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Evaluation and characterization of charcoal briquettes using damar binder for sustainable energy

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Abstract: Palm kernel shells have great potential as biomass and renewable energy sources. Its utilization has not been maximized which is only directly burned which causes air pollution. The accumulation of solid waste in the crude palm oil processing industry negatively impacts the environment. The research aims to determine the characteristics and quality of charcoal briquettes with palm kernel shell carbonization. The main findings of this study are the calorific value, water content, volatile matter, ash content, and fixed carbon in palm kernel shell charcoal briquettes with damar binder. The experimental research method was carried out by carbonizing the raw materials of palm kernel shell briquettes, applying various concentrations of damar binder mixtures. The technical parameters of briquette making were 10 MPa pressure, 60 mesh size, and different carbonization temperatures by furnace. The calorific and proximate were empirically measured by using a bomb calorimeter. This research produced palm kernel shell charcoal briquettes with a calorific value of 30.72 MJ/kg at a carbonization temperature of 500°C and concentration of 85%:15%, a moisture content of 5.18%, volatile matter of 32.72%, ash content of 2.81%, and fixed carbon of 57.90%. Palm kernel shell charcoal briquetting technology is potentially a recommended alternative solid fuel. Consequently, developing renewable energy that is environmentally friendly leads to achieve sustainable energy security. By utilizing waste, the negative impacts on the environment can be overcome and energy needs are also resolved.

Keywords: affordable and clean energy; alternative energy; renewable energy; calorific value

1. Introduction

The need and demand for energy, especially fuel oil, is increasing due to its high usage. Solid fuel adoption is the effective way to accelerate the provision of alternative options, in the form of biomass as Indonesia's great potential on renewable energy for sustainable green energy. Referring to the Sustainable Development Goals (SDGs), the use of biomass as a solid fuel supports clean energy provision, emission reduction, and sustainable waste management. Therefore, more practical development is needed to obtain solid fuels as alternative energy as it is predicted that in 2030, the production of Palm Empty Bunches in Indonesia will reach 54 million tons, with estimated palm kernel shell waste up to 15 million tons [1]. However, the use of palm kernel shells in production has not been optimal yet in Indonesia [2]. Waste from palm oil processing in the form of palm kernel shells is a biomass that is potentially as an energy source with high calorific value and unique physical characteristics [3]. Increasing the potential use of biomass energy can be done by employing briquette densification technology [4]. Briquettes are forms of useful products of solid fuel that is processed by appropriate methods. Briquettes become an excellent solution and cost-saving production method for overcoming the shortage of fossil fuels and renewable energy sources [5].

A method of converting biomass into a specific form which can be easily utilized is briquetting with compaction. Some of the requirements of a good briquette are having a flat texture and no black marks, easy to ignite and not emitting a lot of smoke, non-toxic gas emissions, watertight and not moldy, and having high combustion rate. There are three ways of briquetting technology which are affected by molding pressure, heating, and binders. The briquette binder plays an important role in producing good-quality briquettes. The quality of the briquette binder also influences the quality and performance of the briquettes [6]. The use of organic or inorganic binders affects the bonding ability of compacted materials [7]. Combustion calorific value can be affected by the use and selection of binders. The quality of briquettes is influenced by the nature of the binder, combustion characteristics, mechanical durability, and density of the fuel briquette [8].

In an effort to develop biomass materials and potential into innovative products for energy needs, converting biomass into a highly efficient solid fuel is the subject of much research [9]. Solid fuel as a biomass energy development can be realized by utilizing palm kernel shells. The potential of palm oil waste has been found as an alternative fuel source. Palm kernel shell is the innermost part of the oil palm fruit and has a hard structure. After the oil palm fruit is processed, the shell only becomes the solid waste factory. It have been found that palm kernel shells can be produced into briquettes with promising characteristics. Palm kernel shell as a biomass product, which is as a source of biofuel, has a high content so that it can produce a large maximum heat energy [10]. It is very suitable for further processing to facilitate efficient use as a briquetted solid fuel. The huge and valuable potential of palm kernel shells is to augment energy security through renewable technologies [11]. Research produced an energy source by utilizing palm kernel shells from an economic and environmental perspective [12]. Another one proved an environmentally friendly solid fuel by producing palm kernel shell briquettes that have a calorific value of 18.72 MJ/kg [13]. Research on hybrid briquettes mixed with bagasse and durian peel at a mixture of 80%: 20% has a calorific value of 14.92 MJ/kg [14]. The tibarau biobriquettes through carbonization technology at a temperature of 300 with a concentration of 80%: 20% using damar binder obtained a calorific value of 36.94 MJ/kg [15].

Process innovation to produce briquettes can be developed through carbonization or pyrolysis so as to improve the quality of its structures and characteristics. Carbonization is conducted with thermal decomposition process in the absence of oxygen with fast, slow, medium heating rate [16]. The parameters of the carbonization process can produce good quality charcoal based on the type of biomass and its characteristics [17]. The carbonization process is also able to produce physical properties and increasing the calorific value of palm kernel shell charcoal briquettes [18]. The process can break down the waste into charcoal, volatile matter, and water content [19]. Significant improvements in the mechanical decomposition of char can be achieved by carbonization processes at final temperatures above 500°C [20]. The calorific value of charcoal and ash content can increase, from pyrolysis temperature of 250°C to 450°C [21].

From several studies that have been conducted on palm shell briquettes, further research on examining the significant impact of the carbonization process on palm kernel shells is needed. Additionally, optimization of carbonization temperature with a mixture of raw materials and the use of damar binders that produce information on the characteristics of palm kernel shells charcoal briquettes (calorific value, moisture content, volatile matter, ash content, and fixed carbon) is also demanded. The success of this experimental research is an innovation in producing solid fuels that can guarantee energy sustainability by utilizing waste.

2. Material and methods

The palm kernel shell charcoal used in this study was obtained from industrial waste from a palm oil processing plant. Palm kernel shells contain 33.4 wt% cellulose, 14.4 wt% hemicellulose, and 46.3 wt% lignin [22]. The thermochemical characteristics of palm kernel shells are having a calorific value of 20.89 MJ/kg, moisture content (wt%) 11.89, ash (wt%) 3.87, and carbon (wt%) 50.83 [23]. In this study, damar was used as a binder in making briquettes made from palm kernel shell charcoal. The thermochemical characteristics of damar are having a calorific value of 30.37 MJ/kg, moisture 1.67%, volatile matter 80.55%, ash 17.7%, fixed carbon 0.07%, and carbon 61.145% [24].

The process of making coconut shell charcoal briquettes was carried out in several structured and sequential stages, which were focused on laboratory experimental research. This research is an effort to find the optimal mixture of raw materials and adhesives. Technical parameters of the briquette making process need to be considered, including carbonization temperature, mixture percentage, briquette compressive strength, and particle size. Briquettes production experiment setup is shown in Figure 1.

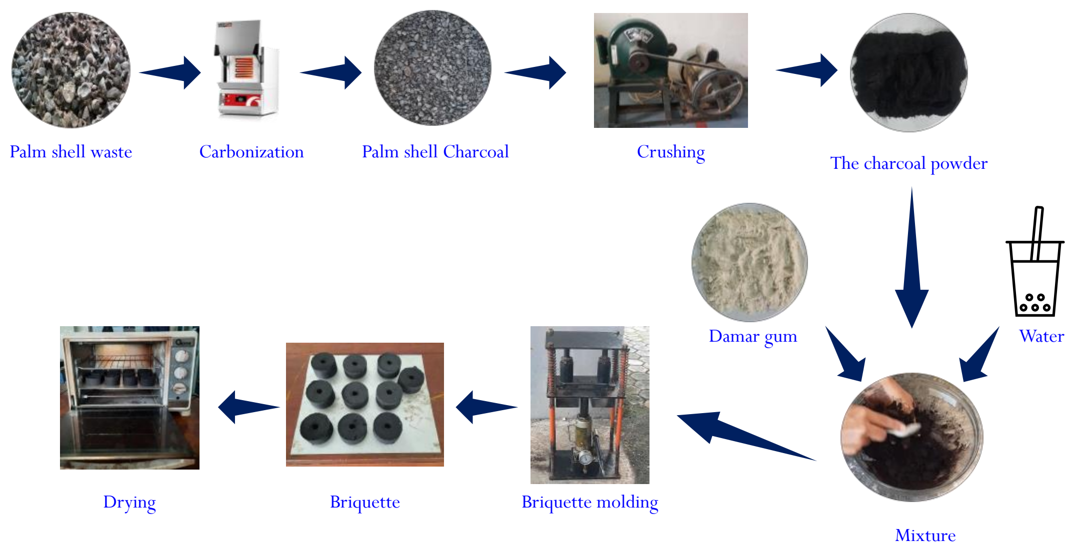

Figure 1. Briquettes production experiment process

The prepared palm shells were cleaned by washing to remove any attached fibers. They were then dried in the sun for several days until totally dry. The dried palm shells were carbonized or pyrolyzed using a CWF 1200 type Carbolite Furnace. Carbonization control parameters, such as final temperature, heating rate, and pressure, can contribute to improving the mechanical resistance of charcoal [20]. The high variability of the energy properties of charcoal and charcoal briquettes requires stricter control of carbonization (process parameters) [25]. The carbonization temperatures used are 400ºC; 450ºC; and 500ºC with a holding time of 1 hour [26], that to clarify the physicochemical characteristics of charcoal and its combustion reactivity, carbonization or pyrolysis can be carried out at temperatures of 400°C to 700°C. The carbonization process of palm shells at high temperatures tends to have an impact on the calorific value and volatile substances [27]. The carbonization process between 280°C to 500°C results in significant mass loss and a decrease in mechanical properties [28].

The finished carbonized palm kernel shells were then grounded and smoothed with a crushing machine. The charcoal powder was used in making briquettes with a size of 60 mesh [29]. The concentration of palm shell charcoal in making biomass briquettes used was 80%wt; 85%wt to

90%wt. The selection of this concentration was based on previous biomass waste research using a raw material concentration of 80%wt [15][30].

In the process of making briquettes, binders were always used to strengthen and maintain the cohesion of raw material particles. Powdered damar binder was used in this study. The use and selection of binders are important in making briquettes, which can affect their characteristics and quality. According to research [24], damar binders have good thermochemical characteristics so that they can increase the thermal efficiency of the briquette combustion process. In addition, it shows the highest calorific value of biobriquettes with the use of damar binders [30]. Based on these studies, however, damar was used as a binder to increase the calorific value of briquettes. The binder concentration in making briquettes used 20%wt; 15%wt; 10%wt, where the selection of values was based on previous research that balances the ratio of the combination to the main raw material to become 100%wt.

In making briquettes, palm shell charcoal was mixed with a damar binder and 50 ml of water was added to facilitate stirring. Mixing and stirring were done in a glass container or cup. The moulding and production of briquettes used a simple hydraulic press moulding tool with a manual jack which was equipped with a pressure gauge. Based on previous research [17], the briquette moulding pressure was 10 MPa. The briquette mould was made of a pipe, resulting its diameter of 55 mm, a height of 29 mm, and a centre hole diameter of 11 mm (dimensions of the produced briquettes). They were then dried by putting them in a heating oven at a temperature of 110°C for 1 hour [31]. The briquettes were then dried in the sun for 4 days [32].

On the next stage, a portion of the dry briquette test sample was cut to test the calorific value and proximate testing (moisture content, volatile matter, ash content, and fixed carbon). This test was carried out based on ASTM using the Boom Calorimeter Analyzer type LECO AC500. In this study, calorific value testing was conducted following ASTM D5865-19 [32] and proximate testing was done following ASTM D7582-15 [33]. The empirical measurement data obtained from the test equipment were made in the form of tables and graphs and were explained in narrative form with easy-to-understand interpretation. The targeted achievement in this study is the characteristics and quality of palm shell biomass briquettes according to the SNI [34] as a solution to achieve environmentally friendly green energy sources in their use. It analysed the variation on mix composition and treatment parameters as indicators of need. Theoretically, mathematical calculations could be obtained for the calorific value of palm kernel shell charcoal briquettes. Hence, the average calorific value of palm kernel shell charcoal briquettes could be revealed.

3. Results and discussion

The results of the conducted experiments showed the quality and characteristics of palm shell charcoal briquettes with damar binders and various variations. In this study, various carbonization temperatures were used. Testing and measurement were focused on obtaining calorific values from empirical measurements using a Bomb Calorimeter Analyzer. Burning a biomass test sample in a bomb vessel and measuring its combustion impact is the working principle of the bomb calorimeter. The heat generated from the combustion of the test sample causes an increase in temperature in the vessel and surrounding water [35]. This calorific value was obtained based on empirical measurement results from the test. Based on testing on the Bomb Calorimeter, the calorific value of the briquettes was obtained as shown in Figure 2.

In Figure 2, the briquette blending concentration at each carbonization temperature produced different heating values. The highest calorific value at each carbonization temperature was at 85%wt:15%wt concentration compared to other blending concentrations. Sequentially, the calorific value of the 85%wt:15%wt blend concentration briquettes at 400, 450, and 500°C carbonization temperatures were 29.61 MJ/kg, 30.58 MJ/kg, and 30.72 MJ/kg, respectively. Based on the test results, it can be said that the calorific value of each briquette specimen is also influenced by the concentration of the mixture used between palm kernel shell charcoal and damar binder. The concentration of the mixture used in this study showed an influence on the calorific value. In addition, the use of binder types in making briquettes can affect the calorific value and quality characteristics [36]. The more damar binder used, the lower the calorific value, but if the binder concentration is smaller, the calorific value will also decrease.

The highest calorific value was at a carbonization temperature of 500°C when compared to that of 400°C and 450°C. It was also applied in each concentration mixture. This condition shows that the higher the carbonization temperature for the three variations, the higher the calorific value. The carbonization temperature set out included medium carbonization between 400 to 500°C which is the optimal temperature to produce biochar with a good pore structure and high fixed carbon content. Biochar in briquettes not only increases the calorific value but also makes briquettes more sustainable and efficient [37][38].

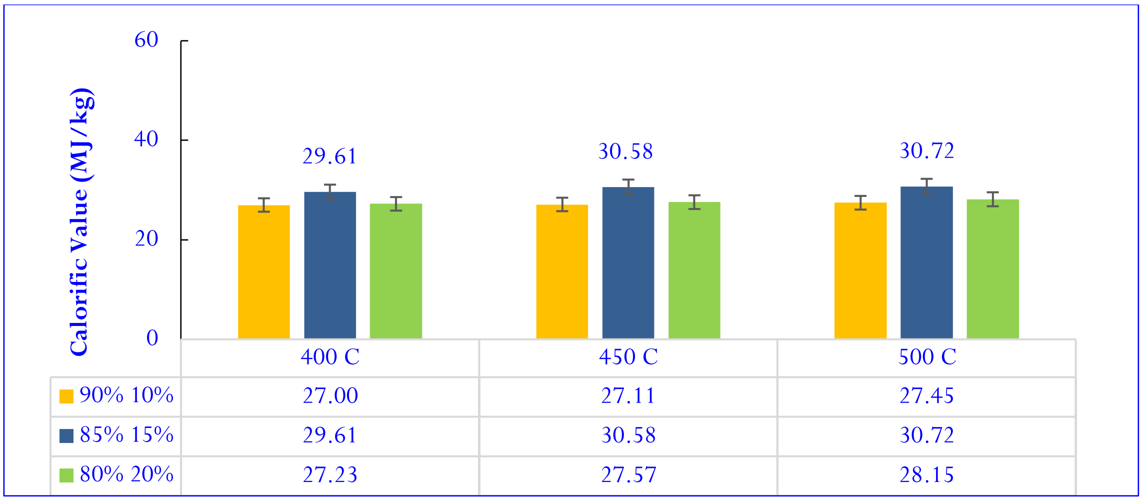

Figure 2. Calorific value of palm kernel shell charcoal briquettes

Palm kernel shell charcoal carbonized at 500°C had a high fixed carbon content (70 - 80%) at a concentration of 85%wt so that the pore structure was well developed, and was estimated to contribute a larger calorific value. In addition, a temperature of 500°C is the optimal point for decomposing volatile compounds (cellulose, lignin) without damaging the carbon structure. The concentration of damar binder 15%wt can increase the energy density without interfering with the combustion of charcoal [30], so that there is no blockage in the pores of the oil palm shell charcoal, and it does not reduce oxygen during combustion. Carbonization of palm shells at 500°C can remove moisture content and volatile matter, but maintain lignin, converted into solid carbon [20]. This temperature also minimizes ash content and increases the high calorific value. The impact of carbonization greatly contributed to the calorific value. The calorific value as a fuel characteristic will increase along with the increase of carbonization or pyrolysis temperature [39]. Increasing the calorific value of briquettes by adding adhesives results in high volatile content and low ash content [40].

Research conducted by Mbada et al., [41] produced palm shell charcoal briquettes, which through the carbonization process, had a calorific value of 26.54 MJ/kg as solid fuel. When it is compared to the results of this study, the calorific value was higher. However, when compared to anthracite coal briquettes, which had a calorific value of 33.5 MJ/kg [42], palm shell charcoal briquettes were still low. Research by Sukarta et al., [43] experimented on coffee wood charcoal briquettes and obtained a calorific value of 28.13 MJ/kg. This result is still lower compared to palm shell charcoal briquettes with damar binder. Comparison with several previous studies, that the calorific value of the palm shell charcoal briquettes produced is better than the calorific value of coffee wood charcoal briquettes and palm shell charcoal briquettes but lower than the calorific value of anthracite coal briquettes. The higher calorific value of carbonized palm kernel shells is relatively higher than that of firewood, peat, and lignin, but lower than that of anthracite coal [41]. Figure 3 compares the calorific value of the palm shell charcoal briquettes produced in this study with several other types of solid fuels.

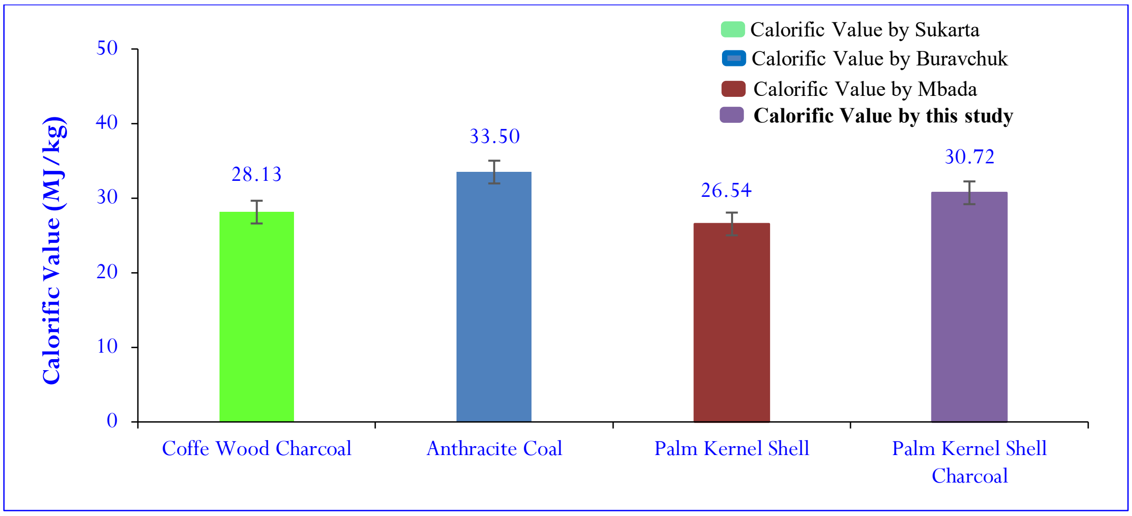

Figure 3. Calorific values of some selected solid fuel

The carbonization process aims to produce smokeless fuel on the flame and remove some of the water content [41]. The effect of carbonization temperature shows that the amount of carbon produced is smaller with higher temperatures, but there is an increase in tar produced. According to research [44], high carbonization temperatures tend to reduce the calorific value, volatile substances, water content, and fixed carbon, but the ash content of the briquettes tends to increase. The following is a classification of charcoal briquettes with the highest heating value based on their carbonization temperature. The classification of briquettes is generated from proximate tests as a test continuation to obtain more detailed characteristics. The briquette characteristics from the proximate test results include moisture content, volatile matter, ash content, and fixed carbon. The classification of palm kernel shell charcoal briquettes and rosin binder with a mixture concentration of 85%:15% at a carbonization temperature of 500°C is shown in Table 1.

Table 1. Classification of palm kernel shell charcoal briquettes with damar binder at 85%:15% mixture at 500°C carbonization

Carbonization temperature (°C)	Calorific value (MJ/kg)	Moisture content (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon (%)
400	29.61	5.64	42.45	3.59	48.33
450	30.52	5.28	37.36	3.11	55.07
500	30.72	5.18	32.72	2.81	57.90

Briquette moisture content is the amount of water contained in the briquette [45]. This parameter was got by measuring the mass of the briquette before and after being heated in the oven. High moisture content impacted on the stability and calorific value of the briquette. Other problems arose when the briquette was stored and distributed [46]. Table 1 shows the moisture content of palm shell charcoal briquettes against carbonization temperature. Based on the test results, it can be seen that the moisture content of each briquette is different. The results of the moisture content test for briquettes with charcoal raw materials at temperatures of 400°C, 450°C, 500°C were 5.64%, 5.28% and 5.18%, respectively. The lower the water content, the higher the calorific value of the briquettes. The difference in moisture content results was caused by the decomposition of charcoal particle absorption resulted from carbonization. Some previous studies have proven that the use of damar binders in briquettes can reduce the moisture content. It is in line with the study, finding that briquettes with damar binders will obtain lower water content, between 3.33 and 4.21% [30]. In addition, the use of damar binders in biobriquettes obtained low moisture content, approximately between 2.21 and 2.72% [5]. Moisture content in this range can ensure stability and durability during storage. In addition, damar binders are known to have a moisture content of 1.67% [24]. In this study, palm kernel shell charcoal briquettes and damar binders with a mixture concentration of 85%wt:15%wt produced a moisture content of 5.18 -5.68%. The results showed that the moisture content of all palm kernel shell charcoal briquettes met the criteria of the Indonesian National Standard (SNI) with a moisture content less than 8% [34].

Volatile matter is a component of carbon, hydrogen, and oxygen contained in biomass briquettes, when heated, vapor containing a mixture of hydrocarbons will be released [47]. Volatile matter is an indicator of briquette quality consisting of various chemical compounds, comprising hydrogen, carbon monoxide, methane, carbon dioxide, and water [48]. Table 1 shows the volatile matter values of palm kernel shell charcoal briquettes and damar binders. The volatile matter values of charcoal briquettes at 400°C, 450°C, and 500°C carbonization were 42.45%, 37.36%, and 32.72%, respectively. The results of this study indicate that the volatile matter content of briquettes is influenced by the use of binders in making charcoal briquettes and carbonization temperature. The volatile matter composition of damar is 80.55%, which results in a high volatile matter content when used in charcoal briquettes [24]. Furthermore, the level of volatile matter in briquettes is influenced by the type of adhesive, and the concentration of the mixture in making charcoal briquettes greatly affects it [49]. High levels of volatile substances will accelerate the combustion of carbon materials which results in lower carbon content and more smoke from combustion. In addition, high volatile matter levels indicate that the fuel samples readily ignite with a proportional flame throughout the combustion process [50]. However, the volatile substances of all briquettes in this study do not meet the criteria of the Indonesian National Standard (SNI) which sets the standard for volatile matter in briquettes is less than15% [34].

Briquettes made from palm kernel shell charcoal produce ash content as a combustion residue [51], [52]. Table 1 shows the effect of carbonized briquette materials with damar binder on the measured ash content. The ash content of charcoal briquettes carbonized at 400°C, 450°C, and 500°C were 3.59%, 3.11%, and 2.81%, respectively. The ash content of damar in the study showed a value of 17.7% [24]. This is not expected to have an impact when rosin was used as a binder in making charcoal briquettes. In fact, the ash content of the charcoal briquettes shown in Table 1 is between 2.81% and 3.59%. Other studies have produced charcoal briquettes with an ash content of 1.02% to 1.13% [53], and a high calorific value. Research on bagasse charcoal briquettes with rosin binder obtained ash content between 2.52% to 4.96% [30]. There is a high ash content of charcoal briquettes which is 17.6% [54]. Another study on alaban biomass waste briquettes with damar binder obtained ash content between 5.34 - 7.86 [5]. High ash content in charcoal briquettes has a serious impact on the environment and human health if it is used inappropriately [55]. The results of this study show that the ash content in all coconut shell charcoal briquette specimens has met the criteria of the Indonesian National Standard (SNI) which is a maximum of 8% [34].

Fixed carbon is the residual carbon trapped in charcoal briquettes after the release of volatiles. Table 1 shows the fixed carbon content of carbonized charcoal briquettes with damar binder. The fixed carbon content of carbonized charcoal briquettes at 400°C, 450°C, and 500°C were 48.33%, 55.07%, and 57.90%, respectively. The results showed that the fixed carbon of charcoal briquettes was influenced by the carbonization temperature, where at 500°C, a fixed carbon content of

57.90% was obtained. The fixed carbon content of charcoal briquettes can reach 60% and the volatile substance content is below 40% [17]. Other briquettes have low fixed carbon values for less than 50% and impact on calorific value [56]. It is in line with statements from other studies that the higher the volatile matter, the lower the bound carbon and vice versa [57]. Moisture content, ash content, and volatile matter have an impact on the fixed carbon content. Lower moisture content, ash content, and volatile matter result on higher fixed carbon content. Conversely, if the fixed carbon content is lower, the moisture content, ash content, and volatile matter will have high values. Carbonization temperature affects the briquette material, where an increase in temperature determines an increase in fixed carbon, and a decrease in volatile matter [17]. The carbonization process of the briquette feedstock affects the fixed carbon content, where increasing the heating rate determines the reduction of volatile substances [58]. In this study, palm kernel shell charcoal briquettes have higher bound carbon content and low volatile matter content. If the opposite happens, the original mass of the final product of charcoal briquettes will lose a lot. There is an increase in the interlock of palm kernel shell charcoal particles and damar binder during the briquetting process, resulting a raise in the fixed carbon content. The higher the fixed carbon content, the better the quality of charcoal briquettes [48].

The quality parameters of charcoal briquettes were determined based on their physical and chemical properties, including moisture content, volatile matter content, ash content, and bound carbon content. Indonesian charcoal briquette quality standards refer to the Indonesian National Standard (SNI) [34]. The quality of charcoal briquettes for each country, including Japan, England, and the USA, also has standards [59]. Compliance of research results with briquette quality standards and determination of the best quality briquettes SNI was used to determine briquette specifications. Table 2 shows the calorific value of briquettes at a composition of 85%:15% palm shell charcoal and damar binder with carbonization 500°C. Based on Table 2, the briquettes produced in this study have met the commercial briquette quality standards of Indonesia, Japan, England, and the USA, have high calorific value, low water content, volatile matter, ash content, and fixed carbon.

Table 2. Comparison of research results based on briquette standards in various countries

Properties	Standard				This study
	Japan	England	USA	SNI	
Moisture content (%)	6 - 8	3 - 4	6	8	5.64 - 6.18
Volatile matter (%)	15 - 30	16.4	19 - 28	15	32.72 - 42.45
Ash content (%)	3 - 6	5.9	8.3	8	3.21 - 3.59
Fixed carbon (%)	60 - 80	75.3	60	77	48.33 - 57.90
Calorific value (cal/g)	6000-7000	7300	6500	5000	7077 - 7342

From the results of the research conducted, it shows that the quality of palm kernel shell charcoal briquettes with damar binder has met SNI standards (briquette calorific value, moisture content, ash content, and fixed carbon). However, in proximate testing, volatile matter is still high compared to SNI standards. When compared with commercial briquettes set by various countries shown in Table 2, it can be concluded that the charcoal briquettes produced in this study are in accordance with the quality standardized by those countries. However, the parameter that must be achieved by briquettes as solid fuel is their calorific value. The results of this study can be recommended as an alternative solid fuel in sustainable and potential energy waste utilization.

The utilization of palm kernel shell waste is an innovation in the development of alternative fuel engineering. The research findings emphasize the need to prioritize and explore blending to improve the energy quality of biomass briquettes that contribute to sustainable energy development [60]. The demand for biomass diversification in achieving progress in renewable energy utilization is highly influential and interdependent on the environment. Dealing with public acceptance of biomass materials and products as alternatives is a challenge in their use, thus affecting the sustainability [61] of waste utilization with energy potential and a major impact on the environment. Energy derived from plant waste (biomass) is one of the renewable energies as a solution in meeting energy needs and can reduce negative environmental impacts [62]. The efforts of waste utilization contributes to energy diversification [63] which leads to the waste value increase, one of them is, by integrating agroindustrial biomass in solid fuel formulations [64]. To balance and save the environment, it is necessary to sustain the development of renewable biomass energy in briquetting technology [65]. By utilizing palm kernel shell waste as raw material for briquettes to obtain solid fuel, the negative impacts on the environment can be overcome. In addition, the utilization of palm kernel shell waste can ensure the energy sustainability of biomass use, renewable energy as green energy.

4. Conclusion

The results show that palm kernel shell waste is suitable for briquetting as it has a high calorific value. Briquettes have potential as solid fuels that require binding additives. Further processing by carbonization at various temperatures is the way to increase their energy content. The combustion characteristics and quality of briquettes made from palm kernel shell waste biomass are based on variations in material composition and concentration. The material composition affects the characteristics and quality of the briquettes. The production of palm kernel shell charcoal briquettes using damar binder has been successfully carried out in this study. The natural damar binder used contributes to the characteristics and quality of the charcoal briquettes, which plays an effective role. The findings of the research evaluating the quality characteristics of palm kernel shell charcoal briquettes and damar binders with an optimum mixture concentration of 85%-15% carbonized at 500ºC produced a moisture content of 5.18%, fly substance content of 32.72%, ash content of 2.81%, fixed carbon of 57.90%, and calorific value of 30.72 MJ/kg. The greater the briquette characteristics obtained, the greater the composition of charcoal briquettes, with lower moisture and ash content, and higher calorific value according to SNI requirements. The study shows that the characteristics of palm kernel shell charcoal as well as the carbonization process parameters, such as final peak temperature and heating rate, affect the mechanical characteristics of the charcoal. The best charcoal briquette characteristics were achieved with carbonization at 500°C which was characterized by the highest heating value parameter compared to other carbonization temperatures. Among the resulted calorific value of briquettes, it is lower than that of coal briquettes (anthracite), but higher than that of wood charcoal briquettes. The compliance of the research results with briquette quality standards shows that briquettes made from palm kernel shell charcoal waste can be used as commercial briquettes. The development of these charcoal briquettes increases the economic value of palm kernel shell waste and overcomes waste problems, thus realizing renewable energy diversification. In utilizing palm oil industry waste to contribute and support the principles on sustainable energy development, palm kernel shell charcoal briquettes with damar binders were explored with various blending strategies to improve the energy quality of biomass charcoal briquettes. In regard to this, further research can be developed by looking for other biomass wastes, users of adhesives for blending to optimize their energy content to ensure their commercial viability and environmental impact.

Author's declaration

Author contribution

Hendri Nurdin: Conceptualization, validation, formal analysis, investigation, Writing-original draft. **Waskito:** Investigation, writing-review & editing. **Dani Harmanto:** Investigation & review. **Purwantono:** Investigation. **Andre Kurniawan:** Writing-review & editing. **Yoszi Mingsih Anaperta:** Investigation & editing. **Dori Yuvenda:** Writing -review & editing.

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Data Availability

The raw data of this study is available. If anyone wishes to use it as a basis for further research, please contact the corresponding author.

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Competing interest

There are no conflicts of interest in this research.

Ethical clearance

This study did not involve human subjects; therefore, approval from the ethics committee was not required

AI statement

This article is the authors' original work, written from original research, and no sections or figures are generated by AI.

Publisher's and Journal's note

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References

[1] E. Hambali and M. Rivai, "The Potential of Palm Oil Waste Biomass in Indonesia in 2020 and 2030," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Jun. 2017. https://doi.org/10.1088/1755-1315/65/1/012050

[2] R. Nabila *et al.*, "Oil palm biomass in Indonesia: Thermochemical upgrading and its utilization," *Renewable and Sustainable Energy Reviews*, vol. 176. Elsevier Ltd, Apr. 01, 2023. https://doi.org/10.1016/j.rser.2023.113193

[3] H. Handaya, H. Susanto, D. Indrawan, and M. Marimin, "Supply and Demand Characteristics of Palm Kernel Shell as a Renewable Energy Source for Industries," *International Journal of Renewable Energy Development*, vol. 11, no. 2, pp. 481–490, May 2022, https://doi.org/10.14710/ijred.2022.41971

[4] E. Carter *et al.*, "Development of renewable, densified biomass for household energy in China," *Energy for Sustainable Development*, vol. 46, pp. 42–52, 2018, https://doi.org/10.1016/j.esd.2018.06.004

[5] N. H. Haryanti *et al.*, "Manufacture of Biobriquettes from Alaban (Vitex pubescens) Biomass Waste and Rubber Seed Shells using Damar Resin Adhesive," *Pak J Life Soc Sci*, vol. 21, no. 1, pp. 194–204, 2023, https://doi.org/10.57239/PJLSS-2023-21.1.0016

[6] G. Zhang, Y. Sun, and Y. Xu, "Review of briquette binders and briquetting mechanism," *Renewable and Sustainable Energy Reviews*, vol. 82. *Renewable and Sustainable Energy Reviews*, pp. 477–487, 2018. https://doi.org/10.1016/j.rser.2017.09.072

[7] O. F. Obi, R. Pecenka, and M. J. Clifford, "A Review of Biomass Briquette Binders and Quality Parameters," *Energies (Basel)*, vol. 15, no. 7, pp. 1–22, 2022, https://doi.org/10.3390/en15072426

[8] T. Olugbade, O. Ojo, and T. Mohammed, "Influence of Binders on Combustion Properties of Biomass Briquettes: A Recent Review," *Bioenergy Res*, vol. 12, no. 2, pp. 241–259, 2019, https://doi.org/10.1007/s12155-019-09973-w

[9] C. Ukpaka, Omeluzor, C. Ulochukwu, and D. Kk, "Production of briquettes with heating value using different palm kernel shell," *Discovery Journals*, vol. 55, no. 281, pp. 147–57, May 2019, [Online]. Available: https://www.discoveryjournals.org/discovery/current_issue/v55/n281/A1.pdf

[10] O. M. Ikumapayi and E. T. Akinlabi, "Composition, characteristics and socioeconomic benefits of palm kernel shell exploitation-an overview," *Journal of Environmental Science and Technology*, vol. 11, no. 5. Asian Network for Scientific Information, pp. 220–232, 2018. https://doi.org/10.3923/jest.2018.220.232

[11] E. C. Okoroigwe and C. M. Saffron, "Determination Of Bio-Energy Potential Of Palm Kernel Shell By Physicochemical Characterization," *Nigerian Journal of Technology (NIJOTECH)*, vol. 31, no. 3, pp. 329–335, Nov. 2012. https://doi.org/10.4314/njt.313.561

[12] W. T. Tsai, "Benefit analysis and regulatory actions for imported palm kernel shell as an environment-friendly energy source in Taiwan," *Resources*, vol. 8, no. 1, Mar. 2019, https://doi.org/10.3390/resources8010008

[13] B. Osei Bonsu, M. Takase, and J. Mantey, "Preparation of charcoal briquette from palm kernel shells: case study in Ghana," *Heliyon*, vol. 6, no. 10, Oct. 2020, https://doi.org/10.1016/j.heliyon.2020.e05266

[14] Nurdin H, Hasanuddin, and Irzal, "Heat Value Analysis of Briquette Hybrid as Alternative Fuel," in *Prosiding SNTTM XVI*, Moch. Solichin and Achmad Syaifudin, Eds., 2017, pp. 103–106. [Online]. Available: https://prosiding.bkstm.org/prosiding/2017/KE-21.pdf

[15] H. Nurdin, Hasanuddin, Darmawi, Y. Setiadhi, and M. Saddikin, "Calorific value of tibarau cane bio-briquette," in *Journal of Physics: Conference Series*, Institute of Physics Publishing, Nov. 2019. https://doi.org/10.1088/1742-6596/1317/1/012110

[16] R. E. Guedes, A. S. Luna, and A. R. Torres, "Operating parameters for bio-oil production in biomass pyrolysis: A review," *J Anal Appl Pyrolysis*, vol. 129, pp. 134–149, Jan. 2018, https://doi.org/10.1016/j.jaap.2017.11.019

[17] S. Pyshyev, D. Miroshnichenko, I. Malik, A. Bautista Contreras, N. Hassan, and A. Abd Elrasoul, "State of the art in the production of charcoal: A review," *Chemistry and Chemical Technology*, vol. 15, no. 1, pp. 61–73, 2021, https://doi.org/10.23939/chcht15.01.061

[18] R. Jelita, D. Putra, M. Hafiz, I. Angreini, and I. Fatyasari Nata, "Palm Oil Shell Pyrolysis: Temperature Effect, Kinetics, and Thermodynamics Study," *International Journal on Advanced Science Engineering Information Technology*, vol. 12, no. 6, pp. 2513–2518, Dec. 2022. https://doi.org/10.18517/ijaseit.12.6.16088

[19] N. A. Haridan, H. Yoshida, M. A. M. Salleh, and S. Izhar, "Carbonization of excess sewage sludge using superheated water vapor to produce fuel," in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing Ltd, Dec. 2020. https://doi.org/10.1088/1757-899X/991/1/012068

[20] M. R. Assis, L. Brancheriau, A. Napoli, and P. F. Trugilho, "Factors affecting the mechanics of carbonized wood: literature review," *Wood Sci Technol*, vol. 50, no. 3, pp. 519–536, May 2016, https://doi.org/10.1007/s00226-016-0812-6

[21] R. K. Ahmad, S. A. Sulaiman, S. B. Yusuf, S. S. Dol, H. A. Umar, and M. Inayat, "The influence of pyrolysis process conditions on the quality of coconut shells charcoal," *Platform : A Journal of Engineering*, vol. 4, no. 1, p. 73, Feb. 2020, https://doi.org/10.61762/pajevol4iss1art7663

[22] P. Ninduangdee, V. I. Kuprianov, E. Y. Cha, R. Kaewrath, P. Youngyuen, and W. Atthawethworawuth, "Thermogravimetric Studies of Oil Palm Empty Fruit Bunch and Palm Kernel Shell: TG/DTG Analysis and Modeling," *Energy Procedia*, vol. 79, pp. 453–458, Nov. 2015, https://doi.org/10.1016/j.egypro.2015.11.518

[23] W. T. Tsai, "Benefit analysis and regulatory actions for imported palm kernel shell as an environment-friendly energy source in Taiwan," *Resources*, vol. 8, no. 1, Mar. 2019, https://doi.org/10.3390/resources8010008

[24] J. Jamradloedluk and C. Lertsatitthanakorn, "Influences of Mixing Ratios and Binder Types on Properties of Biomass Pellets," in *Energy Procedia*, Elsevier Ltd, 2017, pp. 1147–1152. https://doi.org/10.1016/j.egypro.2017.10.223

[25] A. Mencarelli, R. Cavalli, and R. Greco, "Variability on the energy properties of charcoal and charcoal briquettes for barbecue," *Heliyon*, vol. 8, no. 8, Aug. 2022, https://doi.org/10.1016/j.heliyon.2022.e10052

[26] P. Wang, J. Zhang, Q. Shao, and G. Wang, "Physicochemical properties evolution of chars from palm kernel shell pyrolysis," *J Therm Anal Calorim*, vol. 133, no. 3, pp. 1271–1280, Sep. 2018, https://doi.org/10.1007/s10973-018-7185-z

[27] J. Hyväluoma, M. Hannula, K. Arstila, H. Wang, S. Kulju, and K. Rasa, "Effects of pyrolysis temperature on the hydrologically relevant porosity of willow biochar," *J Anal Appl Pyrolysis*, vol. 134, pp. 446–453, Sep. 2018, https://doi.org/10.1016/j.jaap.2018.07.011

[28] S. Y. Adaganti, V. S. Yaliwal, B. M. Kulkarni, G. P. Desai, and N. R. Banapurmath, "Factors Affecting Bioethanol Production from Lignocellulosic Biomass (Calliandra calothyrsus)," *Waste Biomass Valorization*, vol. 5, no. 6, pp. 963–971, Dec. 2014, https://doi.org/10.1007/s12649-014-9305-8

[29] ASTM, *Specification for Woven Wire Test Sieve Cloth and Test Sieves (ASTM E11)*, May 2022. West Conshohocken, PA: ASTM International, 1925. https://doi.org/10.1520/E0011-22

[30] M. Rizki, S. Mustaqilla, W. Rinaldi, and T. Mukhriza, "The Effect of Adhesive Types of Damar and Pine Resin for Biobricket Manufacturing from Sugarcane Bagasse," *Journal of Applied Technology*, vol. 9, no. 1, pp. 35–42, 2022. https://doi.org/10.51354/mjen

[31] F. Inegbedion, "Estimation of the moisture content, volatile matter, ash content, fixed carbon and calorific values of saw dust briquettes," *MANAS Journal of Engineering*, vol. 10, no. 1, pp. 17–20, 2022, https://doi.org/10.51354/mjen

[32] ASTM, *Standard Test Method for Gross Calorific Value of Coal and Coke (ASTM D5865)*. ASTM International, 2019. https://doi.org/10.1520/D5865_D5865M-19

[33] ASTM, *Standard Test Methods for Proximate Analysis of Coal and Coke by Macro Thermogravimetric Analysis (ASTM D7582)*. ASTM International, 2015. https://doi.org/10.1520/D7582-15

[34] SNI, "Standar Nasional Indonesia Briket arang kayu [Indonesian National Standard for Wood Charcoal Briquettes] 'SNI 01-6235-2000,'" 2000.

[35] ASTM, *Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter (ASTM E711)*, April 2023. West Conshohocken, PA: ASTM International, 2004. https://doi.org/10.1520/E0711

[36] N. Hendri, D. Y. Sari, Wagino, D. Sakti, and A. Ramadhan, "The Effect of Use of Adhesive to Calorific Value Cymbopogon Nardus Waste Briquettes," in *Journal of Physics: Conference Series*, Institute of Physics, Apr. 2024, pp. 1–8. https://doi.org/10.1088/1742-6596/2739/1/012008

[37] A. O. Onokwai *et al.*, "Optimization of Pyrolysis Operating Parameters for Biochar Production from Palm Kernel Shell Using Response Surface Methodology," *Mathematical Modelling of Engineering Problems*, vol. 10, no. 3, pp. 757–766, Jun. 2023, https://doi.org/10.18280/mmep.100304

[38] C. Qian, Q. Li, Z. Zhang, X. Wang, J. Hu, and W. Cao, "Prediction of higher heating values of biochar from proximate and ultimate analysis," *Fuel*, vol. 265, Apr. 2020, https://doi.org/10.1016/j.fuel.2019.116925

[39] O. Ioannidou and A. Zabaniotou, "Agricultural residues as precursors for activated carbon production-A review," *Renewable and Sustainable Energy Reviews*, vol. 11, no. 9, pp. 1966–2005, Dec. 2007, https://doi.org/10.1016/j.rser.2006.03.013

[40] I. Made Mara, I. Made Nuarsa, and I. Kade Wiratama, "The effect of particle size and adhesive on the ash content and volatile matter of organic waste bio-charcoal briquettes," *International Journal Of Engineering Research And Development*, vol. 20, no. 3, pp. 67–73, 2024, [Online]. http://www.ijerd.com/paper/vol20-issue3/J20036773.pdf

[41] N. I. Mbada, P. O. Atanda, O. Aponbiede, A. A. Abioye, M. I. Ugbaja, and A. S. Alabi, "Performance Evaluation of Suitability of Carbonized Palm Kernel Shell (PKS) as a Veritable Alternative to Coal and Charcoal in Solid Fuel Fired Furnaces," *International Journal of Metallurgical Engineering*, vol. 2016, no. 1, pp. 15–20, 2016, https://doi.org/10.5923/j.ijmee.20160501.03

[42] N. I. Buravchuk and O. V. Guryanova, "Production of fuel briquettes from anthracite fines," *Solid Fuel Chemistry*, vol. 48, no. 4, pp. 260–264, 2014, https://doi.org/10.3103/S036152191404003X

[43] I. N. Sukarta, I. D. K. Sastrawidana, and I. W. B. Suyasa, "Proximate Analysis and Calorific Value of Fuel Briquettes from Wood and Coffee Skins Biomass as a Renewable Energy Source," *Ecological Engineering and Environmental Technology*, vol. 24, no. 8, pp. 291–298, 2023, https://doi.org/10.12912/27197050/172506

[44] N. G. Zanjani, A. Z. Moghaddam, and S. Dorosti, "Physical And Chemical Properties Of Coal Briquettes From Biomass-Bituminous Blends," *Petroleum & Coal*, vol. 56, no. 2, pp. 188–195, 2014, [Online]. Available: https://www.vurup.sk/wp-content/uploads/dlm_uploads/2017/07/pc_2_2014_moghaddam_285_re.pdf

[45] F. Hamzah, A. Fajri, N. Harun, and A. Pramana, "Characterization of charcoal briquettes made from rubber rods and coconut shells with tapioca as an adhesive.," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics, 2023. https://doi.org/10.1088/1755-1315/1182/1/012071

[46] A. M. K. Abdel Aal, O. H. M. Ibrahim, A. Al-Farga, and E. A. El Saeidy, "Impact of Biomass Moisture Content on the Physical Properties of Briquettes Produced from Recycled Ficus nitida Pruning Residuals," *Sustainability (Switzerland)*, vol. 15, no. 15, Aug. 2023, https://doi.org/10.3390/su151511762

[47] Y. Shiferaw *et al.*, "Preparation and evaluation of clean briquettes from disposed wood wastes," *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, vol. 39, no. 20, pp. 2015–2024, Oct. 2017, https://doi.org/10.1080/15567036.2017.1399175

[48] N. Kongprasert, P. Wangphanich, and A. Jutilarptavorn, "Charcoal briquettes from Madan wood waste as an alternative energy in Thailand," in *Procedia Manufacturing*, Elsevier B.V., 2019, pp. 128–135. https://doi.org/10.1016/j.promfg.2019.02.019

[49] H. Tambunan, A. Nuryawan, A. H. Iswanto, I. Risnasari, M. Basyuni, and W. Fatriasari, "Briquettes Made of Branches Wood of Three Mangrove Species Bonded by Starch Adhesive," *Materials*, vol. 16, no. 15, Aug. 2023, https://doi.org/10.3390/ma16155266

[50] H. A. Ajimotokan, A. O. Ehindero, K. S. Ajao, A. A. Adeleke, P. P. Ikubanni, and Y. L. Shuaib-Babata, "Combustion characteristics of fuel briquettes made from charcoal particles and sawdust agglomerates," *Sci Afr*, vol. 6, Nov. 2019, https://doi.org/10.1016/j.sciaf.2019.e00202

[51] L. Lestari, V. I. Variani, I. N. Sudiana, D. P. Sari, W. O. Sitti Ilmawati, and E. S. Hasan, "Characterization of Briquette from the Corncob Charcoal and Sago Stem Alloys," in *Journal of Physics: Conference Series*, Institute of Physics Publishing, Jun. 2017. https://doi.org/10.1088/1742-6596/846/1/012012

[52] S. Syafrudin, B. Zaman, I. Indriyani, A. S. Erga, and H. B. Natalia, "The Utilization of Bottom Ash Coal for Briquette Products by Adding Teak Leaves Charcoal, Coconut Shell Charcoal, and Rice Husk Charcoal," *Waste Technology*, vol. 3, no. 1, Apr. 2015, https://doi.org/10.12777/wastech.3.1.14-21

[53] R. K. Ahmad, S. A. Sulaiman, S. B. Yusuf, S. S. Dol, H. A. Umar, and M. Inayat, "The Influence of Pyrolysis Process Conditions on The Quality of Coconut Shells Charcoal," *Platform : A Journal of Engineering*, vol. 4, no. 1, p. 73, Feb. 2020, https://doi.org/10.61762/pajevol4iss1art7663

[54] A. Mencarelli, R. Cavalli, and R. Greco, "Variability on the energy properties of charcoal and charcoal briquettes for barbecue," *Heliyon*, vol. 8, no. 8, Aug. 2022, https://doi.org/10.1016/j.heliyon.2022.e10052

[55] Z. Jelonek, A. Drobniak, M. Mastalerz, and I. Jelonek, "Environmental implications of the quality of charcoal briquettes and lump charcoal used for grilling," *Science of The Total Environment*, vol. 747, p. 141267, 2020, https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.141267

[56] H. L. Huang, W. M. G. Lee, and F. S. Wu, "Emissions of air pollutants from indoor charcoal barbecue," *J Hazard Mater*, vol. 302, pp. 198–207, Jan. 2016, https://doi.org/10.1016/j.jhazmat.2015.09.048

[57] J. Y. Tang *et al.*, "Prediction model for biochar energy potential based on biomass properties and pyrolysis conditions derived from rough set machine learning," *Environ Technol*, vol. 45, no. 15, pp. 2908–2922, Jul. 2024, https://doi.org/10.1080/09593330.2023.2192877

[58] T. Rodrigues and A. Braghini Junior, "Charcoal: A discussion on carbonization kilns," *J Anal Appl Pyrolysis*, vol. 143, p. 104670, 2019, https://doi.org/https://doi.org/10.1016/j.jaap.2019.104670

[59] A. Syarif, M. Yerizam, I. Indrayani, and A. Yopinita, "Effect of Composition of Coconut Shell Charcoal and Char Gasification on the Quality of Biobriquettes," 2023, pp. 200–210. https://doi.org/10.2991/978-94-6463-118-0_22

[60] O. O. Oyebamiji, A. S. Olaleru, R. B. Oyeleke, and L. N. Ofodile, "Evaluation and characterization of biochar and briquettes from agricultural wastes for sustainable energy production," *Waste Management Bulletin*, vol. 3, no. 3, Sep. 2025, https://doi.org/10.1016/j.wmb.2025.100198

[61] A. A. Adeleke *et al.*, "Sustainability of multifaceted usage of biomass: A review," *Heliyon*, vol. 7, no. 9. Sep. 01, 2021. https://doi.org/10.1016/j.heliyon.2021.e08025

[62] L. Gibson, E. N. Wilman, and W. F. Laurance, "How Green is 'Green' Energy?," *Trends in Ecology and Evolution*, vol. 32, no. 12. pp. 922–935, Dec. 01, 2017. https://doi.org/10.1016/j.tree.2017.09.007

[63] A. Sagastume Gutiérrez, J. M. Mendoza Fandiño, J. J. Cabello Eras, and S. J. Sofan German, "Potential of livestock manure and agricultural wastes to mitigate the use of firewood for cooking in rural areas. The case of the department of Cordoba (Colombia)," *Dev Eng*, vol. 7, Jan. 2022, https://doi.org/10.1016/j.deveng.2022.100093

[64] S. J. Sofán-Germán, M. E. Doria-Oviedo, and J. D. Rhenals-Julio, "Mechanical and energy assessment of hybrid biofuels: Integrating agro-industrial coconut and rice husk biomass with mineral coal for sustainable energy in Córdoba, Colombia," *S Afr J Chem Eng*, vol. 52, pp. 303–310, Apr. 2025, https://doi.org/10.1016/j.sajce.2025.03.010

[65] Y. M. Yustas *et al.*, "Toward Adaptation of Briquettes Making Technology for Green Energy and Youth Employment in Tanzania: A Review," *Journal of Power and Energy Engineering*, vol. 10, no. 04, pp. 74–93, 2022, https://doi.org/10.4236/jpee.2022.104006