CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical Agrisciences

Use of Coconut Husk as Energy Source in Ghana

MASTER'S THESIS

Prague 2023

Author: Philip Kwame Darko

Chief supervisor: Assoc. Prof. Tatiana Alexiou Ivanova, Ph.D.

Second (specialist) supervisor: Ing. Musa Bappah

Declaration

I hereby declare that I have done this thesis entitled USE OF COCONUT HUSK AS ENERGY SOURCE IN GHANA independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague,22.04.2023

....
Philip Kwame Darko

Acknowledgements

My first and foremost gratitude goes to God for good physical, mental and emotional health to be able to undertake this research thesis successfully. I would like to thank everyone in general who helped me in the preparation of thesis. Special appreciation and gratitude to my supervisor Assoc. prof. Tatiana Alexiou Ivanova, Ph.D. for helping me throughout the time taken to complete this thesis by her professional guidance and always present encouragement and in-depth knowledge and comments whenever needed. My further appreciation also goes to Ing. Musa Bappah for his immense support during experiments in the laboratory.

I am extremely grateful to my family for their love, prayers, caring and sacrifices throughout my study at CULS. My heartfelt thanks go to friends and colleagues for their unwavering support and encouragement throughout this journey.

The research was supported by the Internal Grant Agency (IGA) of the Faculty of Tropical Agrisciences, Czech University of Life Sciences Prague [grant numbers 20213108 and 20223110].

Abstract

The current reliance on fossil fuels is one of the most significant concerns for the future generations as the emissions connected with the use of the fossil fuels are substantial contributors to the popular global warming phenomenon. This thesis is focused on one of the oldest sources of energy, biomass, as an alternative source to the conventional sources of energy in Ghana. Coconut husks were selected as the biomass for this thesis because of its high abundance in the country and the specified district, and its poor nutritional value to be used as a source of feed for livestock. There is abundance of the coconut husks which is mostly considered useless once the fruit is eaten. To evaluate the potential of coconut husks as energy source, main physical and chemical tests were performed. Properties like moisture content, calorific value, ash content, carbon, hydrogen, nitrogen, and sulphur content were evaluated. The samples were then torrefied to selected temperatures and same physical and chemical tests were performed on the torrefied samples. The results generally showed coconut husk to be a very good source of energy biofuel as all the standard limits for graded non-woody biofuels were fulfilled. Physical and chemical tests performed on the torrefied coconut husk also showed a significant improvement of biofuel standard limits in exception of ash content which was increasing with increasing torrefaction temperature. Compression test was also performed on the original coconut husk sample and the results showed that a lot of energy will be wasted to produce briquettes and pellets. However, torrefaction of the coconut husk samples will rather be suitable since less energy will be needed and there were higher energy values recorded. The optimal temperature of torrefaction was at 300°C. The maximum theoretical energy yield/potential was also calculated.

Key words: coconut husks, torrefaction, calorific value, moisture content, Ghana, renewable energy, solid biofuels, mechanical compression, fuel properties, waste biomass

Table of Contents

List of tables

List of figures

List of the Abbreviations

CHNSO Carbon, Hydrogen, Nitrogen, Sulphur, Oxygen

CULS Czech University of Life Sciences

CV Calorific Value

FAO Food and Agriculture Organisation

FAOSTAT Food and Agriculture Organisation Corporate Statistics

GCV Gross Calorific Value

GDP Gross Domestic Product

GHG Greenhouse Gas

KNUST Kwame Nkrumah University of Science and Technology

MC Moisture content

MSW Municipal solid waste

NCV Net Calorific Value

OPEC Organisation of Petroleum Exporting Countries

RES Renewable Energy Sources

TJ Terajoule

UN United Nations

UNDP United Nation Development Program

WBA World Bioenergy Association

Units of measurement

km^2 Square kilometre

% Percentage

°C Degree Celsius

g Gram

h Hour

Ha Hectare

Hg/ha hectogram per hectare

J Joule

kg Kilogram

MJ Megajoule

MW Megawatt

t Ton

TWh Terawatt-hour

1. INTRODUCTION

Energy has become the main driver for development as industries grow, agricultural sectors become more technologically modernized, economies rapidly grow, and countries become wealthier (Aglina, 2016). It is needed for mobility, lighting, heating, and cooling. However, ensuring sustainable energy access has recently become an issue of public concern. The exponential increment of the global population and the current demands for energy have forced an excess exploitation of natural resources around the world. This phenomenon is directly related to the rapid decrease of natural conventional reserves of energy (petroleum, natural gas, coal, among others). Energy crisis is one of the most difficult challenges faced by humankind in the 21st century (Rajvanshi, 2010) as the world becomes increasingly dependent on fossil oil. Global energy consumption is projected to increase by 36% by 2030 (British Petroleum, 2013). In Africa, oil consumption could double in that time (GTZ/MOFA-Kenya, 2008). Since the transport sector relies almost entirely on oil supplies for fuel, countries will have to keenly compete for this limited supply of oil, and this presents more challenging issues. Several other factors, such as energy price increases, increased market volatility, heavy dependence of many countries on imported oil, lingering debate about the ultimate size of remaining recoverable fossil fuel reserves and the growing concern about the environmental impact of fossil fuel usage have provided impetus for the current strong interest in and support for alternative energy in many parts of the world (Mandil and Shihab-Eldin, 2010).

Efforts are being made globally to develop alternative energy sources, such as wind, solar, mini-hydro and biomass that would complement fossil fuel use and hopefully serve as replacement should fossil fuels run out one day. In sub-Saharan Africa, biomass is already a major source of energy for cooking and heating, but it is presently used principally in traditional forms such as firewood and charcoal in largely inefficient stoves (Sielhorst et al., 2008). Inefficient use of biomass in traditional forms present major environmental and health concerns such as indoor air pollution caused by burning biomass and coal in residences (Zuzarte, 2007). Also, the unsustainable sourcing of firewood or wood for preparation of charcoal contributes to the degradation of the local environment. According to Chagwiza (2008), modern biomass energy is a promising long-term renewable energy source, which has the potential to address environmental impacts, rising fossil fuel prices as well as security concerns posed by current dependence on fossil fuels. Modern biomass energy could provide new income and employment opportunities for farmers.

Several African countries, including Ghana, have been considering biofuels as they seek to reduce dependence on imported oil. Ghana imports large quantities of crude oil from Nigeria and Equatorial Guinea at prices that ranged from US$ 120 to US$ 130 per barrel in 2012 (Energy Commission, 2012). In 2020, Ghana imported $133M in crude petroleum, becoming the 73rd largest importer of crude petroleum in the world. In the same year, crude petroleum was the 28th most imported product in Ghana (OEC World 2020). According to Ghana's central bank monetary policy report (Bank of Ghana, 2014), the sharp rise in crude oil prices on the international market is increasing the depreciation of the local currency and may heighten inflation by causing manufacturing input prices upwards which could lead to slowdown in economic activities. There is therefore the need for the country to focus attention on domestically produced biofuels to reduce the challenges posed by oil importation. Ghana's Energy Commission, the agency in charge of energy planning in Ghana, posited that the development of biofuel will enable Ghana to achieve its strategic energy objectives which include energy security, reducing oil bill and saving foreign exchange, climate change mitigation, poverty alleviation and wealth creation through employment generation. The Commission has set a target for Ghana to substitute national petroleum fuels consumption with biofuel by 10% by 2020 and 20% by 2030 (Energy Commission, 2010). The biofuels needed to meet the 10% target in 2020 was estimated at about 336 million liters (Antwi et al., 2010). Meeting this demand requires abundant information on feedstock sources.

Research on feedstock for biofuel production in Ghana is limited and most researchers focus their attention on first- generation feedstocks such as sugar cane, cassava, oil palm and cereal grains for biofuels (see for example, Kemausuor et al., 2013, Osei et al., 2013, Afrane, 2012). However, producing biofuels from these first-generation feedstock’s present social challenges with respect to land grabbing that could potentially cause food supply shortages (Boamah, 2014a, Boamah, 2014b, Schoneveld et al., 2011). Also, first- generation biofuels may not be the answer to climate change mitigation as previously envisaged. Crop residues and biomass from other waste sources are more suited feedstocks for biofuels production with regards to social and environmental benefits and are envisioned as an attractive solution to the aforementioned problems associated with the production of first-generation biofuels. According to Kumarappan (2011), biofuels produced from lignocellulosic biomass feedstocks offer several potential benefits and could serve the purpose of sustainability. The raw materials used are largely waste materials from agriculture, forestry, or other non-food crops. The use of waste overcomes the problems of using food and feed grains, such as corn, for biofuel. Also, cellulosic biofuels help reduce greenhouse gas emissions relative to fossil fuels and other biofuels, such as corn ethanol.

A lot of biomass waste, especially coconut waste, is generated annually in Ghana from cities and towns. People who use the biomass waste directly to burn end-up continuously inhaling the smoke, resulting in diseases. Coconut husk and shell can be burnt and used to generate energy at minimum environmental and economic cost. Ghana produces millions metric tons of biomass waste annually, which could be developed both technically and commercially into high value products since it would help improve quality life of Ghanaians. Coconut wastes are produced on a daily basis, so attention should be focused on converting it into useful source of energy because it resolves the negative environmental consequences and hazards associated with the use of non-sustainable solid fuels and fossil fuels.

This study therefore seeks to identify and analyze how coconut husk waste can be utilized for energy purposes in Ghana.

2. LITERATURE REVIEW

2.1. Introduction

This chapter discusses previous literature relating to renewable energy, biomass and biomass management, composition of coconut, coconut husk and shell, energy content of coconut husk, utilization and economic importance of coconut husk and shell, its social and environmental benefits.

2.1.1. Country Review

Ghana, officially known as the Republic of Ghana, is located in West Africa. It is situated on the coast of the Gulf of Guinea and borders Cote d'Ivoire to the west, Burkina Faso, which lies north, and Togo, to the east. (See Figure 1). The population of Ghana is estimated to be over 31 million people (World Bank 2019). It is the second most populated country in West Africa after Nigeria. Ghana covers an area of 238,535 km^2. The capital city is Accra; other major cities include Kumasi, Takoradi, Cape Coast, Tamale, and Tema.

Ghana has more than 70 ethnic groups and each has their own distinct language making the country very multilingual. English is the official language of the country with the most spoken indigenous language spoken known as Twi, which is spoken by the largest ethnic group in the country known as Akans. In terms of religion amongst the population of the country, 71% are Christians, and 17% are Muslims. (World Population Review 2023)

The world bank estimates that about 13 million of the population live in rural areas which are mostly involved in the agricultural sector of the country.

The topography of Ghana consists of plains, hills, rivers, and the world's largest artificial lake known as Lake Volta, Dodi Island and Bobowasi Island on the south of the Atlantic Ocean coast. The country can be divided into four different geographical ecoregions. The coastline which is mostly sandy with plains and scrubs intersected with numerous rivers and streams. The northern part of Ghana is mostly made of high plains and the Southern central part is made up of a forested plateau region consisting of the

Ashanti uplands and the Kwahu Plateau. There is also the hilly Akwapim-Togo range that is found along the country's eastern international border. The highest point is found in the Akwapim Togo range, which is Ghana's highest mountain, Mount Afadja, 885m above sea level. Ghana is well endowed with water resources. Three main river systems drain the country. The Volta River system which consists of rivers like the Oti and Daka rivers, Black and White Volta rivers (Water Resources Commission, 2023).

Figure 1.The map of the Republic of Ghana

Source: (On the World Map 2021)

The southwestern river system which comprises of rivers like Bia, Tano, Ankobra and Pra rivers and covers 22 percent of the country area. The third river system which is the coastal river system consists of the Ochi- Nakwa, Ayensu and Densu rivers, covering 8 percent of the country area. (Water Resources Commission 2023).

2.1.2. Economy of the country

Ghana has one of the fastest-growing economies in the world, but the country's long-term economic growth is challenged by high energy costs; high levels of government debt, including in the energy sector; low access to credit; high borrowing costs; low agricultural productivity; a business climate that restricts private sector growth; and regional trade barriers. (USAID 2020).

Based on information from the population and housing census, Ghana's unemployment rate has stayed relatively low over the years, ranging from 2.8 percent to 10.4 percent in 2010. Age-related declines in unemployment are seen in Ghana, with youth unemployment being the highest. This can be explained by the fact that young people have less experience in the labour market than older people do, making them more susceptible to economic hardships. Also, they lack the knowledge of the labour market and expertise with job searches that would help them find employment. Lack of work experience mixed with a lack of social capital places young people at a disadvantage for new career prospects, even in prosperous economic times. higher unemployment rate among women than men in recent times have been attributed to the increasing desire of women to participate in market work reflecting in the consistent increase in the labour force participation rate of women against the backdrop of fewer employment opportunities (Baah-Boateng, 2012). Ghana's unemployment is also found to be more prevalent in the urban areas than rural areas. The regular migration of people, particularly the youth from rural areas to the urban centres in search of better economic prospects which are not easy to come by, largely explains the phenomenon of the high urban unemployment rate in Ghana. The non-attraction of rural life due to the absence of amenities such as electricity and water among other thigs and the low income associated with rural economic activity, dominated by farming also pushes many rural youths into the cities (Baah-Boateng, 2013).

Money transfer also plays an important role in Ghana's economic life. Ghana is one of the most remittance dependent countries in Africa where the income from money transfer in 2022 was 4.7 billion dollars, which was slightly higher than the previous year and this covered 6.1 percent of the country's Gross Domestic Product (GDP). A peak was registered in 2015 when remittances corresponded to 20.3 percent of the country's GDP (STATISTA 2023).

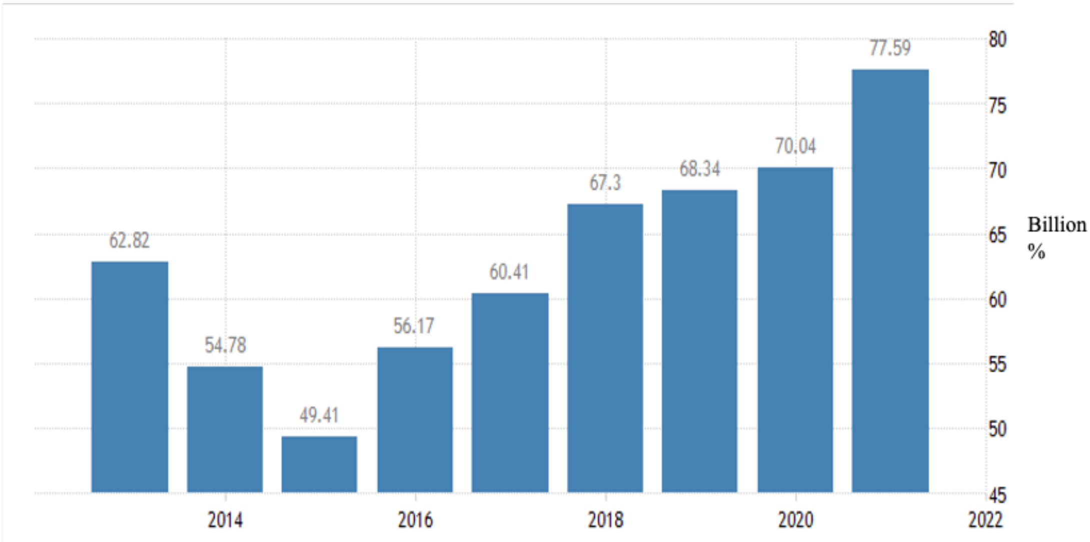


Figure 2. GDP of Ghana

Source: (Trading Economics 2022)

According to STATISTA 2023, the main sectors of the economy in Ghana are Agriculture, Industry, and services. The share of agriculture in the GDP of Ghana in 2021 was 19.71 percent, industry contributed approximately 28.6 percent and the services sector contributed 45.93 percent (STATISTA 2023).

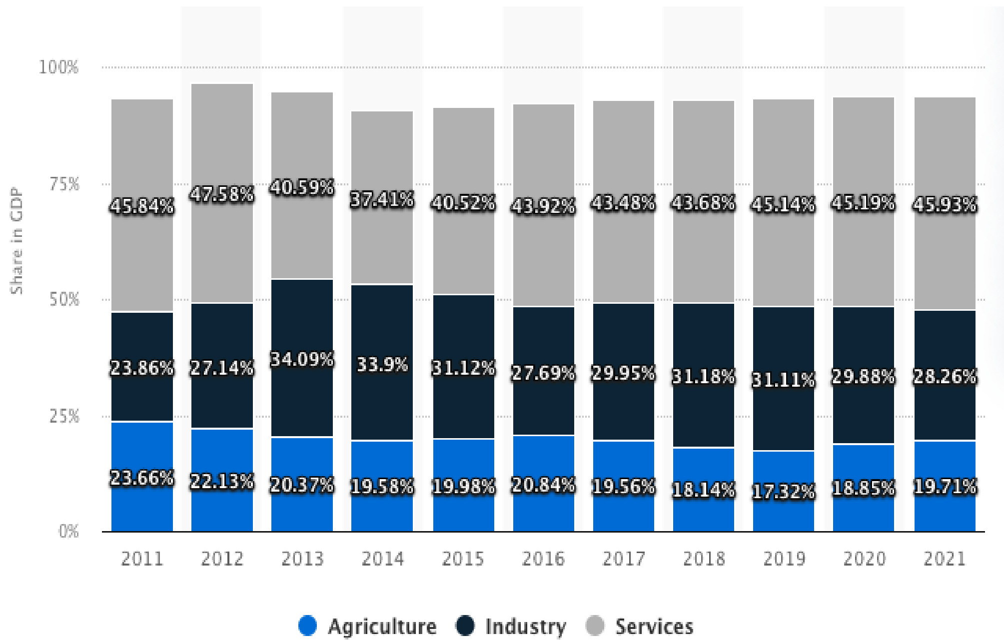


Figure 3. Share of GDP in Ghana

Source: (Statista 2023)

Table 1. Ghana's GDP Growth, %

Sectors	2015	2016	2017	2018	2019	2020	2021
Real GDP growth	2.1	3.4	8.1	6.2	6.5	0.5	5.4
Agriculture	2.1	2.7	6.2	4.9	4.7	7.3	8.4
Industry	1.2	4.3	15.6	10.5	6.4	-2.5	-0.8
Services	2.9	2.8	3.4	2.8	7.6	0.7	9.4
Manufacturing	3.7	7.9	9.5	4.1	6.3	1.9	7.8
Exports	17.6	2.9	23.8	6.6	12.7	-50.7	69.1

Source: (World Bank 2023)

2.1.3. Agriculture Sector in Ghana

As can be seen above, one of the key economic sectors of Ghana is agriculture, which accounts for one-fifth of Ghana's GDP (MOFA). The Ministry of Food and Agriculture (MOFA 2021) is the lead ministry for the agricultural sector, responsible for non-cocoa crops and livestock. The country produces a variety of crops in various climatic zones, which range from dry savanna to wet forests, and they run in East-West bands across the country. The industry is divided into five sub-sectors: fishery, forestry and logging, livestock, crops, and cocoa. The majority of agriculture in Ghana (85%) consists of the production of staple crops, with livestock, poultry, and fisheries accounting for 10% and forestry for less than 1%. Ghana's most significant crop in terms of the economy is cocoa. Ghana is a net importer of agricultural products, importing mainly consumer-ready commodities, such as rice, wheat, sugar, and poultry. In 2021, Ghana imported about USD 1.9 billion in agricultural and related products. (MOFA). Agricultural land is also 126,037 sq.km in the country (Global Economy 2023).

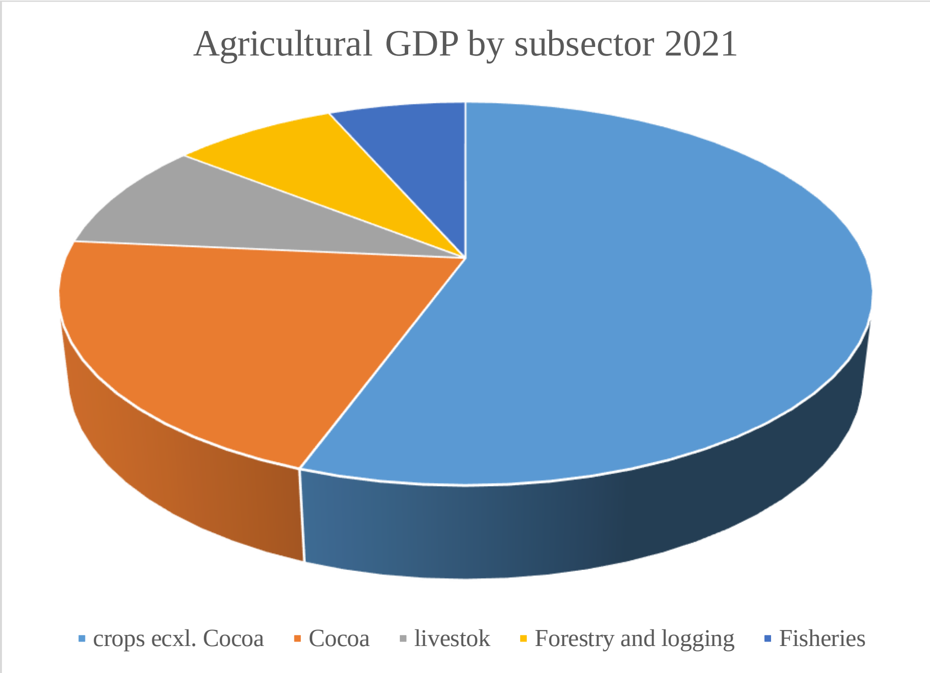


Figure 4. Agricultural GDP in % by subsector

Source: (Ministry of Food and Agriculture Ghana 2021)

Ghana's agriculture mainly consists of smallholder farmers, traditional, and rain fed. Production of food crops by smallholders increased in recent years. However, it is still characterized by low production due to several factors, such as poor extension services, aging farmers, and lack of finance for investment in better inputs.

Over the years, the Government of Ghana has implemented policies and programs to promote growth and development of the agriculture sector. This includes Ghana Agriculture Sector Investment Program, Savannah Investment Program, etc. There has been a general reduction in employment in agriculture over the years but the figure, which stands at 29.75% according to the Global Economy, is still very high as the world average in 2019 based on 180 countries is 23.51 percent.

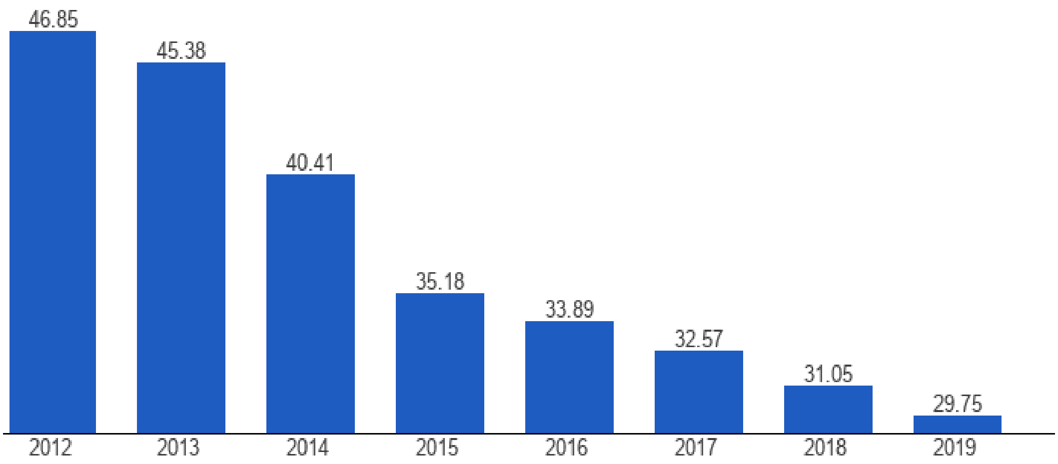


Figure 5. Employment in Agriculture, % of population

Source: (The Global Economy 2019)

Table 2. Annual Production of some major crops in Ghana 2009-2018 (Figures in '000Mt)

CROP	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Maize	1,619.60	1,871.70	1,684.00	1,949.90	1,764.50	1,768.54	1,691.64	1,721.91	2,011.18	2,306.38
Rice (Paddy)	391.40	491.60	464.00	481.10	569.50	604.04	641.49	687.68	722.08	769.40
Millet	245.50	219.00	184.00	179.70	155.10	155.32	157.37	159.02	163.48	181.56
Sorghum	350.60	353.00	287.10	280.00	256.70	259.00	228.40	229.61	277.54	316.24
Cassava	12,230.60	13,504.10	14,240.90	14,547.30	15,989.90	16,523.66	17,212.76	17,798.22	19,008.73	20,845.96
Cocoyam	1,504.00	1,354.80	1,299.60	1,270.30	1,261.50	1,298.97	1,301.19	1,343.73	1,387.29	1,460.94
Yam	5,777.90	5,860.50	5,855.10	6,638.90	7,074.60	7,118.89	7,296.12	7,440.35	7,856.90	7,788.87
Plantain	3,562.50	3,537.70	3,619.80	3,556.50	3,675.30	3,828.01	3,952.44	4,000.42	4,278.83	4,688.28
Groundnuts	485.10	530.90	465.10	475.10	408.80	426.63	417.20	425.83	433.77	521.03
Oil Palm	2,103.60	2,004.30	2,125.60	2,196.10	1,643.82	1,711.71	1,791.90	1,867.14	1,951.96	1,992.75
Cowpea	204.80	219.30	236.70	223.20	200.40	201.26	203.32	206.38	211.47	237.04
Soybean	112.80	144.90	164.50	151.70	138.70	141.47	142.36	143.22	170.49	176.67

Source: (Ministry of Food and Agriculture, Ghana 2018)

Table 3. Annual Cultivated Area of some Major crops in Ghana :2009-2018 (Figures in '000 Ha)

CROP	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Maize	954.4	991.7	1,023.20	1,042.10	1,023.50	1,024.53	880.25	865.28	984.51	1,020.52
Rice (Paddy)	162.4	162.4	197.5	189.5	215.9	224.46	233.27	235.85	240.7	259.71
Millet	186.7	176.7	178.7	172.5	160.7	162.35	162.24	136.92	155.66	141.64
Sorghum	267.2	252.6	243.5	230.8	225.8	226.92	228.39	201.16	223.51	228.14
Cassava	885.8	875	889.4	868.5	875.2	888.61	916.54	879.1	916.84	977.34
Cocoyam	224.6	205.3	204.4	196.3	194	200.4	200.49	205.86	204.24	203.23
Yam	378.7	384.9	403.8	426.3	421.6	428.01	430.2	427.22	470.33	469.69
Plantain	324.9	328	336.5	337.3	340	356.59	362.61	358.2	363.4	387.23
G'nuts	336.5	333.4	356.8	345.2	328.9	334.53	336.45	327.38	316.31	319.68
Oil Palm	352.8	343.3	373.2	387	313.7	321.75	330	338.25	346.71	351.39
Cowpea	162.7	167	182.3	168.8	162	165.83	162.65	146.66	153.91	156.79
Soyabean	77.3	76.2	85.9	85.2	84.8	86.87	86.27	86.88	102.6	102.98

Source: (Ministry of Food and Agriculture Ghana 2018)

The main crops grown in Ghana include Cocoa, Cassava, Maize, Plantain, Rice, Yam, and some vegetables like tomatoes, onions, peppers, and okra. These various crops are grown in different parts of the country and are consumed locally and exported too. Cocoa is Ghana's largest export crop, accounting for over 30% of the country's total export revenue (MOFA, 2019).

2.1.3.1. Coconut cultivation and production in Ghana

In Ghana, coconut was first grown at Keta as an estate crop (Wills, 1962), although some people argue that the crop originated from either America (tropical South America and the Antilles), southeast Asian peninsular (probably Malaysia) or South Africa. The crop is said to have reached Ghana by ocean current and through the actions of missionaries in 1912 (Wills, 1962).

Ghana's environmental conditions are ideal for the growth of coconut palms. Coconuts are found all along the coast, though they are more common in the driest parts of the coastal savannah. If the coconuts were left to spread naturally, the coast would be the only place where they would be found. But humans have aided the dispersal so much that coconuts can be found at any location that meets the silvicultural requirements in Ghana (Anyane 1963). The crop thrives very well in the tropical rainforest zone of Ghana and along the coastal belt. Ghana is ranked the 16th producer of coconut in the world producing about 224 million nuts annually (Codjoe et al.,2021).

Coconut is consumed as a snack on the streets of many communities and cities throughout Ghana. Coconut consumption is an integral part of Ghanaians' daily food, life, and activity, bringing happiness to people from all walks of life and emphasizing the plant's cultural significance. For example, the first International Coconut Festival in 2019 emphasizes the importance and popularity of coconut in Ghanaians' daily lives. Fresh coconut consumption has increased in recent years due to its nutritional and medicinal value. Many rural residents rely on coconut as their primary source of income. The coconut industry employs nearly 762,000 people, both private and public (Abankwah et al., 2010). In 2007, The price of one fresh coconut would sell for as low as 20 Ghana pesewas, The price then started soaring to as high as 60 Ghana pesewas in 2011, and now you will get one coconut for sale between 2-3 Ghana cedis, depending on the size. Currently most of the coconut is consumed domestically, within Ghana. However, there is currently a deliberate effort by the Ghana Government to promote expansion of the acreages under coconut cultivation to take advantage of the increasing demand in the international markets. To this end, Government is making short maturing, improved quality, and disease-resistant seedlings available to farmers and farmer associations to expand their coconut farms and improve productivity (GEPA 2017).

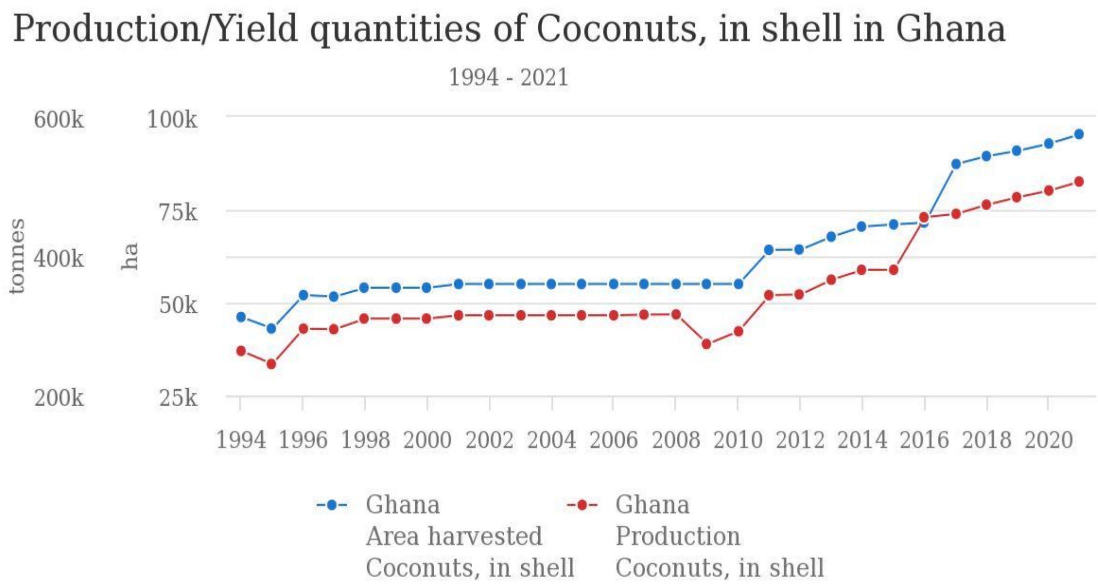


Figure 6. Graph showing yield quantities of coconut shells in Ghana.

Source: (FAOSTAT 2023)

2.1.3.2. Description of coconut

The coconut palm *(Cocos nucifera*) is the most well-known member of the palm family (Last 2001). It is the only recognisable species in the genus *Cocos* (Chan and Elevitch 2006). It belongs to the genus Cocos, family Arecaceae (family of palm trees), subfamily Cocoideae, and species nucifera (Chan and Elevitch 2006). Because of the many uses and products made from the coconut palm, the local name for the plant is often translated as "tree of life," "tree of heaven," or other similar names in many cultures around the world (Chan and Elevitch 2006; Last 2001; Ghana Ministry of Food and Agriculture (A) 2011; Frater 2004). The "West African Tall" species of coconut palms (Quaicoe et al. 2009) is widespread in Ghana's southern regions (Ghana Ministry of Food and Agriculture (A and B) 2011; Noel 2007; Quaicoe 2009; Okorley and Haizel 2004). The varieties are divided into two categories: tall and dwarf. The 'tall' varieties, the more common of the two, are named primarily for their geographical location and, in some cases, the fruit's morphology. The coconut fruit is spherical to oblong in shape, weighs at least 850 g (1.9 lbs), and grows in bunches on the palm. The location and colour of the immature fruit are also used to identify 'dwarf' varieties. In general, dwarf varieties are shorter in stature, have a thinner stem, fruit earlier, and have smaller fruits than tall varieties (Chan and Elevitch 2006).

2.1.3.3. Flowers

According to Chan and Elevitch (2006), Last (2001), Melendez-Ramirez et al. (2004), Okorley and Haizel (2004), a coconut palm takes 3–7 years to flower but some types, typically "Dwarfs," can bear fruit in as little as 3 years. Only one female flower matures into a fruit (Chan and Elevitch 2006). Male and female flowers mature at different times, encouraging cross pollination; however, self-pollination is possible and does not cause problems (Chan and Elevitch 2006; Last 2001). Wind and insects pollinate plants; the latter is more important (Melendez-Ramirez et al. 2004)

2.1.3.4. Fruit

The coconut fruit is made up of a thin hard outermost layer (Exocarp) covering a thick fibrous layer which is known as the husk (mesocarp) and the inner layer known as shell (endocarp). Inside the shell is a white kernel (endosperm when immature, copra when mature). The kernel surrounds a hole which is filled with water when immature, but the water is replaced by an empty space as the fruit ages (Chan and Elevitch 2006). The empty space is very important to the ability of the coconut to be dispersed by the ocean; the hole helps the nut to float (Last 2001).

The size, shape, husk thickness and colour of the coconut fruit depends on the variety. (Last 2001). It can be light or heavy, 850-3700g and can be elongated or spherical (Chan and Elevitch 2006). The coconut water found in the hole is very nutrient rich, isotonic and aseptic enough to be used as an IV fluid (Frater 2004; Ghana Ministry of Food and Agriculture (A) 2011). The coconut kernel, known for its high oil content, contains a high concentration of saturated fatty acids (Frater 2004; Last 2001; Ghana Ministry of Food and Agriculture (A) 2011). Saturated fatty acids are typically thought to be innutritious; however, evidence suggests that fatty acids derived from coconut are not (Rachel et al. 2010). In fact, coconut oil has long been used to treat a variety of sicknesses traditionally. Some Pacific Islanders believe that coconut oil is a cure-all (Ghana Ministry of Food and Agriculture (A) 2011).

Figure 7. Picture showing different varieties of coconut.

Source: (Bourdiex et al., 2005)

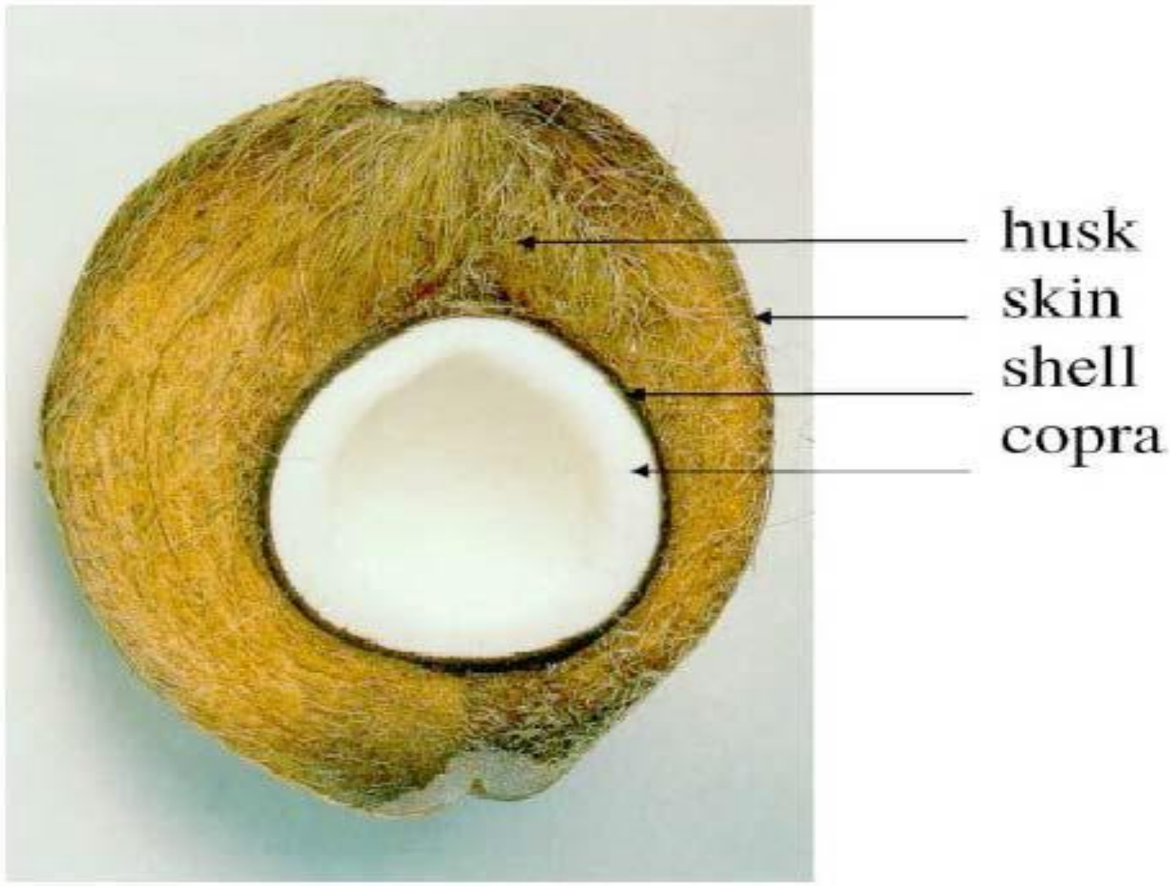


Figure 8. Picture of transverse section of coconut fruit

Source: (Bradley and Huang, 2006)

2.1.3.5. Stem

The stem, which can reach heights of 40 meters (130 feet), serves primarily to keep the palm in the light (Chan and Elevitch 2006; Last 2001). The coconut palm is a monocotyledonous plant, meaning it lacks circumferential thickening and secondary thickening. The coconut palm, on the other hand, reaches maximum diameter early in life and maintains an almost uniform size stem with efficient vascular bundles scattered evenly throughout the stem, giving it a homogeneous cross section. This makes the stem strong yet flexible, capable of withstanding massive amounts of damage while still functioning and supporting the palm (Last 2001).

2.1.3.6. Roots

The coconut palm does not have a tap root system, but it rather has a fibrous network of adventitious roots. (Chan and Elevitch 2006; Last 2001). The individual roots are approximately 1cm in diameter and spread mostly horizontal from the base of the stem. Majority of the roots are in the top of the soil but can reach as deep as 5 m. The roots grow laterally to about 6m from the stem but can reach as far as 30 m in ideal conditions (Chan and Elevitch 2006). The adventitious nature of the root makes it possible for roots to be quickly replaced when broken (Last 2001). This makes it easier to transplant palms regardless of size and age, as it allows them to survive and establish a new rooting system after being transplanted (Meerow and Broschat 1993).

2.1.3.7. Environmental Requirements

Coconut palms have the best advantage on sandy shorelines. Coconut palms have this advantage due to their ability to grow in infertile and saline soil, tolerate short inundations of the roots in salt water, and thrive in a wide range of pH environments. Coconut palms grow naturally on coarse sandy soil but prefer well-drained fertile loam or clay soils for growth. The pH range is 4.5-8, but the ideal range is 5.5-7. Because of the high level of required precipitation, well-drained soil is required. Precipitation should be at least 1000 mm (40 in), preferably 1500-2500 mm (60-100 in). Precipitation should be evenly distributed throughout the year (Chan and Elevitch 2006; Last 2001). Insufficient water supply is not well-tolerated and causes earlier frond death, premature fruit drop, and a low fruit harvest in subsequent years (Chan and Elevitch 2006; Last 2001; Prado et al. 2001). In addition to high precipitation requirements, coconut palms require abundant sunlight and a humid environment; 60 percent humidity is ideal (Chan and Elevitch 2006). Coconuts can grow in the shade, but nut production suffers (Chan and Elevitch 2006; Last 2001). The coconut palm requires the following temperatures: mean annual between 21-30 °C (70-86 °F), maximum of the hottest month 28-37 °C (81-99 °F), a minimum of the coldest month 4-12 °C (39-54 °F), and coldest tolerated temperature of 0 °C (32 °F) (Chan and Elevitch 2006; Last 2001). Seedlings and young palms are killed by freezing, and older palms are killed by prolonged exposure (Chan and Elevitch 2006).

Figure 9. Picture of coconut in Ghana

Source: (Myjoyonline.com 2020)

2.1.3.8. Coconut Husk Management in Ghana

Coconut husk used to be well managed in Ghana, but it has declined dramatically over the years. It was once used in the production of carpets (Fig 10), but little is known about that. It also used to be previously used as mulch for and some rural people also used them to make crates (Fig 11) for their eggs and yarns (Fig 12) for sewing and knitting. Now most people generally use the dry coconut husk to fuel a fire too. The husks are also used in Ghana to fill water pathways to fix erosion and fill potholes.

No management practice is associated with it because its usefulness has been lost in the system. After consuming the copra and juice, the husks are thrown away and they end up rotting in the field or are heaped to be burnt (Meyer, 2001). The coconut husks are littered all around street corners, walkways, backyards, or burnt in open space causing serious carbon pollution (“Greening the Savannah Project’’, 2012). Challenges facing coconut husk management in Ghana as a developing country is in perfect line with observation of Ogawa (2005) such as low collection coverages, irregular collection services, crude open dumping, burning without air and water pollution control. In addition to that, wrong coconut husk management issues in our society are clear evidence of the views from Puopiel, (2010) that, proper waste collection and proper disposal of refuse are daunting issues facing Ghana.

Figure 10. Coconut Husk for making carpets.

Source: http://sites.google.com/a/illinois

Figure 11. Egg Crates Made from coconut husks.

Source: http://sweetdomesticticity.com

Figure 12. Coconut husks Used as yarns.

Source: http://dignitycoconuts.com

Figure 13. Picture of typical dump sites of coconut husk.

Source: (Author 2022)

2.1.4. Energy situation in Ghana

One of the key factors affecting a nation's economic growth is access to electricity. It is essential for carrying out daily tasks including lighting, cooking, heating to powering machines in the industrial sector. Also, electricity is necessary for the provision of high-quality healthcare, education, transportation, effective communication, mineral extraction, and many other activities. It is the foundation upon which every sector of an economy depends to function. This demonstrates how important and necessary electricity is for human existence in the modern world.

The electricity sector in Ghana can be dated back to the colonial days of the Gold Coast, where majority of the country's electricity came from isolated diesel generating plants spread across the country. Most of these systems were owned by industrial facilities like mines, factories, by towns, and other organisations like schools and hospitals.

The Gold Coast Railway Administration established the first public electricity generation system in 1914, to supply electricity for the operations of the railway sector in Sekondi (ISSER, 2005). This was extended to Takoradi in 1928. By the year 1955, electricity had been extended to some major cities in Ghana including Kumasi, Tema, Accra. In 1947, an Electricity Department was established to take over electricity supplies. The Major electricity source at this time was the Diesel Generator Plants. The completion of the Akosombo Dam Project over the Volta River in 1972 provided a total installed capacity of 912 MW for electricity generation. Although the main aim of the project was to provide electricity for the aluminium industry, but it also enabled most of the electricity consumed to be switched from the diesel generators to hydroelectricity. In 1982, the Kpong Hydroelectric Power Station was also commissioned, increasing the total generation capacity by 160 MW (ISSER, 2005).

Even though the country's generation capacity has increased, Ghana had its first electrical crisis in 1984. This resulted from a severe drought between 1982 and 1984, when the total amount of water entering the Akosombo Dam was less than 15% of what was long-term anticipated. As a result of the crisis, Thermal Power Plants were introduced into Ghana's generation mix. The first of these thermal power plants was a 550 MW unit. The total installed capacity of thermal power plants in Ghana has increased to 2,053 MW as at the end of 2015 (Energy Commission of Ghana, 2016a). In Ghana, the electricity crisis has become a household phenomenon, prompting the use of the local term "Dumsor" to describe the situation. The 400 MW Bui Hydroelectric Power Station was commissioned in December 2013 to provide electricity to support the country's peak load, which has been steadily increasing (Energy Commission of Ghana, 2016a).

Over the last decade, Ghana's power sector has been plagued by power supply issues, which have had a significant impact on the country's economic situation. The World Bank ranked electricity as the second most important constraint to business activities in the country and estimated that Ghana lost about 1.8 percent of GDP during the 2007 power crisis (Mathrani, et al., 2013).

The Institute of Statistical, Social and Economic Research (ISSER) at the University of Ghana estimated in a 2014 study that Ghana, on the average, lost production worth about US $2.1 million per day (or, US $55.8 million per month) through the power crisis alone (ISSER,2015). This means that the country lost about US$680 million in 2014 due to the power crisis.

Peak load in Ghana has increased by 49.8% during the past ten years, rising from 1,393 MW in 2006 to 2,087 MW in 2016 (Energy Commission of Ghana,2016a; VRA,2015; Energy Commission of Ghana, 2017). This translates into an annual increase in peak load of 4.29 percent over the period depicted in the figure below. In contrast, generation capacity has more than doubled over the same time, rising from 1,730 MW in 2006 to 3,759 MW in 2016, an average annual increase of 8.60 percent. Furthermore, installed generation capacity increased by 29.14 percent in 2015 over the 2014 figure of 2,831 MW, and by 3.79 percent in 2016, while demand decreased by 1.88 percent in 2015 before increasing by 7.97 percent in 2016. Despite this, the country continues to face a power supply shortage, as it has for the past decade.

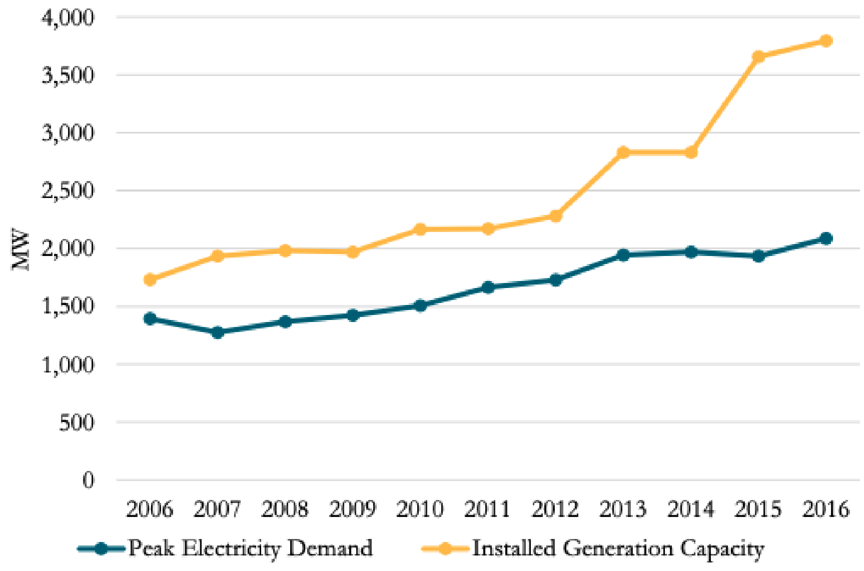


Figure 14. Graph showing Peak electricity demand versus installed generation capacity from 2006 to 2016**.**

Source: (Energy Commission of Ghana 2017)

Ghana's primary sources of power generation have been hydro and thermal. The power generation mix at the end of 2016 was approximately 57.21 percent of thermal energy and 42.79 percent of hydro sources. Renewable energy sources have not played a significant role in the generation mix, accounting for only 0.2 percent of the power generation mix in 2016. However, the nation is making attempts to incorporate considerable amounts of renewable energy in the power generation. The nation published a Renewable Energy Master plan in 2022 with the aim to increase the proportion of renewable energy generation mix to 1,363 MW and promote local content and local manufacturing and assembly in the renewable energy mix. (Energy Commission of Ghana, 2017).

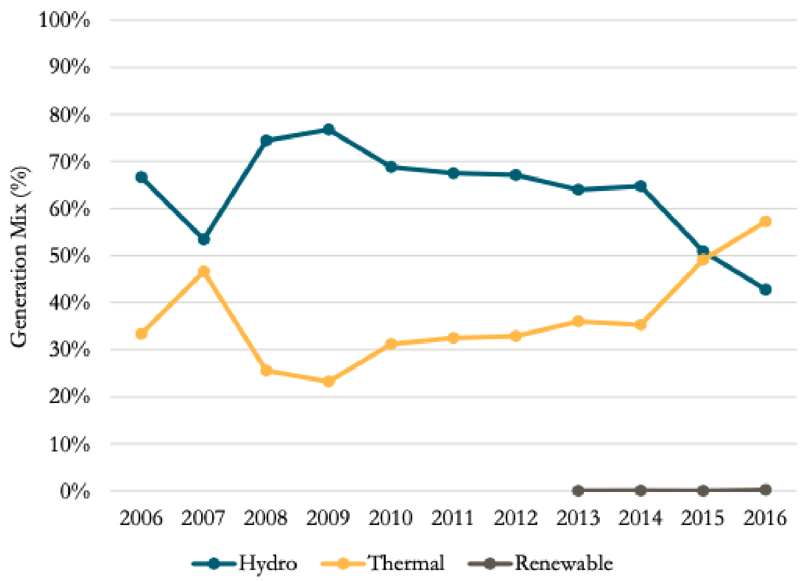


Figure 15. Graph showing Electricity generation mix from 2006 to 2016.

Source: (Energy commission of Ghana 2017).

2.1.5. Renewable Energy

To guarantee a better quality of life to the human communities, it is necessary to provide energy for different purposes (e.g., cooking, lightning, mobility, communication, heat, etc.). As it was explained before, the increment in the population has forced the use of the natural resources, especially referring to water, air quality, soil, and conventional energy resources. As per the urgency to find new sources of energy with low environmental impacts and more important renewable founts, many alternatives have been developed over the years, as it shown in the Table 4 (e.g., solar energy, geothermal energy, hydropower, wind energy, among others). According to the Intergovernmental Panel on Climate Change, 2012 “there are multiple means for lowering greenhouse gases (from now GHG) emissions from the energy system, while still providing desired energy services. Renewable energy technologies are diverse and can serve the full range of energy service needs.”

Table 4. Classification of energy sources

Type	Renewability		Renewable	Non-renewable
Conventional	Commercial		Hydropower (large scale) Geothermal Nuclear (breeder)	Fossil fuels Nuclear
Conventional	Traditional	Other	Solar (air drying) Hydro (mills, pumps) Wind (mills, pumps and sails) Animate (animal and human)	
Conventional	Traditional	Biomass	Fuelwood "cropping" from natural forest/charcoal Twigs, leaves, sticks Crop residues (straw, husks) Animal residues (dung, tallow) Industrial residues (wood waste, sawdust)	Fuelwood "mining" Charcoal
Non-conventional	Novel	Biomass	Plantation and marine crops (for distillation, pyrolysis) Biogas	
Non-conventional	Novel	Other	Solar (collectors, photovoltaic) Hydro (mini and micro) Wind (wind motors) Tidal, wave power Ocean thermal gradients Heat pumps	Nuclear Petroleum from coal, shale Synthetic natural gas

Source: (Mendoza, 2016 and Gritsevskyi, 2006)

The renewable energies nowadays, are playing an important role by providing energy services with sustainable characteristics, particularly fighting the climate change by mitigating the emission of GHG. According to the Global Status Report of Renewables energies written by the Renewable Energy Policy Network for the 21st Century (from now REN21), the estimated share of renewable sources (Figure 2.1) was 19.5% from which 7.8% corresponds to the traditional biomass, 2.2% to nuclear energy and 10.4% to modern renewables (3.7% hydropower, 4.1% renewable sources for heat (including modern biomass), 1.7% for power and 0.9% to biofuels for transport (modern biomas included), with China leading the power capacity, followed by United States, Brazil, Germany and India. On another hand, the Figure 18. shows the historical and predictive shares of an energy production from 2012 until 2023, from which it is possible to observe the fast grow of the renewable electricity especially, with an estimated production of almost 30% by 2023.

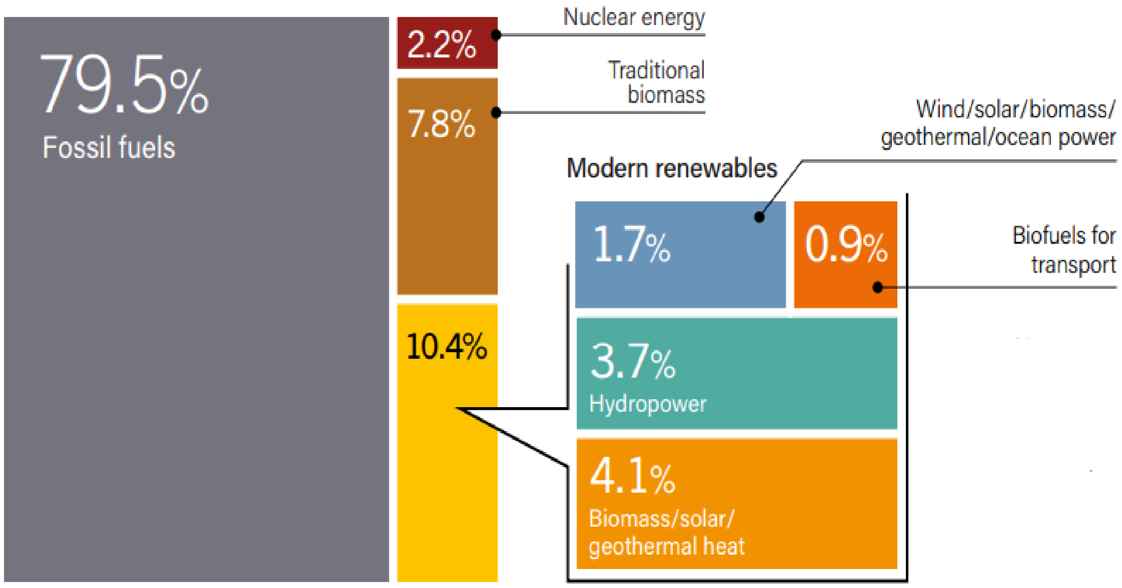


Figure 16. Estimated renewable share of total final energy consumption, 2016.

Source: (REN21, 2017)

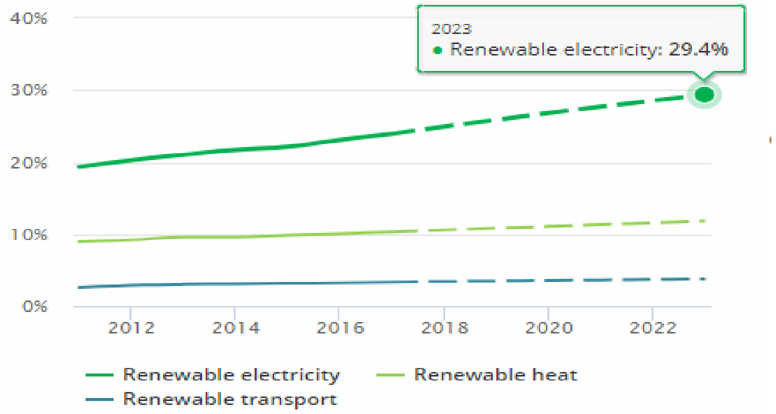


Figure 17. Share of modern renewable energy by sector, 2011 – 2023

Source: (International Energy Agency, 2018)

2.1.6. Biomass sources

Currently there are multiple sources of local biomass around the world, such as the waste coming from agricultural crops, herbaceous, woods production and general organic waste. Some advantages of the biomass sources can be named, in comparison to the traditional fossil sources, the main and the more obvious benefit is the renewability, whereas the fossil sources need thousands of years for the reproduction, the biomass sources are annually renewable or in several years depending on the specific characteristics of the specie (Nonhebel, 2007). The second advantage corresponds to the release of CO_2, which is one of the most major GHG, during the growth of the crops the biomass captures considerable amounts of CO_2 on the biosynthesis process, later when the organic waste is transformed into energy the emission of CO_2 is generally similar or with little delta differences to the concentration captured. Thus, it could be assumed a balance between the absorption and release of CO_2, which is not even compared to the large amounts of CO_2 emissions from burning fossil fuels (Cheng, 2018).

2.1.6.1. Agricultural residues

The agricultural production generates organic residues from either crop or processing activities, which can be used in several ways: as fodder, land supplements, fiber, and energy production (Hall & Overend, 1987). The most abundant and cheap crop residues for energy production are the corn stover, wheat straw and rice straw (Cheng, 2018). Overall, in the United States 155 million tons of agricultural residues could be used as a source of renewable energy in 2030 (UCS, 2012). Nevertheless, these residues are not ignored, "*in the Netherlands about 70% of the concentrate fed to pigs, cattle and poultry originate from residues generated by the food processing industry"* (Nonhebel, 2007) thus an overuse of the organic waste from the agriculture could reduce the availability of food for the cattle industry, and therefore an important source of protein for the human consumption.

2.1.6.2. Herbaceous biomass

One of the most attractive qualities of the herbaceous biomass as a feedstock for energy is the richness in the diversity of the species, the high biomass yield production in several years and high carbon content (Cheng, 2018). For example, according to Cherney et al. (1990) the switchgrass (*Panicum virgatum)* is the perennial grass with the highest potential for energy production purposes, due to its tolerance to resist different air temperatures, fast grown, bio-remedial attributes, carbon sequestration.

2.1.6.3. Woody biomass and forestry residues

One of the most important sources of energy, especially in Africa and third world countries is the wood biomass, where about 81% of the households in the Sub-Saharan Africa are using the wood-based biomass energy for cooking purposes (AFREA, 2011).

There are two main categories of the woody biomass; the softwoods and hardwoods; the first one with needle-like leaves, gymnosperms, and commonly non-flowering, with the pines and spruce as a main example. In contrast, the hardwoods are angiosperms, broad leaves, and commonly flowering plants, with poplar, oak, and willow as the most common examples (Cheng, 2018). The attractiveness of the woody crops is the relatively short rotation (2-5 years) due to its diversity, environmental tolerance, grown rate and non-necessity of irrigation for the growing of poplar (*Populus*); one of the most common species used for direct combustion, gasification and production of briquettes and pellets (IEA Bioenergy, 2002).

2.1.6.4. Other sources

Many different sources of biomass feedstock are reported by different authors, such as oilseeds (i.e., soybeans, canola, sunflower, oil palm, among other) to produce biofuels (bio-ethanol, bio-diesel, etc.); residues of livestock production (i.e., animal excreta and slaughterhouses waste); microalgae (i.e., suspended algae and attached-growth algae production) for the biogas elaboration (McGowan, 2009).

2.1.7. Physical and chemical properties of biomass

The most important properties of the biomass related with the combustion, and its usage as a source of energy are moisture content, calorific value, ash content, bulk density, organic volatile matter, and the chemical composition (Rosillo-Calle et al, 2015). In this part of the chapter those properties will be briefly explained.

2.1.7.1. Moisture Content

According to the British Standard, the simplest definition of moisture content is the amount or share of water in a specific material. Therefore, the efficiency of any biofuel in terms of energy production (calorific value) is inversely proportional to the moisture content, thus even if the wood has higher energy value than the crops residues at a determinate moisture content, is possible for the second source to have higher calorific value if the moisture content is lower (Rosillo-Calle et al., 2015).

There are two ways to measure the moisture content: wet bases and dry bases. The first one represents the moisture content of the material calculated using both dry and water weight of the sample, and it is used mostly in the woody biomass industry. The latter one is calculated using the weight of the water and the weight of the dry material and it used mainly for foresters and producers/manufacturers of wood products (McGowan, 2009).

2.1.7.2. Calorific value

According to Rosillo-Calle et al. (2015) the calorific value is defined as "*the measure of the energy content of a substance determined by the quantity of the heat given off when a unit weight of the substance is completely burned",* its commonly measured in calories or joules and expressed in Kcal/kg or MJ/kg. The most efficient source of energy is the bituminous coal with a calorific value of 7,200 kcal/kg (30.15 MJ/kg), followed by the anthracite coal with 6,810 kcal/kg (28.52 MJ/kg), the lignite (at 35% of moisture) with 3,990 kcal/kg (16.71 MJ/kg), wood (at 40% moisture) with 2,880 kcal/kg (12.06 MJ/kg), bagasse (at 50% moisture) with 2,220 kcal/kg (9.29 MJ/kg) and bark (at 50% moisture) with 2,492 kcal/kg (10.44 MJ/kg) (Environmental Protection Agency, 1995).

There are two main ways to determine the calorific value of a fuel: the Gross Calorific Value -GCV- (also called the Higher Heating Value -HHV-) and the Net Calorific Value -NCV- (also Lower Heating Value -LHV-). The GCV is the total amount of energy released for unit of mass of solids biofuels burned in the presence of oxygen and under specific conditions, it is usually measured by using a Calorimetric Bomb. Whereas the NCV is the value of energy obtained during the combustion of the biofuel under conditions of constant volume and presence of water, which will remain as a water vapor (British Standard Institution, 2010). As reported by Rosillo-Calle et al. (2015) the GCV is always higher than the NCV, since the latter includes the energy to vaporize the water contained in the fuel and the energy to form water from hydrogen contained in the hydrocarbon molecules, and its vaporization.

2.1.7.3. Ash content

As per the British Standard definition, the ash is the "*solid mineral residue obtained from a complete fuel combustion*". Therefore, when the ash content of a fuel is high, it will have a lower calorific value. The content of ash plays an important role during the combustion of the solid biomass, since its high ash content causes problems with combustion automatization, maintenance of the stove (for both industrial and small-scale heat production), and inhalable particle emissions (Obernberger et al., 2006).

The ash chemical composition of the solid biofuels includes Al, Ca, Cl, Fe, K, Mg, P, Na, S, Mn, Si, and Ti which are related with different environmental and technical issues such as emissions of fine particles, low ash fusion temperatures, increment of deposit formation, agglomeration, slagging, corrosion, and abrasion (Vassilev et al., 2017). The ash content in most of the coals (up to 40% depending on the type) is significantly higher than the ash content in biomass (0.2-0.5% for wood, 0.23% for sawdust, 4.7% for shea meal) (Kalembkiewicz & Chmielarz, 2011). Although, the ash is considered as an industrial waste it can be used as fertilizer due to its content of K, Ca, and S; additionally, it is used for different industries such as building and landscaping (Platače & Adamovičs, 2017).

2.1.7.4. Elemental and chemical analysis

The goal of the elemental analysis is to calculate the proportions of the elements carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O) in the organic solid biofuels. For example, during the combustion of biofuels, C and H are oxidized by exothermic reactions producing H2O and CO2 emissions (Valantinavicius & Vonodas, 2012), which is one of the main reasons to measure these values is to determine the precise air for combustion (stoichiometric air) (Perea et al., 2018). Moreover, the elements of Sulfur (S), Chlorine (Cl), Fluorine (F), and Potassium (K) are linked to corrosion in the chamber, whereas the elements of Nitrogen (N), Fluorine (F), Phosphorus (P), and heavy metals are linked to emissions (Stolarski, 2008).

Table 5. Effects of physical and chemical properties in the combustion of biomass.

	Properties	Effects
Physical	**Moisture content**	Storage durability Dry-matter losses Low NCV Self-ignition
	Bulk density	Fuel logistics (storage, transport, handling) costs
	Ash content	Dust, particle emissions Ash utilization/disposal costs
	Particle dimension and size distribution	Determines fuel feeding system Determines combustion technology Drying properties Dust formation Operational safety during fuel conveying
Chemical	**Carbon, C**	GCV (positive)
	Hydrogen, H	GCV (positive)
	Oxygen, O	GCV (negative)
	Chlorine, Cl	Corrosion
	Nitrogen, N	NOx, N_2O, HCN emissions
	Sulphur, S	SOx emissions, corrosion
	Fluor, F	HF emissions Corrosion
	Potassium, K	Corrosion (heat exchangers, superheaters) Lowering of ash melting temperatures Aerosol formation Ash utilization (plant nutrient)
	Sodium, Na	Corrosion (heat exchangers, superheaters) Lowering ash melting temperatures Aerosol formation
	Magnesium, Mg	Increase of ash melting temperature Ash utilization (plant nutrient)
	Calcium, Ca	Increase of ash melting temperature Ash utilization (plant nutrient)
	Phosphorus, P	Increase in ash meting point Ash utilization (plant nutrient)
	Heavy metals	Emissions of pollutants Ash utilization and disposal issues Aerosol formation

Source: (Mendoza 2016)

3. OBJECTIVES

3.1. Main objective

The main purpose of the Thesis is to evaluate the energy potential and fuel-energy properties of coconut husks as well as to investigate the optimal way of conversion into biofuel.

3.2. Specific objectives

In order to fulfil the main objective, several specific objectives were formulated:

- Calculation of the potential yield of Coconut husks: a case study of Ghana.
- Laboratory determination of the chemical, physical and mechanical properties of the biofuels made from coconut husks and comparison with other materials and standards.
- Calculation of the energy potential based on the yield of coconut husks and net calorific value.
- Comparison the loose/initial husks as an energy source vs torrefied biofuel.

4. MATERIALS AND METHODS

4.1. Material

Raw material (Coconut Husk) for analysis was obtained directly from Ghana. They were picked up from undesignated coconut waste dumping sites in the La Nkwantanang District in Accra, Ghana. Figure 19 shows the district on a map for better visualization. Coconut husks are dumped in undesignated sites by vendors who sell the coconut fruits on the streets. Some of them are also disposed of by individuals and households.

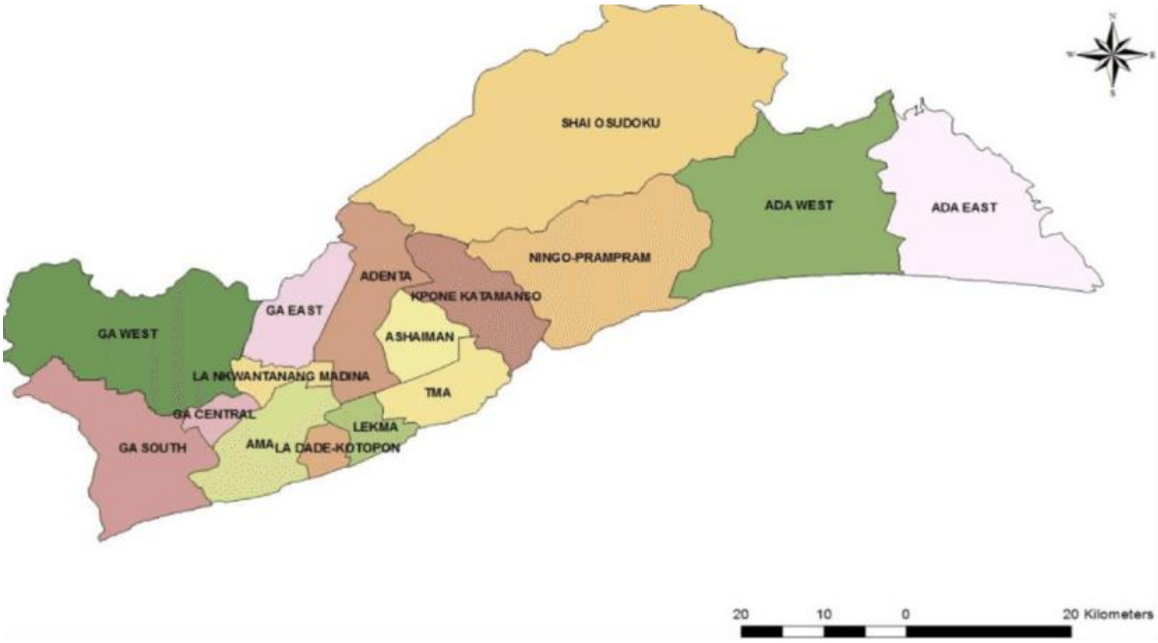


Figure 18. Map of Greater Accra Region Showing the various districts

Source: (Wiki Maps)

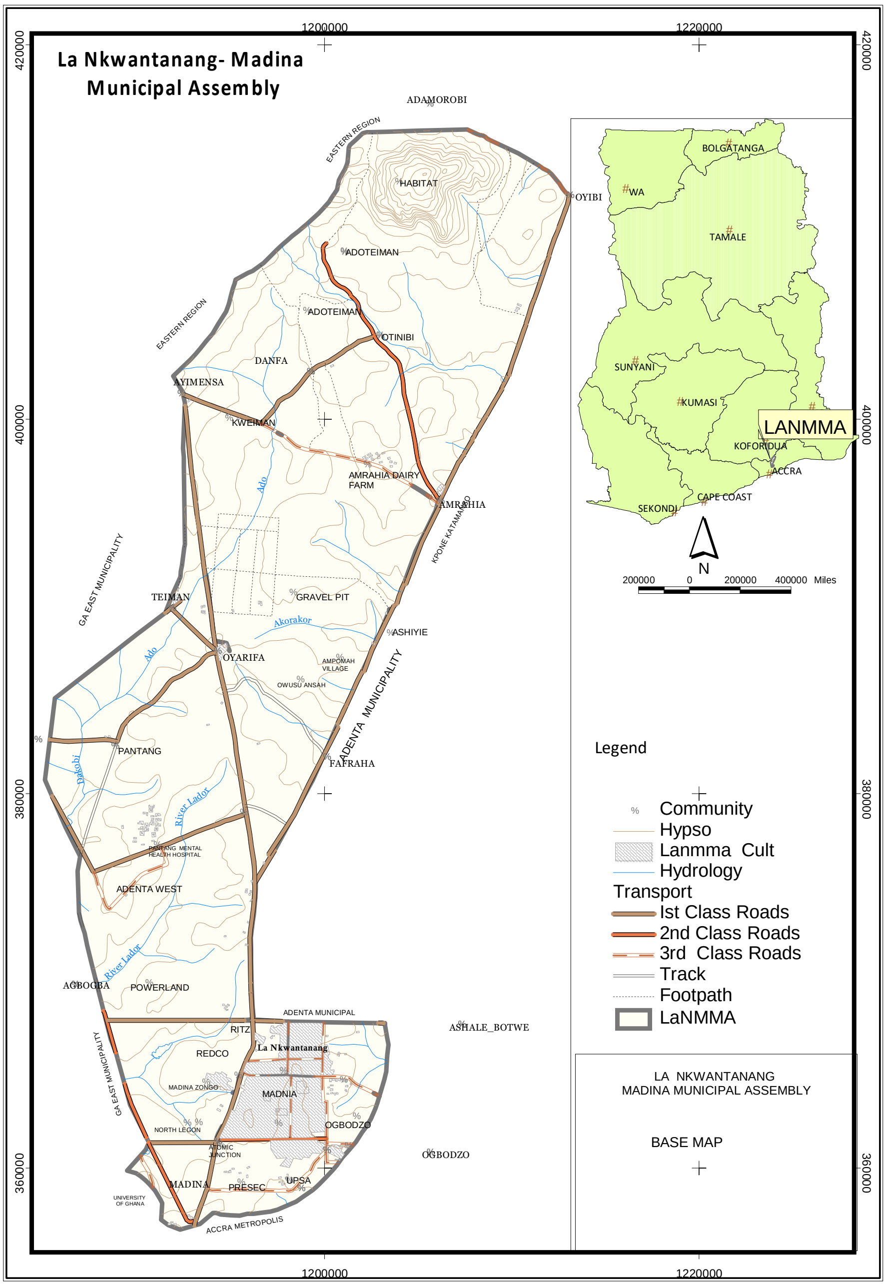


Figure 19. La Nkwatantanang -Madina Municipal District

Source: (lanmma.gov.gh/data-maps/)

The scientific experiments took place in the laboratory of Biofuel Center at the Research Institute of Agricultural Engineering, laboratory of Biofuel in the Faculty of Tropical Agriscience and Laboratory of Biomass characterization, Faculty of Engineering, Czech University of Life Sciences Prague.

4.2. Analytical sample preparation

Samples were homogenized, divided, dried and ground according to ISO 14780:2017 before they were analyzed. Grinding of sample was done using the laboratory mill (model Foss Cyclotec 1093, Foss, Denmark) and a screen with diameter of 0.5mm and FTA mill 9FQ-40°C.

4.3. Determination of physical and chemical properties of coconut husk

4.3.1. Moisture content

The moisture content of the coconut husk was determined and calculated according to Standard EN ISO 18134-3(2015): Solid biofuel- Determination of moisture content-Oven dry method. For the identification of moisture content, the oven used was MEMMERT (Model UFE 500), and for weighting the samples, the digital laboratory weighing scale KERN (Model ABJ 120-4NM) was used. The oven was heated up to 105° C together with empty containers. After a constant temperature was achieved in the oven, the containers were moved out and cooled in a desiccator with desiccant for about 15 minutes till it reached room temperature. The empty containers were then weighed and recorded. The samples were then placed in the weighted containers and weighed together, dried in the oven for about 3 hours at 105 °C until the weight was constant in mass. After the whole drying process, the containers filled with the samples were then taken out, cooled in the desiccator, and then reweighed. The following formula was used for the calculation of the moisture content.

(1)

$$W = \frac{(m2-m3)}{(m2-m1)} x\ 100\%$$

where:

W - moisture content, %.

m_1- mass of empty crucible, g.

m_2- mass of empty crucible with sample before drying, g.

m_3-mass of crucible with sample after drying, g.

Figure 20. MEMMERT drying oven (Model UFE 500) with coconut husk samples.

Source: (Author 2023)

4.3.2. Calorific value

The experiment was conducted strictly under the standard EN 14918 (2009): Solid Biofuels-Determination of gross calorific value and net calorific value. The calorimeter LAGET MS-10A (LAGET Ltd., Prague, Czech Republic) was used. Dried and weighed sample was wrapped in a combustion paper and then put in a crucible which has an ignition wire placed between the electrodes. This was then covered with a high-pressure vessel bomb, to fill it up with oxygen to a pressure of 3.0 $\pm$ 2 MPa. The vessel bomb filled with oxygen, containing the weighted sample and combustion paper was inserted into the calorimeter can, to start the full combustion of the sample. The calorimeter shows a jump of temperature which is used to calculate the Gross Calorific Value by the following equation:

(2)

$$Q_{v,gr} = \frac{\varepsilon \ x \ \theta - (m_{ign} \times Q_{ign} + m_{cb} \times Q_{cb})}{m_s}$$

where:

$Q_{v,gr}$—gross calorific value of a biofuel sample, J·g $^{-1}$.

ε —heat capacity of a calorimeter, 9,099 J/°C.

θ —temperature rise, °C.

m_{ign}—mass of the ignition wire, g.

Q_{ign}—calorific value of the ignition wire, 6,000 J/g.

m_{cb}—mass of a combustion paper, g.

Q_{cb}—calorific value of a combustion paper, 16,279 J/g.

m_s—mass of a tested sample, g.

Figure 21. Picture showing MS-10A calorimeter.

Source: (Author 2023)

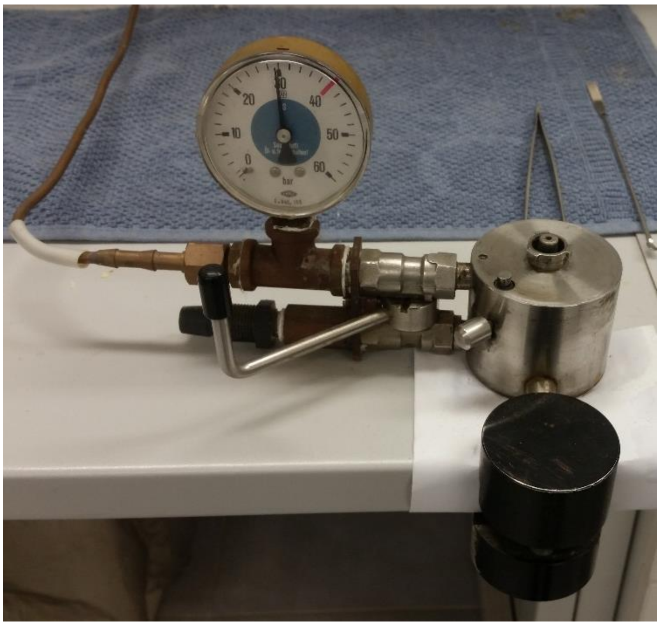


Figure 22. High Pressure Vessel Bomb

Source: (Author, 2023)

Subsequently, the Net calorific value was also calculated by using the following equation and converted to Megajoule per kilogram (MJ/kg) to keep consistency with previous similar studies made.

(3)

$$Q = Q_{v,gr} - 24.42x(M + 8.94xH)$$

where:

Q—net calorific value, J·g $^{-1}$.

Qv, gr—gross calorific value of a biofuel sample, J·g $^{-1}$.

ε —heat capacity of a calorimeter, 9,099 J/°C.

24.42— coefficient corresponding to 1% of the water from the sample at 25°C.

M—moisture content in the sample, %.

8.94—coefficient for the conversion of hydrogen to the water.

H—hydrogen content in the sample, %.

4.3.3. Ash content determination

The ash content of the sample was determined using ISO 18122:2015 by calcination at 550 °C in a muffle furnace (Thermolyne 30400, ThermoScientific, USA).

Figure 23. Dry samples tested in muffle furnace.

Source: (Author, 2023)

The equation below was then used to calculate the ash content.

(4)

$$A=\frac{(m3-m\ 1)}{(m2-m1)}\ x100$$

where:

A —ash content on a dry basis, %.

m1—mass of an empty dish, g.

m2—mass of dish with a sample, g.

m3—mass of dish with ash, g.

4.3.4. Carbon, Hydrogen, Nitrogen and Sulphur Determination

C, H, N was determined by elemental analysis (Leco TruSpec- macro sample CHN elemental analyser) following the ISO 16948:2015 standard. The machine was calibrated before three replicates of 0.1-gram dried tested samples wrapped in aluminum foil were placed into the equipment and combusted into simple compounds. The final compounds were analyzed using the infrared detectors and thermal conductivity at temperatures around 1050ºC in the presence of 100 percent Oxygen. The results from the equipment were calculated by mass %. Following that, the oxygen mass percentages were calculated using the following equation:

(5)

$$O\ (\%) = 100 - (C\ (\%) + H\ (\%) + N\ (\%) + S\ (\%) + Ash\ (\%))$$

where:

O (%)—mass percentages of oxygen, %.
C (%)— mass percentages of carbon, %.
H (%)— mass percentages of hydrogen, %.

N (%)— mass percentages of nitrogen, %.
S (%)— mass percentages of Sulphur, %.

Ash (%)— mass percentages of ash content, %.

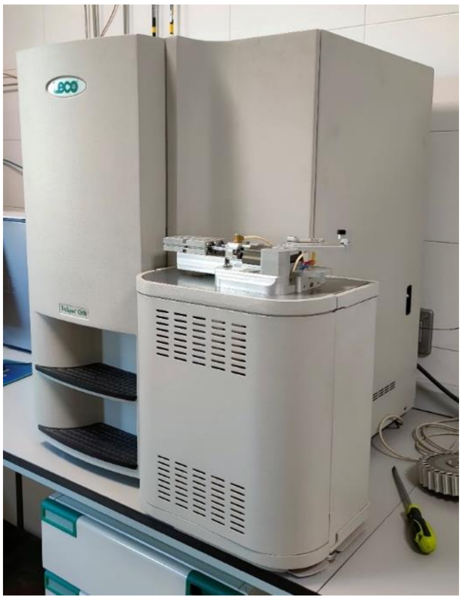


Figure 24. Picture of Leco TruSpec- macro sample CHN elemental analyzer)

Source: (Author,2023)

4.3.5. Estimation of energy required for husk disintegration- Compression Test

A universal compression testing machine (ZDM 50, Czech Republic) of a maximum load capacity of 500 kN was used for the compression test at a speed of 5 mm/min. The samples were loaded in both x and y orientations as shown in Figures 29 and 30 respectively.

(a) (b)

Figure 25. Compression test of coconut sample (a) loaded at y-orientation, and (b) sample with a crack after the test**.**

Source: (Author ,2023)

(a) (b)

Figure 26. Compression test of coconut sample (a) loaded at x-orientation, and (b) sample showing partly plastic deformation**.**

Source: (Author,2023)

The deformation energy is characterized by the area under the force-deformation curve (Gupta and Das 2000; Herak et al., 2015) which can be calculated using equation (6).

(6)

$$E_{DF} = \sum_{n=0}^{n=i-1} \left[\left(\frac{F_{n+1} + F_n}{2}\right) \cdot (x_{n+1} - x_n)\right]$$

where:

E_{DF} is the deformation energy (Joules or J), $F_{n+1} + F_n$ are the compressive force (N) and $x_{n+1} - x_n$ are the deformation (m), n is the number of data points and i is the number of sections in which the axis deformation is divided.

4.3.6. Stoichiometry calculation

The combustion properties of coconut shell/husk were determined from the relationship provided by Malatak & Bradna (2017). The theoretical amount of oxygen for perfect combustion was determined based on equation (7)

$$O_{2,min} = V_m(O_2)\left(\frac{C}{M(C)} + \frac{H}{M(H)} + \frac{S}{M(S)} + \frac{O}{M(O_2)}\right) \qquad (7)$$

where:

The theoretical amount of dry air L_{min} was calculated using equation (8)

$$L_{min} = \frac{O_{2,min}}{C_{atm}(O_2)} \text{x}\, 100 \qquad (8)$$

where: $C_{atm}(O_2)$ = 21% vol. – volumetric concentration of oxygen in air.

The theoretical amount of dry flue gasses $V_{fg,min}$ was determined using equation (9)

$$V_{fg,min} = \frac{V_m(CO_2)}{M(C)} \text{x} C + \frac{V_m(SO_2)}{M(S)} \text{x}\, S + \frac{V_m(N_2)}{M(N_2)} \text{x}\, N + \frac{C_{atm}(N_2)}{100} \text{x} L_{min} \qquad (9)$$

Where: $C_{atm}(N_2)$ – N2 concentration in the air (75.474%vol.)

The volumetric amounts of combustion products, CO2, H2O, N2, SO2, and O2 were calculated using equation (10) to (14)

$$v(CO_2) = \frac{V_m(CO_2)}{M(C)} \text{x}\, C + \frac{C_{atm}(CO_2)}{100} \text{x}\, L_{min} \qquad (10)$$

$$v(H_2O) = \frac{V_m(H_2O)}{M(H_2)} \text{x}\, H + \frac{V_m(H_2O)}{M(H_2O)} \text{x}\, W \qquad (11)$$

$$v_{N_2} = \frac{V_m(N_2)}{M(N_2)} \text{x}\, N + O_{2,min}\, \text{x}\, \frac{C_{atm}(N_2)}{C_{atm}(O_2)} \qquad (12)$$

$$v_{SO_2} = \frac{M(C)}{M(S)} \times S \qquad (13)$$

$$v_{O_2} = O_{2,min} \text{x}(n-1) \qquad (14)$$

where: W – Moisture content in the fuel, (%wt).

4.3.7. Production of coconut based biochar-Torrefaction

For the purpose of the research, the ground coconut husk samples were modified by torrefaction. Torrefaction is generally known to be able to produce a superior fuel compared to original biomass, by increasing the net calorific value and decreasing the oxygen content. (Tamelova et al. 2018). A programmable weighing furnace LECO TGA 701, see in Fig 31 was used at a rate of 10°C.min^{-1} up to a defined temperature which was maintained for 60 minutes. The predefined temperature was set, and then empty crucibles were loaded into the carousel. The machine then closes and automatically weighs the empty crucibles. The samples were loaded into empty crucibles after weighing and then placed in the carousel again and then torrefaction started, the results were then calculated and displayed on a computer screen connected to the machine.

Figure 27. Picture showing weighing furnace LECO TGA 701.

Source: (Author ,2023)

The samples were torrefied to 5 different temperatures as seen in table 6 below.

Table 6. List of samples and torrefied temperature

Sample	Description	Final Temperature
CH0	Original coconut husk sample	-
CH250	Torrefied coconut husk sample	250°C
CH300	Torrefied coconut husk sample	300°C
CH350	Torrefied coconut husk sample	350°C
CH450	Torrefied coconut husk sample	450°C
CH550	Torrefied coconut husk sample	550°C

4.3.8. Determination of biochar (torrefied coconut husk) energy properties.

For the determination of the biochar energy properties, main parameters like calorific value (net and gross, dry basis and as received), ash content, and contents of C, H, N were determined according to the measuring methodology described above (the chapters 4.3.1, 4.3.2, 4.3.3, 4.3.4).

4.3.9. Calculation of total energy yield (EYA)

The maximum theoretical energy yield /potential of agricultural was calculated using the recommended equation developed by Akhmedov et al (Akhmedov, et al.,2019):

(15)

$$EYA = WT \times NCV, \text{ TJ}$$

where:

WT – total yearly quantity of coconut husk waste, t.

NCV – net calorific value of coconut biomass, J g^{-1}.

5. RESULTS AND DISCUSSION

As stated in the methodology, the moisture content test was done according to the Standard EN ISO 18134-3(2015): Solid biofuel- Determination of moisture content- Oven dry method.

The moisture content of coconut husk sample was 8.9% (Table 7). The moisture content of the coconut husk meets the strict moisture content requirements on wood biofuels and standards for non woody pellets and briquettes too. The moisture content of a quality solid fuel (category ‘’A’’) should not exceed 12% for pellets and briquettes. (EN ISO 17255-6: 2014). Raw materials with high moisture content have a negative effect on the final properties of solid biofuels such as the calorific value (Ivanova et al. 2014). The moisture content is one of the main factors used to determine the Net Calorific Value and this is directly related to the burning or combustion potential of the material.

Table 7. Energy properties of coconut husk

Sample	W (% wb)	A (% db)	C (% db)	H (% db)	N (% db)	S (% db)	Cl (% db)	O (% db)	GCV (MJ/kg)	NCV (MJ/kg)
CH	8.90	4.60	49.00	5.50	0.51	0.06	1.20	39.13	18.74	17.32
CH 250C	1.09	6.12	56.73	5.35	0.78	0.06	1.20	29.76	21.73	20.53
CH300C	1.57	8.39	66.27	4.64	1.07	0.06	1.20	18.39	25.44	24.39
CH 350C	1.42	10.06	70.60	3.97	0.99	0.06	1.20	13.11	26.15	25.25
CH450C	3.11	11.93	75.30	3.15	0.94	0.06	1.20	7.43	28.22	27.45
CH 550C	2.22	13.24	80.13	2.50	0.99	0.06	1.20	1.89	29.14	28.54

The calorific value of the biofuels is what ultimately decides how valuable biomass is for energy-related purposes. The Gross Calorific Value was determined using the procedures described in the section 4.3.2. The Net Calorific Value was calculated using the formula (3) described in section 4.3.2. The results are shown in Table 7. The overall moisture content of the coconut husk samples corresponds to the requirement of non woody solid biofuels and even woody solid biofuels.

The material can be categorized as "A" class for both pellets and briquettes (respectively) in accordance with EN ISO 17225 (2014) sections 6 and 7 because the measured Net Calorific Value is greater than 14.5 MJ/kg.

Ash content must be less than 6% for grade "A" products and 10% for grade "B" products, according to the BS EN ISO 17225 (2014) sections 6 and 7. It is therefore clear that the ash content of the coconut husk is well below the limits to be classified as grade ‘’A’’ solid biofuel. The ash content is also one of the most important factors for a solid biofuel as the amount of ash can affect the operation of a combustion device as well as the time required for ash removal because it influences the formation of deposits in boilers (Kamperidou et al., 2017).

Nitrogen content complies with EN ISO 17225 (2014), which requires a nitrogen level of less than 1.5% for grade "A" non woody biomass. The Sulphur content also complies with EN ISO 17225 (2014), which requires a Sulphur level less or equal to 0.2% for grade "A." classification. Nitrogen and Sulphur concentration in biofuels is one of the required criteria since nitrogen and Sulphur has a direct impact on the creation of hazardous nitrogen oxides (NOx) and Sulphur Oxides (SOx) during fuel combustion (Erisman et al. 2010; Ivanova et al. 2014).

The specified standard does not contain the concentration of carbon and hydrogen; however, both were measured to understand the results and the NCV calculation. The amount of carbon has a positive link with GCV; therefore, a larger carbon content relates to a higher calorific value, explaining why GCV is higher in traditional energy sources (fossil fuels) when compared to biomass sources (Fernández et al., 2012).

5.1. Moisture Content

The result obtained was compared with the energy properties of other biomass. Figure 29 shows a clear comparison of moisture content between materials that are most often used for energy purposes.

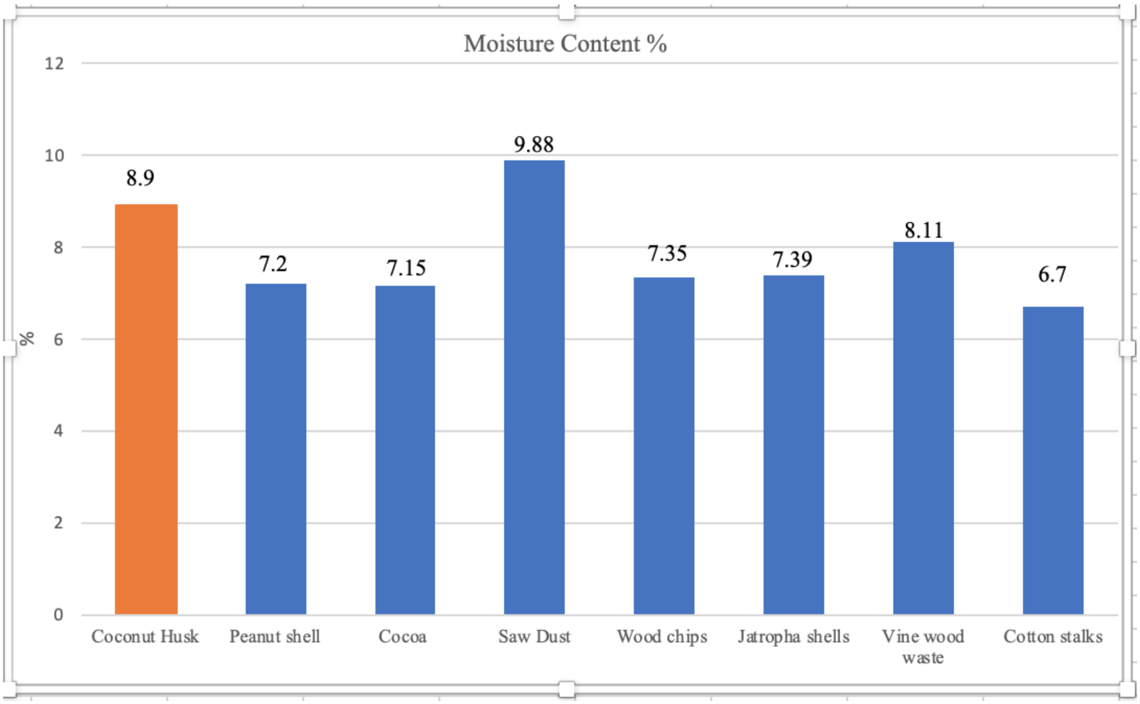


Figure 28. Comparison of moisture content with different raw material sources

Sources: (Author 2023; Higuera 2019; Spilacek et al, 2014; Brunerova et al,2017; Akhemedov et al.2017; Muzikant & Havrland 2010)

5.2. Calorific Value

The results as compared to other materials used as energy source also show that coconut husks samples have suitable Gross and Net calorific value to be used as energy source. See figure 30 below to show Net and Gross Calorific values of coconut husk being compared with other materials suitable for energy purposes.

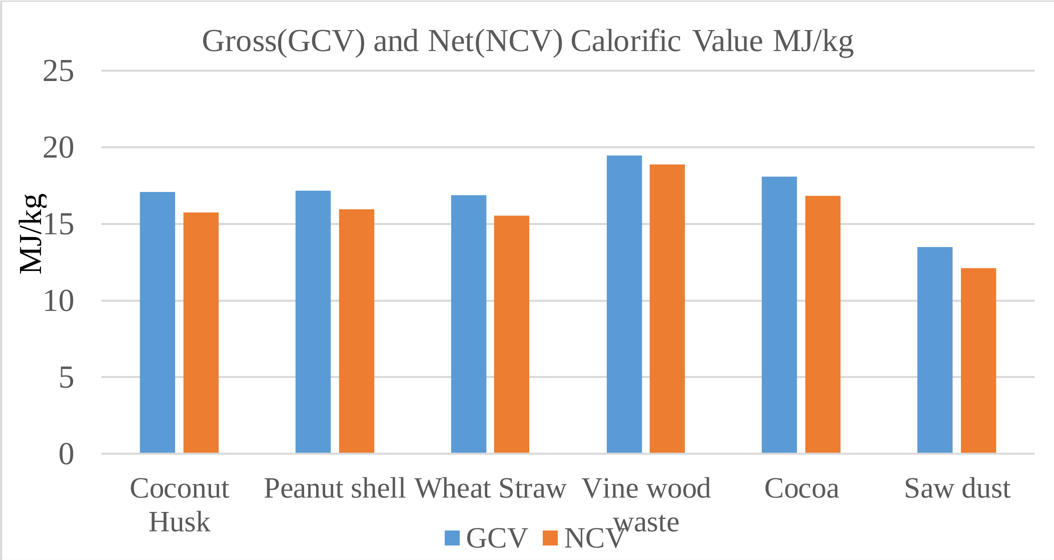


Figure 29. Comparison of the GCV and NCV of coconut husk samples with different raw material sources

Sources: (Author 2023; Higuera 2019; Bradna et al. 2016; Spinelli et al. 2012; Cosereanu et al. 2015)

5.3. Ash content

In comparison with other raw materials for biofuels, the ash content of coconut husks is significantly lower.

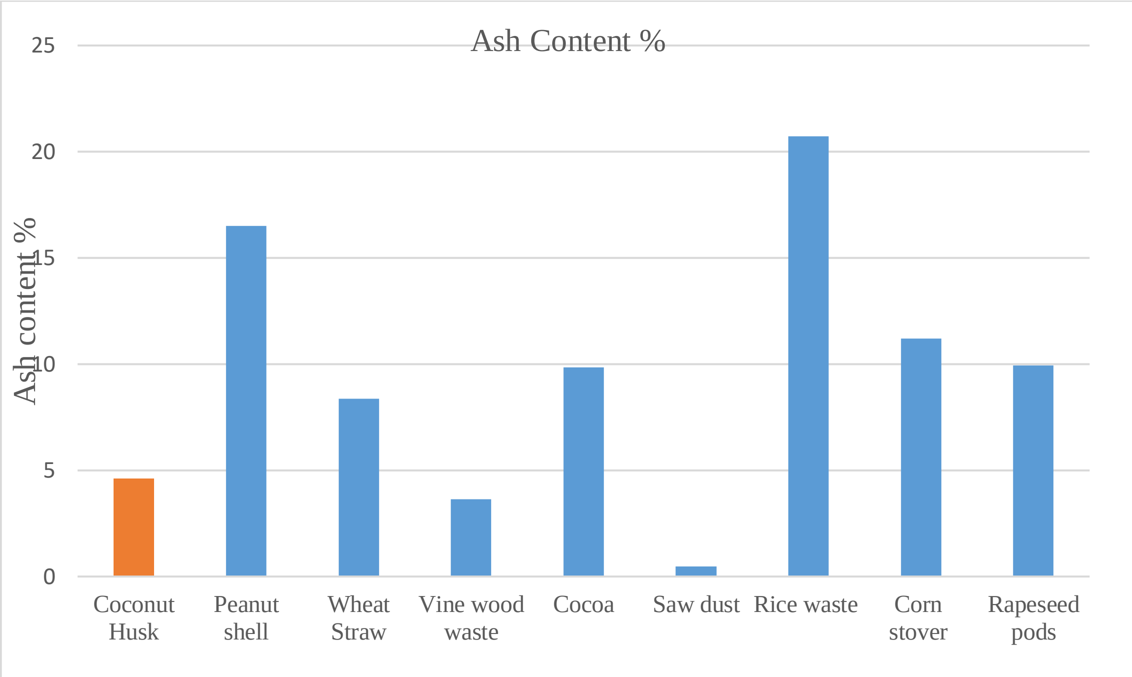


Figure 30. Comparison of Ash content of coconut husk and different raw materials samples**.**

Sources (Author 2023; Higuera 2019; Muzikant & Havrland 2010; Spilacek et al 2014; Brunerova et al,2017; Maj G, 2018)

5.4. Carbon, Hydrogen, Nitrogen and Sulphur determination

Coconut husk has a relatively high carbon content when compared to other biomass sources (see Figure 32) which makes it a suitable biomass source for energy.

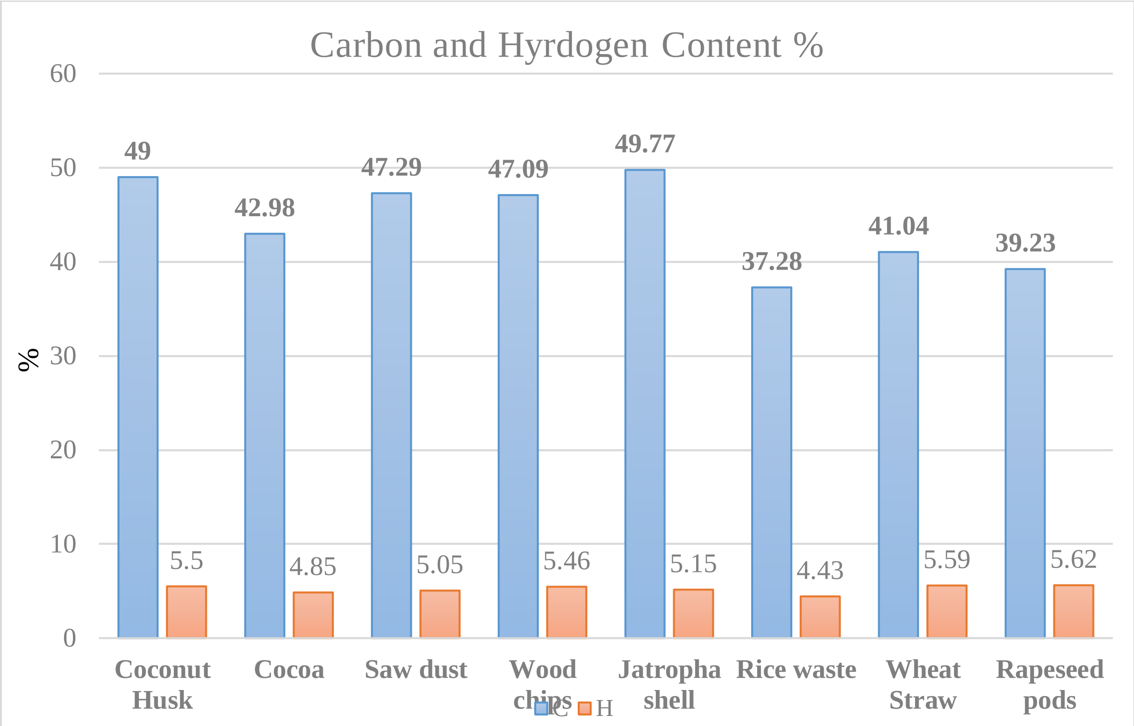


Figure 31. Comparison of Carbon and Hydrogen Content of coconut husk sample with other biomass sources

Sources: (Author 2023; Spilacek et al., 2014; Brunerová et al., 2017; Maj, 2018)

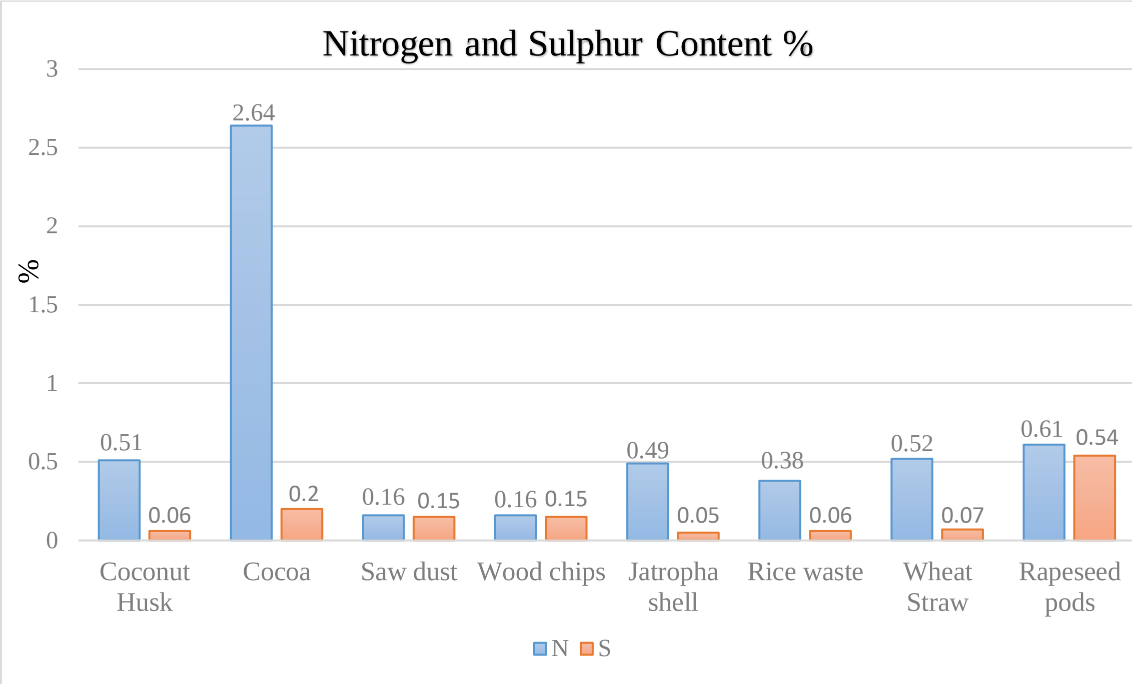


Figure 32. Comparison of Nitrogen and Sulphur Content of coconut husk sample with selected biomass sources.

Sources: (Author 2023; Spilacek et al., 2014; Brunerová et al., 2017; Maj, 2018)

5.5. Estimation of energy required for husk disintegration-Compression test.

Two coconut husk samples that were picked up without grinding were loaded in the x and y orientations,

Compression tests was done to determine the energy involved in crashing the whole husks. the sample at the X orientation recorded 7.24 J while the sample at the Y orientation recorded 795.99 J which means that the energy demand is affected by the loading orientation of the sample.

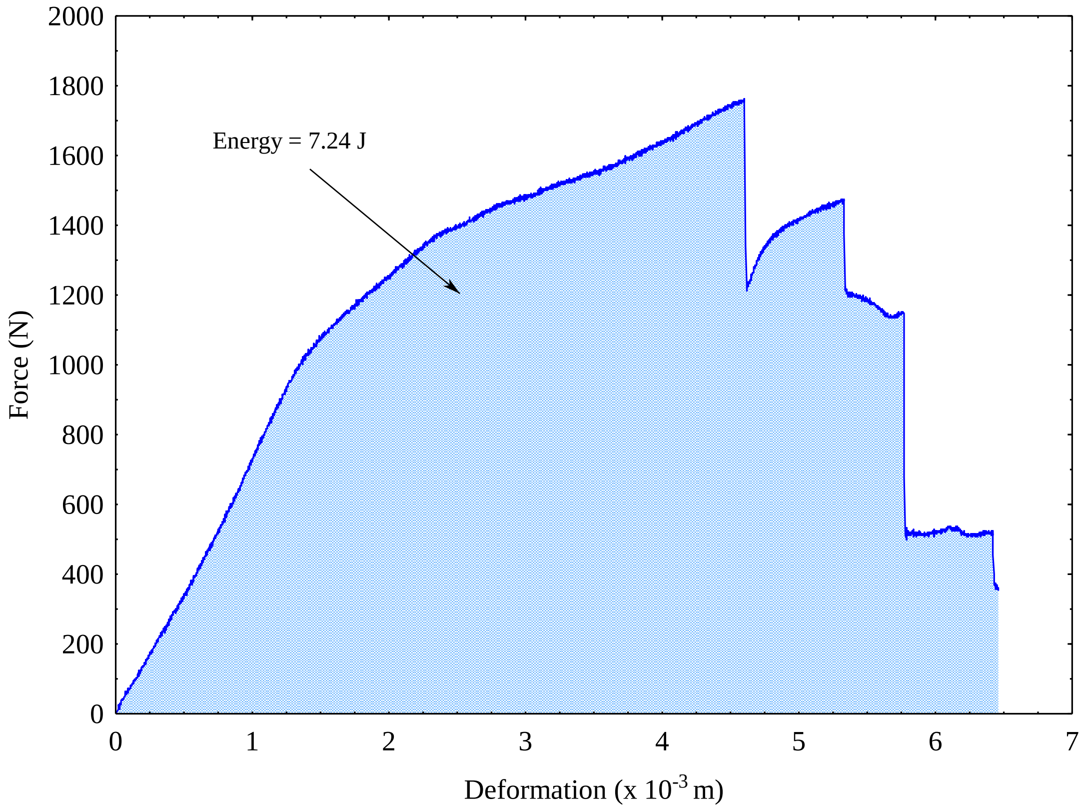


Figure 33. Force-deformation curve of coconut husk sample at a minimum force showing the area under the curve which is the energy.

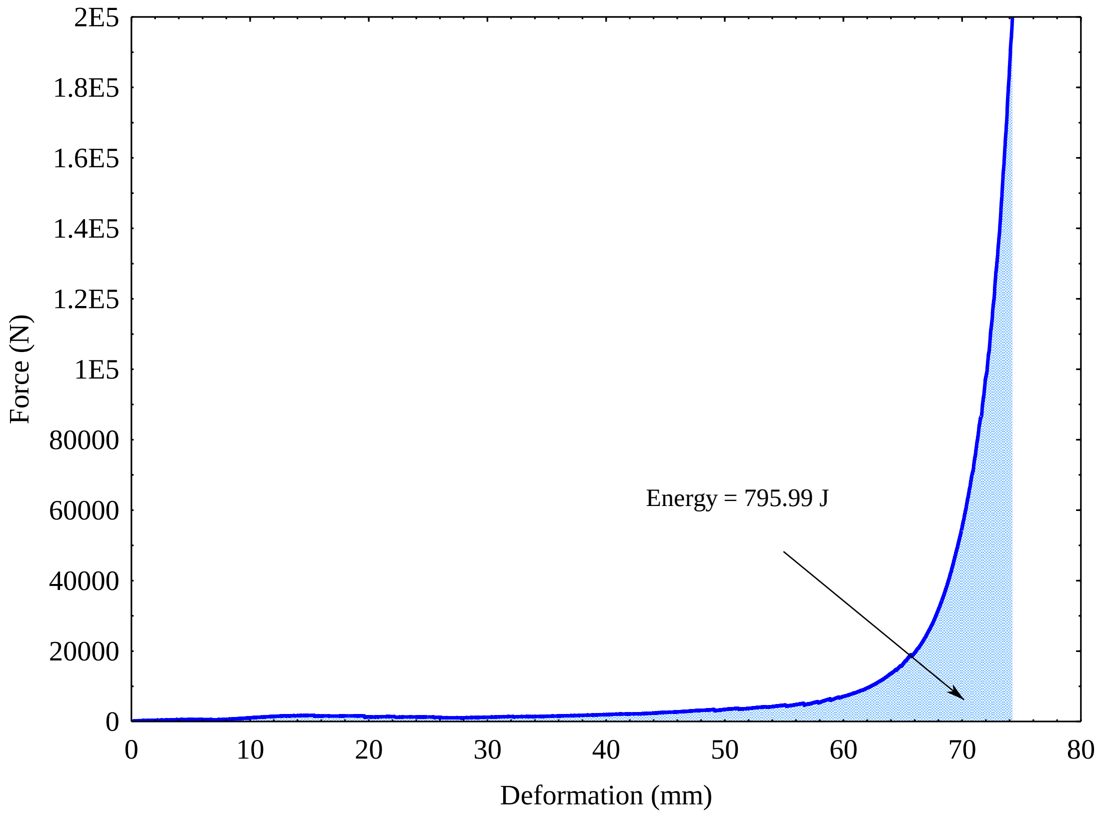


Figure 34. Force-deformation curve of coconut husk sample at a a maximum force showing the area under the curve which is the energy

The results clearly showed that a lot of energy will be needed to compress the original coconut husks therefore there will not be the need of briquettes and pellets.

5.6. Stoichiometric result

The theoretical combustion emission of coconut hut husk was measured, and the result is presented in Table 8.

Table 8. Theoretical combustion emissions

Samples	O_{2min} ($m^3.kg^{-1}$)	L_{min} ($m^3.kg^{-1}$)	$V_{fg,min}$ ($m^3.kg^{-1}$)	v_{CO2} ($m^3.kg^{-1}$)	v_{H2O} ($m^3.kg^{-1}$)	v_{N2} ($m^3.kg^{-1}$)	v_{O2} ($m^3.kg^{-1}$)
Coconut husk/shell	2.34	11.57	9.94	0.91	0.72	9.44	2.67
Torrefied Coconut shell, 250°C	2.47	11.77	10.25	1.06	0.61	9.82	2.72
Torrefied Coconut shell, 300°C	2.41	11.48	10.20	1.23	0.54	9.81	2.65
Torrefied Coconut shell, 350°C	2.31	10.98	9.89	1.31	0.46	9.36	2.54
Torrefied Coconut shell, 450°C	2.17	10.32	9.46	1.40	0.39	8.80	2.38
Torrefied Coconut shell, 550°C	2.07	9.86	9.19	1.49	0.31	8.49	2.28

O_{2min} – Theoretical amount of oxygen for perfect combustion, ($m^3.kg^{-1}$); L_{min} – Theoretical amount of air for perfect combustion, ($m^3.kg^{-1}$); $V_{fg,min}$ – Theoretical volumetric amount of dry flue gas, ($m^3.kg^{-1}$); v_{CO2} – Volumetric amount of CO_2, ($m^3.kg^{-1}$); v_{H2O} – Volumetric amount of H_2O; v_{N2} – Volumetric amount of N_2, ($m^3.kg^{-1}$); v_{O2} – Volumetric amount of O_2, ($m^3.kg^{-1}$).

Emission of CO_2 was found to increase with decreasing torrefaction temperature (Table 8). Untorrefied coconut shell has the least CO_2 emission as compared to the torrefaction temperature. Water vapour and N_2 emissions were discovered to be higher on coconut husk that were torrefied at least temperaturre and lower on those that were torrefied at higher temperature. Unlike water vapour, emission of untorrefied coconut husk which is higher that of the torrefied ones, the N_2 emission of the biomas is between 300^{o}C to 350^{o}C torrefaction temperature of the torrefied samples. Inverse relationship was noticed between CO_2 and N_2 emission of the torrefied coconut husk.

5.7. Determination of biochar (torrefied coconut husk samples) energy properties.

The coconut husk samples were torrefied in set temperatures and the average of results can be seen in the table 12 below. The main components of the orginial coconut husk sample are carbon (49%) and oxygen (39.13%). The moisture content measured was 8.90% and the ash content measured was 4.6%. The net calorific value of the original coconut husk sample was 17.32 MJ/kg. When torrefied at 250°C,the original moisture content which was 8.9% decreased to only 1.09% but the ash content increased from 4.60% in the original coconut husk sample to 6.12 %. It is established that there is an increase in ash content with an increase in torrefied temperature. The carbon content also increases with increasing temperature thereby affecting the Net calorific Value also the same way. However there is also an increase in the moisure content as the temperature of torrefaction increases. Coconut Husk sample that was torrefied at 300°C can be selected as the most suitable for energy purposes as it has quite low moisture content and an average ash content (8.39%), which puts it in the category 'B' of specification of biofuel products, according to the BS EN ISO 17225 (2014) sections 6 and 7.The Net Calorific Value of the Coconut Husk sample torrefied at 300°C was measured to be 24.39 MJ/kg.

Wood, which is a typical biomass used for fuel has low calorific value of 9-12 MJ/kg and Coal which is a common fossil fuel used to produce energy has approximately 23-28 MJ/kg of Net Calorific Value which is similar to coconut husk sample torrefied at 300°C.

Table 9. Energy properties of initial and torrefied coconut husk

Sample	W (% wb)	A (% db)	C (% db)	H (% db)	N (% db)	S (% db)	Cl (% db)	O (% db)	GCV (MJ/kg)	NCV (MJ/kg)
CH	8.90	4.60	49.00	5.50	0.51	0.06	1.20	39.13	18.74	17.32
CH 250C	1.09	6.12	56.73	5.35	0.78	0.06	1.20	29.76	21.73	20.53
CH300C	1.57	8.39	66.27	4.64	1.07	0.06	1.20	18.39	25.44	24.39
CH 350C	1.42	10.06	70.60	3.97	0.99	0.06	1.20	13.11	26.15	25.25
CH450C	3.11	11.93	75.30	3.15	0.94	0.06	1.20	7.43	28.22	27.45
CH 550C	2.22	13.24	80.13	2.50	0.99	0.06	1.20	1.89	29.14	28.54

W-moisture content (%), A-Ash content (%), C-Carbon content (%), H-Hydrogen content (%), N-Nitrogen content (%), S-Sulphur content (%). CL-Chlorine content (%), O-Oxygen content (%), GCV-Gross calorific value (MJ/kg), NCV-Net calorific value (MJ/kg)

5.8. Calculation of total energy yield

The calculation of the Total energy yield is very important in this research. As per the formula 15 in the section 4.3.9, the net calorific value of the original coconut husk sample is 17.32 MJ/kg. According to a study by The Coconut Waste Project (2021), the selected district where the samples were picked up produces an average of 17.73954 tonnes of coconut husks daily. The result of the calculation is presented in table 13 below.

Table 10. Total amount of waste and total energy yield

	Total Amount of waste (t/y)	**Total Energy Yield (TJ)**
Coconut Husk Waste	6,474.9321	112,145.82

Source: (Author,2013)

6. CONCLUSIONS

Generation of waste from production of agricultural commodities can be an important source of bioenergy. They could help reduce the dependency on conventional fuels by the re usage of their waste.

The results show that it is possible to use coconut husks for energy purposes. The moisture content was determined to be 8.9%, Net Calorific value was 17.32 MJ/kg, Ash content,8.9% and Nitrogen and Sulphur, 0.51% and 0.06% respectively. The amount of carbon and hydrogen were also measured as 49% and 5.5%.

The coconut husk can be used for this purpose in the raw from as it met all the given standards. When compared to other biomass already being used for this purpose it was also seen to have similar properties. However, there is no need to compress and crush the shells to be used as briquettes and pellets since a lot of energy will be used for this, instead torrefaction of the coconut husks is rather recommended as this will require less energy input and rather improves the properties of the coconut husks to be used as biofuels. It is important in future that extensive research is done to understand the energy demand for coconut husks samples under the compression tests.

7. REFERENCES

Abankwah, V., Aidoo, R., & Tweneboah-Koduah, B. (2010). Margins and economic viability of fresh coconut marketing in the Kumasi metropolis of Ghana. Journal of Development and Agricultural Economics, 2 (12), 432–440. https:/academicjournals.org/article/ article424431984_Abankwah%20et%20al.pd

Adjei P- (2014). Energy-Growth nexus and energy demand in Ghana: A review of empirical studies. P.28-38.

Aglina M., Agbejule A. and Godwin Y. (2016). Energy policy" policy framework on energy access and key development indicators-EcowAs intervention and the case of Ghana.pp. 332-342.

Akhmedov S, Ivanova T, Krepl V, Muntean A. 2017. Research on solid biofuels from cotton waste biomass – alternative for Tajikistan' s energy sector development. Agronomy Research **15**:1846–1855. Available from http://agronomy.emu.ee/wp-content/uploads/2017/08/Vol15nr5_Akhmedov.pdf#abstract-5633.

Akhmedov, S., Ivanova, T., Abdulloeva, S., Muntean, A., & Krepl, V. (2019). Contribution to the Energy Situation in Tajikistan by Using Residual Apricot Branches after Pruning as an Alternative Fuel. *Energies, 12*(16), 3169. doi: https://doi.org/10.3390/en12163169

Akowuah J. (2015). How to Put Biomass to Productive Use? The Energy Centre (TEC) KNUST. https://www.graphic.com.ghlnews/general-news/ghana-has-potential-to-produce-1I0-mgw-with biomass.html

Antony F., Estelle R. and Tereza S. (2013). The Importance of Coherent and Integrated Energy and Agriculture Policies in Meeting EU Climate Change Objectives. Retrieved from https://www.iai.itlsites/default/files/Tw.wp_25.pdf.

Anyane, S. La. 1963. Ghana Agriculture: Its economic development from early times to the middle of the twentieth century. Accra: Oxford University Press

Ayamga E., Kemausor F. and Addo A. (2015). Technical analysis of crop residue biomass energy in an agricultural region of Ghana. Journal of Resources Conservation and Recycling 98. pp. 51-60.

Baah-Boateng W. 2013. Determinants of Unemployment in Ghana. African Development Review**25**:385–399.

Baah-Boateng, W. (2012), 'Labour Market Discrimination in Ghana: A Gender Dimension', LAMBERT Academic Publishing, Germany

Balogun K. and Liu X. (2012). Biomass production for Energy in Developing (Undergraduate thesis, University of Giivle, Sweden). http://www.divaportal.org/smash/recordjsf?pid:diva2o/o3A538226&.dswid:7774

Bourdeix, R.; J.L. Konan; Y.P. N'Cho. 2005. Coconut: A Guide to Traditional and Improved Varieties. Editions Diversiflora, Montpellier, France

Bradley L. and Huang H. (2006). Converting Coconuts into Value-Added products.' Serving Christ by Serving the Poorest of the Poor.p1-9. Retrieved from https://www.asa3.org/ASA/education/views/coconuts.pdf.

Bradna J, Malatk J, Hajek D. 2016. The properties of wheat straw combustion and use of fly ash as a soil amendment. Agronomy Research **14**:1257–1265.

British Standard Institution. (2010). *BS EN 14588:2010. Solid biofuels - Terminology, definitions, and descriptions.* BSI Standards Publication.

Brunerová, A., Brožek, M., & Müller, M. (2017). Utilization of waste biomass from post–harvest lines in the form of briquettes for energy production. *Agronomy Research 15 (2),* 344-358.

Brunerova, A., Malatak, J., Muller, M., Valasek, P., Roubik, H. (2017). Tropical waste biomass potential for solid biofuels production. *Agronomy Research 15(2), 359-368*

Campbell, J., Lobell, D., Genova, R., & Field, C. (2008). The global potential of bioenergy on abandoned agriculture lands. *Environ Sci Technol 42,* 5791-5794.

Chan, Edward; Craig R. Elevitch. 2006. Cocos nucifera (coconut), Arecaceae (palm family). Permanent Agriculture Resources (PAR). Traditional Tree Initiative – Species Profiles for Pacific Island Argoforestry: 1-27

Cheng, J. (2018). *Biomass to Renewable Energy Processes.* North Carolina, United States: Taylor & Francis Group.

Cosereanu C, Lica D, Lunguleasa A. 2015. Investigation on the Quality of Briquettes Made from Rarely Used Wood Species, Agro-Wastes and Forest Biomass. Pro Lingo. **11**:32–39. Available from www.prolingo.ro.

COWAP. 2021.The coconut waste project, Baseline survey report.COWAP, Ghana. Available from https://coconutwasteproject.com/reports/ (Accessed March 2023).

Dasappa S. (2011). Energy for Sustainable Development. Potential of biomass energy for electricity generation in sub-Saharan Africa, (201 1). pp. 203-213.http://www.sciencedirect.com./sciencelarticle/piils0g730g26lrcoa524 on January 25, 2018.

DOE's Energy Efficiency and Renewable Energy, (EREC) C. 2001. Renewable Energy: An overview. Energy efficiency and renewable energy:1–8. Available from http://www.nrel.gov/docs/fy01osti/27955.pdf.

Donovan C. 2015. Introduction to Renewable Energy Finance. Pages 3–15 Renewable Energy Finance. Imperial College Press. Available from http://www.worldscientific.com/doi/abs/10.1142/9781783267774_0001.

Energy Commission of Ghana. (2016a). *National Energy Statistics (2006-2016).* Retrieved from Energy Commission of Ghana: http://energycom.gov.gh/files/National%20 Energy%20Statistics_2016.pdf

Energy Commission of Ghana. (2017). *National Energy Statistics (2007 - 2016).* Retrieved from http://energycom.gov.gh/files/E N E R G Y _ S T A T I S T I C S _ 2 0 1 7 . p d f

Erisman JW, van Grinsven H, Leip A, Mosier A, Bleeker A. 2010. Nitrogen and biofuels; an overview of the current state of knowledge. Nutrient Cycling in Agroecosystems **86**:211–223. Available from http://link.springer.com/10.1007/s10705-009-9285-4.

Fernández RG, G. C. (2012). Study of main combustion characteristics for biomass fuels used in boilers. *Fuel Processing Technology 103,* 16-26.

Food and Agriculture organization (FAO), 2015. FAO climate change and Bioenergy.https://www.fao.org/climatechange/65923/en/

Francis Nana Yaw Codjoe, Kofi Adade Debrah & Yaw Bonsu OseiAsare | (2021) Food vending safety concerns: Consumer perception on fresh coconut in New Juaben South Municipality of Ghana, Cogent Food & Agriculture, 7:1, 1914908, DOI: 10.1080/23311932.2021.1914908

Frater, Alexander. 2004. The Tree of Life. Geographical 11: 59-64

Ganiron J' (2013)' sustainable Management of waste coconut Shells as Aggregates in concrete Mixture' Journal of Engineering science and technology, Studies 6(5):7-14.

GEPA. 2017.GEPA: Sector Capabilities-Coconut from Ghana. Available from https://www.gepaghana.org/import/ghana-product/coconut-from-ghana/ (Accessed March 2023)

Ghana Innovation Marketplace (GIM), (2009). Waste Management conference and Exhibition-Great Hall, KNUST.

Ghana Investment promotion centre (GIpc), (2016). Management Team-Ghana Investment promotion centre (GIpc). Retrieved from http://gipcghana'com/press-and-media/77-investment-projects/agriculture-and-agribusiness/cash-crops/2g2-sector-overview.html.

Ghana Ministry of Food and Agriculture (A). 2011. Coconut – The Cynosure of Ghana's 2011 World Food Day Celebrations. http://mofa.gov.gh/site/?p=6430#. (Accessed March 2023)

Ghana Ministry of Food and Agriculture (B). 2011. Coconut farmers to have their livelihood restored. http://mofa.gov.gh/site/?p=6578. (March 2023)

Greening the Savannah Project (2012).
Retrieved from http://www.ecofibersghana.com/view-content/15/Projects-2.html on March 2023.

Gupta, R.K., Das, S.K. 2000. Fracture resistance of sunflower seed and kernel to compressive loading. Journal of Food Engineering, 46:1–8.

Hall, D., & Overend, R. (1987). *Biomass; Regenerable energy.* New York, United States. John Wiley and Sons.

Herak, D., Kabutey, A., Sedlacek, A., Gurdil, G. Mechanical behaviour of several layers of selected plant seeds under compression loading. Research in Engineering, 58(1):24–29.

Higuera DM.2019.Utilisation of peanut shells waste biomass for energy purposes [Master thesis]. Czech University of Life Sciences, Prague.

IBRD-IDA' (2017)' Results-based Financing for Municipal Solid waste. World Bank Document - Global partnership on output-Based Aid. Volume 2.2014, pp.1-2.

IEA Bioenergy. (2002). *Sustainable Production of Woody Biomass for Energy.* Whakarewarewa, New Zeland. Retrieved from https://www.ieabioenergy.com/wp-content/uploads /2013/10/25 PositionPaper-SustainableProductionofWoodyBiomassforEnergy.pdf

Intergovernmental Panel on Climate Change. (2012). *Renewable Energy Sources and Climate Change Mitigation.* Cambridge: Cambridge University Press. doi:10.1017/CBO9781139151153

International Renewable Energy Agency (IRENA). (2017). *Renewable Energy Statistics.*

ISO 14780:2017 Solid Biofuels — Sample Preparation. International Organization for Standardization, Geneva.

ISO 16948:2015 Solid Biofuels — Determination of Total Content of Carbon, Hydrogen and Nitrogen. International Organization for Standardization, Geneva.

ISO 16967:2015 Solid Biofuels -- Determination of Major Elements -- Al, Ca, Fe, Mg, P, K, Si, Na and Ti. International Organization for Standardization, Geneva.

ISO 16968:2015 Solid Biofuels — Determination of Minor Elements. International Organization for Standardization, Geneva.

ISO 18122:2015 Solid Biofuels — Determination of Ash Content. International Organization for Standardization, Geneva.

ISO 18123:2015 Solid Biofuels -- Determination of the Content of Volatile Matter. International Organization for Standardization, Geneva.

ISO 18125:2017 Solid Biofuels — Determination of Calorific Value. International Organization for Standardization, Geneva.

ISO 18134-2:2017 Solid Biofuels — Determination of Moisture Content — Oven Dry Method — Part 2: Total Moisture — Simplified Method. International Organization for Standardization, Geneva.

ISO 21404:2020. Solid biofuels — Determination of ash melting behaviour. International Organization for Standardization, Geneva.

ISSER. (2005). Guide to Elerctric Power in Ghana. Institute of Statistical, Social and Economic Research, Accra

Ivanova T, Mendoza Hernández AH, Bradna J, Cusimamani EF, Montoya JCG, Espinel DAA. 2018. Assessment of Guava (Psidium guajava L.) wood biomass for briquettes' production. Forests **9**:1–13.

Ivanova, T., Kolarikova, M., Havrland, B., & Passian , L. (2014). Mechanical durability of briquettes made of energy crops and wood residues. *Conference: Engineering for Rural Development*, 131-136.

Javier G. and Elena S. (2011). The Chemical Element: Chemistry's Contribution to Our Global Future. https://books.google.com.gh/books?isbn:3527635653.

Kalembkiewicz, J., & Chmielarz, U. (2011). Ashes from co-combustion of coal and biomass: New industrial wastes. *Resources, Conservation and Recycling 69,* 109-121.

Kamperidou V, Lykidis C, Barmpoutis P. 2017. Assessment of the thermal characteristics of pellets made of agricultural crop residues mixed with wood. BioResources 12:9263–9272.

Kiss I, and Alexa V. (2016). Biomass from wood processing Industries as an Economically Viable and Environmentally Friendly Solution https://www.researchgate.net/profile/valentin_vladut/publication/304996695_a_review_on_the_durability_of_biomass_pellets/links/577e57b00gaeaa6988b0c23d.pdf

Kuunibe N., Issahaku H. and Nkegbe p. (2013). Energy-Growth Nexus and Energy Demand in Ghana. Journal of Sustainable Development. Studies 3(2): l8l-198.

Last, F.T. 2001. Ecosystems of the world: Tree-crop ecosystems. Amsterdam: Elsevier Science.

LeBIanc R. (2017). An Introduction to solid waste Management. https://www.thebalancesmb.com/an-introduction-to-solid-waste-management-2878102

Lourinho G. (2015). Assessment of biomass energy potential agroforestry sourceshttps://www.cabdirect.org/cabdirect/abstract/20513146395

Lulian-Dan G. (2018). The Benefits of Using Wood Pellets. National Institute of Statistics. Retrieved from (http://woodypellets.eu/wood-pellets.html)

Lunguleasa A, Spirchez C. 2015. An Aggregated Property of Wheat Straw Briquettes. Wood Research **60**:845–856.

Luo F. and Hong Y. (2016). Renewable energy systems: advanced conversion technologies and applications https://www.taylorfrancis.com/books/978l439891100

M.J. Fernández, J.E. Carrasco. Comparing methods for predicting the sintering of biomass ash in combustion. Fuel, 84 (2005), pp. 1893-1900

Maj, G. (2018). Emission Factors and Energy Properties of Agro and Forest Biomass in Aspect of Sustainability of Energy Sector. *Energies (11)*, 1-12.

Mathrani, S., Santley, D., Hosier, R., Bertholet, F., Braud, A., Dawson-Amoah, G., . . . Reinoso, G. (2013). *Energizing Economic Growth in Ghana: Making the power and Petroleum Sectors Rise to the Challenge.* Retrieved from http://documents.worldbank.org/curated/en/ 485911468029951116/Energizing-economic-growth-in-Ghana-making-the-power-and- petroleum-sectors-rise-to-the-challenge.

McGowan, T. (2009). *Biomass and alternative fuel systems. An engineering and economic guide.* New Yersey, U.S.A.: American Institute of Chemical Engineers.

McKendry, P. (2002). Energy production from biomass (part 1): overview of biomass. *Bioresource Technology. Vol. 83*, 37–46.

Meerow, A. W. and Broschat, T. K., 1993. Transplanting Palms. University of Florida extension, Institute of Food and Agricultural Sciences. 1-7.

Melendez-Ramirez, V.; V. Parra-Tabla; P.G. Kevan; I. Ramirez-Morillo; H. Harries; M. Fernandez-Barrera, D. Zizumbo-Villareal. 2004. Mixed mating strategies and pollination by insects and wind in coconut palm (Cocos nucifera L. (Arecaceae)): importance in production and selection. Agricultural and Forest Entomology 6: 155-163

Meyer, C., (2001). Recycled Glass: Waste Material to Valuable Resource. *Construction Materials and Technology*. (1), p. 12-34.

Muzikant M, Havrland B. 2010. Properties of Heat Briquettes Produced from Vine Cane Waste–Case Study Republic of Moldova. Agricultura Tropica et ... **43**:277–284. Available from http://www.projects.its.czu.cz/ats/pdf_files/vol_43_4_pdf/muzikant.pdf.

Muzikant M, Havrland B. 2010. Properties of Heat Briquettes Produced from Vine Cane Waste–Case Study Republic of Moldova. Agricultura Tropica et ... **43**:277–284. Available from http://www.projects.its.czu.cz/ats/pdf_files/vol_43_4_pdf/muzikant.pdf.

Nonhebel, S. (2007). Energy from agricultural residues and consequences for land requirements for food production. *Agricultural Systems*, 587 - 592.

Nunes L, M. J. (2016). Biomass combustion systems: a review on the physical and chemical properties of the ashes. *Renewable and Sustainable Energy Reviews (53),* 235-242.

Nupur S. (2017). Coconut Hybrids: An Elixir of Life.

Obernberger, I., Brunner, T., & Barnthaler, G. (2006). Chemical properties of solid biofuels—significance and impact. *Biomass and Bioenergy 30*, 973–982.http://www.enhanceavillage.org/blog/coconut-hybrids-an-elixir-of-life

OEC.2020. Crude Petroleum in Ghana.OEC, Available from https://oec.world/en/profile/bilateral-product/crude-petroleum/reporter/gha (Accessed March 2023)

Ofori-Agyeman C. (2016). Assessment of coconut Waste Management: A Case Study Kumasi Metropolitan Assembly. (Unpublished undergraduate thesis), Kwame Nkrumah university of Science and Technology, Ghana.

Ofori-Nyarko (2000). Fuel use in Ghana: Social, Economic and Energy dimensions. http://www.fao.org/docrep/003/y3198e/y3198e05.html

Ogawa H (2005). Sustainable solid waste management in developing countries. Accessed from http://www.gdrc.org/uem/swm-fogawal.html on March 2023.

Ogawa, H. (2005). Sustainable Solid Waste Management in Developing Countries. Retrieved from http://www.gdrc.org/uem/waste/swm-fogawa1.html on March, 2023.

Okorley, E. L.; E. Haizel. 2004. Farmers' attitudes and problems associated with the adoption of Cape Saint Paul resistant coconut hybrid in the Western Region of Ghana. Agronomie Africaine 16 (1): 83-89

Otoo W. (2013). Evaluation of Households Solid Waste Generation and Disposal.

Platače, R., & Adamovičs, A. (2017). The evaluation of ash content in grass biomass used for energy production. *Energy Production and Management in the 21st Century, Vol. 2,* 1057 - 1065.

Prado, CHBA; EEM passos; JAPV de Moraes. 2001. Photosynthesis and water relations of six tall genotypes of Cocos nucifera in wet and dry seasons. South African Journal of Botony 67: 169-176

Puopiel F. (2010). Solid waste management in Ghana; the case of Tamale Metropolitan Area. http://ir.knust.edu.gh/bitstream/123456789/5598/Final%2Othesis.pdf

Quaicoe, Robert Nketsia; Sylvester Kuuna Dery; Rene Philippe; Luc Baudouin; Joseph Owusu Nipah; Joe Nkansah- Poku; Ransford Arther; Daniel Dare; Egya Ndede Yankey;

Fabian Pilet; Michel Dollet. 2009. Resistance screening trial on coconut varieties to Cape Saint Paul Wilt Disease in Ghana. Agronomie-Environnement, 16: 132-136

Rachel, Assa Rebecca; Konan Konan Jean-Louis; Prades Alexia; Nemlin Jean; Koffi Ernest. 2010. Physicochemical characteristics of kernel durring fruit maturation of four coconut cultivars (Cocos nucifera L.)

Renee C. (2011). Energy use and Renewable Energy Sources. http://www.nj.gov/dep/dsr/trends/pdfs/energy.pdf

Renee C. (2016). Is Biomass Really Renewable? blogs.ei.columbia.edu/20ll/08/18/is-biomass-renewable/

Renewable Energy policy Network for the 2lst century (REN21), (2016). Mexico, https://gh.linkedin.com /company/renewabe-energy-policy-network-for-the-21st-century-ren2l

Rinkesh (2009). https://www.conserve-energy-future.com/biomassenergy.php.what is Biomass Energy and How Does Biomass Energy work.

Rosillo-Calle, F., Groot, P., Hemstock, S., & Woods, J. (2015). *The biomass assessment handbook: Energy for a sustainable environment.* New York, U.S.A.: Routledge.

Ross Caulum Professional Paper B, Wagner MR, Allen JA, Hoftetter RW. 2012. Coconut Palm on the Coastline of Western and Central regions of Ghana.

Spilacek, M., Lisy, M., Balas, M., & Skala, Z. (2014). The Comparison of Wood Chips and Cocoa Shells Combustion. *Advances in Environmental Sciences, Development and Chemistry*, 217 - 220.

Spinelli R, Nati C, Pari L, Mescalchin E, Magagnotti N. 2012. Production and quality of biomass fuels from mechanized collection and processing of vineyard pruning residues.Applied Energy **89**:374–379. Elsevier Ltd. Available from http://dx.doi.org/10.1016/j.apenergy.2011.07.049.

STATISTA. 2023.STATISTA. Personal remittances received in Ghana from 2010-2022.STATISTA, Available from https://www.statista.com/statistics/1267851/personal-remittances-received-in-ghana-as-a-share-of-gdp/#:~:text=In%202022%2C%20personal%20remittances%20received,percent%20of%20the%20country's%20GDP. (Accessed March 2023)

Stolarski, M. (2008). Content of Carbon, Hydrogen and Sulphur in Biomass of Some. *Biomass, Vol. 13(4)*, 655–663.

Tamelová, B.; Malat'ák, J.; Velebil, J. Energy Valorisation of Citrus Peel Waste by Torrefaction Treatment. *Agron. Res.* **2018**, *16*, 276–285.

The Global Economy. 2023. Ghana Economy. TGE, Available from https://www.theglobaleconomy.com/Ghana/agricultural_land/ (Accessed March 2023).

USAID. 2020.Economic Growth and Trade. USAID, Washington DC. Available from https://www.usaid.gov/ghana/economic-growth-and-trade (Accessed March 2023).

Valantinavicius, M., & Vonžodas, T. (2012). Proximate and elemental analysis of solid biofuel and influence to the combustion process. *Conference CYSENI.* Kaunas, Lithuania.

Vassilev S., V. C.-C.-Y. (2017). Ash contents and ash-forming elements of biomass and their significance for solid biofuel combustion. *Fuel (208)*, 377-409.

Vassilev, S., Andersen, L., Baxter, D., & Vassileva, C. (2013). An overview of the composition and application of biomass ash. Part 1. Phase–mineral and chemical composition and classification. *Fuel 105*, 40-76

VRA. (2015). *Power Generation: Facts and Figures*. Retrieved March 2023, from Volta River Authority: http://vraghana.com/resources/facts.php.

Water Resources Commission. 2023.River Systems.WRC, Available from https://www.wrc-gh.org/water-resources-management-and-governance/river-systems/ (Accessed March 2023)

Wills, J. B. (1962). Agriculture and land use in Ghana. Oxford University Press

World Population Review. 2023.Ghana Population 2023.Available from https://worldpopulationreview.com/countries/ghana-population (accessed March 2023)

Appendices

List of the Appendices:

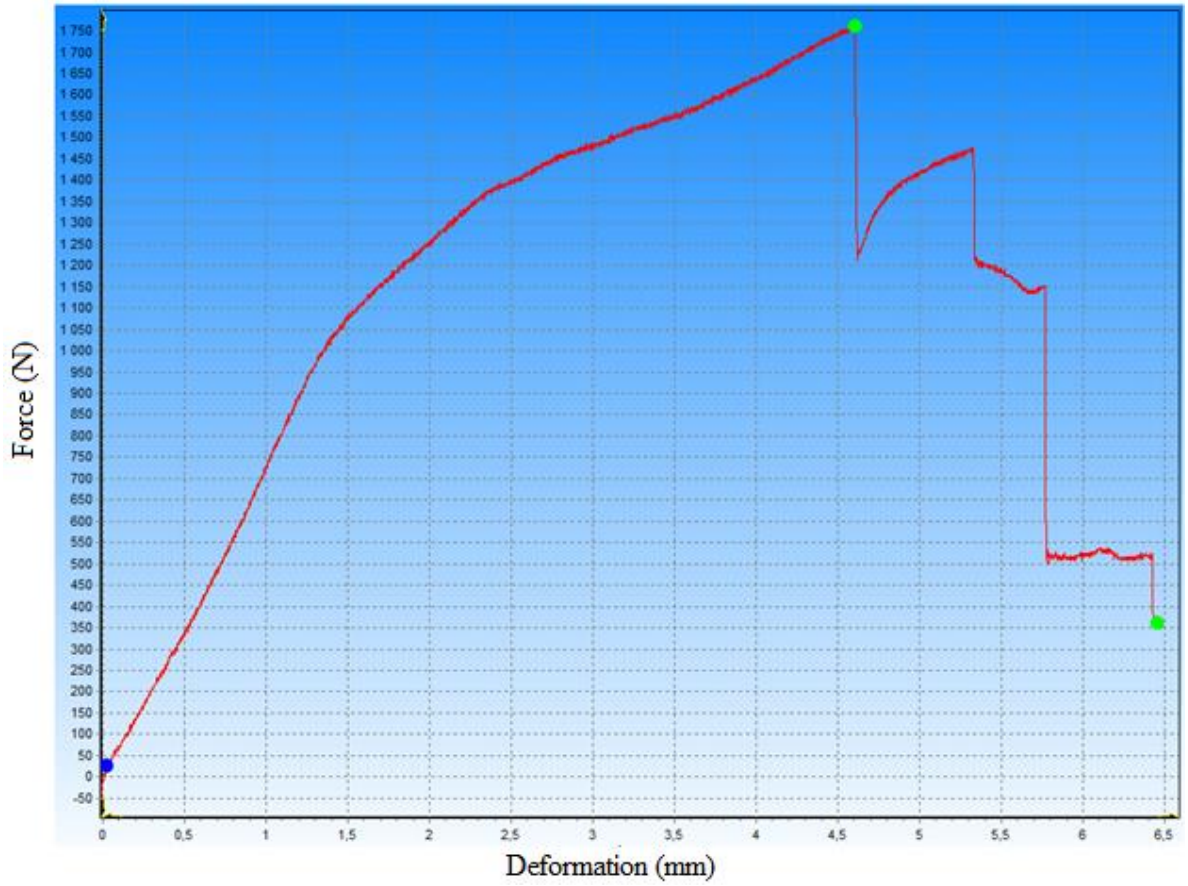
Appendix 1: Calculations of moisture contents of biochar samples

Sample/Temp. (℃)	Mass of Empty dish + lid (g)	Mass of dish+lid+sample before drying (g)	Mass of dish+lid+sample after drying (g)	Moisture content (%)	Average moisture (%)
250	26.0871	27.832	27.8141	1.025846753	**1.093949373**
	26.1626	27.3516	27.3384	1.110176619	
	25.5064	26.7195	26.7056	1.145824747	
300	25.6444	28.0641	28.0318	1.334876224	**1.571860889**
	25.1987	26.3156	26.2971	1.656370311	
	25.4287	26.2986	26.2836	1.724336131	
450	25.0853	26.4697	26.4287	2.9615718	**3.107235957**
	25.5824	26.6257	26.5908	3.345154797	
	26.27	27.872	27.8237	3.014981273	
350	26.2422	27.4522	27.4347	1.446280992	**1.415189915**
	27.3111	28.4838	28.4679	1.355845485	
	25.8063	26.9494	26.9329	1.443443268	
550	33.0617	34.7199	34.6829	2.231335183	**2.221997764**
	25.9621	27.6543	27.6179	2.151045976	
	27.7446	29.1853	29.1524	2.283612133	

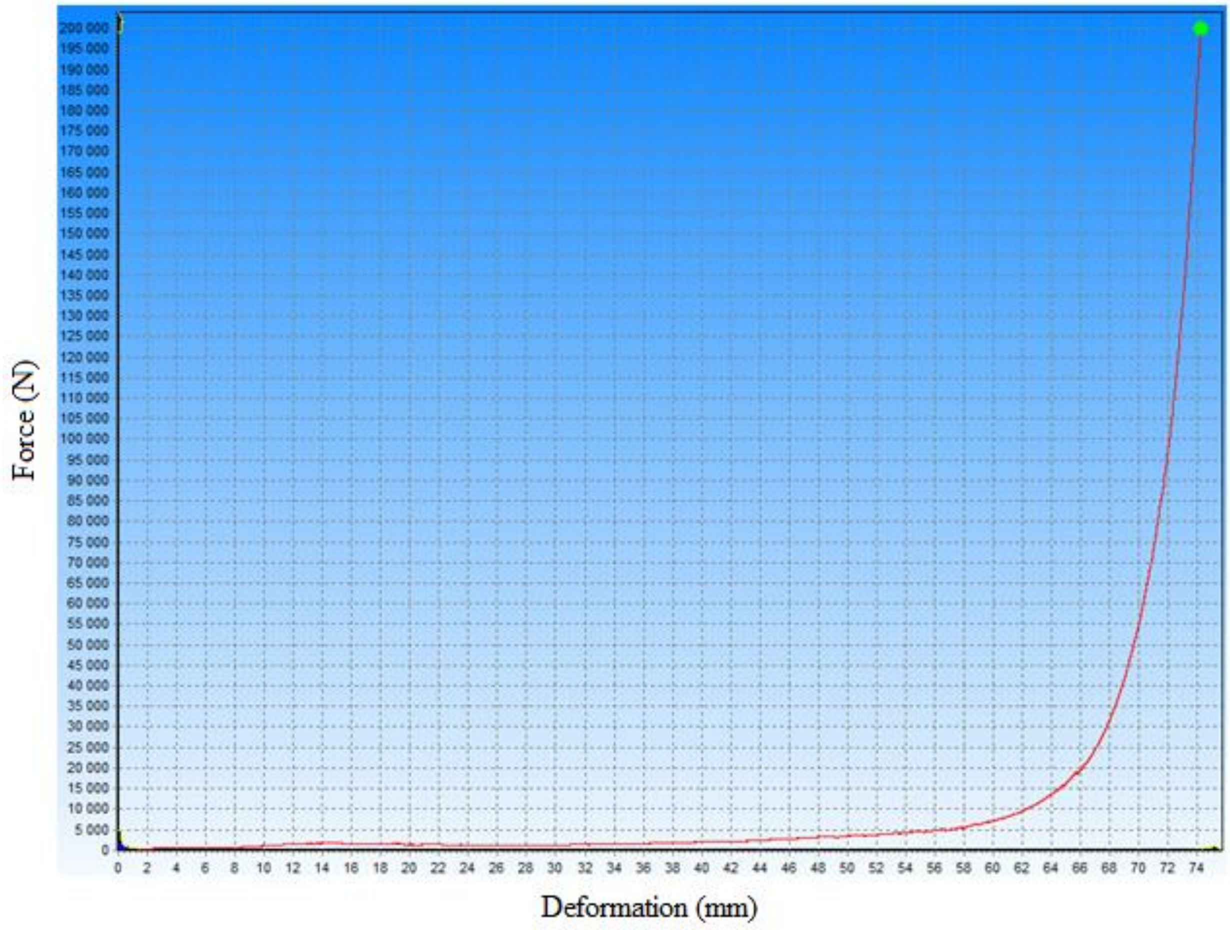
Appendix 2: Calculations of Ash contents of biochars samples

Sample/Temp. (°C)	Mass of crucible (g)	Mass of crucible+sample (g)	Mass of ash+crucible (g)	Moisture content (%)	Ash content (%)	Average Ash content (%)
250	21.6237	22.7464	21.6969	0	6.52	6.12
	20.7111	21.7292	20.7694	0	5.73	
300	22.7114	23.7423	22.7979	0	8.39	8.39
	22.9588	24.003	23.0463	0	8.38	
350	26.084	27.1341	26.1899	0	10.08	10.06
	17.1097	17.9054	17.1896	0	10.04	
450	21.6777	22.7227	21.8028	0	11.97	11.93
	17.7071	18.3485	17.7833	0	11.88	
550	18.4761	19.5471	18.6183	0	13.28	13.24
	18.0705	19.1161	18.2086	0	13.21	
CH	18.4886	19.5839	18.4969	7.152025896	0.82	0.83
	20.3539	21.4008	20.3621	7.192575406	0.84	

Appendix 3: Experimental force deformation curve of coconut husk sample at y orientation.



Appendix 4: Experimental force deformation curve of coconut husk sample at x orientation



Appendix 5: Calculations of Gross Calorific values of biochars samples

Sample/Temp.	Repetition	Mass of an ignition wire (g)	Mass of a combustion bag (g)	Mass of a biofuel sample (g)	Corrected temperature rise	GCV (J/g)	GCV (MJ/kg)	Result GCV (MJ/kg)
								Average GCV
250 (Dried)	1	0.0085	0.0625	0.1768	0.53913	21703.09	21.70	**21.73**
	2	0.0086	0.0612	0.1761	0.53518	21702.03	21.70	
	3	~~0.0091~~	~~0.0458~~	~~0.1615~~	~~0.46398~~	~~21186.23~~	~~21.19~~	
	4	0.0083	0.0606	0.1532	0.48061	21780.44	21.78	
300 (Dried)	1	0.0084	0.0618	0.1526	0.5441	25519.81	25.52	**25.44**
	2	0.0084	0.0606	0.1267	0.46769	25403.35	25.40	
	3	0.0083	0.0437	0.1759	0.57491	25411.68	25.41	
450 (Dried)	1	0.0082	0.0626	0.1479	0.57569	28194.31	28.19	**28.22**
	2	~~0.0082~~	~~0.0621~~	~~0.147~~	~~0.56824~~	~~27961.16~~	~~27.96~~	
	3	0.0088	0.0626	0.1866	0.69792	28287.83	28.29	
	4	0.0087	0.0629	0.1761	0.66346	28169.64	28.17	
	5	~~0.0083~~	~~0.0455~~	~~0.1884~~	~~0.65166~~	~~27276.86~~	~~27.28~~	
350 (Dried)	1	0.0083	0.0441	0.1671	0.56373	26102.19	26.10	**26.15**
	2	~~0.0083~~	~~0.0437~~	~~0.1313~~	~~0.4702~~	~~26787.19~~	~~26.79~~	
	3	~~0.008~~	~~0.0433~~	~~0.144~~	~~0.51045~~	~~27004.~~	~~27.00~~	

		5				89		
	4	0.0084	0.0458	0.1312	0.46539	26208.88	26.21	
	5	0.0091	0.0451	0.1478	0.51148	26151.38	26.15	
550 (Dried)	1	0.0084	0.0427	0.1493	0.56125	29211.66	29.21	**29.14**
	2	0.0085	0.0431	0.1469	0.55279	29116.48	29.12	
	3	0.0083	0.0443	0.1344	0.5146	29102.57	29.10	