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Briquette Fuel Development in Sub-Saharan Africa (SSA): Evidence from Nigeria's Domestic Energy Sector

Joshua Ayodeji Gidigbi[a], Zaharaddeen Sani[a], Aminu Bayawa Muhammad[a], Abdulrasaq Banaru Abubakar[b], Jude Edogbo Eneche[c]

[a]Department of Energy and Applied Chemistry, Usmanu Danfodiyo University, Sokoto, Nigeria
[b]Department of Science Laboratory Technology, Federal College of Horticulture Dadinkowa Gombe
[c]Department of Science Laboratory Technology, Federal Polytechnic, Ohodo Enugu.
Corresponding Author: gidigbijoshua@gmail.com

Abstract: Energy is crucial to the development of any nation and serves as a key indicator of a country's economic strength. Briquettes, a renewable energy source derived from biomass, offer a promising alternative to traditional wood fuel. With good heating value and substantial heating time, briquettes are both eco-friendly and sustainable. They are primarily produced from agricultural residues, and are a viable heating energy option in Sub-Saharan Africa, particularly in Nigeria, an agriculturally rich nation. Nigeria generates a large volume of crop residues such as groundnut shells and straw, rice husks and straw, maize stalks, cobs and husks, as well as cassava peels and stalks. These materials present significant potential for briquette production. However, despite the abundance of these feedstock, briquette production and adoption remain limited in Nigeria. Efforts toward commercialization have largely failed. This underscores the need for an in-depth investigation into the underlying challenges hindering the development of briquette technology in the country. This study reviews the current status, challenges, implications, and strategic approaches necessary for the advancement of briquette technology in Nigeria, drawing comparisons with more successful models in other African countries such as Uganda and Kenya.

Keywords: Briquettes, Woodfuel, Biomass, Agricultural residue, Carbon capture, Eco-friendly

1. Introduction

According Mahoro et al (2022), the growing demand for low-cost and alternative energy for household activities such as cooking, and heating processes is on the increase. This demand is further fueled by the epileptic nature and hike in electricity fee; and high cost of liquified gas in the country. Hamzat et al (2019) report that many households in Nigeria rely on energy to meet their domestic needs and activities. This includes cooking of food for the household and processing of domestic products in order to meet their daily obligations. Unfortunately, the nation's energy sector has been unable to meet the increasing energy demands of the country, largely due to rapid population growth and other factors arising from policy irregularities (Gidigbi, 2023). Moreover, Gidigbi and Abubakar (2023) and Onimisi et al (2021) argue that the unsustainability of fossil fuel has led to inconsistent supply, resulting in huge energy demand for domestic purposes. These demands are felt more acutely in rural communities with limited or no access to fossil fuels and electricity supply, leaving them with wood fuel as the only available alternative to address the shortage.

Moreover, the high cost of non-renewable energy and low access to the fossil fuel, especially in semi-urban and rural communities, has forced majority of low-income

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earners and rural dwellers to rely on wood-fuel, especially charcoal, for domestic chores, including cooking, ironing; and other business engagements, such as blacksmith that require heat energy (Kpalo and Zainuddin, 2020; Obi, et al 2014). According to Aliyu, et al. (2021), wood fuel accounts for more than 37% of total energy usage in Nigeria. The modernised charcoal stoves, kilns and ovens are gradually gaining acceptance even in some major cities such as Lagos, Port Harcourt and Abuja, as alternative sources of cooking system. Major reasons for the wide patronage include: easy accessibility, affordability and quality heat energy supply. According to Ali et al. (2019), the larger patronage of wood fuel has been linked with deforestation, as wood reserves are constantly suffering from premature cutting. This has a severe impact on the quality of air available in the environment as the world gears towards zero-carbon society.

According to the Conscious (2018), the continuous cutting of trees for other uses, including wood fuel, has been linked to severe drought. Also, Africa Union Development Agency (AUPED, 2022) claims that burning of wood fuel has been associated with lungs diseases as an emission of carbon monoxide (CO) usually accompanies burning wood fuel, thereby, causing damage to both health and the environment. The Weinhold (2011) corroborates that exposure to harmful pollutants such as Carbon monoxide and Nitrogen dioxide could lead to elevated blood pressure, which results into increased risk of cardiovascular diseases, such as stroke and renal failure. Also, Barnes (2014) argues that exposure to harmful gasses is mostly responsible for cases of pneumonia amongst children of less than five years of age and in many severe cases could lead to premature deaths. Globally, deaths from indoor air pollution, including wood fuel burning, are estimated to be about 3.8 million annually (Ritchie and Roser (2019). Also, Africa Union Development Agency (AUPED, 2022) attributes the lung diseases, such as lung cancer, to burning of wood processes in which harmful gasses are being emitted into the lungs, which cause damage to the lung. In 2002, the World Health Organisation (WHO, 2007) argued that polluted air was associated with 79,000 deaths recorded in the year, a number which has since been penned between 106,900 to 605,100 annual deaths (Balmes, 2019). Unfortunately, most of the victims of polluted air are those who cannot afford quality healthcare services, thereby contributing to the national diseases burden. Therefore, to minimize the health and environmental challenges arising from utilization of wood fuel for domestic cooking and heating process, it is imperative to devise alternative means of generating fuel energy that is affordable and ecofriendly for domestic and small medium enterprise purposes.

2. Briquette

The briquette (see plate 5), which is also known as a green charcoal, has come up as an alternative fuel for domestic cooking and heating process. According to International Water Management Institute (IWNI, 2017), briquette is a carbon neutral cooking fuel made from renewable biomass wastes such as sugarcane waste, coffee husks, and rice husks, which can be sold as a fuel for cooking and heating. It is a renewable organic resource that contains energy in form of chemical that can be transformed to fuel energy (USAID, 2010).

Briquette fuel has the competitive advantage over wood fuel as it reduces health challenges associated with wood fuel due to inhaling of carbon monoxide and are also beneficial to the environment as they reduce greenhouse effect. The World Health Organisation (2020) reveals that almost 52% of the global population still relies on wood fuel, coal, and solid biomass as means of energy for domestic purposes such as heating and cooking process, and the largest proportion is in Africa and Asia. For instance, United States Agency for International Development (USAID, 2010) reports that apart from Bangladesh and Thailand, the use of biomass briquettes as domestic cooking fuel in Asia is due to cheap wood fuel, which makes larger population depends on wood fuel for their domestic cooking and heating process.

In Malawi, Food and Agricultural Organisation (FAO, 2020) records that the average annual wood fuel removal from forests ranged from 4.8 to 5.7 million m^3 (under bark) from 1991 to 2011, and since 1996, it has been continuously increasing, reaching 5.7 million m^3 in 2011; while the forest area in the nation from 1990 to 2015 decreased from 3.9 million to 3.1 million hectares, with an annual rate of change of -0.9 percent and an overall reduction in this period of 0.8 million hectares. In Darfur, Sudan (USAID, 2010) claims that over two million rural inhabitants heavily rely on fuel wood due to its low cost, and this is responsible for rapid depletion of the country's forest reserve. Moreover, in Ghana, 60% of the population depends on the wood fuel to meet their domestic energy need (Chaney, 2010).

The Global Village Energy Partnership International (GVEP, 2013) accounts that approximately 82% of the Kenya's population relies on wood fuel for their cooking and heating. Similarly, in 2011, Nigeria was ranked among the countries that produce wood fuel in the world, meaning that majority of the rural dwellers still depend on the wood fuel to meet their daily domestic energy need in the country (Ichu et al, 2020). This attests to the fact of high rates of deforestation, desertification, and lack of sustainable forest management that is facing the country. Given the detrimental effects of these negative trends on the environment and climate, briquette fuel emerges as a viable and sustainable alternative source of energy

The implication of this data is that the climate would experience significant relief if an eco-friendly source of fuel energy, such as briquette, is adopted. This is further buttressed by Ben-Iwo et al (2016) and Ibrahim et al (2020) that briquette can be a means of waste management for the agricultural waste/biomass, which will reduce dependence on wood fuel and limit the extent of deforestation and desertification, thereby resulting in lower or negligible emissions of harmful greenhouse gases from the incomplete and toxic combustion of natural plant resources. International Energy Agency (IEA, 2006) posits that the high calorific value of briquette makes it a better source of energy fuel, as it tends to undergo complete combustion in the presence of enough oxygen. Sachez et al (2022) also corroborates that briquette has lower ash content than coal, which limits the emission of harmful substance to the environment. Therefore, bio-mass briquettes can be considered as an alternative energy fuel. Briquette formulation in Nigeria offers numerous advantages such as: the availability of diverse raw materials, indigenous production technology, accessible transportation systems, and a large, readily available market.

2.1 Briquetting Technology

The need to address the drawbacks associated with the direct use of biomass as fuel has necessitated research into techniques for converting biomass into a more efficient and eco-friendly source of energy (Thliza et al, 2020). According to Ali et al (2021), the direct use of biomass either as a cooking or heating energy resource constitutes some difficulties due to its high moisture presence, low energy value, heterogeneity, and low density. Hence, a need for pre-treatment before production. Previous studies highlighted different forms of pre-treatment available for biomass before briquette formulation. For instance, Bach et al. (2017) upholds that torrefaction pre-treatment (see figure 1) involves thermal degradation of biomass in an inert environment at 200-300^{o}C for a specified time, depending on the nature of biomass.

Torrefaction improves the properties of biomass which make it possible for direct usage. Sankaran et al (2018) believes that torresfaction process dehydrates and decomposes protein and carbohydrates to a desired concentration, depending on the reaction time and nature of the biomass. Hemicellulose decomposes from 200°C; cellulose degrades at 27 ^{o}C; while lignin decomposes in-between 250-500^{o}C (Blasi, 2009). Torrefaction process reduces biomass moisture; but it increases density, heating value, and ignitability (Adeleke et al., 2021). Also, Basu (2013) reports that carbonization process (see plate 1) is similar to torrefaction process, but it is done at high temperature (500^{o}C – 900^{o}C) under inert environment by slow heating of biomass to the high temperature. The slow heating allows sufficient yield of solid fuel, while higher heating rate results in higher liquid products (Basu et al, 2013b). Carbonisation does not retain maximum quantity of energy of the biomass and thereby leading to low energy product. Furthermore, pyrolysis process involves heating the biomass at high heating rate with the aim of increasing hydrocarbon while decreasing the biochar (Basu et al 2013b). Pyrolysis is specifically carried out for production of liquid extracts from the biomass. Carbonization, on the other hand, is to maximize fixed carbon and minimize hydrocarbon content of the solid product, while that of torrefaction is to maximize energy and mass yields with reduction in oxygen to carbon (O/C) and hydrogen to carbon (H/C) ratios. Adeleke et al (2019) also report the blend of coal with treated biomass to give an improved briquettes fuel. The effect of heat on the biomass and the corresponding thermochemical is reported in the table 1.

The principle behind briquette production involves densification of treated/untreated biomass feedstock to produce a solid material called briquette (see plate 1). According to Ibrahim et al (2020), briquette technology involves the compressed blocks of agricultural and forestry residues. This can be achieved with binder and without binder. According to Ichu (2020), the binder usually employed in briquette formation includes starch derived from cassava flour, rice flour, and sweet potato, starch derived from molasses, and Arabic gum from the bark of a tree. The essence of a binder is to improve the stability of the briquette.

The Food and Agricultural Organisation (FAO, 2020) emphasizes the need to use binder when the briquette formation is done using manually operated machine (see plate 3), as there is limit to the degree of densification that can be performed by this machine. The choice of binder is also important as it may affect the compact and quality of the briquette, such as stability and smokeless. Bhattacharya and Kumar (2005) assert that mechanized production of briquette is absolutely powered by electricity, so densification/compression pressures will be higher, which means the briquette formed from this method may not require the application of binder as the high pressure leads to more densified product, thereby improving stability and quality of the briquette.

Table 1: Thermochemical process of feedstock at different temperatures

Temperature Range of Heating (^0C)	Process that Occurs	Heating Rate	Process	Solid Product
20-110	The wood is preheated and it approaches 100^0C, moisture starts evaporating	Low/fast	Drying	Bone dry wood
110-200	Further preheating removes traces of moisture and slight decomposition starts	Low/fast	Preheating Postdrying	Preheated dry wood
200-270	Wood decomposes releasing volatile (e.g., acetic acid, methanol, CO, and CO2) that escape	Low	Torrefaction	Mildly torrefied wood
270-300	Exothermic decomposition starts releasing condensable and non-condensable vapours	Low	Torrefaction	Severely torrefied wood
300-400	Wood structure continues to break down. Tar release starts to predominate	Low	Low temperature carbonization	Low fixed carbon charcoal
		High	Pyrolysis	Liquid
400-500	Residual tar from charcoal is released	Low	Carbonization	High fixed carbon charcoal
		High	Pyrolysis	Liquid
>500	Carbonization is complete		High temperature carbonization	Tar-free charcoal
			Pyrolysis	Liquid, higher gas yield

Source: (Basu, 2013)

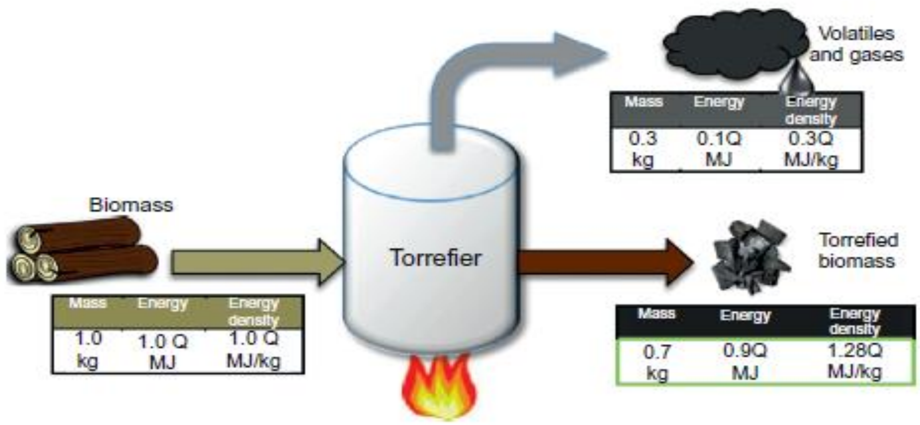
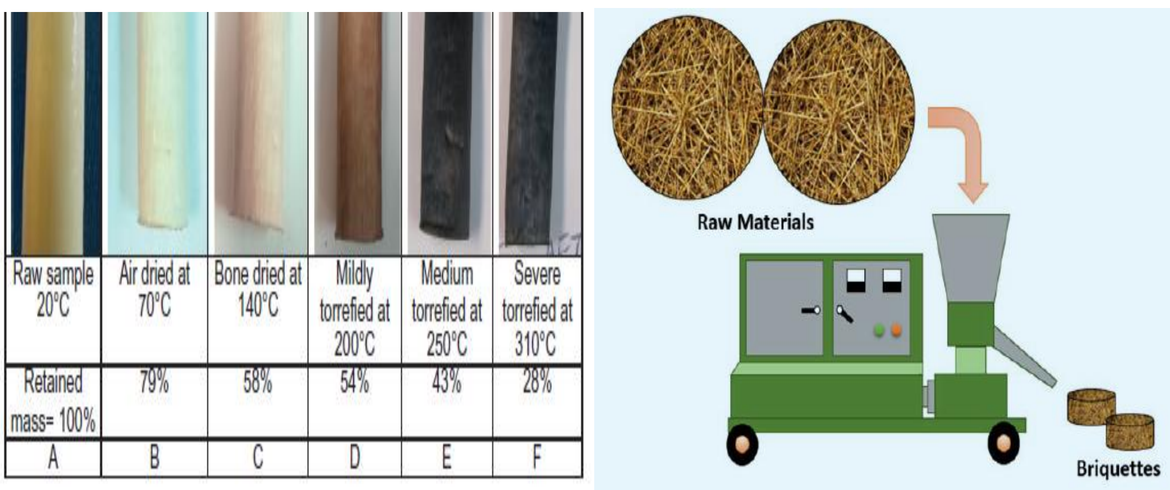


Figure 1: Mass and energy changes of a feed undergoing torrefaction (Basu, 2013).



A B

Figure 2: Progress of Torrefaction of the Branch of Maple Tree (A) and Densification of Biomass to Produce Briquette (B) (FAO, 2020)

According to Mahoro et al (2022), there are two major basic high-pressure technologies. These methods are the ram/piston press machine, which is fabricated by the Europe and the United States; and screw extrusion machine, which is solely designed and produced by Japan (see plate 4). While piston press briquettes are completely solid, screw press briquettes have a concentric hole that increases the surface area of the briquette and so facilitates burning. Most indigenous briquette process technologies in Africa are modelled after plain screw extruders due to their ease of fabrication; they are easy to operate, and their spare parts are readily available.

The Ugandan Poverty Status Report (UPSR, 2005) affirms that briquettes made by screw press are consistent in size, with a high resistance to disintegration; they burn faster and may be utilised in the numerous applications such as coal in a boiler. This is due to their ability to exert high pressure during briquette formation as this impacts the quality of briquette produced (Faxälv and Nyström, 2009). The finished briquette tends to have low ash content, high thermal value, and uniform and low rate of combustion. Also, Low moisture content and high density of briquettes give it better boiler efficiency. Furthermore, Huang et al (2017) opine that biomass briquette can be reused as a compost, as against one time use of coal and oil. Also, Rezania et al (2015) substantiate that briquettes burn with minimal smoke and a steady flame with no odour. This is plausible as a result of no sulphur, low ash content, which makes it an eco-friendly fuel and can replace fossil fuel and wood fuel especially for domestic cooking and heating process. The Pressure-based Briquette Technology is also a major route of briquette production. The technological process involved is fully explained in Table 2

Figure 3: A-Briquettes of various shapes and sizes (Ichu et al.,2020), and B- Ceramic Stove for briquette (Faxälv & Nyström, 2009)

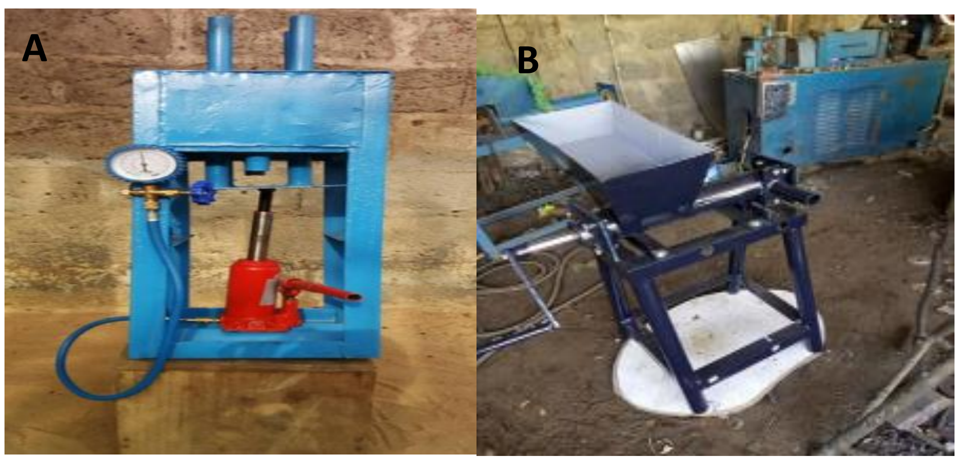


Figure 4: A-Manually fabricated hand press (Aliyu et al., 2021) and B- Mechanical co-centric screw press (CTCT, 2020)

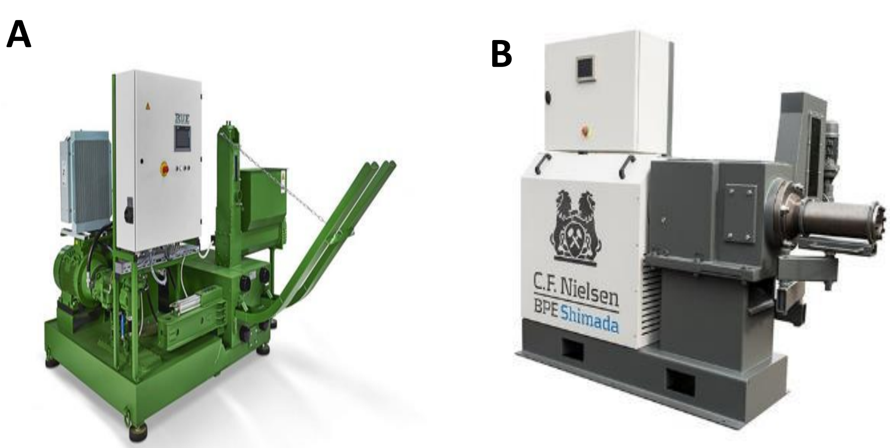


Figure 5: Hydraulic Piston press (A) and Extruder Piston Press (B)

Figure 6: Domestic briquette (A) and Industrial Briquette (B)

2.2 Raw Materials

According to Faxälv and Nyström (2009), the choice of raw materials for briquette production largely depends on their bonding capacity during densification. Biomass with high fibre content has been found suitable due to its ability to form strong bonds following hydrotreatment. Akpenpuun et al (2020) claim that processed materials such as waste paper can be used with other biomass such as charcoal fines and saw dust. The briquette physicochemical properties can be improved vial blending with other materials availability and closeness to markets (CTCT, 2020). According to Food and Agricultural Organization (FAO, 2014), the common biomass used for the production of briquettes are briefly listed at Table 3 while Tables 4 and 5 list the briquette raw materials available in Nigeria.

Table 2: Pressure-based Briquette Technology

Densification technologies	**Advantages**	**Disadvantages**
Low pressure technologies	i. Low start up-cost ii. Minimum technical skills required for operations iii. The producer can easily take care of the breakdowns	i. Low volume production ii. Variable quality iii. Requires high manpower
Medium pressure technologies (e.g. screw extruders, agglomerator, roller drums, and hydraulic presses)	i. Technology is locally available ii. Spare parts can be sourced locally iii. Higher production volumes compared to low pressure technologies iv. Higher quality compared to the low-pressure technologies v. Minimum labour is required	i. Local machines are of poor quality and are therefore prone to breakdowns ii. Require electricity to run iii. Compared to low pressure technologies the cost is higher
High pressure technologies (heated-die screw, ram/piston, and hydraulic presses)	i. High production volumes ii. Less labour is required as most work is automated	i. High initial cost ii. Requires skilled manpower, iii. Spare parts may not be locally available, iv. High electricity costs and maintenance cost compared to medium and low-cost technologies

Source: (CTCT, 2020 ; Atluri, Pramod Kumar, K., & K., 2017)

Table 3: Common materials used for briquette and their sources

Source	**Raw materials that can be used**
Agricultural wastes	Cassava stalk, coconut frond, cotton stalks, corn stalks, straw, millet, oat straw, frond palm oil, rice straw, rye straw, sorghum straw, soybean straw, sugar reed leaves, wheat straw
Industrial processing residues from agriculture	Cocoa beans, coconut shells, coffee husks, cotton seed hulls, peanut shells, cobs and wrap corns, oil palm stalks, waste from olive pressing, rice ball, sugar cane bagasse
Forestry development	Leaves, branches and twisted trunks.
Bioenergy crops	Acacia spp, Cunninghamialanceolata, Eucalyptus spp, Pinus spp., Populus spp., Platanus spp., Robiniapseudoacacia y Salix spp

Table 4: Biomass availability in Nigeria (ECN, 2013)

Types	Sources	Quantity
Biomass (non-fossil organic matter)	Municipal waste	18.5 million tonnes produced in 2005 and now estimated at 0.5kg/capita/day
	Fuel wood	43.4 million tonnes/yr. fuel wood consumption.
	Animal waste	245 million assorted animals in 2001.
	Agricultural residues	91.4 million tonnes/yr. produced.
	Energy crops	28.2 million hectares of arable land; 8.5% cultivated.

3. Challenges Associated with Briquette Technology in Nigeria

According to Food and Agricultural Organization of United Nations (FAO, 2016), Nigeria practices much agricultural activities with 71,000,000ha out of the 91,077,000ha available land areas being utilised for the purpose of agricultural activities. This generates much agricultural waste, which can be converted to biomass. Unfortunately, despite this huge availability of biomass, briquetting in Nigeria has remained underdeveloped, even with the appropriate funding and conducive environment (Ichu et al., 2020). A lot of people in suburban and rural areas have little access to briquettes, which may affect its affordability. A locally made briquetting machine has been made in order to encourage the indigenous technological process, but the production has not been commercialised. This section explores barriers to commercialising briquette technology in Nigeria. Some of the barriers discussed here are sourced from literatures; and interactions with scholars, charcoal retailers and charcoal end users. The barriers are discussed below:

i. Poor planning

Planning for briquetting requires inclusive evaluation of all factors of production involved in converting the residue to final product till it gets to end users. This involves sustainability; continuous supply of raw materials and feasibility studies to predict the market demand-supply system. Unfortunately, there are no in-depth studies on the part of organizations with assumption of free supply of feedstock. Other factors such as transportation, technicality around machine operations, and economic considerations should be adequately considered.

Table 5: Crop residue available in Nigeria (Ichu et al., 2020)

Crop	Production('000)	Component	Weight available in million tons	Total energy available (PJ)
Groundnut	3,799.25	Shells	1.81	28.35
		Straw	4.37	76.83
Rice	3,368.24	Straw	7.86	125.92
		Husk	1.19	23.00
Maize	7,676.85	Stalk	10.75	211.35
		Cob	2.10	34.19
		Husk	0.92	14.32
Cassava	42,533.17	Stalks	17.01	297.68
		Peelings	76.56	812.30
Soybean	365.06	Straw	0.91	11.27
		Pods	0.37	4.58
Sugar cane	481.51	Bagasse	0.11	1.99
		Tops/Leaves	0.14	2.21
Cotton	602.44	Stalk	2.25	41.87
Millet	5,170.45	Straw	7.24	89.63
Sorghum	7,140.96	Straw	7.14	88.39
Cowpea	3,368.24	Shell	4.89	95.06
Total			**145.62**	**1,958.94**

ii. Alternative uses of Agricultural Residue

According to USAID (USAID, 2010), alternative uses of agricultural residue has remained a major setback to successful briquetting in Africa. The alternative usage includes using agricultural residue such as sorghum; maize as a perimeter to wither house or farm near the resident areas. Also, residue with fibre content are usually used to reinforce the mud block for either building or perimeter fence. This has severe impact on the quantity of feedstock available for briquetting and the continuous supply of such feedstock.

iii. The low cost of wood fuel in Nigeria

The low cost of wood fuel such as firewood and charcoal in Nigeria has led to poor acceptance of briquette fuel among the populace. This problem is similar to cases in Darfur, Sudan. The low cost of wood fuel sabotages the effort for establishing briquette as an alternative fuel (USAID, 2010). While in Malawi, the price of briquette can compete with the price of charcoal, making briquette partially patronised in the country (Faxälv and Nyström, 2009). Also, Uganda is doing well with briquetting technology.

iv. Lack of Funding

Private investors remain the major reason behind the booming of briquetting in Uganda. The investors partner with local farmers in terms of funding to make feedstock abundantly available for briquetting. However, lack of funding, resulting from the disinterest of private investors in briquetting, has significantly hindered its production in Nigeria. Most of the briquettes produced are left on the shelf in the laboratory with no hope of commercializing the technology.

v. Poor Marketing

Wood fuel has been a major means of domestic cooking and heating for a long time. Accepting briquette may take a long time as more effort need to gear towards sensitization on the important of using briquette. It is unfortunate that even residents of urban areas are largely unaware of briquettes, let alone those in suburban and rural communities who are in greater need of this technology. The poor briquette image is as a result of poor marketing of the production, and its accompanying benefit both to the individual and the environment.

vi. Technicality challenges

The technicality deals with operation and maintenance of the machine. This has been partially handled by patronising indigenous or locally fabricated machines with simple principle of operation. Also, lack of internal maintenance capability and unrealistic support services from indigenous fabricator underlines the challenges surrounding the adoption of the technology.

4. Implications

i. High rate of Unemployment

The recent sharp down curve of the national Gross Domestic Product (GDP) according to the National Bureau of Statistic can be attributed to lesser engagement of labour resource. According to Olorunfemi (2021), about half of the Nigeria's population is made up of youth of which some 42% are below the age of 15 and another 29% are between the ages of 15 and 29. This is an indication of abundant labour force. Unfortunately, the abundant labour force translates to abundant unemployment as the few organisations operating could not absorb even half of the population. According to National Bureau of Statistics (NBS, 2020), the youth (between age 15–34 years) unemployment rate was at 35 per cent (%). While 28 per cent of youth employed were reported to be underemployed (working 20–39 hours a week) and 37 per cent were working full time (40 or more hours per week). The establishment of briquetting factory can be an answer to this high level of unemployment in the country. For instance, (GVEP, 2013) estimated that briquette operations can employ 9 employees on the average, while Food and Agricultural Organisation (FAO, 2020) affirmed that briquetting can be another source of job opportunities, even among the females as the process is inclusive and physically less demanding.

ii. Deforestation and Desertification

The forestation and tree planting have been deployed as a general means of carbon capture technology (plant absorbs carbon monoxide (CO_2) for photosynthesis while emits oxygen (O_2) as by-products). According to Ogunwale (2015), deforestation refers to the rangy and rapid clearing of forests while leaving the soil exposed to weather. (Rainforest, 2020). Tree removal without replanting leads to reduced forests, habitats, and biodiversity. This practice has a detrimental effect on the environment. Nigeria's Forest Reserves consist of 1,160 designated areas covering approximately 107,527.02 square kilometres (41,516.41 sq mi). These reserves constitute around 11% of Nigeria's total landmass, spread across 362 local government areas.

According to Global Forest Watch (GFW, 2023), deforestation activities in Nigeria are estimated to be at 163 Kha/year, while the nation has lost more than 12% of total trees between 2001 and 2022. Also, Ahmed and Aliyu (2019) report an activity of deforestation in different geopolitical zones of the nation. Accordingly, between 1979 and 1995, total forest deteriorated by 48% in the North-central; 60% in the North-west, 7% in the North-east, 12% in the South-west, 13% in the South-south, and 53% in the south-east respectively.

Wood fuel among other factors are responsible for massive deforestation in Nigeria as (Ogunbunmi & Mwando, 2014) report that over 120 million Nigerians rely on woodfuel (charcoal and firewood) for their domestic need such as cooking and heating as a result of high cost of cooking gas and kerosene. According to World Wildlife Fund (Infoguide, 2015), woodfuel is responsible for more than 50% of trees illegally removed from the forest. Therefore, securing alternative to woodfuel is alternatively preventing the forest.

iii. Green House Gas (GHG)

The releasing of carbon dioxide (CO_2) gas and its equivalent to the atmosphere has been reported to cause ozone layer depletion, whose consequence is reflected in rises in temperature known as global warming. Nigeria is privy to international climate change treaties, like the Paris Agreement, which prioritise the global goal of achieving carbon net-zero by 2050 by engaging in activities that reduce greenhouse gas (GHG) emission to the atmosphere through techniques like biological approaches, such as planting trees and increasing the amount of carbon stored in the soil; and engineered approaches, such as enhancing the rate of certain minerals, weather, and devices that directly capture CO_2 from the air.

According to the cable climate (Climate Cable, 2022), Nigeria witnessed 46% increase greenhouse gas emission (GHG) with CO_2 accounted for 56 percent of the total GHGs in the nation. Also (Carbon brief profile) documents that Nigeria was occupying 25th position with nations that emit greenhouse gases in 2019, while occupying second highest emitter of GHGs in Africa. The severe impact of this GHGs was witnessed in massive flood (The carbonbrief, 2022) and untold rise in temperature, creating difficulties for middle and low income earners, who cannot afford air conditioner (The conversation). In order for Nigeria to meet its carbon net-zero vision by 2060, there is a need to shift to low-carbon energy. Briquetting may promise this since more than 50% of Nigeria engaged in wood fuel.

iv. Respiratory Diseases

According to Ferkol and Schraufnagel (2014), respiratory diseases are responsible for global major burden of morbidity, with health conditions such as tuberculosis and acute lower respiratory tract infections being the foremost issues. Also, allergy and related conditions such as asthma, chronic obstructive pulmonary disease (COPD) and lung cancers contribute to the high burden of respiratory diseases. In Nigeria, Akor et al, (2019) corroborate that an estimated 10.4% of hospital admissions at the emergency ward are related to respiratory diseases. Therefore, effort to curb respiratory disease is tantamount to reducing the cases of emergency at the hospital. While most of respiratory diseases are caused by biological processes such as tuberculosis by bacteria (Agbalaya, 2020; Ahmad et al, 2019), there are few that are caused by habit or environmental factors. For instance, inhaling of smoke could lead to lung cancer and weak lungs (Dobbie et al. 2019; Oladele, 2012). It is a common tendency that people who usually utilise fuel wood inhale smoke inform of CO_x, NO_x and other harmful compounds such as Sulphur. On long exposure, it may cumulate to respiratory difficulty or worsens the existing respiratory condition. Therefore, briquetting can help in reducing burden of diseases associated with air pollution.

5.0. Strategy to Adopt

i. Media Sensitization of the Briquette

It is a known fact that briquette fuel is in obscurity in Nigeria. Most middle-income earners who are patronising woodfuel are aware of the its carbon credit to the environment but unaware of the low-cost alternative fuel such as briquette. As such, there is a need for mass sensitization on the advantages of patronising briquette fuel for mass acceptability.

ii. Meeting with the stakeholders

The Federal Government through its research and technology agencies such as National Research Incubator should have a meeting with stakeholders such as investors, captain of industries, researchers, and community and religious leaders on how to develop a low-cost and quality briquette product that will gain acceptability from the masses.

iii. Research and Development on alternative raw materials

Since the agricultural residue has alternative usage in Nigeria, waste materials can be incorporated into agricultural residue to produce a quality briquette. For instance, environmental campaign to reduce the use of polyethylene nylon (especially one-time use) has increased paper usage, which generates a lot of waste. This paper can incorporate into other agricultural residues to produce briquette as the similar case in Malawi. Also, waste and leftover food such as rice; eba, tuwo etc when dried can also be used with another biomass for briquette production. This will reduce the cost of briquette and make it feasible to compete with the price of charcoal.

iv. Funding for small and medium enterprises in briquetting

The briquetting production would not thrive more than the encouragement and support received from external body. Accordingly, the briquette production will be encouraged by the fund made available by the government for the sole purpose of briquetting and gasification of biomass. For instance, (USAID, 2010) reports that Indian Government encourages the commercialization of the briquette technology through financial assistance and technical support. As at 2001, Indian Agency (IREDA) has supported briquetting in the form of loans up to INR 174 million. The Federal Government of Nigeria can borrow a leaf by creating an agency that will give platform for funding and technical support for briquetting formulation.

v. Enforcement of Environmental Control and Drought Mitigation Regulation

In 2011, Federal Government of Nigeria (FGN, 2011) established environmental (desertification) control and drought mitigation regulation, which is saddle with the responsibility of developing framework to protect forest and tree cutting, while sensitizing the masses on the causes and detrimental effects related to desertification and land degradation. This regulation should be enforced in order to reduce the indiscriminate felling of trees. In some localities, especially the rural areas, the impact of State is always at minimal level. Therefore, there is a need to mobilise local hands in enforcing the regulation.

6.0. Conclusion

Briquette technology, though an old innovation, holds significant potential not only for contributing to a zero-carbon environment but also for reducing respiratory illnesses caused by indoor air pollution. This is due to its eco-friendly nature and lower inhibit of harmful substance during usage. Also, like other bioenergy sectors, briquetting is a means of employment for both teeming Nigeria youth population and adults, while utilising various feedstock that are abundantly available in the country. However, there is a need for collaborative efforts in order to harness the opportunities embedded in briquette production and to overcome barriers that have relegated briquette formation to the laboratory. The commercialisation of briquette will reduce dependency on wood fuel, preserve the forest, improve quality of life, and contribute to overall National Gross Domestic Product (GDP).

Authors' Contributions

GJA, ABM and AA conceptualised and developed the manuscript, while ZS and EJE reviewed and revised at each stage of development.

Declaration of Competing Interest

The authors declare no competing interests.

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References

Abdul – Wahab, T. T. (2019). Biodiesel Production from Neem (Azadirachtaindica) Seed Oil . *International Journal of Innovative Research and development, 8*(8), 1-8.

Adeleke, A. A., Odusote, J., Paswan, D., Lasode, O., & Malathi, M. (2019). Influence of torrefaction on lignocellulosic woody biomass of Nigerian origin. *J Chem Technol Metallur, 54*, 274–285.

Adeleke, A., Odusote, J., Ikubanni, P., Lasode, O., Malathi, M., & Pasawan, D. (2021). Physical and mechanical characteristics of composite briquette from coal and pretreated wood fines. *Int J Coal Sci Technol , 8*(5), 1088–1098. doi:https://doi.org/10.1007/s40789-021-00438-0

Agbalaya, M. A. (2020). Prevalence of Bovine Tuberculosis in Slaughtered cattle and factors associated with risk of disease transmission among cattle handlers at Oko-Oba Abattoir, Lagos, Nigeria. *Veterinary World*, 1721-1731.

Ahmad, I., & al, e. (2019). Disseminated tuberculosis in a cow and a dromedary bull-camel in Zamfara State in Nigeria. *Veterinary Medicine and Science, 5*, 93–98. doi:DOI: 10.1002/vms3.132

Ahmed, Y., & Aliyu, I. (2019). Climate Change Induced Challenges on Deforestation: The Needs to Educe Mitigation Measures in Nigeria. *Analele Universităţii din Oradea, Seria Geografie, 29*(2), 64-76. doi: https://doi.org/10.30892/auog.292107-807

Akor, A., Idenyi, E., Hilary, C., & Akor, B. (2019). Patterns and outcome of respiratory disease among adult in-patients, in Abuja-Nigeria. *Res. J. of Health Science, 7*(3), 211-216. doi:http://dx.doi.org/10.4314/rejhs.v7i3.5

Akpenpuun, T., Salau, R., Adebayo, A., Adebayo, O., Salawu, J., & Durotoye, M. (2020). Physical and Combustible Properties of Briquettes Produced from a Combination of Groundnut Shell, Rice Husk, Sawdust and Wastepaper using Starch as a Binder . *J. Appl. Sci. Environ. Management, 24*(1), 171-177 .

Ali, N., Nina, P., Patricia, T. J., & Nakanwagi, R. (2019). Assessment of Biomass Briquette use as Alternative Source of Renewable Energy in Kampala District. *African Journal of Environment and Natural Science Research, 2*(1), 68-76. Retrieved 2019

Aliyu, M., Mohammed, I. S., Lawal, H. A., Dauda, S. M., Balami, A. A., Usman, M., . . . Ndagi, B. (2021). Effect of Compaction Pressure and Biomass Type (Rice Husk and Sawdust) on Some Physical and Combustion Properties of Briquettes . *Arid Zone Journal of Engineering, Technology and Environment , 17*(1), 61-70.

Atluri, P., Pramod Kumar, K. V., K., R. R., & K., P. M. (2017). Evaluation of Briquettes made of Biodegradable materials as an alternate source of energy. *International Journal of Mechanical Engineering and Technology , 8*(11), 977–983.

AUPED. (2022). *Preserving the Lungs of Africa: Leveraging on Briquettes from Agricultural Waste as an alternative waste.*

Bach, Q. V., Trinh, T., Tran, K., & Thi, N. (2017). Pyrolysis characteristics and kinetics of biomass torrefied in various atmospheres. *Energy Convers Management, 141*, 72–78.

Balmes, J. R. (2019). Household air pollution from domestic combustion of solid fuels and health. *J Allergy Clin Immunol. , 143*(6), 1979–1987.

Barnes, B. R. (2014). Behavioural Change, Indoor Air Pollution and Child Respiratory Health in Developing Countries: A Review. *Int J Environ Res Public Health, 11*(5), 4607–4618.

Basu, P. (2013). *Biomass gasification, pyrolysis, and torrefaction* (3rd ed.). London: Elsevier Academic Press.

Basu, P., Rao, S., Acharya, B., & Dhungana, A. (2013b). Effect of torrefaction on the density and volume changes of coarse biomass particles. *Can. J. Chem. Eng.* doi: http://doi.org/10.1002/c3ce-2817

Ben-Iwo, J., Manovic, V., & Longhurst, P. (2016). Biomass resources and biofuels potential for the production of transportation fuels in Nigeria. *Renewable and sustainable energy reviews, 63*, 172-192.

Bhattacharya, S., & Kumar, S. (2005). *Technology Packages: Screw-press Briquetting Machines and Briquette-fired Stoves.* Regional Energy Resources Information Center (RERIC). Bangkok, Thailand: Asian Institute of Technology.

Blasi, C. (2009). Combustion and gasification rates of lignocellulosic chars. *Prog. Energ.Combust. Sci. , 35*(2), 121-140.

Carbon brief profile. (n.d.). *Nigeria Profile.* Retrieved 2024, from https://www.carbonbrief.org/the-carbon-brief-profile-Nigeria/

Chaney, J. (2010). *Combustion Characteristics of Biomass Briquettes.* Nottingham, United Kingdom: The University of Nottingham .

Climate Cable. (2022). *Net-zero target: Nigeria's greenhouse gas emissions increased by 46% in 18 years.* Retrieved 2024, from https://www.thecable.ng/net-zero-target-nigerias-greehouse-gas-emissions-increased-by-46-in-18-years/amp/

CTCT. (2020). *Urban Briquette Making Pilot: Identification of biomass waste-based briquettes making technologies .* Nairobi – Kenya: Center for Technology and Climate Change.

Dobbie, F., Purves, R., & McKell, J. e. (2019). Implementation of A Peer-Led School Based Smoking Prevention Programme: A Mixed Methods Process Evaluation. *BMC Public Health , 742*(19). doi: https://doi.org/10.1186/s12889-019-7112-7

ECN. (2013). *Renewable Energy Master Plan (2013) .* Abuja, Nigeria: Energy Commission of Nigeria.

FAO. (2016). *Country fact sheet.* Retrieved 2024, from http://www.fao.org/nr/water/aquastat/data/cf/readPdf.html?f=NGA-CF_eng.pdf

FAO. (2014). *Bioénergie et sécuritéalimentaire evaluation rapide (BEFS RA), Manuel d'utilisation (Briquettes).* Food and Agricultural Organisation of the United Nations.

FAO. (2020). *Improved charcoal technologies and briquette production from woody in Malawi.* Bioenergy and Food Security (BEFS) . Food and Agricultural Organisation of United Nations.

Faxälv, O., & Nyström, O. (2009). *Biomass Briquettes in Malawi.* Institute of Technology. Linkoping University.

Ferkol, T., & Schraufnagel, D. (2014). The Global Burden of Respiratory Disease. *Annal America Thoracic Society, 11*(3), 404-416.

FGN. (2011). *National Enviromental (Dessertifcation) Control and Drought Mitigation Regulation.* Abuja, Nigeria: Federal Governement of Nigeria.

Gidigbi, J. (2023). The Nigeria's Drainage Challenges: An Opinion Paper on the In- street waste water and its Environmental Consequences. *Review of Environment and Earth Sciences, 10*(1), 1-7. doi:https://doi.org/10.18488/80.v10i1.3359

Gidigbi, J., & Abubakar, A. (2023). Optimisation of Bio-diesel made from non-edible Avocado Seed Oil (ASO) using Homogenous Catalyst H2SO4/KOH. *International Journal of Chemistry , 10*(4), 242-257. doi:https://doi.org/10.22034/IJNC.2023.1995852.1327

Global Forest Watch. (2023). (Global Forest Watch) Retrieved from https://www.globalforestwatch.org/dashboards/country/NGA/?category=forest-change&map=eyJjYW5Cb3VuZCI6dHJ1ZX0%3D

GVEP. (2013). *Assessment of the Briquette Market in Kenya.* Nairobi, Kenya: Global Village Energy Partnership International. Retrieved from www.gvepinternational.org

Hamzat, A., Gombe, S., & Pindiga, Y. (2019). Briquette from Agricultural Waste a Sustainable Domestic Cooking

Energy . *Gombe Technical Education Journal , 12*(1), 63-69 .

Huang, B., Zhao, J., & Geng, Y. T. (2017). Energy-related GHG emissions of the textile industry in China. *ResourConservRecycl , 119*, 69-77.

Ibrahim, M., Bello, S., & Ibrahim, A. (2020). Biomass Briquettes as an Alternative Source of Cooking Fuel towards Green Recovery Post COVID-19. *Saudi Journal of Engineering and Technology*, 285-290. doi:DOI: 10.36348/sjet.2020.v05i06.005

Ichu, C. B., Nwogu, N., Agulanna, A. C., & Nwakanma, H. O. (2020). Potentials of biomass briquetting and utilization: the Nigerian perspective. *Pacific International Journal, 3*(1), 07-12. doi:DOI: 10.55014/pij.v3i1.87

IEA. (2006). *World Energy Outlook.* Paris, France: IEA/OECD.

Infoguide. (2015). *Deforestation in Nigeria: 7 Causes, 5 Effects and 6 Ways to Stop It*. (InfoGuideNigeria.com) Retrieved from https://infoguidenigeria.com/deforestation-nigeria-7-causes-5-effects-6-ways-stop/

IWNI. (2017). *Resource recovery from waste: Business models for energy, nutrient and water reuse in low-and middle-income countries.* Earthscan/Routledge, London: International Water Management Institute.

Kpalo, S. Y., & Zainuddin, M. F. (2020). Briquettes from Agricultural Residues; An Alternative Clean and Sustainable Fuel for Domestic Cooking in Nasarawa State, Nigeria . *Energy and Power, 10*(2), 40-47. doi:DOI: 10.5923/j.ep.20201002.03

Mahoro, B. G., Eniru, I. E., Omuna, E., Akiyode, O., & Danson, M. (2022). Adoption of Briquettes of Organic Matter as an Environmentally Friendly Energy Source in Uganda. *KIU Journal of Science, Engineering and Technology, 1*(1), 23 - 30.

NBS. (2020). *Labour Force Statistics: Unemployment and Underemployment Report- Abridged Labour Force Survey under COVID-19.* Abuja: National Bureau of Statistics.

Obi, O., Adeboye, B., & Aneke, N. (2014). Biomass Briquetting and Rural Development in Nigeria. *Int J Sci Environ Technology, 3*(3), 1043–1052.

Ogunbunmi, K., & Mwando, M. (2014). *Africa's climate policiesburned by firewood dependence* . (Thomson Reuters) Retrieved from (https://news.trust.org/item/20140530183509-63ekq/)

Ogunwale, A. (2015). Deforestation and Greening the Nigerian Environment. *International Conference on African Development Issues (CU-ICADI)* (pp. 212-219). Renewable Energy Track .

Oladele, D. (2012). *The Public Health Challenge of Smoking in Nigeria/Africa.* University of Alberta, School of Public Health. Edmonton, Alberta: University of Alberta.

Olaoye, J. O., & Kudabo, E. A. (2017). Evaluation of Constitutive Conditions for Production of Sorghum Stovers Briquette. *Arid Zone Journal of Engineering, Technology and Environment, 13*(3), 400 – 412.

Onimisi, M. O., Ajibola, V. O., & Dallatu, Y. A. (2021). Production and Characterization of Biodiesel from Palm Oil Sludge and Palm Kernel Oil using Non-Heating Method. *Nigerian Research Journal of Chemical Sciences, 9*(1), 114 - 131. Retrieved from http://www.unn.edu.ng/nigerian-research-journal-of-chemical-sciences/

Rainforest. (2020). *Deforestation statistics for Nigeria*. Retrieved from https://rainforests.mongabay.com/deforestation/archive/Nigeria.htm

Rezania, S., Ponraj, M., Din, M. F., Sairan, F. M., & al, e. (2015). The diverse applications of water hyacinth with main focus on sustainable energy and production for new era: an overview. *Renew SustEnerg Rev , 41*, 943-954.

Ritchie, H., & Roser, M. (2019). *Indoor Air Pollution - Our World in Data.* Retrieved from https://ourworldindata.org/indoor-air-pollution

Sanchez, P. D., Mia Me T. Aspe, M., & Sindol, K. (2022). An Overview on the Production of Bio-briquettes from Agricultural Wastes: Methods, Processes, and Quality. *Journal of Agricultural and Food Engineering* , 1-17.

Sankaran, R., Show, P., Nagaranjan, D., & Chang, J.-S. (2018). Ecploitation and Biorefinery of Microalgae. In *Waste Biorefinery* (pp. 571-601). Elsevier. doi:10.1016/B978-0-444-63992-9.00019-7.

The carbonbrief. (2022). *The west-africas deadly rainfall.* Retrieved from https://www.carbonbrief.org/west-africasdeadly-rainfall-in-2022-made-80-times-more-likely-by-climate-change/

The Conscious Challenge. (2018). *The ecological footprint.* Retrieved 2023, from https://www.theconsciouschallenge.org/ecologicalfootprintbibleoverview/oxygen-deforestation.

The conversation. (n.d.). Retrieved 2024, from https://theconversation.com/lagosstate-is-likely-to-get-hotter-and-more-humid-leading-to-greater-health-risks-140327

The United Nations (2024) *Air Pollution, percentage of population using biomass fuels, Millennium Indicators Database.* Department of Economic and Social Affairs, Economic and Social Development, Statistics Division. Geneva: The World Health Organization. Retrieved 2024, from http://millenniumindicators.un.org/unsd/mi/mi_series_results.asp?rowId=712

Thliza, B. A., Abdulrahman, F. I., Akan, J. C., Chellube, Z. M., & Kime, B. (2020). Determination of Compressive Strength and Combustibility Potential of Agricultural Waste Briquette. *Journal of International Chemical Science , 29*(1), 30-46.

UNEP. (2011). *Towards a green economy: pathways to sustainable development and poverty eradication.* Geneva, Switzerland: United Nations Environment Programme.

UPSR. (2005). *Uganda Poverty Status Report .* Retrieved from www.mcgil.ca

USAID. (2010). *Biomass Briquetting in Sudan: A Feasibility Study .* The United States Agency for International Development.

Weinhold, B. (2011). *Indoor PM pollution and elevated blood pressure: cardiovascular impact of indoor biomass burning.* Environmental health perspectives.

World Health Organization (WHO). (2007). *Indoor air Pollution: National Burden of Disease Estimates 2007.* Retrieved 2023, from http://www.who.int/indoorair/publications/fuelforlife/