Heliyon 6 (2020) e05009

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Techno-economic analysis of bio-briquette from cashew nut shell waste

La Ifa [a,**], Setyawati Yani [a], Nurjannah Nurjannah [a], Darnengsih Darnengsih [a], Andi Rusnaenah [b], Maizirwan Mel [c], Mahfud Mahfud [d,***], Heri Septya Kusuma [d,*]

[a] Department of Chemical Engineering, Faculty of Industrial Technology, Jalan Urip Sumoharjo Km 05 Makassar, Universitas Muslim Indonesia, Makassar, South Sulawesi 90231, Indonesia
[b] Department of Chemical Engineering Polymers, Politeknik STMI Jakarta, Jakarta 10510, Indonesia
[c] Department of Biotechnology Engineering, Faculty of Engineering, International Islamic University Malaysia, IIUM Gombak 53100, Kuala Lumpur, Malaysia
[d] Department of Chemical Engineering, Faculty of Industrial Technology, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia

ARTICLE INFO

Keywords:
Chemical engineering
Energy
Energy economics
Bioenergy
Biomass
Cashew nut shells
Pyrolysis
Bio-briquettes
Economic analysis

ABSTRACT

The implementation of this research consists of 2 (two) aspects: the making and testing of bio-briquettes called technological aspects and economic analysis called economic aspects. Bio-briquettes is made from cashew nutshell waste obtained from Southeast Sulawesi, Indonesia. It is followed by pyrolysis, which is carried out in a simple batch type reactor by heating using liquefied petroleum gas (LPG). The bio-briquettes product has a calorific value of 29.49 MJ/kg, moisture content of 5.3%, ash content of 4.96%, volatile substances content of 17.16%, and carbon content of 72.62%, which meets the universally accepted bio-briquettes standard (SNI 016235-2000), Japanese, English and ISO 17225. The bio-briquettes product is suitable as an energy source. The economic analysis of the cashew nutshell was analyzed to determine its economic feasibility. For the bio-briquettes production capacity in 2,000 tons/year, cashew nut shell-briquettes products can be sold at 1,052,878 USD/year. The total production cost is USD842,304/year. The net profit is of USD147,402/year. The cost of LPG for 2,000 tons/year production capacity is USD954,358/years. The replacement of LPG with cashew seed bio-briquettes tends to help the average household of Muna Regency community to reduce the annual cost by 37.00%. In conclusion, bio-briquettes production's economic feasibility as analyzed from the investment rate is 23.55%, payout time is 3.42 years, and break-even point is 50.09%.

1. Introduction

The development of the Eastern Indonesia region, which generally comprises remote areas and small islands, makes it difficult for proper fuel distribution due to its poor infrastructure. These constraints lead to fuel scarcity and increase in price (Sirajudin et al., 2013). Therefore, the Indonesian community in the Eastern region needs to search for an alternative energy source to replace fossil fuel consumption, environmentally friendly, and sustainable. The change in fuel usage from liquid petroleum gas (LPG) to bio-energy, such as biomass, can reduce household costs. Some sources of biomass converted into bio-briquettes could be sawdust (Akowuah et al., 2012), bagasse (Onchieku et al., 2012), agricultural products (Stolarski et al., 2013), cotton dust (Suvunnapob et al., 2015), wood, waste paper (Tamilvanan, 2013), coconut shell, palm shell biochar, empty palm fruit bunches, banana peels, rice husks, peanut shells, jatropha, durian peels, cocoa shells, corn cobs (Faizal, 2017), textile industry solid waste (Avelar et al., 2016), peat (Hakizimana and Kim, 2016), banana leaves (Maia et al., 2014), agro waste (Sharma et al., 2015), bagasse and corn starch waste (Zanella et al., 2016), palm kernel shell (Abdillahi et al., 2017), wood (Borowski, Stępniewski, & Wójcik-Oliveira, 2017), cashew shell (Sawadogo et al., 2018), cotton stalk (Wu et al., 2018), blend of areca nut husk, simarouba seed shell (Ujjinappa and Sreepathi, 2018), cashew nut waste (Ifa et al., 2019) and carbon (Mousa et al., 2019).

The advantages of using of the biomass bio-briquettes are as follows: (a) cost-effective; (b) renewable source; (c) no sulfur, therefore, it is unable to pollute the environment; (d) it has a higher calorific value than other solid fuel sources; (e) ash content in bio-briquettes is lower than coal at 2–10% and 20–40%, respectively; (f) its combustion is more uniform compared to coal; (g) theyproduced near the consumers;

* Corresponding author.
** Corresponding author.
*** Corresponding author.
E-mail addresses: la.ifa@umi.ac.id (L. Ifa), mahfud@chem-eng.its.ac.id (M. Mahfud), heriseptyakusuma@gmail.com (H.S. Kusuma).

https://doi.org/10.1016/j.heliyon.2020.e05009
Received 27 March 2020; Received in revised form 20 July 2020; Accepted 17 September 2020

therefore, supplies are not dependent on transportation over long distances; and (h) due to the low moisture content and higher density, it provides much higher boiling efficiency compared to firewood or waste biomass (Sharma et al., 2015).

The transport of the fuels, as mentioned earlier, is very safe and straightforward to manage compared to other types of fuels, such as coal, petroleum products, and bio-briquettes. It can be used for burning purposes in various areas, such as hotels, dairies, and factories, instead of firewood, coal, LPG, et cetera (Tamilvanan, 2013). Therefore, bio-briquettes generally have better energy parameters, higher density, and calorific value and lower water content than other raw materials (Stolarski et al., 2013). Similarly, the bio-briquettes from cashew nutshells are cheaper, act as cleaner energy for domestic cooking (Lubwama and Yiga, 2017), and are also applied to the casting industry (Mousa et al., 2019).

Most rural people in Southeast Sulawesi, Indonesia, prefer to use firewood because imported petroleum goods are often considered relatively much more costly. A limited number of rural people use kerosene for heating, and only households with high incomes use LPG. LPG is also very expensive; in 2020, it cost USD0.47718/kg; therefore, only high-income households can afford its use. For example, taking LPG's price for cooking as the reference price (USD0.01072/MJ), kerosene is the most expensive with USD0.01449/MJ (i.e., 35% more expensive). According to (MINIFRA, 2008) using conventional charcoal for cooking as the comparison price (USD0.06/MJ), LPG is the most expensive with USD0.20/MJ (approximately 233% more expensive), followed by electricity with USD0.099/MJ (around 65% more expensive) and kerosene with USD0.071/MJ (around 18% more expensive). Utilizing this cashew nutshell bio-briquettes waste as household energy for cooking isan effective way that leads to a sustainable livelihood, which gives the rural communities an ample income. Based on the benefits available to the producer and consumer, the cashew nutshell bio-briquettes can be a feasible and practical alternative energy solution for Indonesia. This study's primary objectives were to review bio-briquettes technology and examine the economic feasibility of cashew nutshell bio-briquettes waste. The investigation of its production is seen from the investment rate, pay out time, and break-even point.

2. Materials and methods

2.1. Materials

Due to its availability in large quantities, almost zero cost, and the suitability of its energy parameters for the formulation of bio-briquettes, cashew nutshell waste has been used in this study in formulating bio-briquettes. The materials were obtained from Muna Regency, Southeast Sulawesi, Indonesia (USD25.05/tons). The material dried on direct sunlight to reduce moisture content before being pyrolyzed. It is most economical to dry out as much of this moisture as possible using the sun's heat before the wood is carbonized (FAO, 1985). It was important in saving on the cost of energy used during pyrolysis (Kers et al., 2010; Onchieku et al., 2012). Compared with other mechanical drying processes, sun-drying is the simplest and cheapest process for drying biomass. Nevertheless, mechanical drying is the only way to remove biomass in the rainy season (Sen et al., 2016). It is first converted into biocharby pyrolysis in a simple batch type reactor heated externally by LPG. The tapioca flour (USD17.89/tons) acts as a bio-briquettes binder, with its adhesive used and ethanol.

2.2. Apparatus

The main biochar production tool is pyrolysis reactors equipped with the thermocouple, condenser, tar, and liquid container, as shown in Figure 1. The pyrolysis equipment specifications are pyrolysis reactors made of stainless steel plate with 40 cm high and 27 cm diameter. The length of the condenser is 1.07 m. The outside wall of the reactor is fitted

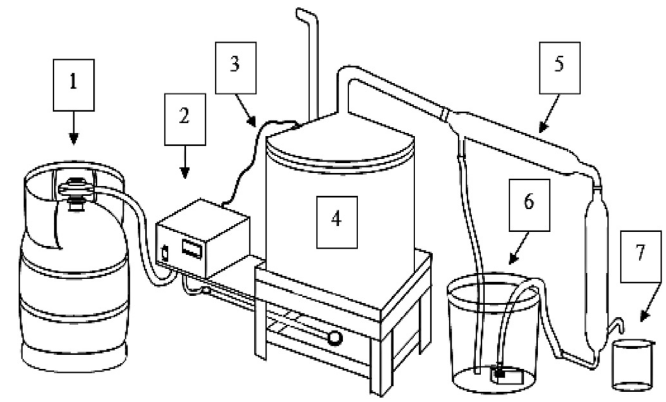

Figure 1. Pyrolysis toolset (Description: 1. LPG cylinder; 2. Temperature indicator; 3. Thermocouple; 4. Pyrolysis reactor; 5. Condenser; 6. Condensate and pump; 7. Liquid container).

with a 1.5 cm thick layer of insulation. The bio-briquetting process was conducted by employing the hydraulic press, as shown in Figure 2. Bio-briquettes were produced using bio-briquettes press machines (Krisbow hydraulic press floor type 10T obtained from Johnson Store Makassar, Indonesia. The specification of bio-briquettes press machines are type: floor type, dimension (L x W x H) (cm): 77 × 56 × 174). The supporting tools consist of a crusher, electric furnace, scale, stopwatch, tub, mixer, and oven. The printing is performed manually by using the pressing tools which are equipped by the hydraulic pump. The pressing was carried out using a universal strength testing machine with 29.4 MPa capacity that is higher than reported in the literature Olorunnisola (2007); Haykiri-Acma and Yaman (2010); Pallavi et al. (2013); Suvunnapob et al. (2015); Ndindeng et al. (2015); Lubwama and Yiga (2017) (Ahmad et al., 2018).

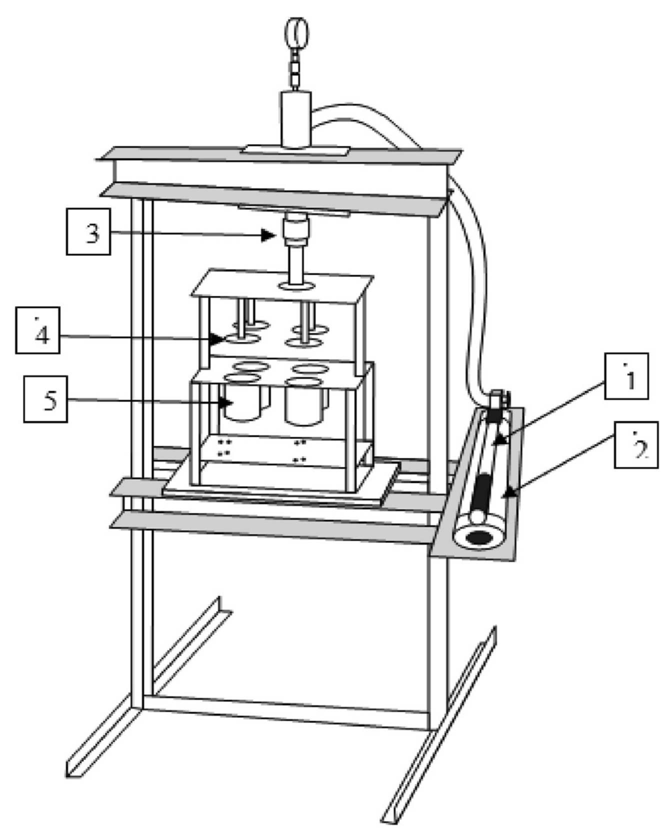

Figure 2. Bio-briquettes hydraulic press (Description: 1. Lever; 2. Bio-briquettes press tools; 3. Spring; 4. Bio-briquettes suppressant; 5. Bio-briquettes printing container).

However, It is also lower than that reported (Kers et al., 2010; Akowuah et al., 2012). It was found useful for briquetting press because it allows the mixture to solidify, which was accomplished by increased pressure (Onchieku et al., 2012). The bio-briquettes strength increases along withan increase in pressure. However, it can only be increased within the strength of the densified material. Bio-briquettes strength increases with the increase of the pressure. Bio-briquettes strength can be increased only to the strength limit of the compacting material (Kers et al., 2010). Meanwhile, the calorific value equipment is the PARR-calorimeter bomb.

2.3. The bio-briquettesprocess (Ifa et al., 2019)

In this research, bio-briquettes were produced by pyrolysis of cashew nutshell waste. The flow chart of the cashew nutshell bio-briquettes production activity can be seen in Figure 3. The cashew nutshell waste dried by drying it in the sun for 5 h. The pyrolysis process is carried out by inserting 2 kg of cashew nutshell into the pyrolysis reactor, as shown in Figure 1. Three products were obtained due to pyrolysis at a temperature of 350 °C: liquid smoke, tar, and biochar. The smoke produced is condensed into liquid and inserted into a separating funnel using a filter paper. The obtained biochar was milled manually using traditional tools and a blender until the particles attained a tiny size and became homogeneous.

Meanwhile, the biochar produced is grounded and sieved in 70, 140, and 200 mesh sizes. Particles of biochar that could not pass through the sieves were milled again. The biochar was then characterized by proximate (moisture content, ash content, volatile matter, and fixed carbon) and calorific value analyses. Proximate analyses performed in the Laboratory Superintending Company of Indonesia (Sucofindo) Makassar, Indonesia. The size of raw materials, which met requirements for bio-briquettes manufacture, was 200 mesh from the test results. Biochar was mixed with tapioca flour and added ethanol and warm water (ratio 50% ethanol: 50% water) to make a slurry or a dough. The mixture was then stirred until it became. Afterward, the adhesive was then added respectively at a ratio of 8%, 10%, and 12% of the total slurry. The mixture was then inserted into a mold in the press, and compression proceeded for 5 min until the pressure reached 29.4 MPa (300 kgf/cm^2). The bio-briquettes were molded into the shape of a hollow cylinder. After removing the mold, the obtained bio-briquettes were weighed to get the initial weight and dried in the oven at temperature 50 °C for 4–6 h until completely dry. During drying, the bio-briquettes were flipped so that they would dry evenly distributed.

The proximate analysis was carried out following ISO 562 and 1171 standard procedures for moisture, ash, and volatile, respectively (Montiano et al., 2016) as reported in the following points:

2.3.1. Moisture content

It is defined as the ratio of the moisture to the dry weight of the solid fuel. This research was determined by drying the samples with a calibrated free space oven at a temperature of 105 °C–110 °C, using a minimum free space oven and a volume of 1.4 L. The gas flow rate was approximately 15 times/hour with a volume of 350 mL/min and calculated from the mass lost after heating the charcoal bio-briquettes using the ASTM D-3173 2017 standard is as follows by Eq. (1).

$$\text{Moisture content}(\%) = \frac{W_0 - W}{W_{s0}} \cdot 100\% \tag{1}$$

Where W_0 is sample and saucer weight before drying (g), W is sample and saucer weight after drying (g), and W_{S0} is the initial sample weight (g).

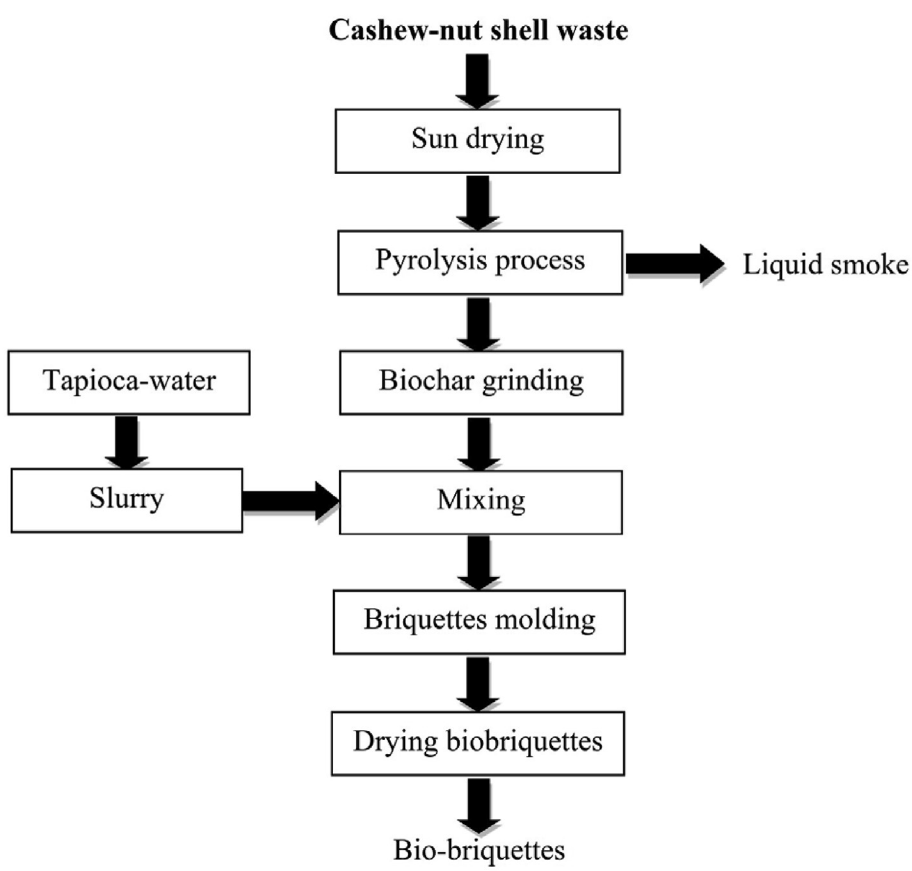

Figure 3. Flow chart of the production of cashew nutshell bio-briquettes.

2.3.2. Ash content

Ash is a constituent obtained from solid heating fuel to a constant weight. Furthermore, the higher its content, the harder it takes to combust, with the values calculated under the ASTM D-3174 2012 standard formulas by the follows by Eq. (2).

$$\text{Ash content }(\%) = 100 - \frac{W_0 - W}{W_{s0}} \cdot 100\% \tag{2}$$

Where W_0 is sample and saucer weight before ashing (g), W is the weight of saucer and ash (g), and W_{so} is sample weight before ashing (g).

2.3.3. Volatile matter (VM)

The more volatile content in bio-briquettes, the easier it combusts. The test sample was heated at 900 °C for 7 min, and the percentage of volatile content is calculated based on the weight loss after being reduced by moisture. The amount of volatile is calculated using ASTM D-3175 2018 standard with the following formula by Eq. (3) and Eq. (4).

$$\text{Lost weight}(\%) = A = \frac{W_0 - W}{W_{s0}} \cdot 100\% \tag{3}$$

$$\text{VM}(\%) = \text{lost weight} - \text{moisture content} \tag{4}$$

Where W_0 is sample weight and initial cup (g), W is the weight of cup and ash after heating (g), and W_{so} is the initial sample weight (g).

2.3.4. Fixed carbon (FC)

A higher level of carbon bound leads to an increase in its calorific value. The fixed carbon (FC) was determined using the data previously obtained in the proximate analysis. In this study, the released moisture content is considered in the volatile matter percentage, as in Eq. (5). It is according to the following by Eq. (5) (García et al., 2012):

$$\text{FC}(\%) = 100 - (\text{Ash}(\%) + \text{VM}(\%)) \tag{5}$$

A PARR-bomb calorimeter was used to determine the calorific values of cashew nutshells under ASTM and D5865 2013 standard. The test sample used was an isoperibol calorimeter microprocessor, which was calculated to determine the temperature rise and heat capacity in line with the standard procedure of the American Society for Testing and Materials (ASTM, 2013).

2.4. Economic analysis

Data processing was conducted using literature and experiments in this research. The experiment was performed via the processing of cashew nut shell waste bio-briquettes, beginning with the pyrolysis stage. The presumption in this analysis is that the bio-briquettes industry's location is near the post-harvest industry of cashew nut production so that there are no costs needed for shipment. Smaller production of bio-briquettes near feedstock sources or its sites with energy recovery integration will reduce the production costs (Maroušek et al., 2019). According to Suvunnapob et al. (2015), even though the residue is nominally free, it is normal for transport costs to be incurred in taking the residue to the briquette factory. For units situated at the point of pesticide processing, the shipping costs may be a significant part of the running costs. Furthermore, if full-time drivers are working, transport expenses can be added to the general labor costs.

The economic analysis is intended to determine the profitability of a business. The analysis is carried out with the following assumptions:

a. Bio-briquettes production capacity is 2,000 tons/year. The pyrolysis product is biochar of 41.0%, liquid smoke of 39.3%, and the rest is gas. In producing 2,000 tons/year of bio-briquettes, cashew nutshell waste is needed 4,878 tons/year and tapioca flour 585 tons/year with prices of USD122,204 and USD10,475, respectively;
b. The factory location is in Muna Regency, Southeast Sulawesi, Indonesia;
c. Bank interest 5.5%/year;
d. An inflation rate of 3.18%/year;
e. The factory existence is estimated at ten years, with an annual10% depreciation;
f. The product's sold price consists of bio-briquettes as the main product and liquid smoke as a by-product.

3. Results and discussion

3.1. The results of proximate analysis and calorific value

The pyrolysis product is biochar of 41.0%, liquid smoke of 39.3%, and the rest is gas. The biochar is carried out on proximate analysis to determine its moisture, ash, volatile matter, fixed carbon, and calorific value. The results of the analysis are shown in Table 1.

The quality of the bio-briquettes is determined by moisture content in the biomass used as the input material. There will be more energy loss required for water evaporation during combustion at the expense of the bio-briquettes calorific value if the biomass moisture content is higher (Aina et al., 2009). The moisture content of the bio-briquettes cashew nut waste has lower moisture content than the other raw materials. Table 1 showed the moisture content of the materials. The moisture content content meets SNI 016235-2000 (<8%) and ISO 17225 (2.2%–15.9%) bio-briquettes standards.

There is a deficiency in the composition of high volatile matter, which is low carbon bound. In Table 1, the volatile content for cashew nut waste bio-briquettes was 17.16 %. Levels of high volatile matter the results of this study is lower than reported in the literature (Akowuah et al., 2012; Onchieku et al., 2012; Stolarski et al., 2013; Tamilvanan, 2013; Maia et al., 2014; Suvunnapob et al., 2015; Zanella et al., 2016; Avelar et al., 2016; Moreira et al., 2016; Abdillahi et al., 2017; Faizal, 2017; Borowski et al., 2017; Sawadogo et al., 2018; Ujjinappa and Sreepathi, 2018; Wu et al., 2018). It supports Suvunnapob et al. (2015) findings that wood with high density will produce bio-briquettes with a more volatile matter. At a low content of volatile substances, the smoke from the bio-briquettes combustion will below. It makes bio-briquettes from cashew nut waste an environmentally friendly bio-briquettes because it can reduce the global warming effect and serve as a potential source of solid renewable fuels. The volatile matter content meets the Japanese (15%–30%) bio-briquettes standard for ash content of products seen in Table 1. The high ash volume is a drawback since it would result in toxic powder from dust and the atmosphere. The sum of it has a powerful effect on fuel combustion (Sawadogo et al., 2018). This study's ash content was 4.96wt%, lower than that reported (Tamilvanan, 2013; Abdillahi et al., 2017; Ujjinappa and Sreepathi, 2018). It is better if the coal has a lower percentage of ash content, as it saves on handling and disposal costs after using the charcoal (Onchieku et al., 2012). The ash content meets SNI 016235-2000 (<8%), Japanese (3–6%), and ISO 17225 (3.3–11.7%) bio-briquettes standards. The criteria of Thai Community Quality Standards (657/2547) stipulated that the residual ash content should be less than 10% by weight after burning (Suvunnapob et al., 2015).

Charcoal's fixed carbon content ranges from a low of around 50 % to about 95 %, but charcoal mostly consists of biomass. The carbon content is commonly measured as a "difference," i.e., all other constituents are excluded as percentages from 100, and the remaining is considered to be the amount of "original" or "set" carbon (FAO, 1985). Determination of the overall carbon content (Table 1) was compatible with other literature (Mardoyan and Braun, 2015) and that the volume of carbon has a close relation to the thermal values in biofuels (Mardoyan and Braun, 2015). The higher the carbon content, the better the carbon produced, since the corresponding calorific energy is typically high (FAO, 1985). The bonded carbon content meets the Japanese (60%–80%) and UK (75.0%) bio-briquettes standards.

Table 1. Proximate analysis and heating value of bio-briquettes from various materials.

Material	Moisture (wt%)	Ash (wt%)	Volatile matter (wt%)	Fixed carbon (wt%)	Calorific value (MJ/kg)	Reference
Cashew nut waste	5.30	4.96	17.16	72.62	29.49	(Ifa et al., 2019)
Blend of areca nut husk, Simarouba seed shell	5.75	2.48	73.71	18.19	18.81	(Ujjinappa and Sreepathi, 2018)
Cashew shell	-	5.80	29.65	64.55	27.73	(Sawadogo et al., 2018)
Cotton stalk	4.50	7.30	60.30	39.70	27.90	(Wu et al., 2018)
Palm Kernel Shell	1.75	4.83	55.95	39.22	29.60	(Abdillahi et al., 2017)
banana peels, corn cobs, and Coal mixture	5.14	6.06	26.18	62.62	26.36	(Faizal, 2017)
Wood	-	5.0–10	25–30	60–68	26.50	(Borowski et al., 2017)
Textile industry solid waste	-	12.76	77.99	9.24	19.41	(Avelar et al., 2016)
Bagasse and corn starch waste	6.86	8.59	48.50	42.92	10.30	(Zanella et al., 2016)
Sawdust charcoal	5.30	5.08	18.40	71.27	29.51	(Akowuah et al., 2012)
Agricultural and forest origin biomass	12.04	5.57	74.29	-	16.21	(Stolarski et al., 2013)
Banana leaves	7.17	10.70	75.3	14,00	17.70	(Maia et al., 2014)
Cotton dust	5.63	7.35	70.37	16.65	14.94	(Suvunnapob et al., 2015)
Waste paper	6.23	12.38	69.12	8.49	16.32	(Tamilvanan, 2013)
Dried leaves and waste paper	6.52	12.48	75.78	5.02	17.30	
Maiz starw and waste papper	8.67	14.72	78.93	20.46	18.75	
Coconut husk and waste paper	7.19	15.62	65.44	19.08	18.83	
Bagasse andwaste paper	5.95	18.48	72.53	9.63	19.01	
Bagasse, sawdust, and waste paper	5.96	13.58	63.65	22.16	20.42	
The mixture of bagasse and coffee husk	4.40	12.00	24.00	64.00	11.13	(Pallavi et al., 2013)
Bagasse	4.10	36.4	27.20	36.40	18.38	(Onchieku et al., 2012)
Hazelnut Shell	-	7.00	72.00	21.00	18.89	(Haykiri-Acma and Yaman, 2010)

Calorific value is a significant property of bio-briquettes because it represents the fuel's energy content (Aina et al., 2009). The biomass fuel's calorific value depends on its chemical composition and moisture content (Akowuah et al., 2012). The calorific properties of bio-briquettes produced in this study suggested that cashew nut waste is very suitable for bio-briquettes production, as shown in Table 1. The calorific value of bio-briquettes produced from cashew nut waste (29.49 MJ/kg) in this work is higher than those made by Akowuah et al. (2012) at 20.18 MJ/kg; Tamilvanan (2013) at 20.42 MJ/kg; Moreira et al. (2016) at 28 MJ/kg; Abdillahi et al. (2017) at 29.6 MJ/kg; Faizal (2017) at 26.36 MJ/kg; Borowski et al. (2017) at 26.50 MJ/kg; Sawadogo et al. (2018) at 27.73 MJ/kg; Wu et al. (2018) at 27.90 MJ/kg and Ujjinappa and Sreepathi (2018) at 18.81 MJ/kg. The bio-briquettes produced have properties suitable for use as an energy source. The calorific value meets the (SNI 016235-2000) (>20.93) and the Japanese (25.12 MJ–29.31 MJ). The results obtained in the present study show that bio-briquettes from cashew nut waste can compete favorably with those coal providing a source of renewable energy.

The bio-briquettes produced from cashew nutshell waste recommended bio-briquettes characteristics and have market potential in Indonesia. The proximate characteristics and calorific value analyses of the bio-briquettes assessed in this study showed that bio-briquettes manufactured from cashew nutshell waste had low moisture content (5.30%), low ash content (4.96%), and high calorific value (29.49 MJ/kg) (Ifa et al., 2019).

3.2. Economic analysis

According to Bhujel (2014), bio-briquettes have been used as renewable biomass resources for a decade. There are chances to produce and substitute fossil fuel using wastage vegetation and local citizens' economic empowerment. Supply and demand conditions are currently growing trends that are available in supermarkets, convenience stores, and other outlets. It is used mainly for cooking, heating for children/elders, house, and office purposes. The production of renewable biomass energy through the implementation of sustainable markets is a high opportunity. Biochar lowers red nitrate levels; biochar increases the exchange potential of soil cation (Maroušek et al., 2018).

The primary business goal in designing and developing a chemical factory is to achieve economic value from raw materials. The advancement of economic value is accomplished by turning raw materials into a higher market value commodity to gain some profits. The following variables have been defined as the most critical items: profit or loss and value-added (Machová and Vrbka, 2018). Upon cessation of business, the income from selling the properties is expected to surpass the value of the announced earnings (Vochozka et al., 2019).

According to Aries and Newton (1955), an economic review is carried out to decide the chemical industry development feasibility. The excellent chemical industry refers to the chemical industry that would be beneficial financially as it exists. The amount of tax has to be paid by calculating the amount of fixed and working capital, the production cost, the revenue from the product's selling, and the amount of the infinite investment.

3.2.1. The estimated fixed capital investment (FCI)

The capital investment is the amount of money spent establishing and operating a factory to manufacture goods from raw materials. There are two types of capital, namely fixed and working. Fixed Capital Investment (FCI) is needed to make factories and facilities. It is also defined as the total installation cost of the process equipment, buildings, assistive devices, and engineering involved in creating a new factory (Aries and Newton, 1955). The price of purchased equipment delivered is first calculated as seen at www.matche.com and presented in Table 2.

The total price of process equipment is USD114,440. The equipment's total price is 10% of the process equipment's total price at USD125,884. This equipment price is calculated using the FCI as follows: all components of direct cost (D) are estimated by testing the price of purchased equipment delivered, which consists of purchased equipment delivered, installation, instrumentation & controls, piping, electrical systems, yard improvements, buildings and service facilities. The Indirect costs (i), such as engineering and construction, are tested with the purchased equipment delivered. Furthermore, the contractor's fee and contingency are

Table 2. List of process equipment (www.matche.com).

No	Equipment	Total	Price/Unit (USD)
1	Belt Conveyor (hopper)	1	3,440
2	Coconut Shell Warehouse	1	180
3	Belt Conveyor (in front of the hopper)	1	3,440
4	Tapioca flour container	1	140
5	Pyrolysis reactor	1	7,800
6	Dryer	1	4,920
7	Low material hopper	1	1,440
8	Storage tank	1	1,440
9	Mixer	1	3,336
10	Belt conveyor (above the storage tank)	1	3,680
11	Belt conveyor (above the storage tank)	2	7,360
12	Low material storage tank	1	9,520
13	Belt conveyor (in front of the storage tank)	1	3,680
14	Bio-briquettes press	1	10,720
15	Conveyor for transporting waste	1	3,680
16	Turntable	1	8,720
17	Bomb calorimeter	2	17,440
18	Liquid smoke tank	1	2,480
Total Equipment Price			114,440

Table 3. The estimated fixed capital investment (Peters and Timmerhaus, 2003).

Components	Cost (USD)
Price of the equipment arrived (E)	125,884
Installation of tools, installation 39% E	49,095
Instrument and control, 28% E	16,365
Piping (installation), 31% E	39,024
Electricity (installation), 10% E	12,588
Building and maintenance, 22% E	36,506
Yard repair, 10% E	12,588
Facility improvements, 55% E	69,236
Land, 6% E	7,553
Total Direct Cost, D	368,840
Engineering and supervision, 32% E	40,283
Construction costs, 34% E	42,801
Total Direct + Indirect cost, (D + I)	451,924
Contractor fees, 5% (D + I)	22,596
Unforeseen expenses, 10% (D + I)	45,192
Total Fixed cost Investment	519,712

determined based on the total (D + I) percentage, as shown in Eq. (6) and Table 3.

$$FCI = D + I + \text{Contractor fee} + \text{Contingency} \tag{6}$$

The total amount of fixed capital investment for installing process equipment, buildings, assistive devices, and engineering is USD519,712.

3.2.2. Working Capital Investment (WCI)

Working Capital Investment is defined as the costs required to carry out business. It includes raw material inventory, in-process inventory, product inventory, extended credit, and available cash. According to Aries and Newton (1955), working capital is 10–15% of total investment or 25% of annual production sales value. For this process, 15% of TCI is calculated by Eq. (7).

$$WCI = 15\% \cdot TCI \tag{7}$$

$$TCI = FCI + WCI \tag{8}$$

$$TCI = FCI + 0.15 \cdot TCI \tag{9}$$

$$TCI = \frac{FCI}{0.85} \tag{10}$$

The total money spent to establish and operate the factory (TCI) is USD611,426.

3.2.3. Production cost

The production costs are directly and indirectly related to other components, such as administration, marketing, development, etcetera. In general, it is divided into two, namely Manufacturing Costs and general expenses. Maintenance Cost is incurred for the maintenance of process equipment. It is the sum of all direct, indirect, and fixed costs obtained when manufacturing a product.

i. Direct Manufacturing Cost includes Raw materials, operating labor (OL), supervision costs, utilities, maintenance & repairs, operating supplies, laboratories, patents, and royalties.
ii. Indirect Manufacturing Cost is expenses incurred as an indirect result of production operations, namely depreciation, local taxes, and insurance.
iii. Fixed Manufacturing Cost (FMC). It is an expense related to initial fixed capital investment and price, independent of time or production level, including depreciation, taxes, insurance, and rent. The calculation results of direct, indirect, and fixed manufacturing costs are shown in Table 4.

$$MC = DMC + IMC + FMC \tag{11}$$

$$MC = 487,949 + 175,086 + 65,423 \tag{12}$$

$$MC = 728,457$$

3.2.4. General Expenses (GE)

GE is factory expenses comprising of administrative costs, product sales, research, and expenditure. Furthermore, it consists of 3% administrative costs, 5% distribution & marketing costs, 3.5% R&D costs and 5% TCI expenditure costs.

$$GE = \text{Administration cost } (3\%\ MC) + \text{Distribution\&marketing cost}(5\%MC) + R\&D\ cost(3.5\%MC) + expenditure\ (5\%\ TCI) \tag{13}$$

Table 4. Manufacturing cost components (Aries and Newton, 1955).

No	Components	Cost (USD)
1	Raw material	132,679
2	Labor	220,874
3	Supervision	6,626
4	Maintenance	10,394
5	Plant supplies	1,559
6	Royalty and patens	10,529
7	Utilitas	105,288
Direct Manufacturing Cost (DMC)		487,949
8	Payroll overhead	41,577
9	Laboratory	5,197
10	Plant overhead	5,197
11	Packaging	42,115
Indirect Manufacturing Cost (IMC)		175,086
12	Depreciation	41,577
13	Property taxes	5,197
14	Insurance (1%FCI)	5,197
15	Bank interest (5.5% bank loan capital)	13,451
Fixed Manufacturing Cost (FMC)		65,423
Manufacturing Cost (MC)		728,457

Table 5. Estimated profits (Aries and Newton, 1955).

Sales, USD		1,052,878
Manufacturing Cost, USD	728,457	
General expense, USD	114,293	
Total Cost, USD	842,304	
Profit before taxes, USD		210,574
Income taxes (30%), USD		63,172
Profit after taxes, USD		147,402

$$GE = (3\% \cdot 728,457) + (5\% \cdot 728,457) + (3.5\% \cdot 728,457) + (5\% \cdot 611,426) \tag{14}$$

Total factory expenses, excluding manufacturing, is USD114,293.

$$TPC\ (USD) = MC + GE = 728,457 + 114,293 \tag{15}$$

The total production cost (TPC) is USD842,304.

3.2.5. Sales, profit and project feasibility profitability analysis

Sales are factory products sold to customers' perspectives based on market or minimum factory prices. Assuming the factory product already has a competitor, the selling price is set with the competitors' selling price or below. The estimated gross and net profits are shown in Table 5.

The revenue is gained by subtracting net revenue from the cost of production. There are two kinds of incomes correlated with this measure: gross and net incomes, which are excluded before and after-tax wages. The net profit of USD147,402/year is greater than Stolarski et al. (2013), amounting to € 37,627.4 or USD43,000.59/year.

Beside profit-driven, the business has to recover the money gained from the loan, conceived as a measure of income with fixed capital or Paid Out Time (POT). The level of Return on Investment and Paid Out Period varies based on the risk presented by the operation in the factory (Peters and Timmerhaus, 2003).

An economic feasibility test is also a form of a graph on the production capacity relationship and costs. It forms the Shut Down and Break-Even Point. Factories tend to incur losses, assuming it operates at a capacity below Break-Even Point. A good break-even point value for chemical factories usually ranges between 40%-60% (Aries and Newton, 1955).

3.2.6. Net Present Value (NPV)

NPV is the sum of every current value of the net revenue projected every year (Smith, 2005). Each cash flow is reduced and split by a number that reflects the opportunity cost of owning capital until it is earned or expended. NPV is one of the criteria used to evaluate expenses (cash outflows) and revenue (cash inflows) simultaneously (Dhaundiyal and Tewari, 2015).

It is the approach used to measure the net present value. The current assumptions define the original time of estimation coinciding with the year zero (0) measurement by measuring cash flow investments (Hakizimana and Kim, 2016).

The current value of dollars earned or paid in the future is obtained by multiplying the cash flow by the discount factor of the present value, as shown in Eq. (16) ((Short et al., 1995) and Satyasai (2014)).

$$NPV = -TCI + \sum\left(\frac{CF}{(1+i)^n}\right) \tag{16}$$

TCI is total capital investment, CF is cash flow in the n^{th}-year, n is the year, and $1/(1+i)^n$ is the discount factor.

3.2.7. Rate of Return on Investment

The return rate on investment based on discounted cash flow is an interest rate where all revenues cover capital expenditures using the trial price. Therefore, it fulfills the following by Eq. (17).

Table 6. Discounted cash flow for i value.

n^{th}-year	Net Cash Flow (CF)	Trial i = Present Value
1	86,677	86,677
2	99,074	99,074
3	97,922	97,922
4	79,805	79,805
5	65,037	65,037
6	53,000	53,000
7	43,188	43,188
8	35,192	35,192
9	28,675	28,675
10	23,364	23,364
Total PV		611,230

$$\Sigma = \frac{CF}{(1+i)^n} = TCI \tag{17}$$

CF is cash flow in the n^{th}-year, n is the year, and $1/(1+i)^n$ is the discount factor (see Table 6).

$$Ratio = \frac{TPV}{TCI} = 1.0 \tag{18}$$

(Peters and Timmerhaus, 2003)

$$Ratio = \frac{611,230}{611,426} = 1.0 \tag{19}$$

The correct interest rate (i) is determined by plotting the total present value against the initial investment and guessing the interest rate (i). The ratio needs to equal 1.0 to obtain the project's right interest rate (Peters and Timmerhaus, 2003). Based on the above calculation, a price of 23.55%/year is obtained, which is greater than the banks' capital loans at 5.5%. A project/investment is carried out, assuming the return rate is greater than the ROI value. However, this research is the ROI of Hakizimana and Kim (2016) at 24.94%, showed that the factory deserves further development (Hakizimana and Kim, 2016).

3.2.8. Pay Out Time (POT)

POT is a quick assessment used to determine the time in which capital investment is risky (Short et al., 1995). POT is calculated as Table 7.

Table 7 shows that by interpolating between the fourth and fifth years, POT was obtained in 3.42 years at an FCI value of USD519,712. POT of this study is shorter than the POT of Hakizimana and Kim (2016), which is 5–6 years (Hakizimana and Kim, 2016) and Maroušek et al. (2019), which is 4–6 years (Maroušek et al., 2019). Before taxes, the maximum acceptable POT for industrial chemicals is five years for low risk and two years for high risk (Aries and Newton, 1955).

Table 7. Cumulative cash flow (USD).

n^{th}-year	Net Cash Flow	Cumulative Cash
1	107,061	107,061
2	151,152	258,213
3	184,528	442,741
4	185,754	628,495
5	186,980	815,475
6	188,206	1,003,681
7	189,432	1,193,113
8	190,659	1,383,772
9	191,885	1,575,656
10	193,111	1,768,767

Table 8. Fixed cost, variable cost, semi-variable cost, and sales.

No	Description	USD
1	Fixed Cost, FC	65,423
2	Variable Cost, VC	
	a. Raw materials	132,679
	b. Utilities	105,288
	c. Packaging & shipping	42,115
	d. Royalty and patent	10,529
	Total Variable Cost (VC)	290,611
3	Semi Variable Cost, SVC	
	a. Labor	220,874
	b. Supervision	10,394
	c. Maintenance & repairs	6,626
	d. Laboratory	1,559
	e. General Expenses	22,087
	f. plant overhead cost	114,293
	g. Operating supplies	110,437
	Total Semivariable cost	486,271
4	Total Sales (S)	1,052,878

3.2.9. Break-Even Point (BEP)

The BEP study is used to assess the sum of production capacity, where the total cost is equivalent to sales performance. The value of the transaction is equal to the accrued costs. The dividing point, fixed cost, and the semi-variable production activities shall be determined using a graphic form (Aries and Newton, 1955) (see Table 8).

$$BEP = \frac{FC + 0.3 \cdot SVC}{S - 0.7 \cdot SVC - VC} \cdot 100\% \tag{20}$$

(Aries and Newton, 1955)

$$BEP = \frac{65,423 + 0.3 \cdot (486,271)}{1,052,878 - 0.7 \cdot (486,271) - 290,611} \cdot 100\% \tag{21}$$

$$BEP = 50.09\%$$

Where FC is fixed cost, S is sales, SVC is semi-variable cost, and VC is the variable cost.

The BEP value of 50.09% means that this capacity produces 2,000 tons/year and at 1,018.00 tons/year BEP in USD at 286.80, which means if the industry has been operating as much as 1,018.00 tons/year, then the industry is not loss and no profit. This study's BEP value is better than the research of Hakizimana and Kim (2016) at 38.02%. According to Aries and Newton (1955), a good break-even point value for a chemical factory usually ranges from 40% -60%.

3.2.10. Comparison of household energy consumption costs

The profit is taken from the deviation between the total production cost, and the sold cost of the bio-briquettes is USD210,574/year. Net profit/year after diminished by the tax is USD147,402/years. The net present value is USD611,230; it means that for over the next ten years, the project will produce the net present value (NPV) of USD611,230, and the Rate of Return on Investment is 23.55%. Pay Out time is 3.42 years; it means at 3.42 years is the period in which fixed capital released by industry will return. The break-even point is 50.09%, it means if the industry has been operating as much as 1,018.00 tons/year, the industry is not loss and no profit.

Organic bio-briquettes are made from waste that is easily obtained, available abundantly, and are affordable prices. In finding out the efficiency/fuel savings, it also can be done by comparing the price/calorific value. From the fuel efficiency comparison data in Table 9, it can be seen that the price/MJ of cashew nutshell bio-briquettes is lower than the prices of kerosene and LPG.

Table 9. Comparison of household energy consumption costs.

Item	Kerosene	LPG	Cashew nutshell bio-briquettes
Price (USD/kg)	0.60840	0.47179	0.28631
Calorific Value (MJ/kg)	42.00*	44.00*	29.49**
Price/cal (USD/MJ)	0.01449	0.01072	0.00971
Consumption price: For example, taking the price of LPG as the reference price (USD0.01072/MJ)	0.821265	0.47718	0.25631

* Based on studies that have been conducted by Surange et al. (2014).

** Based on studies that have been conducted by Ifa et al. (2019) and 29.49 MJ/kg is equal to 8.31667 kWh/kg (1 MJ is equal to 0.27778 kWh).

Suppose a household needs LPG as much as 1 kg/day, where the calorific value of LPG is 44.00 MJ/kg, and the calorific value of kerosene is 42.00 MJ (Surange et al., 2014). For example, taking LPG's price for cooking as the reference price (USD0.01072/MJ), and the household energy cost for LPG is USD0.47718/day. If kerosene's current price is USD0.60840/kg, one family needs an energy cost of USD0.81265/day. A comparison of this fuel's energy consumption can be seen in Table 9. In contrast, by cashew nut shell waste bio-briquettes, the cost of energy consumption to meet household energy needs is USD0.25631.

Price/cal cashew nutshell bio-briquettes (USD0.00971/MJ) = (USD9.71/GJ) (Table 9) higher than reported in the literature (Maroušek et al., 2015; Mardoyan and Braun, 2015). According to the results of the energy consumption costs ratio, it is evident that the efficiency which is produced when using the cashew nutshell waste bio-briquettes. Moreover, to reduce unrenewable and unsustainable dependency on fossil fuels, the use of bio-briquettes can also be an alternative to low-budget energy, especially for rural communities' economies. In this study, it has been shown that there is a potential future market among households for bio-briquettes.

4. Conclusion

In conclusion, the results obtained from the cashew nut bio-briquettes analysis confirmed its technical feasibility of being used as a cooking fuel for households. Furthermore, the economic feasibility was determined from the Rate on Investment of 23.55%, with a pay out time of 3.42 years and break-even point of 50.09%. The cashew nutshell bio-briquettes is more economical than liquified petroleum gas (LPG). Therefore, it can help Muna Regency community's average household reduce its annual cost by 37.00%. This study confirms the development of cashew nutshell bio-briquettes as a competitive and financially sustainable economy for investment.

Declarations

Author contribution statement

La Ifa: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Setyawati Yani: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data.

Nurjannah Nurjannah: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Darnengsih Darnengsih: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Andi Rusnaenah, Maizirwan Mel, Mahfud Mahfud & Heri Septya Kusuma: Conceived and designed the experiments; Analyzed and interpreted the data.

Funding statement

This work was supported by the Ministry of Research, Technology and Higher Education of Indonesia through the PUPT research scheme (Project No. 5077/H.25/UMI/VIII/2016).

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors are also grateful to Universitas Muslim Indonesia (UMI) for providing the necessary laboratory equipment and facilities to carry out this research and crews of Operation Chemical Engineering Laboratory, Department of Chemical Engineering, Universitas Muslim Indonesia.

References

Abdillahi, N., Sulaiman, F., Safana, A.A., 2017. Bio-oil and biochar derived from the pyrolysis of palm kernel shell for briquette. Sains Malays. 46 (12), 2441–2445.
Ahmad, K.K., Sazali, K., Kamarolzaman, A.A., 2018. Characterization of fuel briquettes from banana tree waste. In: Materials Today: Proceedings, 5. Elsevier Ltd, pp. 21744–21752.
Aina, O., Adetogun, A., Iyiola, K., 2009. Heat energy from value-added sawdust briquettes of albizia Zygia. Ethiopian J. Environ. Stud. Manag. 2 (1), 42–49.
Akowuah, J.O., Kemausuor, F., Mitchual, S.J., 2012. Physico-chemical characteristics and market.pdf. Int. J. Energy Environ. Eng. 3 (20), 1–6.
Aries, R.S., Newton, R.D., 1955. Chemical Engineering Cost Estimation. McGraw-Hill Book Co, New York. Toronto. London.
Avelar, N.V., Rezende, A.A.P., Carneiro, A. de C.O., Silva, C.M., 2016. Evaluation of briquettes made from textile industry solid waste. Renewable Energy J. 91, 417–424.
Bhujel, K.B., 2014. Market situation of bio-briquette in Kathmandu, Nepal. Initiation 5, 55–62.
Borowski, G., Stępniewski, W., Wójcik-Oliveira, K., 2017. Effect of starch binder on charcoal briquette properties. Int. Agrophys. 31, 571–574.
Dhaundiyal, A., Tewari, P.C., 2015. Comparative analysis of pine needles and coal for electricity generation using carbon taxation and emission reductions. Acta Technol. Agric. 18 (2), 29–35.
Faizal, M., 2017. Utilization biomass and coal mixture to produce alternative solid fuel for reducing emission of green house gas. Int. J. Adv. Sci. Eng. Inf. Technol. 7 (3), 950–956.
FAO, 1985. Industrial Charcoal Making, FAO Forestry Paper No. 63. Mechanical Wood Products Branch. Forest Industries Division. FAO Forestry Department.
García, R., Pizarro, C., Lavín, A.G., Bueno, J.L., 2012. Bioresource Technology Characterization of Spanish biomass wastes for energy use. Bioresour. Technol. 103 (1), 249–258.
Hakizimana, J. de D.K., Kim, H., 2016. Peat briquette as an alternative to cooking fuel : a techno-economic viability assessment in Rwanda. Energy 102, 453–464.
Haykiri-Acma, H., Yaman, S., 2010. Production of smokeless bio-briquettes from hazelnut shell. In: Proceedings of the World Congress on Engineering and Computer Science, 2. WCECS, San Francisco, USA, pp. 1–3.
Ifa, L., Yani, S., Nurjannah, N., Sabara, Z., Yuliana, Y., Kusuma, H.S., Mahfud, M., 2019. Production of bio-briquette from biochar derived from pyrolysis of cashew nut waste. Ecol. Environ. Conserv. 25 (Suppl. Issue), S125–S131.
Kers, J., Kulu, P., Aruniit, A., Laurmaa, V., Križan, P., 2010. Determination of physical, mechanical, and burning characteristics of polymeric waste material briquettes. Est. J. Eng. 16 (4), 307–316.
Lubwama, M., Yiga, V.A., 2017. Development of groundnut shells and bagasse briquettes as sustainable fuel sources for domestic cooking applications in Uganda. Renew. Energy 111, 532–542.
Machová, V., Vrbka, J., 2018. Value generators for businesses in agriculture. In: The 12th International Days of Statistics and Economics, pp. 1123–1132. Prague.
Maia, B.G. de O., Souza, O., Marangoni, C., Hotza, D., Oliveira, A. P. N. de, Sellin, N., 2014. Production and characterization of fuel briquettes from banana leaves waste. Chem. Eng. Transact. 37, 439–444.
Mardoyan, A., Braun, P., 2015. Analysis of Czech subsidies for solid biofuels. Int. J. Green Energy 12 (4), 405–408.
Maroušek, J., Hašková, S., Zeman, R., Váchal, J., Vaníčková, R., 2015. Processing of residues from biogas plants for energy purposes. Clean Technol. Environ. Policy 17, 797–801.
Maroušek, J., Kolář, L., Vochozka, M., Stehel, V., Maroušková, A., 2018. Biochar reduces nitrate level in red beet. Environ. Sci. Pollut. Control Ser. 25 (18), 18200–18203.
Maroušek, J., Strunecký, O., Stehel, V., 2019. Biochar farming: defining economically perspective applications. Clean Technol. Environ. Policy 21 (7), 1389–1395.
MINIFRA, (Rwanda Ministry of Infrastructure), 2008. Biomass Strategy Workshop of 30th April 2008. In: Biomass Strategy Workshop of 30th April 2008, 2. Kigali.
Montiano, M.G., Faes, E.D., Barriocanal, C., 2016. Effect of briquette composition and size on the quality of the resulting coke. Fuel Process. Technol. 148, 155–162.
Moreira, R., Orsini, R., dos, R., Vaz, J.M., Penteado, J.C., Spinacé, E.V., 2016. Production of biochar, bio-oil and synthesis gas from cashew nut shell by production of biochar, bio-oil and synthesis gas from cashew nut shell by slow pyrolysis. Waste Biomass Valorization 8 (October 2017), 217–224.
Mousa, E., Kazemi, M., Larsson, M., Karlsson, G., Persson, E., 2019. Potential for developing biocarbon briquettes for foundry industry. Appl. Sci. 9 (5288), 1–15.
Ndindeng, S.A., Mbassi, J.E.G., Mbacham, W.F., Manful, J., Graham-acquaah, S., Moreira, J., Futakuchi, K., 2015. Quality optimization in briquettes made from rice milling by-products. Energy Sustain. Dev. 29, 24–31.
Olorunnisola, A.O., 2007. Production of fuel briquettes from waste paper and coconut husk admixtures. Agric. Eng. Int. CIGR J. 9 (6), 1–11.
Onchieku, J.M., Chikamai, B.N., Rao, M.S., 2012. Optimum parameters for the formulation of charcoal briquettes using bagasse and clay as binder. Eur. J. Sustain. Dev. 1 (3), 477–492.
Pallavi, H.V., Srikantaswamy, S., Kiran, B.M., Vyshnavi, D.R., Ashwin, C.A., 2013. Briquetting agricultural waste as an energy source. J. Environ. Sci. Comput. Sci. Eng. Technol. 2 (1), 160–172.
Peters, M.S., Timmerhaus, K.D., 2003. Plant Design and Economics for Chemical Engineers, fourth ed. McGraw-Hill Book Co, Singapore.
Satyasai, K.J.S., 2009. Application of modified internal rate of return method for watershed evaluation. Agric. Econ. Res. Rev. 22, 401–406.
Sawadogo, M., Tanoh, S.T., Sidib, S., Kpai, N., Tankoana, I., 2018. Cleaner production in Burkina Faso : a case study of fuel briquettes made from cashew industry waste. J. Clean. Prod. 195, 1047–1056.
Sen, R., Wiwatpanyaporn, S., Annachhatre, A.P., 2016. Influence of binders on Physical properties of fuel briquettes produced from cassava rhizome waste. Int. J. Environ. Waste Manag. 17 (2), 158–175.
Sharma, M.K., Priyank, G., Nikita, S., 2015. Biomass briquette Production : a propagation of non-convention technology and future of pollution free thermal energy sources. Am. J. Eng. Res. 4 (2), 44–50.
Short, W., Packey, D.J., Holt, T., 1995. A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies. National Renewable Energy Laboratory, Colorado.
Sirajudin, N., Jusoff, K., Yani, S., Ifa, L., Roesyadi, A., 2013. Biofuel production from catalytic cracking of palm oil. World Appl. Sci. J. 26, 67–71.
Smith, R., 2005. Chemical Process Design and Integration. John Wiley & Sons, Ltd, England.
Stolarski, M.J., Szczukowski, S., Tworkowski, J., Krzyzaniak, M., Gulczynski, P., Mileczek, M., 2013. Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass. Renew. Energy 57, 20–26.
Surange, J.R., Patil, N.K., Rajput, A.V., 2014. Performance analysis of burners used in LPG cooking stove-A review. Int. J. Innovative Res. Sci., Eng. Technol. 3 (4), 87–97.
Suvunnapob, S., Ayudhya, B.I.N., Kusuktham, B., 2015. A study of cotton dust mixed with wood dust for bio-briquette fuel. Eng. J. 19 (4), 57–70.
Tamilvanan, A., 2013. Preparation of biomass briquettes using various agro- residues and waste papers. J. Biofuel. 4 (2), 47–55.
Ujjinappa, S., Sreepathi, L.K., 2018. Evaluation of physico-mechanical-combustion characteristics of fuel briquettes made from blends of areca nut husk, simarouba seed shell and black liquor. Int. J. Renew. Energy Dev. 7 (2), 131–137.
Vochozka, M., Rowland, Z., Suler, P., 2019. The specifics of valuating a business with a limited lifespan. AD ALTA: J. Interdisciplinary Res. 9 (2), 339–345.
Wu, S., Zhang, S., Wang, C., Mu, C., Huang, X., 2018. High-strength charcoal briquette preparation from hydrothermal pretreated biomass wastes. Fuel Process. Technol. 171, 293–300.
Zanella, K., Gonçalves, J.L., Taranto, O.P., 2016. Charcoal briquette production using orange bagasse and corn starch. Chem. Eng. Transact. 49, 313–318.