Energy and Power 2020, 10(2): 40-47
DOI: 10.5923/j.ep.20201002.03

Briquettes from Agricultural Residues; An Alternative Clean and Sustainable Fuel for Domestic Cooking in Nasarawa State, Nigeria

Sunday Yusuf Kpalo[1,2,*], Mohamad Faiz Zainuddin[2]

[1]Faculty of Environmental Sciences, Nasarawa State University, Keffi, Nasarawa State, Nigeria
[2]Faculty of Forestry and Environment, Universiti Putra Malaysia UPM Serdang, Selangor, Malaysia

Abstract In Nasarawa state, over 70% of the population are involved in subsistence farming. Varied agricultural resources are produced in millions of tons annually. Large quantity of residues is generated that are either left to rot on farmlands or disposed of by burning in open air. In many rural areas, the residues are also used in their raw form for cooking purposes which is inefficient. The disposal and use of the residues cause pollution in the environment which affects human health. Residues can provide a source of clean and renewable energy in the form of solid biofuel called briquettes through densification. Briquetting is a densification technology that converts residues with a low heating value per unit volume into high density and energy concentrated fuels. This paper offers a perspective on the potentials of agricultural residues in Nasarawa state to produce briquettes as an alternative clean and sustainable domestic cooking fuel. The paper concludes that briquettes could be economically and environmentally friendly alternative to fuelwood. The use of biomass briquettes would reduce dependence on fuelwood, environmental pollution and the amount of time spent on cooking. Adopting the briquetting technology will enhance access to clean and affordable energy in line with the 7th goal of the United Nation's Sustainable Development Goals.

Keywords Agricultural residues, Briquettes, Domestic cooking, Fuelwood, Pollution, Sustainable fuel

1. Introduction

The household cooking sector in Nigeria is the largest consumer of energy. According to International Energy Agency [1], about 73% of cooking energy is mainly derived from biomass (67% fuelwood and 6% charcoal). Women, being the chief cooks, spend more than 6 hours each day collecting and preparing fuelwood to make meals [2]. Significant time is lost in the process and as Katimbo et al [3] noted, it results in low production in agriculture, low incomes and household food insecurity. The unsustainable consumption rate of fuelwood requires interventions to increase the efficiency of use [4]. Apart from fuel wood and charcoal, agricultural residues also provide cooking energy option particularly in the rural communities. However, a major issue with the use of these fuels in their traditional form for cooking is indoor air pollution from burning in open fires and usually in poorly ventilated kitchens. The exposure to health damaging pollutants has been hypothesized to contribute to elevated blood pressure which leads to increased risk of cardiovascular diseases, stroke and kidney diseases [5], pneumonia amongst children of less than five years of age [6] and premature deaths [7,8]. Globally, deaths from indoor air pollution caused by biomass burning are estimated to be about 3.8 million deaths annually [9]. In Nigeria, about 79,000 deaths were recorded in the year 2002 [10] but an estimated 106,900 to <605,100 deaths occurred recently based on the report from the latest World Health Organization (WHO) and Global Burden on Diseases (GBD) risk assessment [11].

In Nasarawa state, agriculture is the main economic activity of the people. The state is a major producer of agricultural products with an abundance of agricultural residues. The residues are mostly left to rot on farmlands encouraging leachate and emission of methane or cleared and burnt openly in readiness for the next planting season. Additionally, where they are not abandoned or burnt, they are used as alternative to charcoal and fuelwood for domestic cooking purposes, particularly in the rural areas. The use of the residues in their traditional state does not give room for efficient utilization because of poor energy characteristics of low density, low heating value and high moisture content [12]. These limited characteristics make

* Corresponding author:
kpalosy@nsuk.edu.ng (Sunday Yusuf Kpalo)
Published online at http://journal.sapub.org/ep

cooking a burden because of the long hours spent and the likelihood of indoor air pollution from incomplete combustion. Charcoal and firewood, being major sources of domestic cooking fuel in the state are acquired from a diminishing forest resource. The alternative fuels such as LPG (cooking gas) and kerosene are seldom used due to their cost and inaccessibility. Therefore, it is necessary to resolve the persistent need for an eco-friendly, sustainable, affordable and readily available cooking energy source to decrease the consumption of fuelwood. Densification of agricultural residues by briquetting can produce energy in the form of solid fuel for cooking at the household level in rural settings. The use of these materials as alternative sources of energy is desirable because it could tackle problems of waste disposal, energy shortages as well as mitigate against indoor air pollution [13]. Furthermore, the 7th goal of the United Nation's Sustainable Development Goals (Affordable and Clean Energy) seeks to ensure access to affordable, reliable, sustainable and modern energy for all by the year 2030 [14]. Therefore, this paper offers a perspective on the potentials of agricultural residues in Nasarawa state to produce briquettes as an alternative clean and sustainable domestic cooking fuel.

2. Geography of Nasarawa State

Figure 1. Map of Nasarawa state, Nigeria [15]

Nasarawa State is centrally located in the Middle Belt region of Nigeria and lies between latitude 7° 45' and 9° 25' N of the equator and between longitude 7° and 9° 37' E of the Greenwich meridian. It shares a boundary with Kaduna state in the North, Plateau State in the East, Taraba, and Benue states in the south while Kogi and the Federal Capital Territory flank it in the West (Figure 1). The state has a total land area of 26,875.59 square kilometers and a population of about 1,826,883, according to the 2006 population census estimate with a density of about 67 persons per square kilometer. The soils are rich in humus and laterite and are found in most parts of the state which adequately supports crop production [15]. Nasarawa state experiences extreme seasonal variation in monthly rainfall with the rainy period of the year lasting for over 8 months (March to November) and a sliding 31-day rainfall of at least 0.5 inches. The most rain falls during the 31 days centered around August 29, with an average total accumulation of 9.2 inches. Over the course of the year, the temperature typically varies from 63°F to 95°F and is rarely below 57°F or above 101°F [16]. The state is made up of thirteen local government areas and major tribes found includes Gwandara, Alago, Eggon, Gbagi, Egbira, Mada, and settler groups like the Igbo, Yoruba, and Hausa.

3. Agriculture in Nasarawa State

Agriculture is the mainstay of the economy of the state with over 70% of the population involved in subsistence farming [15]. Irrigation farming is not widely practiced despite the substantial number of rivers in the state. There are several crops grown comprising of tubers, legumes, grains, fruits, and vegetables (Table 1) The bulk of crop production is undertaken by small scale farmers most of whose labour force, management and capital originate from the households [17]. Nasarawa state has similar climatic conditions like any other tropical environment. The wet season which lasts for over 8 months comes with enough rainfall to support the growth and development of crops grown during the season.

Table 1. Distribution of Agricultural Crops in Nasarawa State

S/No	LGA*	Agricultural products
1	Akwanga	Maize, Groundnut, Yam, Guinea Corn, Millet, Melon, Rice, Sweet Potato, Cassava.
2	Awe	Maize, Rice, Groundnut, Yam, Cassava, Guinea Corn, Millet, Beniseed, Melon, Cassava.
3	Doma	Maize, Rice, Groundnut, Yam, Cassava, Guinea Corn, MilletBeniseed, Sugarcane, Fisheries.
4	Karu	Yam, Cassava, Guinea Corn, Groundnut, Millet, Sugarcane
5	Keana	Cotton, Maize, Yam, Cassava, Groundnut, Guinea Corn, Millet, Potato.
6	Keffi	Rice, Maize, Groundnut, Guinea Corn, Yam, Cassava, Fruits
7	Kokona	Maize, Rice, Guinea Corn, Yam, Cassava, Melon, Irish Potato, Vegetables.
8	Lafia	Yam, Cassava, Guinea Corn, Groundnut, Millet, Rice, vegetables
9	Nassarawa	Yam, Rice, Cassava, Guinea Corn, Groundnut, Millet, Vegetables, Fruits, Fisheries.
10	Nassarawa Eggon:	Yam, Cassava, Guinea Corn, Millet, Groundnut, Fruits
11	Obi	Yam, Cassava, Rice, Sugarcane, Millet, Mellon
12	Toto	Maize, Rice, Yam, Groundnut, Guinea Corn, Sugarcane, Millet, Vegetables, Fruits.
13	Wamba	Cassava, Yam, Guinea Corn, Groundnut, Maize, Millet, Vegetable, Fruit.

Source: [18].
* Local Government area

Table 2. The Yields of Main Agricultural Crops in Nasarawa State (2014)

Crop	Prod ('000MT)	Area ('000HA)	Yield MT/HA
Maize	434	184.2	2.36
Guinea corn	158.1	130.4	1.21
Millet	14.78	16.42	0.9
Rice	168.2	86.6	2.36
Yam	4370.6	225	19.43
Cassava	2544.9	129.8	19.61
Sweet potatoe	32.19	2.3	14
Groundnuts	240.1	150.2	1.6
Melon seed	46.99	68.27	0.69
Beniseed	70.4	88.71	0.79
Soybean	10.71	14.11	0.76
Sugarcane	46.9	2.4	19.54
Okra	44.13	3.8	11.61
Watermelon	960.61	50.3	19.1

Source: [18].

4. Energy Potential of Agricultural Residues

Table 3. Energy Potential of Major Agricultural Residues in Nigeria Based on FAO Statistics

Agricultural crop	Generated residue	Production quantity (103 t)	Calculated generated residue	Energy potential (TJ)
Maize	Stalk	7306	10,959	169.65
Rice	Straw	3219	4829	75.14
Sorghum	Stalk	4784	12,534	213.08
Wheat	Stalk	34.2	51.3	0.99
Coconut	Shell	170	102	1.08
Oil palm fruit	Empty fruit bunch	8500	2125	32.96
Sugarcane	Bagasse	1414	424.3	5.68
Cocoa	Husk	428	428	6.63
Millet	Stalk	4125	12,375	191.94

Source: [19].

As a major producer of agricultural product, Nasarawa state has abundant agricultural residues that could be sustainably used for bioenergy production. Agricultural residues for energy production have a very insignificant threat to food security; hence, they could be one of the most reliable bio-energy resources [19]. The residues are classified into crop residues (materials left on the farm after harvest) and process residues (materials left on industrial sites after processing). The crop residues include straw, leaves and stalk of cereals such as rice, maize/corn, sorghum, and millet, cassava stalk/peelings and cocoa pods. The process residues include corn cob, cocoa husk, coconut shell and husk, rice husk, oil seed cakes, sugar cane bagasse, and empty fruit bunch (EFB) of oil palm [20,21]. The energy potential of these residues can be attributed to their lignocellulosic nature (Table 3) and the lignin content enables their use for heat and power production. Studies have shown that these kinds of wastes can be densified into briquettes rather than be burnt openly or left to rot on farmlands [22,23,24]. The resources are usually very available at the end of every harvest season and there is currently no rural energy arrangement existing for the utilization of these residues.

5. Important Qualities of Biomass Residues Appropriate for Briquetting

According to Grover & Mishra [25], apart from biomass residue availability in large quantities, there are many factors to consider before it qualifies for use as feedstock for briquetting. These include moisture content, ash content and composition, and flow characteristics. Finding a balance for moisture content is central prior to densification in order to ensure briquette quality. What is considered as optimum moisture content for briquetting varies with the type of feedstock, however, Kaliyan and Morey [26] suggested that a value of 8-12% is generally suitable. Low ash content is also desirable as ash content in biomass above 4% may cause slagging [25]. Table 4 shows ash content of different types of biomass. Additionally, other relevant characteristics of biomass to consider before briquetting of biomass may include high calorific value, no major alternative use and low nutritive value to avoid food resource problem.

Table 4. Ash content of different types of biomass

Biomass	Ash content (%)	Biomass	Ash content (%)
Corn cob	1.2	Coffee husk	4.3
Jute stick	1.2	Cotton shells	4.6
Sawdust (mixed)	1.3	Tannin waste	4.8
Pine needle	1.5	Almond shell	4.8
Soya bean stalk	1.5	Areca nutshell	5.1
Bagasse	1.8	Castor stick	5.4
Coffee spent	1.8	Groundnut shell	6.0
Cocoanut shell	1.9	Coir pith	6.0
Sunflower stalk	1.9	Bagasse pith	8.0
Jowar straw	3.1	Bean straw	10.2
Olive pits	3.2	Barley straw	10.3
Arhar stalk	3.4	Paddy straw	15.5
Lantana camara	3.5	Tobacco dust	19.1
Subabul leaves	3.6	Jute dust	19.9
Tea waste	3.8	Rice husk	22.4
Tamarind husk	4.2	Deoiled bran	28.2

Source; [25]

6. Briquettes and Briquette Technology

Briquettes are a form of solid biofuel that can be burned for energy made from biomass resources including agricultural residues (Figure 2). They are made of different qualities and dimensions depending on the raw materials, mold and technologies applied during production [27,28]. They are typically cylindrical in shape with a diameter of between 25 and 100 mm and lengths ranging from 10 to 400 mm [29]. Other shapes of briquettes include square, rectangle and polygon and also in different sizes. The use of agricultural residues to produce briquettes can reduce waste of resources and consumption of fossil fuels [30]. Production of briquette helps to solve the problem of residue disposal and deforestation which eases the pressure on the forest reserve. [31]. The advantages briquettes have over conventional fuelwood include higher heat content, ease of use, cleanliness and compact size [32].

a b

Figure 2. Sample of agricultural residue (a) and produced briquettes (b)

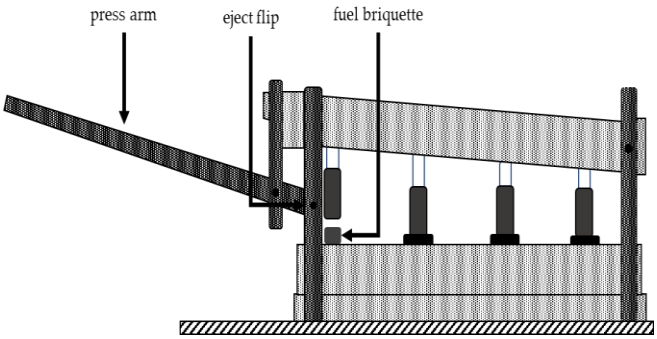

Figure 3. Manually operated machine (WU Presser) Adapted from [44]

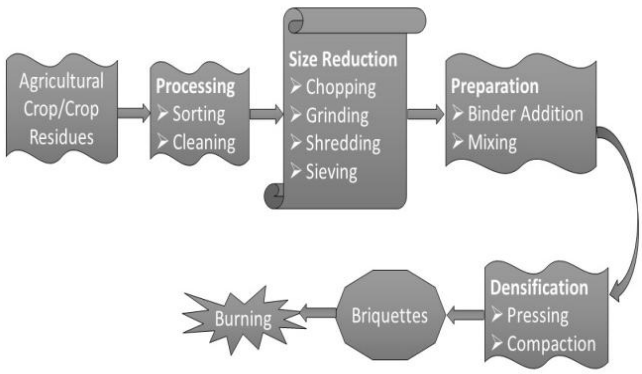

Figure 4. Briquette production flow chat

Briquettes are products of briquetting technology which is the densification or compaction of residues into a product of higher density than the raw materials [33]. The process converts low bulk density biomass into high density and energy-concentrated fuel [34,35] and it involves basically drying, grinding, sieving, compacting and cooling operations [36]. Briquetting machines used for densification of agricultural residues are of various types. They include the roller press, screw press extruder, the piston press which can either be mechanical or hydraulic [27,33,37]. These machines can either be operated manually or with high energy depending on whether it is low compaction pressure or high compaction pressure technology. Additionally, the manual press is another type of briquetting machine. A typical example is the WU-presser (Figure 3) which can be made from either wood or metal. The locally available raw material determines the type of briquette machine to be used [36] and the type of fuel briquette produced [38]. Briquettes can be produced with or without a binder. According to Pallavi et al., [39], briquette production may require binders such as starch or clay soil to bind the matter together depending on the material, the pressure and the speed of compaction. Briquetting technology is yet to get a strong foothold in many developing countries, including Nigeria, because of the technical constraints involved and the lack of knowledge to adapt the technology to suit local condition [25]. However, a few attempts have been made in the past to develop machines used to produce the briquettes [40,41,42,43]. Figure 4 show the stages involved in the briquetting process.

7. Characteristics of Briquettes

Table 5. Characteristics of briquettes

Characteristics	Parameters	Values in literature	Source
Physical	Density	0.24-0.37 g/cm^3	[48]
	Moisture content	5.55-12.33%	[48]
	Water resistance	87.60-92.00%	[13]
Mechanical	Shatter index	98.28-99.08%	[13]
	Comprehensive strength	18.47-21.75 MPa	[13]
	Durability	96%	[49]
Thermal	Calorific value	16.54-16.91 MJ/kg	[13]
	Proximate composition (Volatile matter, Ash content and Fixed carbon)	68.20%, 16.10% and 15.70% respectively	[50]
	Ultimate composition (Carbon, Hydrogen, Nitrogen, Oxygen, and Sulphur)	45.20%, 5.80%, 1.02%, 47.60% and 0.21% respectively	[50]

The characteristics of briquettes are categorized in terms of physical, mechanical, and thermal properties, depending on the measured parameters. (Table 5). These characteristics are a representation of the handling, transportation, storage and combustion ability of the briquettes. Produced briquettes are characterised based on such parameters which consequently defines their quality. The quality of briquettes is indicative of the effectiveness of the densification process and influences their ability to endure certain impacts. Quality attributes of the densified biomass are important in the end-user applications [45]. However, these attributes depend mainly on the types of feedstock material and briquetting machine used to produce them [46]. According to Arewa et al [47], low moisture content, high crushing strength, high density, slow flame propagation and high calorific value are properties expected of a good briquette.

8. Utilization of Briquettes

Briquettes can be utilized in several applications ranging from residential cookstoves to large scale industrial powerplants. They can be easily adopted in any biomass-based energy conversion devices, such as residential boilers, residential stoves, gasifiers, industrial boilers (Table 6). Briquettes are good alternatives because the contemporary domestic fuels (fuelwood, kerosene and gas) are getting scarce and expensive.

Table 6. Potential Use of Briquettes

Industry	Possible application
Domestic use	Cooking, water heating, and space heating
Commercial and institutional catering	Cooking, water heating, grilling
Hospitality	Cooking, water heating, space heating (outdoor dining areas)
Industrial Boilers	Generation of heat and steam
Food processing	Distilleries, bakeries, canteens, restaurants, drying
Textiles	Dyeing, bleaching
Crop processing	Tobacco curing, tea drying, oil milling
Ceramic production	Brick kilns, tile making, pot firing, etc.
Gasification	Fuel for gasifiers to produce electricity
Charcoal production	Initiating pyrolysis to make charcoal production more efficient
Poultry	Incubation and heating of chicks

Source: [35]

9. Achieving the UN's Affordable and Clean Energy Goal

Affordable and Clean Energy (SDG 7) is the 7th goal of the United Nation's Sustainable Development Goals. Briquetting of agricultural residues presents a sustainable means of achieving that goal in Nasarawa state. Studies have opined that for biomass densification to expand, there must be residue availability, adequate technologies and the market for briquettes [12,51]. The availability of variety and abundance of agricultural residue resources in the state (see Tables 1&2), the potential and existing market due to high cost of fossil fuels [2], and the locally developed and potentially available densification technology makes the state an ideal environment for briquette production. The impact of briquetting technology can be felt on the environment as well as economically. Studies have shown that developing bio-mass energy from agricultural residues can provide clean and sustainable energy for rural areas, reduce dependence on fossil fuels and help mitigate the environmental and eco-nomic security threats that they pose [37,52].

9.1. Clean Energy

The carbon emissions from the burning of fossil fuels results in an increase of greenhouse gas (GHG) emissions that cause climate change [53]. The global carbon dioxide (CO2) emissions from fuel combustion reached 32.8 billion tons in 2018 [54]. Biomass is a renewable energy resource because of its biogenic origin and the CO2 released from its burning and consumption methods does not lead to an increase in atmospheric CO2. [55]. Energy from biomass is renewable, carbon-neutral and non-toxic which can be produced locally to boost energy security [49,56]. Briquette is made from biomass material and its energy can thus, be considered carbon neutral. Kuhe et al [57] observed that after burning agricultural waste briquettes, emission of carbon into the atmosphere is 50 times less than coal, 15 times less than natural gas and sulfur emission is 0.032%, which practically does not contaminate the atmosphere. In a study by Singh et al [58], it was also noted that briquettes have better physical, mechanical, and combustion properties and greatly reduces the emission of CO2, SO2, and NOx with calorific values greater than biomass. Combustion properties were shown to increase by 20% after biomass was molded into solid briquettes and the emissions of greenhouse gas, NOx, and SO2 were only one-ninth, one-fifth, and one-tenth that of coal [59]. This attribute makes briquettes safe, clean and environmentally friendly source of energy for cooking and other purposes.

9.2. Affordable Energy

Dinesha et al [32] noted that if briquettes are produced at low cost and are readily available to consumers, they can complement domestic cooking fuels like firewood, charcoal and kerosene, thus decreasing the high demand for other fuels. In their study, Kuhe et al [57] found out that 1 kg of fuelwood goes for about N100.00 which is equivalent to about USD0.75, while 2 liters of kerosene which produces the same amount of energy as 1 kg of fuelwood is sold for USD1.75. An estimate of the average cost of production of 1 kg of agricultural waste briquettes will cost about N73.50, which is equivalent to USD0.50 (Fifty cents). In another

instance, Romallosa & Kraft [60] concluded that a kilogram of briquette from municipal solid waste can be sold for Php15.00 which is equivalent to USD0.34. Similarly, briquettes were sold to residents of Kahawa Soweto and environs at a price between Ksh3 and Ksh5 (USD0.04 and USD0.06) per piece [61]. The significance of these is that the briquettes are cheap and affordable for the would-be consumers. Jingura et al [62] noted, biofuels would be a viable alternative if their costs are less than those of the fossil fuels, they are meant to complement of replace. Furthermore, the economic impact of using agricultural residue to produce energy can be felt more due to the likelihood of proper distribution in rural areas, providing economies with limited industry, an effective impetus to operate [63,64].

10. Conclusions

Agricultural resources are diverse and their distribution cuts across the entire state. The residues are produced in large quantities evidenced from the estimates of crop production and yield in the state. A lot of the residues are discarded by burning in the open or are left to rot on farmlands thereby causing environmental pollution. The use of these residues for cooking purposes in their raw form encourages indoor air pollution resulting in respiratory diseases leading to deaths. The large volume of agricultural residues available in Nasarawa state can be utilized efficiently when they get converted into briquettes. Briquetting at low pressure could provide a means for people with limited equipment and resources to upgrade residues that could have been wastefully discarded. Because they can be produced at low cost, other domestic cooking fuels can be complimented and reduce their high demand. This will provide clean and sustainable energy for rural areas and reduce the risk of environmental pollution which leads to climate change, thereby meeting the goal of affordable and clean energy championed by the United Nation's SDG.

ACKNOWLEDGEMENTS

The authors would like to thank the Sultan Abdul Samad library in UPM for the access and use of its electronic and print resources.

REFERENCES

[1] International Energy Agency. Africa Energy Outlook 2019 World Energy Outlook Special Report. 2019 Available from: www.iea.org/t&c/ [accessed on 20 November 2020].

[2] Obi OF, Adeboye BS, Aneke NN. Biomass Briquetting and Rural Development in Nigeria. Int J Sci Environ Technol. 2014; 3(3): 1043–1052.

[3] Katimbo A, Kiggundu N, Kizito S, Kivumbi HB, Tumutegyereize P. Potential of densification of mango waste and effect of binders on produced briquettes. Agric Eng Int CIGR J. 2014; 16(4): 146–155.

[4] Gujba H, Mulugetta Y, Azapagic A. The Household Cooking Sector in Nigeria: Environmental and Economic Sustainability Assessment. Resources. 2015; 4(2): 412–133.

[5] Weinhold B. Indoor PM pollution and elevated blood pressure: cardiovascular impact of indoor biomass burning. Vol. 119, Environmental health perspectives. 2011.

[6] Barnes BR. Behavioural Change, Indoor Air Pollution and Child Respiratory Health in Developing Countries: A Review. Int J Environ Res Public Health. 2014 25; 11(5): 4607–4618.

[7] Smith KR, Mehta S. The burden of disease from indoor air pollution in developing countries: Comparison of estimates. Int J Hyg Environ Health. 2003; 206: 279–289.

[8] Ritchie H, Roser M. Indoor Air Pollution - Our World in Data. 2019 Available from: https://ourworldindata.org/indoor-air-pollution [accessed on 22 November 2019].

[9] Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Belesova K, Boykoff M, et al. The 2019 report of The Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. Lancet. 2019; 394: 1836–1887.

[10] World Health Organization. Indoor air Pollution: National Burden of Disease Estimates 2007. Available from: http://www.who.int/indoorair/publications/fuelforlife/ [accessed on 22 November 2019].

[11] Balmes JR. Household air pollution from domestic combustion of solid fuels and health. J Allergy Clin Immunol. 2019; 143(6): 1979–1987.

[12] Felfli FF, Mesa P JM, Rocha JD, Filippetto D, Luengo CA, Pippo WA. Biomass briquetting and its perspectives in Brazil. Biomass and Bioenergy 2011; 35(1): 236–242.

[13] Kpalo SY, Zainuddin MF, Manaf LA, Roslan AM. Production and Characterization of Hybrid Briquettes from Corncobs and Oil Palm Trunk Bark under a Low Pressure Densification Technique. Sustainability. 2020; 12(6): 1–16.

[14] United Nations. UN Sustainable Development Goals. 2015 Available from: https://sustainabledevelopment.un.org/?menu=1300 [accessed on 26 September 2019].

[15] Nasarawa State Government. About Nasarawa State].. Available from: http://www.nasarawastate.gov.ng/about.php [accessed on 13 February 2019]

[16] Weather Spark. Average Weather in Nasarawa, Nigeria, Year-Round. Available from: https://weatherspark.com/y/55086/Average-Weather-in-Nasarawa-Nigeria-Year-Round [accessed on 19 May 2020].

[17] Aboki MP, Mailafiya MA, Osabo PA. Vegetation and Forest Resources of Nasarawa State. In: Geographic Perspective on Nasarawa State. Keffi: Onaivi printing and publication company; 2005.

[18] Nasarawa Agricultural Development Programme (NADP). Distribution and Yield of Agricultural Crops in Nasarawa State. Available from:http://www.nasarawastate.gov.ng/about.php [accessed on 13 February 2019].

[19] Mohammed YS, Mustafa MW, Bashir N, Ogundola MA, Umar U. Sustainable potential of bioenergy resources for distributed power generation development in Nigeria. Renew Sustain Energy Rev. 2014; 34: 361–370.

[20] Cooper CJ, Laing CA. A macro analysis of crop residue and animal wastes as a potential energy source in Africa. J Energy South Africa. 2007; 8(1): 10–19.

[21] Agbro EB, Ogie NA. A comprehensive review of biomass resources and biofuel production potential in Nigeria. Res J Eng Appl Sci. 2012; 1(3): 149–155.

[22] Hu J, Lei T, Wang Z, Yan X, Shi X, Li Z, et al. Economic, environmental and social assessment of briquette fuel from agricultural residues in China – A study on flat die briquetting using corn stalk. Energy. 2014; 64: 557–566.

[23] Muazu RI, Stegemann JA. Effects of operating variables on durability of fuel briquettes from rice husks and corn cobs. Fuel Process Technol. 2015; 133: 137–145.

[24] Shuma R, Madyira DM. Production of Loose Biomass Briquettes from Agricultural and Forestry Residues. Procedia Manuf. 2017; 7: 98–105.

[25] Grover PD, Mishra SK. Biomass Briquetting: Technology and Practices. Regional Wood Energy Development Programme In Asia. Field Document No 46, Food and Agriculture Organization; 1996.

[26] Kaliyan N, Vance Morey R. Factors affecting strength and durability of densified biomass products. Biomass and Bioenergy. 2009; 33: 337–359.

[27] Oladeji J. Theoretical Aspects of Biomass Briquetting: A Review Study. J Energy Technol Policy. 2015; 5(3): 72–82.

[28] Asamoah B, Nikiema J, Gebrezgabher S, Odonkor E, Njenga M. A Review on Production, Marketing and Use of Fuel Briquettes. 2016 Available from: http://www.iwmi.cgiar.org/Publications/wle/rrr/resource_recovery_and_reuse-series_7.pdf [accessed on 18 October 2018].

[29] Kristoferson LA, Bokalders V. Renewable Energy Technologies-their applications in developing countries. Pergamon Press, Oxford; 1986. 319 p.

[30] Wang Z, Lei T, Yang M, Li Z, Qi T, Xin X, et al. Life cycle environmental impacts of cornstalk briquette fuel in China. Appl Energy. 2017; 192: 83–94.

[31] Bhattacharya SC, Leon MA, Rahman MM. A study on improved biomass briquetting. Energy for Sustainable Development. 2002.

[32] Dinesha P, Kumar S, Rosen MA. Biomass Briquettes as an Alternative Fuel: A Comprehensive Review. Energy Technol. 2018; 1(11): 1–21.

[33] Kaur A, Roy M, Kundu K. Densification of Biomass by Briquetting: A Review. Int J Recent Sci Res. 2017; 8(10): 20561–20568.

[34] Surendra KC, Khanal SK, Shrestha P, Lamsal B. Current status of renewable energy in Nepal: Opportunities and challenges. Renew Sustain Energy Rev. 2011; 15: 4107–4117.

[35] Mwampamba TH, Owen M, Pigaht M. Opportunities, challenges and way forward for the charcoal briquette industry in Sub-Saharan Africa. Energy Sustain Dev. 2013; 17: 158–170.

[36] Tripathi AK, Iyer PVR, Kandpal TC. A Techno-economic evaluation of biomass briquetting in India. Biomass and Bioenergy. 1998; 14(5/6): 479–488.

[37] Chen L, Xing L, Han L. Renewable energy from agro-residues in China: Solid biofuels and biomass briquetting technology. Renew Sustain Energy Rev. 2009; 13(9): 2689–2695.

[38] Rousset P, Caldeira-Pires A, Sablowski A, Rodrigues T. LCA of eucalyptus wood charcoal briquettes. J Clean Prod. 2011; 19(14): 1647–1653.

[39] Pallavi H V, Srikantaswamy S, Kiran BM, Vyshnavi DR, Ashwin CA. Briquetting Agricultural Waste as an Energy Source. J Environ Sci Comput Sci Eng Technol. 2013; 2(1): 160–172.

[40] Olorunnisola A. Production of Fuel Briquettes from Wastepaper and Coconut Husk Admixtures. CIGR Ejournal. 2007; IX: 1–11.

[41] Obi, O.F, Akubuo, C.O, Nwankwo V. Development of an Appropriate Briquetting Machine for Use in Rural Communities. Int J Eng Adv Technol. 2013; 2(4): 578–582.

[42] Ajieh MU, Igboanugo AC, Audu TOK. Design of grass briquette machine. Niger J Technol. 2016; 35(3): 527–530.

[43] Dairo OU, Adeleke AE, Shittu T, Ibrahim NA. Development and Performance Evaluation of a Low-Cost Hydraulic-Operated Biomass Briquetting Machine 1*. FUOYE J Eng Technol. 2018; 3(1): 1–6.

[44] Legacy Foundation. Fuel Briquette Press Kit – A Construction Manual. 2003.

[45] Tumuluru SJ, Christopher WT, Kenny KL, Hess JR. A Review on Biomass Densification Technologies for Energy Application. Idaho; 2010.

[46] Stolarski MJ, Szczukowski S, Tworkowski J, Krzyzaniak M, Gulczyński P, Mleczek M. Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass. Renew Energy. 2013; 57: 20–26.

[47] Arewa ME, Daniel IC, Kuye A. Characterization and comparison of rice husk briquettes with cassava peels and cassava starch as binders. Biofuels. 2016; 7(6): 671–675.

[48] Kpalo SY, Zainuddin MF, Halim HBA, Ahmad AF, Abbas Z. Physical characterization of briquettes produced from paper pulp and Mesua ferrea mixtures. Biofuels. 2019; 1–8. https://doi.org/10.1080/17597269.2019.1695361.

[49] Tumuluru JS. Effect of pellet die diameter on density and durability of pellets made from high moisture woody and herbaceous biomass. Carbon Resour Convers. 2018; 1(1): 44–54.

[50] Efomah AN, Gbabo A. The Physical, Proximate and Ultimate Analysis of Rice Husk Briquettes Produced from a Vibratory Block Mould Briquetting Machine. IJISET-International J Innov Sci Eng Technol. 2015; 2(5): 814–822.

[51] Eriksson S, Prior M. The Briquetting of agricultural wastes for fuel. Rome, Italy: Food and Agricuture Organization; 1990. 131 p.

[52] Bajwa DS, Peterson T, Sharma N, Shojaeiarani J, Bajwa SG. A review of densified solid biomass for energy production. Renew Sustain Energy Rev. 2018; 96: 296–305.

[53] Lyheang C, Limmeechokchai B. The role of renewable energy in CO2 mitigation from power sector in Cambodia. Int Energy J. 2018; 18(4): 401–408.

[54] International Energy Agency. CO2 emissions from fuel combustion - Highlights. 2019 Available from: www.iea.org/t&c/ (accessed on 20 November 2019).

[55] Tursi A. A review on biomass: importance, chemistry, classification, and conversion. Biofuel Res J. 2019; 22: 962–979.

[56] Kumar D, Singh B. Role of biomass supply chain management in sustainable bioenergy production. Biofuels. 2017; 1–11.https://doi.org/10.1080/17597269.2017.1368060.

[57] Kuhe A, Ibiang FA, Igbong DI. Potential of low pressure agricultural waste briquettes: An alternative energy source for cooking in Nigeria. J Renew Sustain Energy. 2013; 5(1): 1–8.

[58] Singh RM, Kim HJ, Kamide M, Sharma T. Biobriquettes-an Alternative Fuel for Sustainable Development. Nepal J Sci Technol. 2010 Apr 16; 10: 121–127.

[59] Chen H. Lignocellulose biorefinery product engineering. In: Lignocellulose Biorefinery Engineering. 1st ed. Cambridge, UK: Woodhead Publishing Limited; 2015. p. 125–165.

[60] Romallosa A, Kraft E. Feasibility of Biomass Briquette Production from Municipal Waste Streams by Integrating the Informal Sector in the Philippines. Resources. 2017; 6(12): 2–19.

[61] Njenga M, Karanja N, Prain G, Malii J, Munyao P, Gathuru K, et al. Community-based energy Briquette production from urban organic waste at Kahawa Soweto Informal Settlement, Nairobi. Urban Harvest Working Paper Series No. 5. International Potatoe Center, Lima, Peru; 2009.

[62] Jingura RM, Musademba D, Kamusoko R. A review of the state of biomass energy technologies in Zimbabwe. Renew Sustain Energy Rev. 2013; 26: 652–659.

[63] Popp J, Lakner Z, Harangi-Rákos M, Fári M. The effect of bioenergy expansion: Food, energy, and environment. Renew Sustain Energy Rev. 2014; 32: 559–578.

[64] Portugal-Pereira J, Soria R, Rathmann R, Schaeffer R, Szklo A. Agricultural and agro-industrial residues-to-energy: Techno-economic and environmental assessment in Brazil. Biomass and Bioenergy. 2015; 81: 521–533.