% and bagasse reduced to 25%, the fixed carbon content increased slightly to 19.27±0.99%. In comparison, the combination of 50% maize cobs and 50% *Prosopis juliflora* had the highest fixed carbon content 21.11±1.42%, while the combination of

50% bagasse and 50% *Prosopis juliflora* had the lowest fixed carbon content 17.89$\pm$0.22%. The other combinations achieved intermediate fixed carbon contents. Overall, the proportion of maize cobs in the mixtures appears to have a greater impact on the fixed carbon content, with higher proportions resulting in increased fixed carbon. However, the proportion of *Prosopis juliflora* and bagasse also had a moderate effect on the fixed percentage carbon content.

The combination of 100% *Prosopis juliflora* had a calorific value of 18.99$\pm$0.21 MJ/kg. When 50% maize cobs were added to 50% *Prosopis juliflora*, the calorific value increased to 19.73$\pm$0.05 MJ/kg. However, when the proportion of *Prosopis juliflora* was increased to 75% and maize cobs reduced to 25%, the calorific value decreased to 19.27$\pm$0.05 MJ/kg. Similarly, it was observed that when 50% bagasse was added to 50% *Prosopis juliflora*, the calorific value decreased to 19.14$\pm$0.07 MJ/kg. But when the proportion of *Prosopis juliflora* was increased to 75% and bagasse reduced to 25%, the calorific value decreased further to 19.07$\pm$0.07 MJ/kg. In comparison, the combination of 50% maize cobs and 50% *Prosopis juliflora* had the highest calorific value of 19.73$\pm$0.05MJ/kg, while the combination of 50% bagasse and 50% *Prosopis juliflora* had the lowest calorific value at 19.14$\pm$0.07 MJ/kg. The other combinations achieved intermediate calorific values. Overall, the proportion of maize cobs in the mixtures appears to have the greatest impact on the calorific value, with higher proportions resulting in higher calorific values. However, the proportion of *Prosopis juliflora* and bagasse also had a moderate effect on the calorific value of *Prosopis juliflora* briquettes. It is worth noting that while the differences in calorific value between the combinations are relatively small, they can be important when considering the suitability of the different mixtures for different applications.

4.2.1 Percentage Moisture Content (%MC)

Moisture content for all the five samples ranged between 5.27-5.90% as shown in Figure 4-1 which is within acceptable limits of between 4-12% needed for biomass fuels (Nurek *et al.,* 2021). Comparatively, moisture content for coals varies in the range 2-30% and for the eucalyptus (popularly used woody biomass in boilers and domestic homesteads) is in the range of 6-12%. This makes *Prosopis juliflora* briquettes at 100% and its binary combinations good candidates for energy production considering the five briquettes samples moisture content.

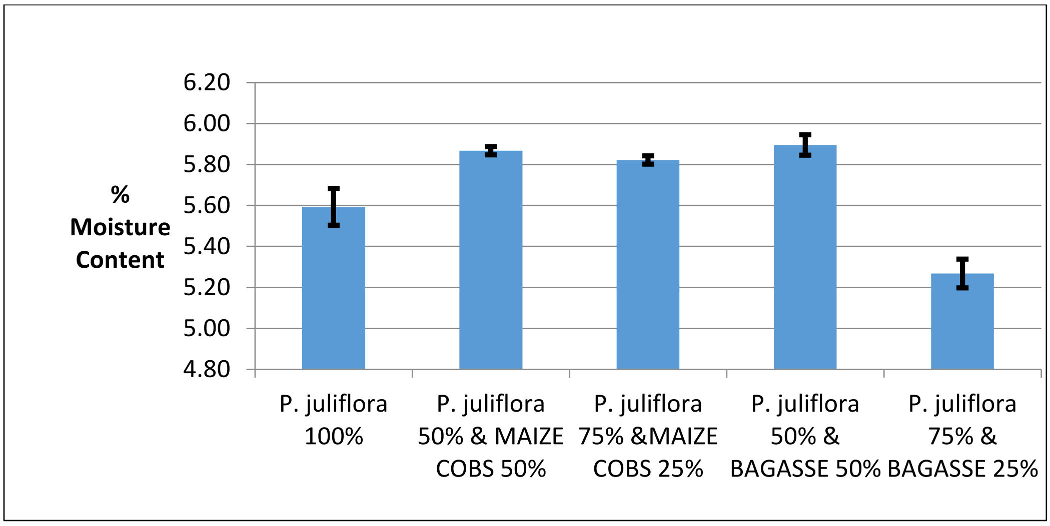

Figure 4.1: Percentage Moisture Content (%MC)

The moisture content of biomass fuels is an important factor to consider when assessing their potential for energy production. According to Osei, Takase, and Mantey ,(2020), the moisture content of biomass fuels should fall between 4% and 12% to ensure optimal combustion. This range is consistent with the findings of Marreiro *et al*., (2021), who also noted that a moisture content of less than 4% can lead to excessive dust emissions, while a moisture content of more than 12% can result in incomplete combustion and decreased energy output.

In this study, the moisture content of five briquette samples made from *Prosopis juliflora* were analysed and found to fall between 5.27% and 5.90%. This indicates that the briquettes are within the desirable range for biomass fuels, making them usable for energy production. This finding is consistent with the results of other studies that have evaluated the moisture content of biomass fuels, such as Urbanovičová *et al*., (2022), who found that the moisture content of eucalyptus, a popular woody biomass used for energy production, falls within the range of 6% to 12%.

It is worth noting that the moisture content of coal, another common source of energy, can vary greatly from 2% to 30%, as reported by Omwenga (2021). This highlights the importance of carefully selecting the appropriate type of fuel for a given energy application. The moisture content of the five briquette samples analysed in this study, however, suggests that they are a viable alternative to charcoal and firewood, particularly given the negative environmental impacts associated with firewood and charcoal combustion.

Other studies have evaluated the use of *Prosopis juliflora* as a source of energy production. Ng'ang'a, (2021) found that briquettes made from *Prosopis juliflora* and other waste materials had a moisture content ranging from 5% to 10%, which falls within the desirable range for biomass fuels. Mokaya *et al.*, (2020) investigated the use of *Prosopis juliflora* as a source of bio-char, which can be used for energy production as well as soil improvement. They found that the moisture content of the bio-char was between 3% and 10%, suggesting that it may be a promising source of energy.

Chweya, (2020) reported similar findings in a study on the potential of *Prosopis juliflora* as a source of energy in Kenya. The study found that the moisture content of the fuel ranged from 2.76% to 4.14%, which is below the desirable range for biomass fuels. However, the study noted that the fuel had a high calorific value, making it a potentially valuable energy source if the moisture content can be reduced.

Other studies have evaluated the use of different types of biomass fuels for energy production. Nunes *et al.*, (2019) investigated the use of coffee waste as a source of energy and found that the moisture content of the waste ranged from 10% to 20%. Isah *et al.*, (2021) evaluated the potential of rice husk as a source of energy and found that the moisture content of the husk was between 8% and 13%. Abdulkareem *et al.*, (2020) studied the use of palm kernel shells for energy production and found that the moisture content of the shells ranged from 5% to 8%.

Additionally, the use of *Prosopis juliflora* briquettes and its binary combinations as energy sources could potentially have positive environmental impacts. Biomass fuels are considered to be carbon-neutral, as the carbon dioxide released during combustion is roughly equivalent to the amount that the plant absorbs during photosynthesis (Nunes *et al.*, 2019). As a result, they have been identified as one of the most promising alternatives to fossil fuels, which contribute significantly to climate change (Aransiola *et al.*, 2019).

It is paramount noting that the production of biomass fuels requires a significant amount of energy and resources, which can have negative environmental impacts (Nurek *et al.,* 2021). However, compared to other forms of biomass, *Prosopis juliflora* can be considered to be highly efficient in terms of biomass production and has the potential to improve soil quality in degraded areas (Omwenga, 2021). Therefore, the use of *Prosopis juliflora* briquettes could potentially provide a sustainable and environmentally-friendly source of energy, especially in areas where deforestation and soil degradation are prevalent.

In addition, the results of the study indicate that *Prosopis juliflora* briquettes and its binary combinations have promising potential as a source of energy. The briquettes exhibit good combustion properties, high energy density, and acceptable levels of moisture content, making them suitable for use in various applications, including household and industrial energy production. Moreover, their use could potentially have positive environmental impacts, making them a sustainable alternative to conventional fuels. However, further research is needed to determine the feasibility and scalability of production, as well as potential environmental impacts of large-scale implementation.

4.2.2 Percentage Volatile Matter (%VM)

Volatile matter represents the components of carbon and hydrogen present in the biomass that when heated turn to vapour, usually a mixture of short and long chain hydrocarbons. From the experimental results summarized by Figure 4-2, the five samples %VM ranged between 75.65-77.81%. Considering that biomass generally has a volatile content of around 70-86% of the weight of the dry biomass which makes biomass a more reactive fuel; giving a much faster combustion rate during the devolatisation phase than other fuels such as coal; this makes *Prosopis juliflora* at

100% and binary combinations at different levels a good candidate to energy production.

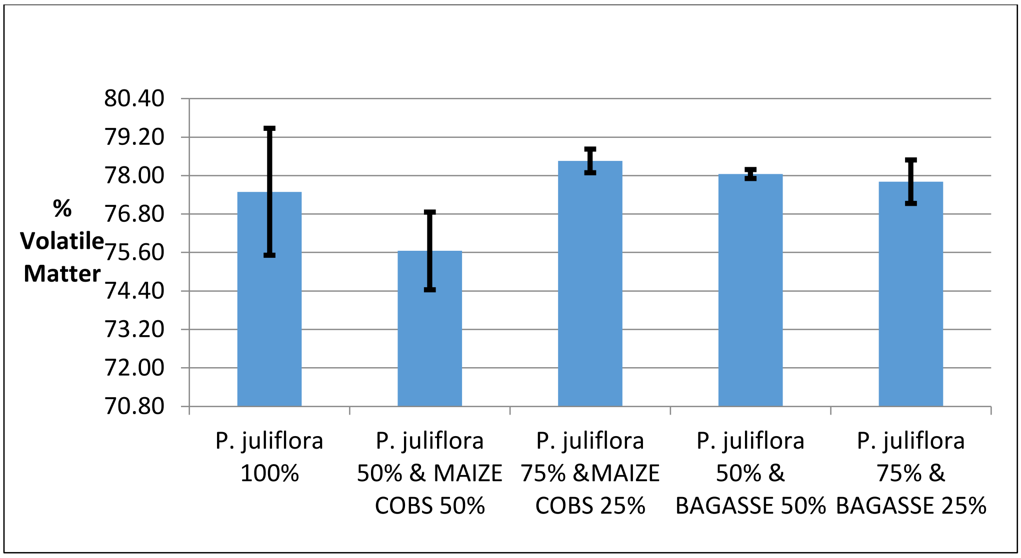

Figure 4.2: Percentage Volatile Matter (%VM)

One of the critical components of biomass used in briquette production is volatile matter. Volatile matter comprises carbon, hydrogen, and oxygen, which vaporize during combustion, apart from moisture (Sarakikya, 2020; Variani, 2021). Akowuah *et al.*, (2019) suggest that volatile matter influences the thermal properties of solid fuels, including briquettes. Biomass components of briquettes often have a high volatile matter content of about 70% or more, which leads to high reactivity and combustion levels (Feleke *et al*., 2020). A study by Chandrasekaran *et al.*, (2021) on the characterization of *Prosopis juliflora* reported a volatile matter content of 80.66 ± 2.26%, which is within the typical range of biomass volatile matter content.

Feleke *et al.*, (2020) examined the characterization of charcoal briquettes using *Prosopis juliflora*, *Arundinaria alpina*, *Acacia melifera*, and *Oxytenanthera abyssinica*. The study investigated the interaction effect of *Proposopis juliflora* with sawdust and charcoal and found moisture content ranging from 6.63% to 7.95%. The volatile matter percentage ranged from 20.56% to 63.05%, with the interaction effect of *Proposopis juliflora* and sawdust having the highest percentage. The ash content ranged from 5.6% to 16.66%, with the interaction effect of *Proposopis juliflora* and sawdust having the highest percentage.

According to Ramesh and Somasundaram, (2020), the proximate analysis of *Prosopis juliflora* denoted 71.25% volatile matter. The experimental results of the volatile matter content of the five *Prosopis juliflora* samples studied by Variani, (2021) showed that the %VM ranged between 75.65-77.81%. These results indicate that *Prosopis juliflora* is a suitable candidate for energy production, given that biomass generally has a volatile content of between 70-86% of the weight of dry biomass fuel.

4.2.3 Percentage Ash Content (%AC)

Ash which is the non-combustible inorganic component of biomass was determined and results observed was between the ranges of 2.34 to 4.06% for the five samples as shown in Figure 4-3. The percentage ash acceptable limits for biomass are between the ranges of 4 to 20%. This is to aid against problems of slagging and fouling within combustion chambers. Comparatively, coal and eucalyptus %AC ranges between 8.5-20.0% and 3.0-4.0%, respectively, making *Prosopis juliflora* at 100% and its binary levels combinations a good alternative.

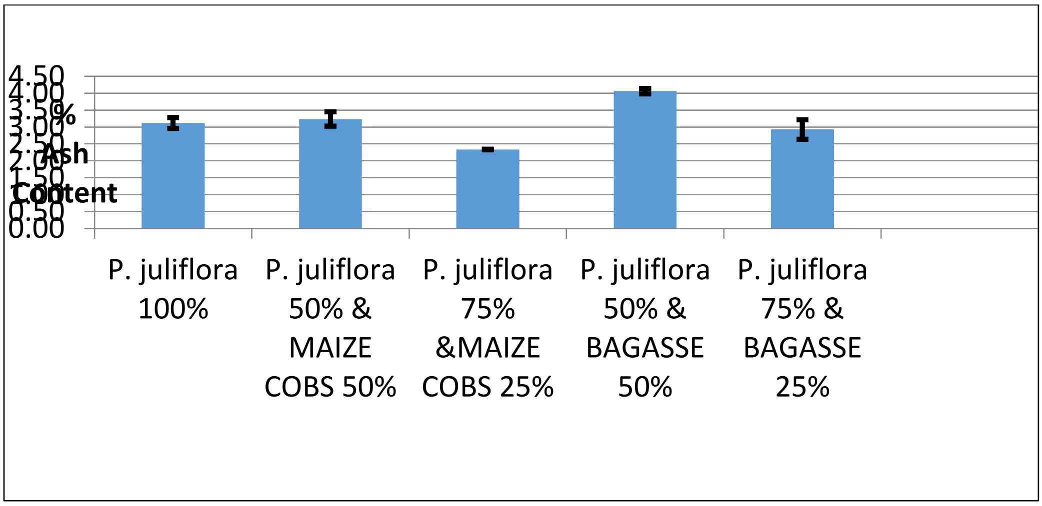

Figure 4.3: Percentage Ash Content (%AC)

Biomass briquettes have been increasingly adopted as an alternative source of fuel due to their eco-friendliness, renewability, and economic benefits. However, the ash content of the briquettes is an important parameter to consider as it affects the efficiency of the briquettes when used for heating and cooking. According to Ikelle *et al.*, (2020), ash content refers to the amount of matter that remains after complete burning of briquette. The percentage acceptable limits for biomass ash are between the ranges of 4% to 20%.

The results obtain in this study showed that the ash content of the briquettes was highly dependent on the proportions of the different types of biomass used. The pure 100% *Prosopis juliflora* obtained ash content of 3.12$\pm$0.16%. However, when 50% maize cobs were mixed with 50% *Prosopis juliflora*, the ash content increased slightly to 3.24$\pm$0.21%. This indicates that the addition of maize cobs to the mixture increased the ash content of the briquettes.

On the other hand, when the proportion of *Prosopis juliflora* was increased to 75% and maize cobs were reduced to 25%, the ash content decreased significantly to 2.34$\pm$0.01%. This implies that the higher proportion of *Prosopis juliflora* in the mixture led to a reduction in the ash content. The same trend was observed when 50% bagasse, a sugarcane residue, was added to 50% *Prosopis juliflora*, resulting in an increase in ash content to 4.06$\pm$0.08%. Further, when the proportion of *Prosopis juliflora* was increased to 75% and bagasse reduced to 25%, the ash content decreased to 2.93$\pm$0.29%.

Further, the ash content of the mixtures is highly dependent on the proportions of the different types of biomass. Mixtures with higher proportions of *Prosopis juliflora* tend to have lower ash content, while mixtures with higher proportions of maize cobs or bagasse tend to have higher ash content. The study suggests that the optimal combination of biomass for briquette production should be carefully selected to balance the ash content and heating efficiency.

It is important to note that the ash content of briquettes can affect the efficiency of the briquettes when used for heating and cooking. Ullah *et al.*, (2021) assert that the impacts on the efficiency of the briquettes through lowering of heating efficacy leads to slagging effect. Sette *et al.*,(2021) also emphasize those briquettes with high ash content need regular removal of the ashes when used in the process of heating and cooking. Therefore, it is important to consider the ash content of the briquettes when selecting the optimal combination of biomass for briquette production to ensure high efficiency and reduce the need for regular maintenance.

In conclusion, the ash content in biomass briquettes is an important parameter to consider when selecting the optimal combination of biomass for briquette production. The results of the study suggest that the proportion of *Prosopis juliflora* in the mixture plays a significant role in determining the ash content of the briquettes.

4.2.4 Percentage Fixed Carbon (%FC)

The %FC of a fuel which is the percentage of carbon available for char combustion was determined to be in the ranges of 17.90% to 21.11% for the five samples of *Prosopis juliflora* at 100% and its binary levels combinations as showed in Figure 4-4. The ranges are impressive and significant since according to Pruthviraj, (2021) charcoal briquettes ranged between 20% to 30% fixed carbon and eucalyptus has about 18.3% FC; this makes *Prosopis juliflora* a resourceful plant and an alternative to coal and eucalyptus.

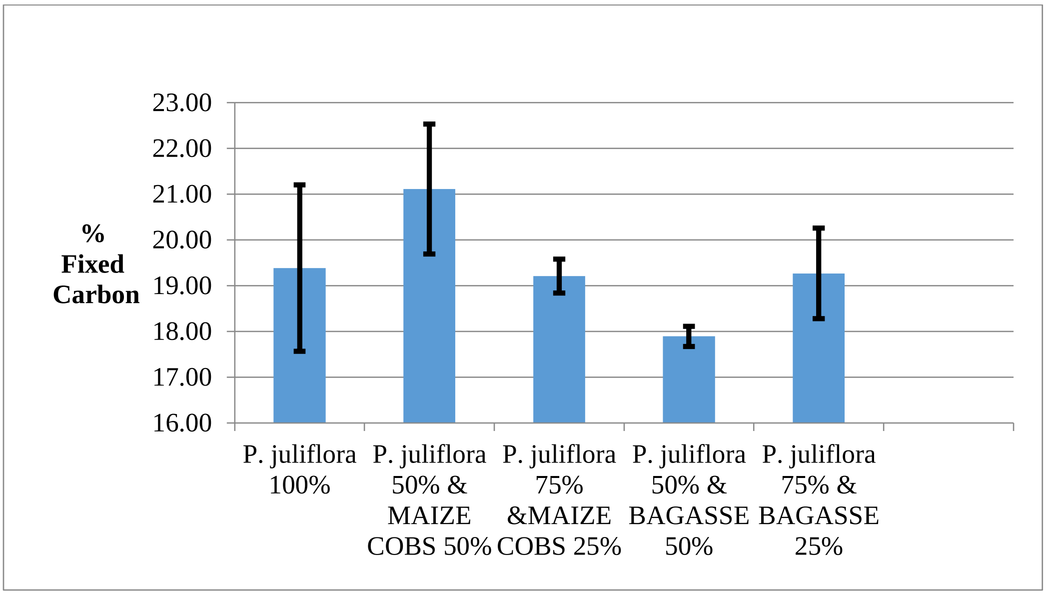

Figure 4.4: Percentage Fixed Carbon (%FC)

Fixed carbon is an important factor to consider in biomass energy production. It refers to the portion of biomass that remains as a residue after volatile matter distils off, once the cumulative sum of moisture and ash content in the biomass is deducted (Chweya, 2020). The percentage of fixed carbon content is a measure of the carbon left in the fuel after burning, and it is used to determine the quality of the fuel.

The fixed carbon content in biomass materials comprises elemental carbon and any other carbonaceous residue formed during the combustion process (Gemeda, 2019). It gives information about the amount of char formation in the thermochemical conversion process (Nurek *et al*., 2021). A high fixed carbon percentage is associated with higher heating values, while a low fixed carbon percentage indicates low heating value. Therefore, understanding the amount of fixed carbon innate to a biomass feedstock is essential in choosing a fuel source for combustion equipment.

This study aimed to investigate the fixed carbon content of different biomass combinations, namely *Prosopis juliflora* 100%, *Prosopis juliflora* 50% and maize cobs 50%, *Prosopis juliflora* 75% and maize cobs 25%, *Prosopis juliflora* 50% and bagasse 50%, and *Prosopis juliflora* 75% and bagasse 25%. The results showed that the fixed carbon content varies with the proportion of biomass combinations.

For *Prosopis juliflora* 100%, the average fixed carbon content was $19.39 \pm 1.82\%$, while for *Prosopis juliflora* 50% and maize cobs 50%, it was $21.11 \pm 1.42\%$. The combination of *Prosopis juliflora* 75% and maize cobs 25% had an average fixed carbon content of $19.21 \pm 0.37\%$. For *Prosopis juliflora* 50% and bagasse 50%, the average fixed carbon content was $17.89 \pm 0.22\%$, while for *Prosopis juliflora* 75% and bagasse 25%, it was $19.27 \pm 0.99\%$. Therefore, it can be observed that the combination of *Prosopis juliflora* 50% and maize cobs 50% had the highest fixed carbon content, while *Prosopis juliflora* 100% had the lowest fixed carbon content.

The combination of *Prosopis juliflora* 50% and maize cobs 50% had a higher fixed carbon content than *Prosopis juliflora* 100%. This could be due to the fact that maize cobs have higher fixed carbon content than *Prosopis juliflora*. The higher fixed carbon content of the *Prosopis juliflora* 50% and maize cobs 50% combination is an important finding since it indicates that it is possible to achieve a higher fixed carbon content by combining biomass with different fixed carbon percentages of maize cobs. This finding is in agreement with a study by Mokaya *et al.*, (2020), which found that blending maize cob with other biomass feedstock, increased the fixed carbon content of the blends.

In conclusion, the results of this experiment showed that the fixed carbon content of biomass feedstock combinations is highly dependent on the proportions of the different types of biomass. The combination of *Prosopis juliflora* 50% and maize cobs 50% had the highest fixed carbon content at 21.11$\pm$1.42%, while the combination of *Prosopis juliflora* 100% had the lowest fixed carbon content at 19.39$\pm$1.82%. These findings are useful in identifying the most suitable biomass feedstock combinations for biomass energy production, and for selecting the most appropriate combustion equipment. Overall, the study highlights the potential of using mixed feedstocks for briquette production, as it allows for the optimization of different properties such as ash and fixed carbon content, which can improve the quality of the briquettes and ultimately lead to more efficient and sustainable biomass energy production. However, further research is needed to explore other aspects of briquette production, such as the mechanical strength and durability.

4.2.5 Calorific Value

The calorific value observed from the experimental results of *Prosopis juliflora* at 100% and at various binary levels combinations ranged between 18.99 MJ/kg to 19.73 MJ/kg as showed in Figure 4-5; which is sufficient enough to produce heat required for household cooking and industrial applications. Comparatively, coal and eucalyptus have calorific values ranging from 20-30 MJ/kg and 17-19 MJ/kg respectively; making *Prosopis juliflora* a potential alternative.

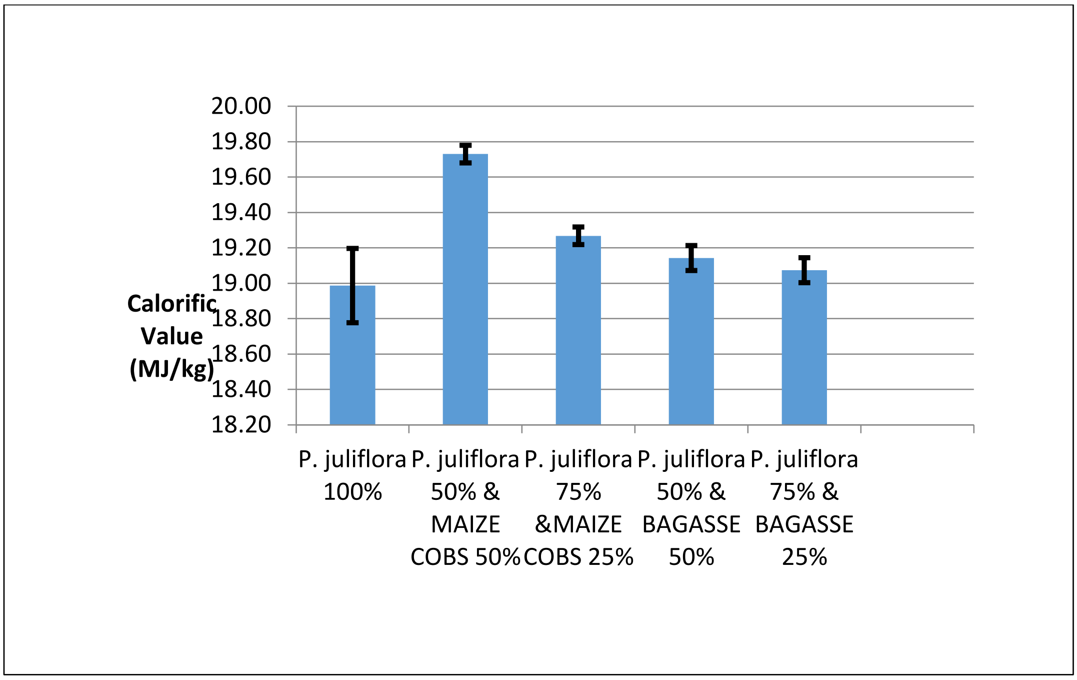

Figure 4.5: Calorific Values in MJ/kg

The calorific value of biomass is an essential parameter in determining the energy content of briquettes. The study of different biomass combinations in briquette production provides insights into the optimization of the quality and efficiency of briquettes.

The study shows that the calorific value of the fuel mixture is affected by the proportion of the different biomass components. When 100% *Prosopis juliflora* was used the calorific value obtained stood at 18.99±0.21 MJ/kg. Observation was made that when maize cobs are added in equal proportion to *Prosopis juliflora* (50:50), the calorific value increases to 19.731 MJ/kg. This increase in calorific value can be attributed to the higher lignin content and lower ash content of maize cobs compared to *Prosopis juliflora* (Anatasya *et al*., 2019). The higher lignin content provides higher energy content when burned, while the lower ash content reduces the amount of non-combustible material in the briquette, resulting in a higher energy output.

Relatively, it was observed that when bagasse is added in equal proportion to *Prosopis juliflora (*50:50), the calorific value decreases to 19.14±0.07 MJ/kg. Bagasse is a residue of sugarcane after the extraction of juice, and its lower calorific value is due to its high moisture and ash content, which reduces the energy output when burned (Kumar *et al.*, 2021). However, it should be noted that bagasse is a readily available and is a low-cost raw material, which can make it an attractive option for briquette production in areas where it is abundant.

When the proportion of *Prosopis juliflora* is increased to 75% and maize cobs or bagasse reduced to 25%, the calorific value reduces compared to the 50:50 ratios. This reduction in calorific value can be attributed to the lower energy content of *Prosopis juliflora* compared to maize cobs and bagasse in higher ratios. However, it's good to point out that calorific value obtained by *Prosopis juliflora* at 100% is well sufficient compared to other biomass sources meaning it can as well be used in its pure form since biomass feedstock usually achieves calorific values of between 16 MJ/kg to 20 MJ/kg (Deng, Liu and Wang, 2020).

The combination of 50% maize cobs and 50% *Prosopis juliflora* had the highest calorific value of 19.73$\pm$0.05 MJ/kg, while the combination of 50% bagasse and 50% *Prosopis juliflora* had the lowest calorific value of 19.14$\pm$0.07 MJ/kg. The other combinations attained intermediate calorific values. This shows that the choice of biomass combination can significantly affect the energy output of briquettes. In areas where maize cobs are readily available, their combination with *Prosopis juliflora* can produce high-quality briquettes with a high energy output.

The results from this study have important implications for the production of biomass briquettes. In particular, they suggest that the use of *Prosopis juliflora* can enhance the calorific value of briquettes when used in combination with other biomass materials, such as maize cobs.

These findings are consistent with previous studies that have examined the use of *Prosopis juliflora* in briquette production. For example, Kumar and Chandra, (2020) found that a combination of *Prosopis juliflora* and sugarcane bagasse had a higher calorific value than briquettes made solely from sugarcane bagasse. Similarly, Efomah *et al.*, (2020) found that briquettes made from a combination of *Prosopis africana* and sawdust had a higher calorific value than briquettes made from sawdust alone.

The use of *Prosopis juliflora* in briquette production has several advantages beyond its high calorific value. For one, it is a highly invasive abundant and fast-growing plant species that can be easily cultivated in arid and semi-arid regions (Munga, 2020). Additionally, it is a highly drought-resistant species that can survive in harsh environmental conditions, making it a useful source of biomass in regions with limited water resources.

4.3 Ultimate Analysis

Ultimate analysis was done to obtain the percentage elemental composition of carbon, hydrogen, nitrogen and sulphur for *Prosopis juliflora* and its binary combinations. As illustrated in Table 4-2 is the ultimate analysis results obtained of the sample briquettes at various ratios.

Table 4.2: Ultimate Analysis

	Composition (%)			
	Carbon	**Hydrogen**	**Nitrogen**	**Sulphur**
***P. juliflora* 100%**	46.26±0.70	5.75±0.14	0.27±0.03	0.44±0.05
***P. juliflora* 50% & MAIZE COBS 50%**	48.90±0.11	6.18±0.24	0.20±0.02	0.12±0.00
***P. juliflora* 75% &MAIZE COBS 25%**	46.90±0.03	5.73±0.03	0.21±0.01	0.23±0.01
***P. juliflora* 50% & BAGASSE 50%**	46.89±0.33	4.91±0.22	0.21±0.02	0.21±0.03
***P. juliflora* 75% & BAGASSE 25%**	46.24±0.40	4.99±0.17	0.20±0.02	0.30±0.01

From Table 4-2 it can be observed that the *Prosopis juliflora* briquettes at 100% and that of binary combinations had elemental carbon ranging from 46.24±0.40% to 48.90±0.11, elemental hydrogen ranged between 4.91±0.22% to 6.18±0.24% and both elemental nitrogen and sulphur had below 1% in composition.

4.3.1 Elemental Carbon Composition

Figure 4-6 shows that *Prosopis juliflora* and its binary combination briquette fuels had carbon composition dominating and taking the highest percentages across all the fuel combinations compared to hydrogen, nitrogen and sulphur. The highest being

48.90±0.11% that of *Prosopis juliflora* 50% combined with maize cobs at 50%; *Prosopis juliflora* at 100% had 46.26±0.70%, 46.90±0.03% for *Prosopis juliflora* 75% combined with maize cobs 25%, 46.89±0.33% for *Prosopis juliflora* 50% combined with bagasse 50% and lastly *Prosopis juliflora* 75% combined bagasse 25% attained 46.24±0.40%.

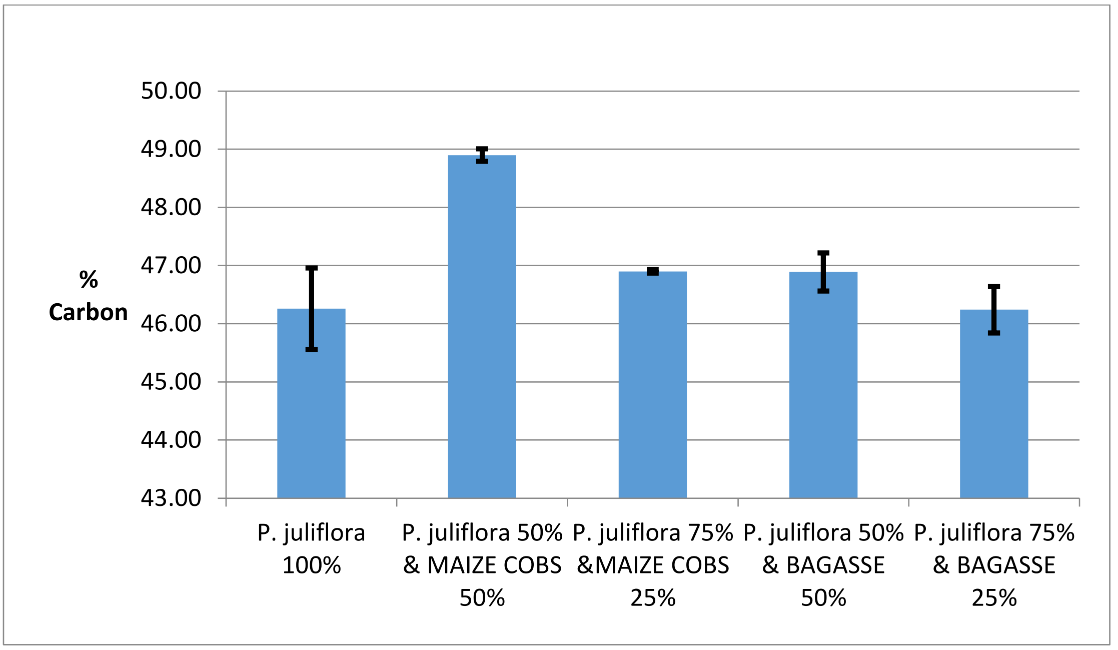

Figure 4 6: Percentage elemental Carbon

Elemental carbon in a biomass fuel is associated with high-energy bonds that release an increased amount of energy when broken during combustion. Therefore, the higher the carbon composition in a fuel briquette translates to increased calorific values. It is also observed that binary combination of bagasse and maize cobs increased the elemental carbon composition in comparison to *Prosopis juliflora* 100% briquettes. With elemental carbon composition leading with high percentages in *Prosopis juliflora* briquettes and its binary combinations of bagasse and maize cobs points into the feedstocks producing high-heat quality fuels that can be utilized for cooking and industrial applications.

4.3.2 Elemental Hydrogen Composition

As illustrated by Figure 4-7 the *Prosopis juliflora* briquettes and those of its binary combinations attained 5.75±0.146%, 18±0.2%, 45.73±0.03%, 4.91±0.22% and 4.99±0.17% for *Prosopis juliflora* at 100%, *Prosopis juliflora* 50% combined with maize cobs at 50%, *Prosopis juliflora*75% combined with maize cobs at 25%, *Prosopis juliflora* 50% combined with bagasse at 25% and that of *Prosopis juliflora* 75% combined with bagasse at 25% respectively.

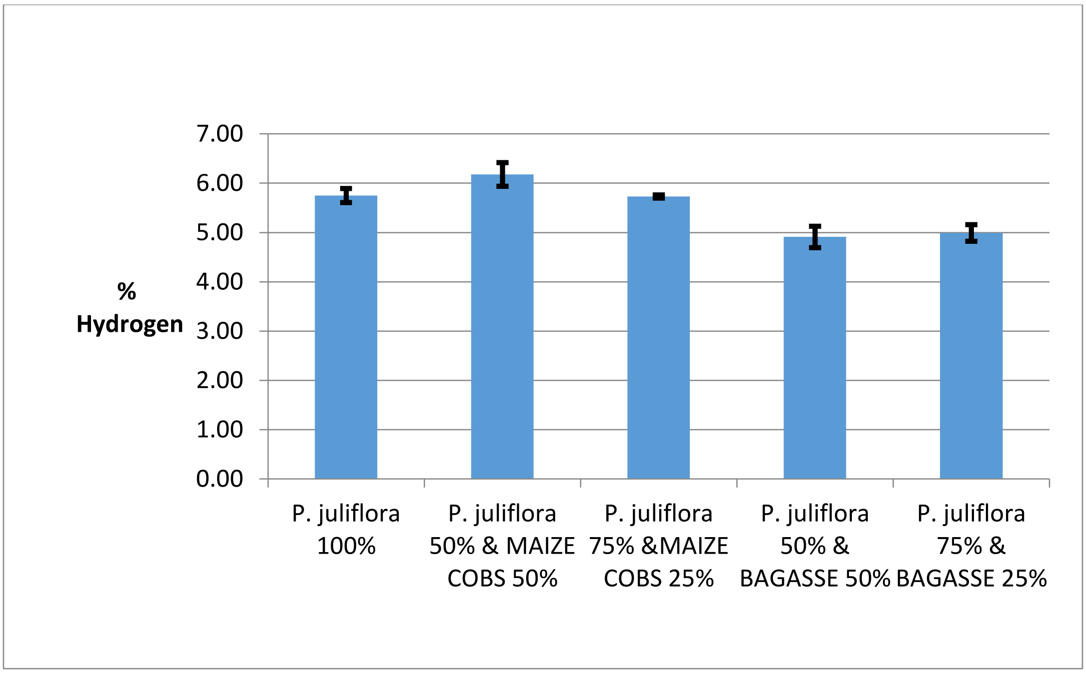

Figure 4 7: Percentage elemental Hydrogen

Hydrogen high energy bonds releases increased amounts of heat when broken during combustion of a biomass fuel; hence the higher the elemental hydrogen composition in a fuel the quality the biomass fuel. This shows that the briquettes herein tested proves to be of high quality since the elemental hydrogen percentages were all above 1%.

4.3.3 Elemental Nitrogen Composition

As shown in Figure 4-8 *Prosopis juliflora* and its binary combination attained elemental nitrogen compositions of 0.27±0.03%, 0.20±0.02%, 0.21±0.01%, 0.21±0.02% and 0.20±0.02% for *Prosopis juliflora* at 100%, *Prosopis juliflora* 50% combined with maize cobs at 50%, *Prosopis juliflora*75% combined with maize cobs at 25%, *Prosopis juliflora* 50% combined with bagasse at 25% and that of *Prosopis juliflora* 75% combined with bagasse at 25% respectively.

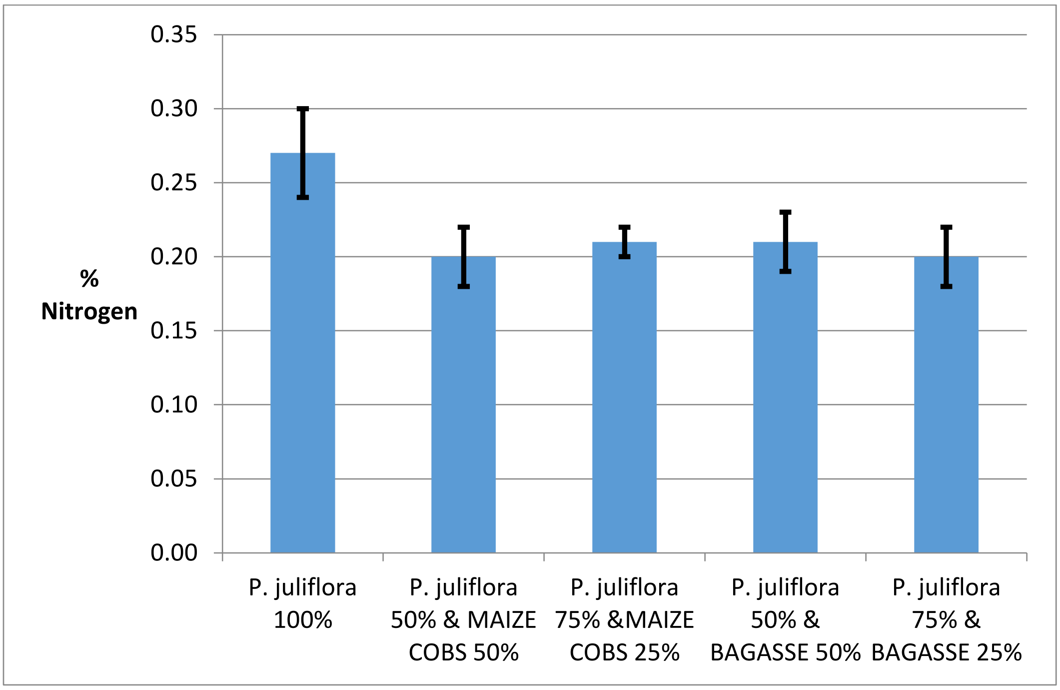

Figure 4 8: Percentage elemental Nitrogen

Elemental nitrogen is undesirable in a biomass fuel since it has no calorific value and when released to the atmosphere can lead to negative impacts to the environment such as intensifying the greenhouse effect, smog and acidic rain. *Prosopis juliflora* and its binary combination briquettes had below 1% elemental composition of nitrogen as shown in Figure 4-8, which signifies ideal fuels that can be utilized for cooking and industrial applications.

4.3.4 Elemental Sulphur Composition

As shown in Figure 4-9 *Prosopis juliflora* and its binary combination attained elemental nitrogen compositions of 0.44±0.05%, 0.12±0.00%, 0.23±0.01%, 0.21±0.03% and 0.30±0.01% for *Prosopis juliflora* at 100%, *Prosopis juliflora* 50% combined with maize cobs at 50%, *Prosopis juliflora*75% combined with maize cobs at 25%, *Prosopis juliflora* 50% combined with bagasse at 25% and that of *Prosopis juliflora* 75% combined with bagasse at 25% respectively.

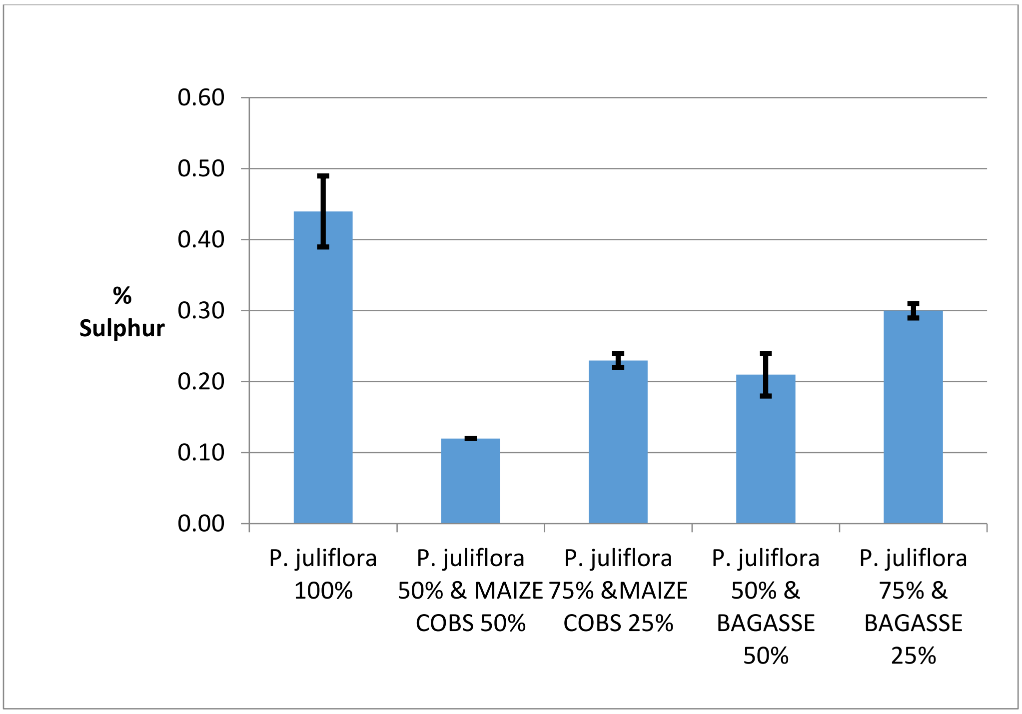

Figure 4 9: Percentage elemental Sulphur

Elemental sulphur, although contributes to the heating value of a biomass fuel, yet on combustion produces acidic gases like SO_3 and SO_2, which not only corrodes the combustion equipment but also harm the environment making it undesirable in a biomass fuel. As shown in Figure 4-9, *Prosopis juliflora* briquettes and those produced from its binary combinations of bagasse and maize cobs attained below 1% on elemental sulphur composition; making the briquettes quality for use.

4.4 Techno-Economic Analysis of the Briquetting Process

Techno-economic analysis of the briquetting process was done to establish the economic viability and economic performance of the technology used in this study. Estimates were obtained from the investment cost it took Ecoline briquetting plant in Nakuru County to install the unit.

4.4.1 Installation Cost

The briquetting machine together with its accompanying equipment will be installed on the site for a fixed cost charged by the equipment supplier. Taking consideration on the unit installed at Ecoline, Nakuru County, the total initial investment varied between Kshs. 4,000,000 - Kshs. 5,000,000. The study considered the highest value. Making the total initial investment used in this study as Kshs. 5,000,000. Note that at the time the study was being carried out, the exchange rate was Kshs. 140.98 against 1USD.

4.4.2 Operational Cost

The operational cost of briquetting unit consisted of various inputs such as raw materials, oil lubricant, electricity and manpower required operating the unit. Raw material cost is zero (*Prosopis juliflora* being invasive is considered a ready material for disposal). Electricity cost was obtained from accumulating the machine ratings as; Machine ratings-45 kW (Briquetting machine) +6.5 kW (rotary drier) +7.5 kW (wood crusher) getting total machine rating as 59 kW; hence (briquetting unit rating being 59 kW; working for 8 hrs. a day) translating to a total of 472 kWh electricity used per day. This amounts to Kshs. 9, 897.84 on total cost of electricity on operational cost per day when using Kenya Power and Lighting Company (KPLC) Small Commercial (SC) tariff of Kshs. 20.97 kWh. Oil and lubricant cost the unit Kshs. 400 per day. Manpower costs Kshs. 500 per day (8 men working in two shifts – 8×500) will cost a total of Kshs. 4,000. By accumulating the total operational electricity, lubrication and manpower costs, the total operational cost amounts to Kshs. 14,297.84 (9897.84+400+4000) per day.

4.4.3 Maintenance Cost

Briquetting unit need be maintained on daily, weekly, monthly, and half-yearly basis. Briquetting press requires daily maintenance from a trained expert which includes removal of accumulated dirt, checking of oil level in the press and making sure the sieves are clean. Weekly maintenance includes cleaning of oil filter, replacement of filter cartridge, cleaning of air filter, cleaning die holder cooling circuit and tightening of all screws and nuts. Maintenance of screw gear box and change of oil is necessary at 6 months' interval. Repair and maintenance cost was estimated by having a technician who is paid Kshs 45,000 per month; translating to Kshs.1500 per day.

4.4.4 Unit Cost of Briquette Production

Total briquette production per day will be 10 tons; the total working hours per day will be 8 hours; this means that production of 1-ton briquette requires 0.8 hours. To find out the expenses of producing 1 ton of briquettes, the study considered initial investment over the economic period of 7 years as; initial investment's 15% is added for cost calculation up to first 7 years which translates to Kshs. 750,000 per year and Kshs. 260.42 per hr.; therefore, 1-ton initial investment cost (Kshs. 260.42 ×0.8 hrs.) will be Kshs. 208.34. Operating cost for 1 hr. will be Kshs. 1,787.23; therefore, to produce 1 ton the operational cost (Kshs. 1,787.23*0.8 hrs.) will be Kshs. 1,429.78. Repairing and maintenance cost for 1 hour will be Kshs. 187; making maintenance cost to produce 1 ton (Kshs.187.5*0.8 hrs.) to be Kshs. 150. Total Cost for producing 1 ton of briquettes (initial investment Kshs. 208.34+Operational cost Ksh.1, 428.78+maintenance cost Kshs.150) becomes Kshs. 1,788.12.

4.4.5 Economic Analysis

Due to maintenance period, weekends and holidays it is assumed that the briquetting unit will operate optimally for at least 20 days every month. This translates to 10 tons of briquette production per day and 200 tons per month; assuming an efficiency of 50% and selling the briquettes at Kshs. 6000 per ton; will attract Kshs. 600,000 per month. Therefore, annual income will be Kshs. 7,200,000 with initial capital outlay of Kshs. 5,000,000. The annual production cost will be obtained by-(cost of production 1 ton Kshs. 1,788.12*10 tons/day working*20 days*12 months) – Kshs. 4,291,488. Net Cash flow annually will be - (7,200,000-4,291,488) = Kshs. 2,908,512. Taking 7 years as economic life and 13% Discount Rate; then the FI_n, PV_n, *NPV*, *IRR*, *PI* and amortization time was calculated as shown in Table 4-3.

Table 4.3: Future Income (FIn), Present Value (PVn), NPV, IRR, Amortization Time and Profitability index (PI)

Time (years)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
FI_n (Kshs)	-5,000,000	2,908,512	2,908,512	2,908,512	2,908,512	2,908,512	2,908,512	2,908,512
PV_n Factor	1.00	0.885	0.783	0.693	0.613	0.543	0.480	0.425
PV_n (Kshs)		2,573,904	2,277,792	2,015,745	1,783,845	1,578,624	1,397,012	1,236,294
Payment Balance (Static)-Ksh	-5000000	-2091488	817024	3725536	6634048	9542560	12451072	15359584
Payment Balance (Dynamic)-Ksh	-5000000	-2426096	-148304	1867441	3651286	5229910	6626922	7863216
Nominal Discount Rate (per annum)			13%					
Net Present Value (Kshs)			7863216					
Internal Rate of Return (%)			55					
Amortization Time (Static)			1.70 years					
Amortization time (Dynamic)			2.07 years					
Profitability Index			1.57					

As shown in Table 4-3 *NPV* is a positive value of Kshs. 7,863,216, meaning the briquetting technology considered in this study has a viable application. This means that briquetting investor will, at the end of receiving all the money from the project, in 7 years' economic lifetime; receive extra Kshs. 7,863,216, in present value. The ratio of the *NPV* to the total installation costs which in this case is referred to as the profitability Index (*PI*) is 1.57. As alluded to earlier in subsection 3.3.7 of chapter 3, *PI* of one or more shows that the project is profitable while *PI* of less than one shows that the project is not profitable (Alrikabi, 2022; Zeraatpisheh *et al.*, 2018). The shortcoming of the static amortization time is that the depreciation in value of money with time is not put in consideration, therefore, the need to calculate the dynamic amortization time. From the above deduction, the project is considered economically profitable. The *IRR* obtained was 55% which is greater than the nominal discount rate of 13% indicating a profitable technology if used. In addition, the profitability index attained is greater than one with dynamic amortization time (discounted payback period) of 2.07 years, showing that the project will breakeven from the second year of operation. However, it is noteworthy that the *NPV* method is not applicable when comparing projects that have differing investment amounts and requires guessing about future cash flows and estimating the cost of capital. In addition, the nominal discount rate of 13% did not take into account effects of inflation.

4.4.6 Comparison with Commonly Used Fuels in Kenya

Considering that 6 kg LPG retails at Kshs. 1,350 in the Kenyan market according to vandenBerg, (2022), a stack (1 m^3) of eucalyptus wood (estimated at 0.6 tons when wet with 20% moisture content) costs Kshs. 3,500 as reported by Africa, (2022). Charcoal briquettes cost Kshs. 8,000 per ton as recorded by Cohen and Marega, (2022). The present study went ahead and compared these commonly used types of fuels in Kenya with briquettes from a binary combination of *Prosopis juliflora* 50% & Maize cobs 50%. ~~**Error! Reference source not found.**~~ shows the four types of fuels omparatively with their respective calorific values. The calorific values were taken as 46 MJ/kg, 17.01 MJ/kg and 20.12 MJ/kg for LPG, Eucalyptus firewood and Charcoal briquettes, respectively (vandenBerg, 2022).

Observe in Table 4-4 that a consumer using 1 kg/day of LPG, where the calorific value of LPG is 46.00 MJ/kg and the calorific value of Eucalyptus firewood and Charcoal briquettes are 17.01 MJ/kg and 19.75 MJ/kg, respectively. For example, taking LPG's price as the reference price (Kshs. 4.891 per 1 MJ), and the household energy cost for Kshs. 225 per day on using LPG source of energy; comparing the respective usable fuels the consumer will use Kshs. 19.71 and Kshs. 18.31 per day if the fuel chosen for use will be Eucalyptus wood and Charcoal briquettes, respectively. Further, the consumer will spend Kshs. 13.97 per day for using *Prosopis juliflora* at 50% and Maize cobs at 50% combination briquettes.

Table 4.4: Fuel Comparison with LPG as Reference

	LPG	**Eucalyptus firewood (20% MC)**	**Charcoal briquettes**	***P. juliflora*50% &Maize cobs 50% briquettes**
Price (Kshs/kg)	225.00	7.29	8.00	6.00
Calorific Value (MJ/kg)	46.00	17.01	20.12	19.73
Price (Kshs/MJ)	4.891	0.429	0.398	0.304
Using 1 kg of LPG as reference (Kshs)	**225.00**	**19.71**	**18.31**	**13.97**

Comparatively, it can be concluded that *Prosopis juliflora* at 50% and Maize cobs at 50% combination briquettes are cheaper for household, institution and industrial usage against the usage cost of 1 kg per day of LPG, Eucalyptus firewood and charcoal briquettes of Kshs. 225.00, Kshs. 19.71 and Kshs. 18.31, respectively.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Briquettes biomass fuel were analysed to determine their moisture content, volatile matter, ash content, fixed carbon, and calorific value. Further; carbon, hydrogen, nitrogen and sulphur elemental composition on the briquettes were also investigated. The fuel combinations included *Prosopis juliflora* in its pure form, mixed with maize cobs and bagasse in different binary proportions.

The moisture content of the fuel combinations ranged from 5.27$\pm$0.07% to 5.90$\pm$0.09%, with the highest moisture content found in the combination of 50% *Prosopis juliflora* and 50% bagasse. The combination of 75% *Prosopis juliflora* and 25% bagasse had the lowest moisture content and is considered a better fuel option due to its potential for more complete combustion and higher heat output. However, considering moisture of ranges 5% to 12% as a standard acceptable limit for biomass on briquette production, it's observed that *Prosopis juliflora* and its binary combinations of both maize cobs and bagasse all qualify to make functional fuels.

The volatile matter content of the fuel combinations ranged from 75.65$\pm$1.21% to 78.46$\pm$0.37%, with the highest volatile matter content found in the combination of 75% *Prosopis juliflora* and 25% maize cobs. The lowest volatile matter content was found in the combination of 50% *Prosopis juliflora* and 50% maize cobs. Acknowledging that plant biomass usually have volatile matter in the ranges of 70% to 86%; it can be concluded that *Prosopis juliflora* and its binary combinations are within acceptable ranges of volatile matter with the binary combination of *Prosopis juliflora* at 50% and maize cobs at 50% being a better fuel having obtained relatively lower average volatile matter of 75.65$\pm$1.21%

The ash content of the fuel combinations ranged from 2.34$\pm$0.01% to 4.06$\pm$0.08%, with the highest ash content found in the combination of 50% bagasse and 50% *Prosopis juliflora*, and the lowest ash content found in the combination of 75% maize cobs and 25% *Prosopis juliflora*. In terms of ash content *Prosopis juliflora* and its binary combinations are well within acceptable ranges.

Fixed carbon percentages obtained for *Prosopis juliflora* and its binary combinations were significant enough to produce enough heat needed in our households and industrial applications. However, binary combination of *Prosopis juliflora* and maize cobs at 50% to 50% ratios proved a better fuel comparatively having given a fixed carbon of 21.11±1.42%.

On biomass feedstock calorific value, *Prosopis juliflora* and its binary combination of maize cobs and bagasse attained impressive values of between 18.99±0.21 MJ/kg and 19.73±0.05 MJ/kg. This signifies that all the combinations are well above the expected values of providing enough heat needed for cooking and industrial operations. However, the binary combination of maize cobs at 50% to *Prosopis juliflora* at 50% had a relatively higher heating value of 19.73±0.05 MJ/kg making it a better choice than using *Prosopis juliflora* at its pure form or other binary combinations.

The ultimate analysis exhibited high amounts of carbon at the ranges of 46.24±0.40% to 48.90±0.11% and significant amounts of hydrogen at the ranges of 4.91±0.22% to 6.18±0.24% which is a desirable thing in a biomass fuel since high carbon and hydrogen is characterized by high calorific values during combustion. Sulphur and nitrogen stood at the ranges of 0.12±0.00% to 0.44±0.05% and 0.20±0.02% to 0.27±0.03% which are all below 1%; low enough to make these briquettes a quality biomass fuel since sulphur and nitrogen do not add to the calorific value of a biomass fuel, rather there oxides gives a detrimental impact to environment. *Prosopis juliflora* 50% and Maize cobs 50% binary combination briquettes attained a higher calorific value of 19.73±0.05 MJ/kg with a significant fixed carbon of 21.11±1.42%, coupled with these desirable proximate parameters exhibited by the fuel. In addition, carbon and hydrogen percentages of 48.90±0.11 and 6.18±0.24, respectively, was achieved; making *Prosopis juliflora* 50% and Maize cobs 50% binary combination briquettes comparatively the optimum binary combination for briquette production. The piston type technology used in this study showed to be viable having attained a positive *IRR* of 55% against a discounting rate of 13% plus having a positive *NPV* of Kshs.

7863216; a discounted payback period of 2.07 years was attained meaning the project will start earning profits from the third year of operations; as well as profitability index of 1.57 which is greater than one indicating a viable project. Further, the resulting briquettes of *Prosopis juliflora* 50% and Maize cobs 50% binary combination proved cheaper retailing comparatively at Kshs. 13.97 with respect to Kshs. 225.00, 19.71 and Kshs. 18.31 for LPG, Eucalyptus wood and charcoal briquettes respectively, on usage cost of 1 kg per day.

5.2 Recommendations

Despite the promising results generated by aforementioned findings emerging from the study, we observed the following important issues that might be recommended for future work:

1. Further investigation should be done to establish the effect of different processing techniques on the physical and energy characteristics of briquettes made from the selected binary combination of *Prosopis juliflora* with maize cobs and bagasse; this could include exploring the use of binders or other additives to improve the quality of the briquettes.
2. In order to ascertain potential of other biomass resources for energy generation, such as agricultural residues, wood waste, and other non-food crops further studies can be explored. This could include comparing the physical and energy characteristics of different biomass resources to determine the most suitable options for briquette production at tertiary combination levels.

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APPENDICES

Appendix I: Proximate Analysis Detailed Results

Measured in Duplicates	Wt. of Crucible	Sample Wt. **(W_1)**	Crucible + Sample Wt.	Dry Sample Wt. **(W_2)**	**%Solid Matter**	**%MOISTURE CONTENT**
***P. juliflora* 100%**						
1	30.007	2.000	31.897	1.890	94.500	**5.500**
2	27.526	2.005	29.417	1.891	94.314	**5.686**
Average	28.767	2.003	30.657	1.891	94.407	**5.593**
***P. juliflora* 50% & MAIZE COBS 50%**						
1	31.037	2.004	32.923	1.886	94.112	**5.888**
2	18.262	2.001	20.146	1.884	94.153	**5.847**
Average	24.650	2.003	26.535	1.885	94.132	**5.868**
***P. juliflora* 75% &MAIZE COBS 25%**						
1	32.578	2.002	34.463	1.885	94.156	**5.844**
2	35.676	2.000	37.560	1.884	94.200	**5.800**
Average	34.127	2.001	36.012	1.885	94.178	**5.822**
***P. juliflora* 50% & BAGASSE 50%**						
1	34.559	2.003	36.443	1.884	94.059	**5.941**
2	18.599	2.000	20.482	1.883	94.150	**5.850**
Average	26.579	2.002	28.463	1.884	94.104	**5.896**
***P. juliflora* 75% & BAGASSE 25%**						
1	32.446	2.002	34.344	1.898	94.805	**5.195**
2	28.375	2.003	30.271	1.896	94.658	**5.342**
Average	30.411	2.003	32.308	1.897	94.732	**5.268**

Appendix II: Proximate Analysis Detailed Results

	Volatile matter				Ash content			Fixed Carbon	Calorific Value	
	Crucible + Sample Wt.	Sample Wt.	Sample Wt. **(W_3)**	**% VM**	Crucible + Sample Wt.	Sample Wt. **(W_4)**	**% Ash**	**%FC**	Sample Wt.	**MJ/Kg**
***P. juliflora* 100%**										
1	30.395	0.388	1.502	**79.471**	30.063	0.056	**2.963**	**17.566**	0.504	**18.776**
2	27.989	0.463	1.428	**75.516**	27.588	0.062	**3.279**	**21.206**	0.502	**19.197**
Av	29.192	0.426	1.465	**77.493**	28.826	0.059	**3.121**	**19.386**	0.503	**18.987**
***P. juliflora* 50% & MAIZE COBS 50%**										
1	31.519	0.482	1.404	**74.443**	31.094	0.057	**3.022**	**22.534**	0.500	**19.779**
2	18.698	0.436	1.448	**76.858**	18.327	0.065	**3.450**	**19.692**	0.500	**19.682**
Av	25.109	0.459	1.426	**75.650**	24.711	0.061	**3.236**	**21.114**	0.500	**19.731**
***P. juliflora* 75% &MAIZE COBS 25%**										
1	32.991	0.413	1.472	**78.090**	32.622	0.044	**2.334**	**19.576**	0.502	**19.318**
2	36.075	0.399	1.485	**78.822**	35.720	0.044	**2.335**	**18.843**	0.500	**19.218**
Av	34.533	0.406	1.479	**78.456**	34.171	0.044	**2.335**	**19.209**	0.501	**19.268**
***P. juliflora* 50% & BAGASSE 50%**										
1	34.970	0.411	1.473	**78.185**	34.637	0.078	**4.140**	**17.675**	0.508	**19.075**
2	19.015	0.416	1.467	**77.908**	18.674	0.075	**3.983**	**18.109**	0.502	**19.210**
Av	26.993	0.413	1.470	**78.046**	26.656	0.076	**4.062**	**17.892**	0.505	**19.143**
***P. juliflora* 75% & BAGASSE 25%**										
1	32.854	0.408	1.490	**78.504**	32.507	0.061	**3.214**	**18.282**	0.505	**19.008**
2	28.809	0.434	1.462	**77.110**	28.425	0.050	**2.637**	**20.253**	0.500	**19.140**
Av	30.832	0.421	1.476	**77.807**	30.466	0.056	**2.926**	**19.267**	0.503	**19.074**

Appendix III: Ultimate Analysis Detailed Results

	Composition (%)			
	Carbon	**Hydrogen**	**Nitrogen**	**Sulphur**
P. juliflora 100%				
1	46.962	5.614	0.293	0.399
2	45.563	5.890	0.238	0.489
AV	46.263	5.752	0.266	0.444
P. juliflora 50% & MAIZE COBS 50%				
1	49.012	5.945	0.212	0.114
2	48.790	6.421	0.182	0.121
AV	48.901	6.183	0.197	0.1175
P. juliflora 75% &MAIZE COBS 25%				
1	46.920	5.764	0.215	0.208
2	46.862	5.701	0.204	0.231
AV	46.891	5.733	0.210	0.2195
P. juliflora 50% & BAGASSE 50%				
1	47.213	4.691	0.188	0.236
2	46.562	5.120	0.232	0.184
AV	46.888	4.906	0.21	0.21
P. juliflora 75% & BAGASSE 25%				
1	46.631	5.160	0.223	0.311
2	45.845	4.823	0.182	0.296
AV	46.238	4.992	0.203	0.304