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Synthesis and Characterization of Briquette from Carbonized *Pinus Patula* Saw Dust as Alternative Energy Source

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ABSTRACT

This study aimed at the synthesis and characterization of briquette from *Pinus patula* saw dust using different binders. The effects of particle size and type of binder on the fuel qualities of the briquette were investigated. The bulk density of biomass causes handling, storage, and transportation problems that limit its large application. Densification of biomass into briquettes can solve these problems. The experimental results indicate that briquette produced from waste paper, fruit waste, cow dung, and starch flour binders has higher calorific value, higher fixed carbon, and lower ash content. Whereas, molasses and wood ash binders decreased the calorific value and fixed carbon and increased the ash content of the briquette. As a result, a maximum calorific value of 6596 cal/g, fixed carbon content of 62.6%, and ash content of 3.66% are obtained using waste paper. The calorific value of 6232 cal/g, fixed carbon of 48.74%, and ash content of 3.33% was obtained using fruit waste while the calorific value of 6194 cal/g, fixed carbon content of 59.94 %, and ash content of 5.35% was observed when cow dung is used. When starch flour is used, a calorific value of 6170 cal/g, fixed carbon content of 54.63%, and ash content of 2.63 was obtained. Therefore, waste paper, fruit waste, cow dung, and starch flour are promising binders that improve the fuel qualities of biomass briquettes.

INTRODUCTION

Energy is an important resource for human development and existence on the planet. The need for clean and sustainable energy sources is rising as a result of population growth, urbanization, and higher living standards (Perea-Moreno et al., 2019). One of today's greatest problems is the absence of affordable and clean fuel for cooking in the home and industrial processes (Nwabue et al., 2017). Because fossil fuels harm the environment, and are not sustainable, relying solely on them is not sustainable (Kotcher et al., 2019). Thus, renewable energy sources are attracting the attention of countries since they are environmentally benign and more competitive (Riti & Shu, 2016).

Biomass is a promising clean energy source (Regmi et al., 2021; Sher et al., 2020). Solid biomass, or over 280 million tons of oil equivalent from wood, straw, charcoal, or dried animal and human waste, accounts for more than 90% of the energy used in sub-Saharan Africa (Africa Energy Outlook, 2014). According to different reports about three billion people in the world rely on wood fuel for household cooking activities (Yank et al., 2016). Approximately 25,000 tonnes of wood residue are obtained annually from sawmilling companies in Ethiopia. However, because of its low bulk density, high moisture content, and low energy content, the residue is underutilized.

As a result, it has little economic value in its raw form (Benti et al., 2021). In Ethiopia, wood fuel is the most popular forest product for cooking and home heating. Every year, more than 100 million cubic meters of wood fuel are used. This leads to the unsustainable use of woodlands and forests, which exacerbates environmental issues including deforestation and land degradation (Hirpa et al., 2023; MEFCC, 2017). Moreover, about 92% of biomass energy is used in a traditional way which causes indoor air pollution and negative effects on public health and the environment (Sanbata et al., 2014).

After oil, coal, and gas, biomass ranks as the fourth most important primary energy source. It contributes roughly 14% of the world's primary energy supply (Shiferaw et al., 2017). Ethiopia has huge and inexhaustible biomass resources, but for a variety of reasons, they aren't transformed into economic value. Wood waste from home industries such as sawdust and chips is not used to generate electricity except at a few restricted places. Currently, 171,000 m³ is thought to be the total amount of wood waste produced (MEFCC, 2017).

Woody biomass accounts for around 95% of the country's energy supply, which is roughly 68% of the total energy supply (Berhanu et al., 2017; MEFCC, 2018). Despite its potential resource, direct utilization of biomass as a source of energy is not suitable because it has low bulk density, high smoke, and low energy intensity (Weldemedhin, et al., 2014). Densification of biomass into briquettes, pellets, and other densified biomass energies can solve these problems.

Briquettes are combustible materials produced by densifying agricultural and biomass residues such as sawdust (Andrew Ndudi Efomah & Gbabo, 2015). It is a solid biofuel that can be made from rise husk (Duangkham & Thuadaij, 2023), coffee husk (Tesfaye et al., 2022a), sugar cane bagasse (Mekonen et al., 2024), corn cob (Nagarajan & Prakash, 2021), bamboo species (Krishnamoorthi et al., 2023) by biomass densification with or without additives (Gwenzi et al., 2020).

Briquette is a biofuel that offers clean and affordable sources of energy to many people in rural areas (Abdu Zubairu, 2014; Nsubuga et al., 2020). It has good fuel qualities in terms of density and calorific value (Avelar et al., 2016). This research aimed to obtain an alternative renewable energy source from sawdust charcoal. Moreover, it investigates the physicochemical characteristics and potential of *p.patula* sawdust for the production of briquette.

METHODS

Sample Collection and Preparation

Pinus patula sample sawdust was collected from *Arsi Negelle* sawmill industry. Then, the collected sawdust sample was transported to the Forest Products Innovation Center of Excellence laboratory for briquette production. The necessary steps of the briquette production; milling, drying, and pressing (Lela et al., 2016) were conducted. After spreading the sawdust over a canvas carpet that was 4 cm thick, it was left to dry in the shade for two weeks at an average temperature of 29^0C until the moisture content fell below 12%. The dried sawdust was sieved into three different mesh sizes (0.6 mm, 1.18 mm, and 2.36 mm). Sieve size influences the fuel quality of briquettes (Chaloupková et al., 2018). Twelve treatments comprising three levels of sieve sizes and six levels of binding agents (Molasses-MOL, cow dung-CD, fruit waste-FW, wood ash-WA, Waste Paper-PW, and Starch Flour-SF) were used according to experimental design (Completely Randomized Design, CRD).

Carbonization Process

The sawdust from *P. patula* was carbonized in a metal kiln in oxygen deficient environment for an average of 1 hour and 30 minutes. Then, the carbonized sawdust was removed from the kiln and spread over the floor to cool it. Then, the carbonized sawdust was packed according to the sieve size. The absence of smoke, soot, or carbon deposits is a benefit of carbonized sawdust briquette than raw sawdust briquette. They either don't produce fly ash at all or very little, and they don't release any gas or harmful substances like sulfur, depending on the base material. Compared to raw biomass, carbonization can improve hydrophobicity and energy density (Niedziólka et al., 2015).

Briquetting Process

Briquette making process (briquetting) needs a binding material to produce densified solid briquette (Anatasya et al., 2019). Organic Binders such as molasses (Mol), cow dung (CD), fruit waste (FW), waste ash (WA), and waste starch flour (SF) were used as a binding agent to make biomass briquette. During the process, 3 kg of the carbonized sawdust charcoal was mixed manually with 1 kg of each binder (3:1) (Merete et al., 2014). To aid in mixing and promote intermolecular adhesion, a small amount of water was added. This was left in place for 15 minutes until homogenous molds were formed.

Volatile Matter

Volatile matter (VM) was determined using the standard method (ASTM D3175-18, 2018). 2 g of briquette sample was pulverized and oven-dried at 105 ºC until its weight was constant. The sample was then heated at 550ºC for 10 min and weighed after cooling in desiccators. The VM was calculated as:

$$VM = \frac{W1\text{-}W2}{W1} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where:

VM is the percentage of volatile matter.

W1 is the original weight of the sample.

W2 is the weight of the sample after cooling.

Fixed Carbon

Fixed carbon (FC) was determined using standard (ASTM D3172-2015) by subtracting the sum of VM, PAC, and MC content from 100 as:

$$\text{Fixed Carbon} = 100\% - (AC+MC+VM) \ldots\ldots\ldots \text{(2)}$$

Calorific Value

The caloric value (CV) of the produced briquette was determined by using a Parr Oxygen bomb calorimeter according to the standard method (ASTM D5865-13, 2019). Two grams of the briquette samples were placed in the crucibles and put in to bomb calorimeter. By comparing the rise in galvanometer deflection with that produced when a sample of known calorific value of benzoic acid is burned, the greatest deflection obtained in the galvanometer was converted to the energy value of the sample.

Sulfur Content

The sulfur content was determined using the method described by the standard (ASTM D 3177 – 02, 2018). 1 g of pulverized briquette sample was put into a porcelain crucible and mixed with 3gm of Eschka mixture. The mixture was then covered with 1gm of Eschka mixture. The crucibles were then put in a cold muffle furnace and heated gradually to 800°C for 60 minutes. The total sulfur content was calculated as:

$$\text{Total sulphu} = A\text{-}B * \frac{13.738}{C} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where:

A is the mass of barium sulfate from the sample.

B is the mass of barium sulfate from the blank.

C is the mass of a sample.

Ultimate Analysis

The ultimate analysis (C, H, O, N) was done with ASTM analytical methods. Statistical analysis of data was carried out using SAS Software, Version 9, and Microsoft Excel (2016). The means that exhibited significant differences were compared using the Least Significant Difference (LSD) at ($P < 0.001$) level.

RESULTS AND DISCUSSION

Variation in Proximate, Calorific Value, and Sulphur Content of Briquette

The findings of the two-way analysis of variance for analyzing the presence of significant differences in briquette properties based on binders and particle size are shown in (Table 1). This ANOVA analysis also showed which factors and their interactions have an important influence on the produced briquette quality. The impacts of binders on the briquettes' proximal characteristics showed a highly significant difference ($P < 0.001$). The particle size of the feedstock showed significant differences in the volatile matter, calorific value, and fixed carbon content ($P<0.001$). On the other hand, moisture content was a significant difference ($P < 0.01$).

The ANOVA results also revealed that there were no significant differences ($P>0.05$) in the qualities of the briquettes produced from the different particle sizes of the sawdust with reference to the ash and sulfur content. The interaction effects of binding agent and energy value showed significant differences in volatile matter, fixed carbon, and calorific value ($p< 0.001$) but significant in moisture content ($P<0.05$) and insignificant in ash and sulfur ($P>0.05$).

Table 1. Analysis of variance (ANOVA) for proximate, calorific value and Sulphur content son briquette

Source of variation	DF	Mean Square					
		MC	VM	FC	Ash	CV	S
Particle Size	2	0.68**	28***	4.47***	3.64ns	95509***	0.017ns
Type of binding agent	5	18***	660***	847***	1026***	6189922***	0.43***
Interaction effect	10	0.24*	14***	20***	5ns	105565***	0.006ns
CV		5.03	2.37	1.3	18.13	0.84	39
R2		0.96	0.99	0.996	0.98	0.99	0.91

****= significant at P < 0. 001; **=significant at P < 0.01; *= significant at P < 0.05; and ns=non-significant at P > 0.05 CV = coefficient of variation, R = regression factor, DF = degree of freedom.*

The Effects of Particle Size, and Binding Agents on Fuel Qualities of Briquette Moisture Content

As a result of endothermic evaporation, a briquette's moisture content influences its internal temperature and determines the total energy needed to get it to the temperature required for pyrolysis. Maximum moisture content of 8.78% at 1.18 mm particle size was obtained for briquettes produced from fruit waste binder (table 2) and the lowest moisture content briquette was produced using wood ash binding agent which was 5.03% at 0.6 mm particle size (table 2). The range of moisture content for these briquettes was ranging from 5% to 8.78%. Briquettes with wood ash as binders showed the lowest moisture content.

The type of binding agent used also caused variation in moisture content. Briquettes have an average moisture content of 6.2 % to 10.2 % according to (Kpalo et al., 2020a). Briquette can have moisture content as high as 15 % (Kpalo et al., 2020b). According to (Akpenpuun et al., 2020), briquette can have a moisture content of 8% to 15% on average. The moisture content obtained in this study is in agreement with the standard range for briquettes and previous studies. Similar results were discovered by (Abdu Zubairu, 2014).

Table 2. Result for proximate analysis of briquette

Test parameter	Particle size	Binding agents					
		Fruit waste	Waste paper	Cow dung	Molasses	Starch flour	Wood Ash
Moisture content	0.6	8.237^{b}	5.957^{c}	7.543^{b}	5.123b^{c}	7.933b^{c}	5.03^{b}
	1.18	8.78^{a}	6.52^{a}	7.96^{a}	5.07^{c}	8.41^{a}	5.15^{a}
	2.36	7.79^{c}	6.23^{b}	7.09^{c}	5.39^{a}	8.08^{b}	5.35^{a}
Volatile Matter	0.6	41.9^{a}	32.133^{a}	28.44b	48.23^{b}	36.437^{b}	27.37^{a}
	1.18	39.41^{b}	27.71^{c}	26.21c	49.5^{a}	34.9^{c}	25.46^{c}
	2.36	41.34^{a}	28.1^{b}	31.29^{a}	47.42^{c}	42.34^{a}	26.7^{b}
Fixed Carbon	0.6	46.72^{b}	58.2^{c}	58.757^{b}	37.607^{a}	53.197^{a}	38.923^{b}
	1.18	48.74^{a}	61.55^{b}	59.94^{a}	35.83^{b}	54.63^{b}	37.42^{c}
	2.36	46.43^{b}	62.6^{a}	56.9^{c}	37.53^{a}	46.56^{c}	42.52^{a}
Calorific Value	0.6	6232^{a}	6312^{c}	6110^{c}	5126^{b}	6090^{b}	4240^{b}
	1.18	6112^{b}	6481^{b}	6194^{ab}	4973^{c}	6170^{a}	3947^{c}
	2.36	6038^{c}	6596^{a}	6196^{a}	5421^{a}	5440^{c}	4582^{a}

There is no significant difference in means with the same letter along the column

Volatile Matter

The sample with low volatile matter has a higher energy value (Onukak et al., 2017). Due to its high volatile matter content, the fuel would release huge pollutants and smoke while burning. Carbonization can lower the volatile matter of substances (C. N. Ibeto et al., 2016). The results showed that volatile matter content has a statically difference within the particle size (table 2). The highest volatile matter content was recorded at 49.5% binding with molasses at 1.18mm particle size and the lowest value of 25.46 % binding with wood ash with the same particle size. This result is in agreement with previous findings of (Akpenpuun et al., 2020).

Fixed Carbon

Fixed carbon is the major fuel quality parameter that determines the energy characteristics of (Messay et al., 2021). Fixed carbon content obtained binding with waste paper at 2.36 mm particle size was the highest value (62.6%) and the lowest value was binding with wood ash (35.83%) (table 2). This result is in agreement with previous studies by Kebede et al. (2022).

Calorific Value

Calorific value is the most important fuel characteristic that affects its energy content (Onochie et al., 2022). The result showed briquettes made from *P. Patula* sawdust binding with waste paper using 2.36mm particle size recorded the highest calorific value of 6,596 cal/g (Table 2). On the other hand, sawdust binding with wood ash using 1.18mm particle size recorded the lowest value of 3947 cal/g. The literature on biomass briquette revealed that the quality of briquette differs based on the type of biomass used. (Tesfaye et al., 2022b) reported that briquette made from coffee husk has a calorific value of 8,480 cal/g which is higher than that of this study.

On the other hand, the calorific value of briquette obtained in this research was higher than the calorific value of briquettes produced from grass, which was 3817.6 cal/g (Messay *et al.*, 2021; Onukak *et al.*, 2017). Briquettes produced from *P.patula* sawdust have higher calorific values than other wood biomass, which has a calorific value of 3,296.82 cal/g as reported by (FAO, 2018). According to (Prince Ofori & Osei Akoto, 2020). Wood and sawdust, which contain high levels of lignin, have higher calorific values due to the extractives bond that raises the heating value of the biomass.

Sulfur Content

As the result showed (Table 3) the main effect of the binding agent, the sulfur content was significant and statically uniform. Due to the toxic nature of sulfur released into the atmosphere, biomass fuel with lower sulfur contents is preferred. The percentage of sulfur recorded was within an acceptable range in all binding agents except for Molasses which was 0.64%. According to (Adekunle et al., 2015), the sulfur content of biomass should be less than 1%. The sulfur and nitrogen contents reported were below 1% indicating that there is minimum sulfur and Nitrogen release into the atmosphere.

Ash Content

The mean effects of binding agents within particle sizes revealed that SF, WP, and FW binding agents had shown significant and statistically equivalent ash content values of 2.64 %, 3.66 %, and 3.33% respectively. However, comparing ash content within particle size, the result indicated statistically uniform ash content (Table 3). The maximum ash content recorded was 30.33 % when binding with wood ash and the lowest value obtained was 2.64% when binding with starch flour. The high ash content recorded for the carbonized *P.patula* sawdust sample could be due to the high level of inorganic elements in the sawdust (calcium, potassium, and silicon) which remained after burning (Adamovics et al., 2018). Since ash is a non-combustible waste, high ash content reduces the heat value of the briquette (Waluyo & Pratiwi, 2018).

Table 3. Main effects of binding agent and particle size on ash and sulfur content

Treatment	Mean Separation	
Binding agents	Ash	Sulfur (%)
FW	3.3311d	0.117^{b}
WP	3.6644d	0.104^{b}
CD	5.35c	0.129^{b}
MOL	9.6489b	0.646^{a}
SF	2.6378d	0.139^{b}
ASH	30.3322a	0.078^{b}

	sieve size	
0.6 mm	9.3294a	0.172^{b}
1.18 mm	9.5017a	0.200^{ab}
2.36 mm	8.6511a	0.233^{a}

Ultimate Analysis (C, H, O, N) Result

Ultimate value is the chemical composition of fuel that affects the heating value (Onochie et al., 2023). The experimental result revealed that the C, H, O, and N values showed significant differences between binding agents and particle size. *P.patula* briquette has a high carbon content that shows its higher combustion efficiency and calorific value. It has a lower N value. As the N value of fuels increases, NOx is increases and results in air pollution.

Table 4. Ultimate analysis of *P. patula* briquette

	Binding agents					
Test parameters	Fruit waste	Waste paper	Cow dung	Molasses	Starch flour	Wood Ash
Carbon (C)	47.295	52.115	47.679	45.685	45.369	31.581
Hydrogen (H)	5.137	5.393	4.983	5.280	4.867	3.945
Oxygen (O)	34.193	34.195	31.516	35.753	32.137	23.425
Nitrogen (N)	1.545	1.676	1.520	1.516	1.458	1.077

The experimental result showed that maximum Carbon, Hydrogen, Oxygen, and Nitrogen content briquette was produced using cow dung, waste paper, molasses, and waste paper as binders with values of 47.67%, 5.39%, 35.75%, 1.67 respectively and the lowest Carbon, Hydrogen, Oxygen, and Nitrogen content obtained was 31.58%, 3.94%, 23.42%, and 1.07% using wood ash binder in all cases (table 3). These results agreed with the previous results reported by (Andrew Ndudi Efomah & Gbabo, 2015) and (Onochie et al., 2023).

CONCLUSION

The increasing population number, and urbanization has increased the energy demand of the world. The increasing price of fossil fuels and their environmental problems has pushed countries to search for clean and alternative energy sources. Despite the potential biomass energy resource in Ethiopia, it is underutilized due to its low bulk density, high moisture content, and low energy density.

Briquette is a densified biomass fuel produced from various biomass materials using different binders. Briquettes produced from biomass sources for household cooking, heating, and industrial applications serve as a substitute for wood fuel and fossil fuels. The advantages of biomass briquette are it can be produced from abundant biomass sources with low production cost, it has good fuel quality, is sustainable and it is environmentally friendly.

The proximate and ultimate properties of *P. patula* sawdust briquettes prepared using different binding agents and particle sizes were investigated in this study. The fuel quality of the briquettes was influenced by the type of binding agent and sieve size used. Briquettes produced in this study with waste paper have the best fuel qualities when compared to the other binding agents.

In this study, the type of binder used and sieve size showed a significant effect on the result of fuel properties. Briquette produced using a waste paper binding agent with a 2.36mm sieve size has the highest calorific value, high fixed carbon, and low ash content with respective values of 6596 cal/g, 62.6%, and ah content of 3.66%. Whereas, the lowest calorific value, lower fixed carbon, and highest ash content were observed when wood ash binder was used with respective values of 3947 cal/g, 37.42%, and 30.33%. Briquette produced from Fruit waste, cow dung, and starch flour binders has better fuel qualities than briquette bonded with molasses and wood ash binders. Therefore, Fruit waste, waste paper, cow dung, and starch flour are promising binders for the sustainable production of biomass briquette from *pinus patula saw* dust in Ethiopia.

REFERENCES

1. Abdu Zubairu. (2014). Production and Characterization of Briquette Charcoal by Carbonization of Agro-Waste. *Energy and Power*, *4*(2), 41–47.
2. Adamovics, A., Platace, R., Gulbe, I., & Ivanovs, S. (2018, May 23). *The content of carbon and hydrogen in grass biomass and its influence on heating value*. 17th International Scientific Conference Engineering for Rural Development. https://doi.org/10.22616/ERDev2018.17.N014
3. Adekunle, J., Ibrahim, J., & Kucha, E. (2015). Proximate and Ultimate Analyses of Biocoal Briquettes of Nigerian's Ogboyaga and Okaba Sub-bituminous Coal. *British Journal of Applied Science & Technology*, *7*(1), 114–123.
4. Africa Energy Outlook. (2014). *A focus on energy prospects in Sub-Saharan Africa. International Energy Agency IEA*. International Energy Agency.
5. Akpenpuun, T. D., Salau, R. A., Adebayo, A. O., Adebayo, O. M., 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. *Journal of Applied Sciences and Environmental Management*, *24*(1), 171.
6. Anatasya, A., Umiati, N. A. K., & Subagio, A. (2019). The Effect of Binding Types on the Biomass Briquette Calorific Value from Cow Manure as a Solid Energy Source. *E3S Web of Conferences*, *125*, 13004.
7. Andrew Ndudi Efomah, & Gbabo, A. (2015). The Physical, Proximate and Ultimate Analysis of Rice Husk Briquettes Produced from a Vibratory Block Mould Briquetting Machine. *International Journal of Innovative Science, Engineering & Technology*, *2*(5).
8. ASTM D 3177 – 02. (2018). *Standard Test Methods for Total Sulfur in the Analysis Sample of Coal and Coke*.
9. ASTM D3173-11. (2017). *Standard Test Method for Moisture Analysis of Particulate Wood Fuels*.
10. ASTM D3174-12. (2018). *Standard Test Method For Ash in Wood*.
11. ASTM D3175-18. (2018). *Standard Test Method for Volatile Matter in the Analysis of Particulate Wood Fuels*.
12. ASTM D5865-13. (2019). *Standard Test Method for Gross Calorific Value of Coal and Coke*.
13. Avelar, N. V., Rezende, A. A. P., Carneiro, A. D. C. O., & Silva, C. M. (2016). Evaluation of briquettes made from textile industry solid waste. *Renewable Energy*, *91*, 417–424.
14. Benti, N. E., Gurmesa, G. S., Argaw, T., Aneseyee, A. B., Gunta, S., Kassahun, G. B., Aga, G. S., & Asfaw, A. A. (2021). The current status, challenges and prospects of using biomass energy in Ethiopia. *Biotechnology for Biofuels*, *14*(1), 209.
15. Berhanu, M., Jabasingh, S. A., & Kifile, Z. (2017). Expanding sustenance in Ethiopia based on renewable energy resources – A comprehensive review. *Renewable and Sustainable Energy Reviews*, *75*, 1035–1045.
16. C. N. Ibeto, C. N. Anyanwu, & J. A. Ayodele. (2016). *Evaluation of Pollution Potentials and Fuel Properties of Nigerian SubBituminous Coal and its blends with Biomass*. *7*(8), 2929–2937.
17. Chaloupková, V., Ivanova, T., Ekrt, O., Kabutey, A., & Herák, D. (2018). Determination of Particle Size and Distribution through Image-Based Macroscopic Analysis of the Structure of Biomass Briquettes. *Energies*, *11*(2), 331.
18. Duangkham, S., & Thuadaij, P. (2023). Characterization of charcoal briquettes produced from blending rice straw and banana peel. *Heliyon*, *9*(6), e16305.
19. FAO. (2018). *Bioenergy and Food Security (BEFS), Improved Charcoal Technologies and Briquette Production from Woody Residues in Malawi.*
20. Gwenzi, W., Ncube, R. S., & Rukuni, T. (2020). Development, properties and potential applications of high-energy fuel briquettes incorporating coal dust, biowastes and post-consumer plastics. *SN Applied Sciences*, *2*(6), 1006.
21. Hirpa, G. Y., Letema, S. C., & Ming'ate, F. L. M. (2023). Effect of Forest Landscape Restoration on Ecosystem Services in Ethiopia: Review for Future Insight. *Indonesian Journal*

of Social and Environmental Issues (*IJSEI*), 4(3), 327-338.

22. Kebede, T., Berhe, D. T., & Zergaw, Y. (2022). Combustion Characteristics of Briquette Fuel Produced from Biomass Residues and Binding Materials. *Journal of Energy*, *2022*, 1–10.
23. Kotcher, J., Maibach, E., & Choi, W.-T. (2019). Fossil fuels are harming our brains: Identifying key messages about the health effects of air pollution from fossil fuels. *BMC Public Health*, *19*(1), 1079.
24. Kpalo, S. Y., Zainuddin, M. F., Manaf, L. A., & Roslan, A. M. (2020a). A Review of Technical and Economic Aspects of Biomass Briquetting. *Sustainability*, *12*(11), 4609.
25. Kpalo, S. Y., Zainuddin, M. F., Manaf, L. A., & Roslan, A. M. (2020b). Production and Characterization of Hybrid Briquettes from Corncobs and Oil Palm Trunk Bark under a Low Pressure Densification Technique. *Sustainability*, *12*(6), 2468.
26. Krishnamoorthi, S., Divya, M. P., Sekar, I., Varuvel, G. J., Ravi, R., & Hemalatha, P. (2023). Production and Characterization of Sustainable Biomass Briquettes from Selected Bamboo Species. *Journal of Biobased Materials and Bioenergy*, *17*(5), 650–661.
27. Lela, B., Barišić, M., & Nižetić, S. (2016). Cardboard/sawdust briquettes as biomass fuel: Physical–mechanical and thermal characteristics. *Waste Management*, *47*, 236–245.
28. MEFCC. (2017). *Ethiopia Forest Sector Review Focus on commercial forestry and industrialization*. https://www.forestcarbonpartnership.org/system/files/documents/Ethiopia%20FSR%20final.pdf
29. MEFCC. (2018). *National Forest Sector Development Program, Ethiopia. Vol I. Situation Analysis.*
30. Mekonen, A. G., Berhe, G. G., Desta, M. B., Belete, F. A., & Gebremariam, A. F. (2024). Production and characterization of briquettes from sugarcane bagasse of Wonji Sugar Factory, Oromia, Ethiopia. *Materials for Renewable and Sustainable Energy*. https://doi.org/10.1007/s40243-023-00248-1
31. Merete, W., Haddis, A., Alemayehu, I., & Argaw Ambelu2. (2014). The Potential of Coffee Husk and Pulp as an Alternative Source of Environmentally Friendly Energy. *East African Journal of Sciences*, *81*(1), 29–36.
32. Messay, E. G., Birhanu, A. A., Mulissa, J. M., Genet, T. A., Endale, W. A., & Gutema, B. F. (2021). Briquette production from sugar cane bagasse and its potential as clean source of energy. *African Journal of Environmental Science and Technology*, *15*(8), 339–348.
33. Nagarajan, J., & Prakash, L. (2021). Preparation and characterization of biomass briquettes using sugarcane bagasse, corncob and rice husk. *Materials Today: Proceedings*, *47*, 4194–4198.
34. Niedziółka, I., Szpryngiel, M., Kachel-Jakubowska, M., Kraszkiewicz, A., Zawiślak, K., Sobczak, P., & Nadulski, R. (2015). Assessment of the energetic and mechanical properties of pellets produced from agricultural biomass. *Renewable Energy*, *76*, 312–317.
35. Nsubuga, D., Banadda, N., Kabenge, I., & Wydra, K. D. (2020). Potential of Jackfruit Waste for Biogas, Briquettes and as a Carbondioxide Sink-A Review. *Journal of Sustainable Development*, *13*(4), 60.
36. Nwabue, F. I., Unah, U., & Itumoh, E. J. (2017). Production and characterization of smokeless bio-coal briquettes incorporating plastic waste materials. *Environmental Technology & Innovation*, *8*, 233–245.
37. Onochie, U. P., Ofomatah, A. C., Onwurah, C., Tyopine, A. A., Akingba, O. O., Kubeynje, B. F., Aluma, C. C., & Alozie, C. (2023). Potentials of Biomass Waste Resources with Respect to their Calorific Value, Proximate and Ultimate Analysis for Energy Utilization. *IOP Conference Series: Earth and Environmental Science*, *1178*(1), 012012.
38. Onukak, I., Mohammed-Dabo, I., Ameh, A., Okoduwa, S., & Fasanya, O. (2017). Production and Characterization of Biomass Briquettes from Tannery Solid Waste. *Recycling*, *2*(4), 17.
39. Perea-Moreno, M.-A., Samerón-Manzano, E., & Perea-Moreno, A.-J. (2019). Biomass as Renewable Energy: Worldwide Research Trends. *Sustainability*, *11*(3), 863.
40. Prince Ofori & Osei Akoto. (2020). Production and Characterisation of Briquettes from

Carbonised Cocoa Pod Husk and Sawdust. *OALib*, *7*(2), 1–20.

41. Regmi, S., Dahal, K. P., Sharma, G., Regmi, S., & Miya, M. S. (2021). Biomass and Carbon Stock in the Sal (Shorea robusta) Forest of Dang District Nepal. *Indonesian Journal of Social and Environmental Issues* (*IJSEI*), 2(3), 204-212.
42. Riti, J. S., & Shu, Y. (2016). Renewable energy, energy efficiency, and eco-friendly environment (R-E5) in Nigeria. *Energy, Sustainability and Society*, *6*(1), 13.
43. Sanbata, H., Asfaw, A., & Kumie, A. (2014). Indoor air pollution in slum neighbourhoods of Addis Ababa, Ethiopia. *Atmospheric Environment*, *89*, 230–234.
44. Sher, F., Iqbal, S. Z., Liu, H., Imran, M., & Snape, C. E. (2020). Thermal and kinetic analysis of diverse biomass fuels under different reaction environment: A way forward to renewable energy sources. *Energy Conversion and Management*, *203*, 112266.
45. Shiferaw, Y., Tedla, A., Melese, C., Mengistu, A., Debay, B., Selamawi, Y., Merene, E., & Awoi, N. (2017). Preparation and evaluation of clean briquettes from disposed wood wastes. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *39*(20), 2015–2024.
46. Tesfaye, A., Workie, F., & Kumar, V. S. (2022a). Production and Characterization of Coffee Husk Fuel Briquettes as an Alternative Energy Source. *Advances in Materials Science and Engineering*, *2022*, 1–13.
47. Tesfaye, A., Workie, F., & Kumar, V. S. (2022b). Production and Characterization of Coffee Husk Fuel Briquettes as an Alternative Energy Source. *Advances in Materials Science and Engineering*, *2022*, 1–13.
48. Waluyo, J., & Pratiwi, Y. (2018). Analysis Proximate, Ultimate, and Thermal Gravimetric Based on Variations Dimensions of Briquettes from Waste Jackfruit Crust. *International Journal of Scientific Engineering and Science*, *2*(10), 36–39.
49. Weldemedhin, Alemayehu Haddis, Esayas Alemayehu, & Argaw Ambelu. (2014). The Potential of Coffee Husk and Pulp as an Alternative Source of Environmentally Friendly Energy. *East African Journal of Sciences*, *8*(1), 29–36.
50. Yank, A., Ngadi, M., & Kok, R. (2016). Physical properties of rice husk and bran briquettes under low pressure densification for rural applications. *Biomass and Bioenergy*, *84*, 22–30.