Research Article

Optimal Design and Techno-economic Analysis for Corncob Particles Briquettes: A Literature Review of the Utilization of Agricultural Waste and Analysis Calculation

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Received: 2 August 2021; Revised: 16 August 2021; Accepted: 31 August 2021; Published online: 15 October 2021

Abstract
Corncob is usually disposed of directly as waste, creating environmental problems, while it can be converted into valuable materials. This research aimed to evaluate the literature review on briquette production from agricultural waste by using non-binder and cold press with a binder. The techno-economic analysis was conducted to select the optimal processing method and to propose an optimal design for the production of briquette from corncob waste. The engineering perspective based on stoichiometry and mass balance showed the potential corncob briquette manufacture in both home and large scales due to the possible use of inexpensive and commercially available equipment and raw materials. The economic perspective based on several economic evaluation factors (i.e., gross profit margin, payback period, break-even point, cumulative net present value, return of investment, internal rate return, and profitability index) under ideal and non-ideal conditions by considering internal (i.e., sales, raw materials, utilities, and variable cost) and external aspects (i.e., tax) confirmed the prospective development of the project in the large-scale production with a lifetime of more than 18 years The main issue in the project is the raw material (i.e., tapioca flour), giving the most impact on the project's feasibility. Even in severe conditions, the project is feasible. The great endurance was also confirmed in the case of a higher tax rate. This study demonstrates the importance of producing corncob-based briquettes to improve economic value and give alternative for problem solvers in the utilization of agricultural waste.

Keywords: Corncob briquettes, Chemical engineering plant design, Economic evaluation, Feasibility study, Techno-economic analysis

1 Introduction

A briquette is a block of combustible material used as fuel to start and maintain a flame. The most commonly used briquettes are coal briquettes, charcoal briquettes, peat briquettes, and biomass briquettes. Nowadays, fuel briquettes are widely used to supply households and the industry with energy and play an essential role as a renewable and sustainable alternative to woody biomass [1]. Briquettes made from biomass, such as agricultural waste, have drawn much interest due to their ability to turn low-grade combustible material into a reasonably high-quality fuel source [2]. This biomass has a lower calorific value than the produced bio-briquettes; thus, calorific value of biomass can be increased by converting it to bio-briquettes [3].

In general, to convert agricultural waste into briquettes, two methods are available: (i) the non-binder briquetting technique and (ii) the cold-press briquetting with the binder technique [4]. In short, agricultural waste which is densified into carbon in the absence or limited supply of air [5], can be essential to remove volatile components from the feedstock. Carbonization is effective in increasing fixed carbon and heating value [6].

Recently, efforts on converting agricultural waste into briquette increase. Several agricultural wastes as the source of briquettes have been suggested: rice husk [7], coconut shell [8], sawdust [9], coffee husk [10], cotton stalk [11], and corncobs [12]. The use of these wastes were supported with the ideas of various methods and types of binders. However, there is less information on investigating potential large production of briquette using a techno-economic analysis. Techno-economic analysis can be used to determine whether the project is prospective or not. This analysis process is sustainable by estimating at the economic scale and broader implications.

This paper aimed to review the briquetting production and mechanism and current studies on techno-economic analysis, propose the optimal design of corncob-based briquette production, and analyze the selected optimal design using techno-economy analysis.

The techno-economic analysis has been used for analyzing the feasibility of the process. It is calculated to get the information from engineering and economical evaluation perspectives. Engineering analysis was done by predicting the synthesis process using commercially available apparatuses and raw materials. In the economic analysis, several economic evaluation parameters were analyzed to inform the potential production of corncobs briquettes, such as payback period (PBP), gross profit margin (GPM), break-even point (BEP), cumulative net present value (CNPV), return of investment (ROI), internal rate return (IRR), and profitability index (PI). The economic evaluation was conducted in ideal or non ideal conditions by varying the value of taxes, sales, raw materials, variable cost, and utility under several conditions.

This paper focused on briquette production from corncobs with cold-press briquetting technique and tapioca binder [4]. The cold-press briquettes are more stable compared to the non-binder briquettes. The binder used in the cold-press method helps carbon to bind each other. Then, the binder also gives the possibility for the use of various sizes of carbon. Binder can affect the strength, compressive strength, particle adhesion, thermal stability, combustion performance, and cost of briquettes [12]. Different types of raw materials need different types of binders, informing the need to select a suitable binder for a particular briquette type. Overall, the binder majorly affected the bonding mechanism of particles in the briquette.

The novelties of this research are the evaluation from engineering and economic evaluation for the production of briquettes from corncob particles. At the same time, current reports have limitations to the lab-scale process only, and there is limited information on the techno-economic analysis for this production. In addition, this study is important for increasing economic value as well as giving good problem-solving, and the new perspectives in utilization of agricultural waste [13], [14].

2 Literature Review

2.1 *Characteristics of corncob*

Corncob is one of the prospective agricultural biomass resources for renewable energy industries in Southeast Asia countries, especially Indonesia, which might help alleviate existing energy and greenhouse gas issues [15]. Corncob may be utilized to make heat [16], electricity [17], gas/liquid fuels[18], and a range of chemicals such furfural [19], xylitol [20], and activated carbon [21].

Corncob is particularly ideal for heating since it has a low ash level (less than 2% d.b.) in comparison to other agricultural waste [12], [22]. Corncobs had heating values (HHV) ranged from 18.3 to 18.8 MJ/kg of dry matter [23] because corncobs contain a high amount of organic material [24] (Table 1).

Table 1: Composition of corncob compared to other types of agricultural waste (adopted from the literature [24])

Agricultural Waste	Composition (%)					
	Cellulose	Hemicellulose	Lignin	Silica	Other Components	Silica Content in Ash
Corncob	42	32	15	10	0	> 50
Rice husk	36	26	21	17	0	> 90
Rice straw	44	20	20	16	0	> 65
Sugarcane bagasse	38	27	22	9	4	> 70

On a dry mass basis, the proximate analysis of corncob revealed 80.10% of volatiles and 1.36% of fixed carbon. Furthermore, the ultimate analysis of corncob resulted in 46.58% of carbon, 45.46% of oxygen, 5.87% of hydrogen, 0.47% of nitrogen, 0.21% of chlorine, 1.40% of ash, and 0.01% of sulfur [22]. On a wet basis, corncob approximately has 8–20% moisture content [23].

2.2 *Current processes for producing briquettes*

The present techniques for generating briquettes using non-binder briquetting and cold-press with binder method are summarized in Table 2, showing a literature review analysis for the production of briquettes from various raw materials, including advantages and disadvantages from the use of specific raw materials.

After conducting a literature study, agricultural waste has shown great potential as an alternative fuel in the form of briquettes [24]. Such material is abundantly available and accumulated as waste, and thus it is inexpensive for the process [13]. Although raw agricultural waste can be changed into briquettes directly, the carbonization process improved the briquettes' qualities. Briquettes from carbonized agricultural waste have low moisture content, low relaxation ratio, high compaction ratio, high burning rate, low specific fuel consumption, high compressive strength, and low water absorption. Specifically, this study focused on corncob briquettes.

Table 2: Current studies for producing briquettes

Briquetting Mechanism	Material	Additional Processing	Result	Ref.
Non-binder briquetting	Lignite and water	-	- The increase of pressure increased the contact area, which increased the compressive strength. - The increase in temperature made the coal softer and easier to be compacted. - Increased pressure and temperature reduced residual moisture content in the briquette, which improved compressive strength. - Humic acid in the lignite, which is rich in functional groups, affected the compressive strength of the briquette. - By establishing hydrogen bonds between the surfaces of lignite particles, carboxyl and hydroxyl increased the compressive strength of briquettes.	[25]
Non-binder briquetting	Chinese Hulunbeir lignite	Mechanical thermal expression	- The compressive strength increased with increasing briquetting pressure. - The optimum moisture content (14–16%) and highest compressive strength were obtained at higher briquetting pressures, - The compressive strength of the briquette mixture was increased by increasing the small particle fraction. - The optimum briquetting temperature was discovered to be 150 °C, and raising the briquetting temperature caused the compressive strength to decrease. - Compressive strength increases due to the increases in humic acid contents.	[26]
Non-binder briquetting	Oil palm mesocarp fiber and *C. pentandra* sawdust	Without carbonization	- Low compacting pressure (40 MPa) at room temperature produced briquettes with good relaxed density, compressive strength, and impact resistance index. - Increases in oil palm mesocarp fiber content attributed to the percentage change in length and diameter of briquettes. - *C. pentandra* is better than the oil palm mesocarp fiber due to its high volatile content. - Ash content for *C. pentandra* sawdust was 4.7248%, while oil palm mesocarp fiber was 6.5330%. - The impact resistance index increased with increasing compacting pressure and dropped as the oil palm mesocarp fiber quantity in the mixing ratio increased.	[27]
Cold-press with a binder (starch)	Corncob and starch paste Rice husk and starch paste	Without carbonization	- Compared with briquettes from rice husk, Briquettes created from corncobs have greater compressive strength, heating value, compaction ratio, density ratio, relaxation ratio, and afterglow time. - The moisture content of briquettes made from corncob was higher than briquettes made from rice husks.	[28]

Table 2: Current studies for producing briquettes (*Continued*)

Briquetting Mechanism	Material	Additional Processing	Result	Ref.
Cold-press with binder (tapioca paste)	Sea mango, tapioca flour, and water	With carbonization	- Briquette with larger particle size has a shorter drying time since moisture easily escapes from pores. - Increases in particle size reduced the water resistance but improved the compressive strength, burning rate, caloric value, and specific fuel consumption of the briquettes. - Sea mango charcoal has a higher calorific value than cocoa shell charcoal.	[29]
Cold-press with a binder (dextrin)	Bamboo fiber, dried clove leaves, and dextrin	With carbonization	- Dextrin is the binder that can attract water and form a solid texture by binding the substrates. - Decreases of dextrin composition attributed to decreases in relaxation ratio, showing stability and minor shrinkage. - Decreases of dextrin composition attributed to better combustion properties (higher burning and specific fuel consumption value).	[30]
Cold-press with a binder (cassava paste)	Madan wood branches, coconut shell, and cassava paste.	Madan wood was carbonized, whereas coconut shell was not.	- Decreases in coconut shell amount in the blends resulted in lower moisture content. - Madan wood (100%) has high flammability, released a significant amount of smoke. - The calorific characteristics of charcoal briquette samples made from Madan wood (6,622 cal/g) were higher than those made from coconut shells (6,310 cal/g). - Madan wood briquette has the highest burning rate (0.53 g/min), while coconut shells had the lowest value (0.44 g/min).	[31]
Cold-press with a binder (cassava peels)	Rice husk and cassava peels.	Without carbonization	- Maximum density = 977.6–176.5 kg/m^3 - Relaxed density = 571.1–622.9 kg/m^3 - The prepared briquettes may have a higher calorific value, burning rate, and relaxed density when compared with briquettes made with cassava starch binder. - The briquettes took a shorter combustion time for a given weight loss compared to briquettes with cassava peels as the binder.	[32]
Cold-press with a binder (cassava paste + clayey soil)	Mango seed, cassava paste, clayey soil, and water	Without carbonization	- The addition of the bulky densities material to the blends influenced the final briquette density result. - The addition of clayey soils decreased the compressive strength of the briquette. - Clayey soils have insignificant organic matter but are pre-dominant with inorganic particles. - The chosen binder was improving the volatile matter content in the briquette. - Smaller particles were favorable for briquetting. - Starch briquettes also have more benefits linked to less release of carbon, ash, and emissions that affect the atmosphere.	[33]

Briquette manufacture has no standard mechanism, but it can be divided into: non-binder briquetting and cold-press briquetting with a binder. The non-binder technique was usually performed for lignite briquettes. The technique can be used on biomass, but requires high pressure during the briquetting process. Some biomass materials cannot agglomerate unless a binder is added. Additional binder reduced equipment wear and provided strong interparticle bonding between briquette components. The binder also affects the briquettes properties such as burning time, moisture content, compressive strength, relaxation ratio, and water resistance. Based on the binder composition, the briquette binder can be divided into three categories: organic, inorganic, and hybrid compound. Briquettes from agricultural waste were usually used biomass binder with some advantages such as high mechanical strength, wide source, low price, high heat value, and good cohesiveness. Based on the literature review, this study decided to use the cold-press technique and tapioca paste as a binder since it shows good binding ability and is easy to sustain for a long-term project.

2.3 *Current reports on techno-economic analysis*

Techno-economic analysis has been used for analyzing the feasibility of an industrial process, product, or service.

To support the analysis, economic evaluation parameters are usually analyzed, such as GPM, PBP, BEP, CNPV, ROI, IRR, and PI. The analysis was then computed in a flexible manner, which can be conducted for ideal and non-ideal scenarios. Several studies showed that techno-economy analysis is useful for determining a project's feasibility when facing a crisis such as higher tax, higher raw material, low sales, and higher utility price.

Table 3 summarizes recent researches on techno-economic analysis. The table shows several methods for producing materials. The techno-economic analysis was analyzed in the case of inorganic and organic components. This table is important for comparing our study and previous works. This review analysis is critical for comparing existing approaches to obtaining feasibility assessments for specific projects.

Table 3: Current studies about techno-economic analysis

Material	Product	Result	Ref.
Nanogold particles	It was produced by the citrate reduction method.	- Chloroauric acid acting as the primary raw material had a significant effect on GPM, followed by sodium borohydride and sodium citrate. - PBP has obtained in the 3rd year with the assumption that the production runs 100% without constraints. - By producing ten products per day, the industry did not experience gains or losses. - Although the variable cost was varied, the PBP and BEP remained constant. This showed that the gold nanoparticle manufacture has relatively high stability in fairly volatile market conditions. - When the variable tax was varied, the industry was not stable in high tax conditions. - The production was still profitable in various production capacities.	[34]
NiO nanoparticles	122,604 kg per year by homogeneous precipitation method	- The project takes four years to reach the PBP point. - An increase in the price of raw materials has a negative effect on the project. If the raw materials price is up to 115%, the PBP was obtained in the 8th year. - A selling price of less than 90% was not recommended since the PBP was obtained in the 7th year. - Increases in equipment price by 10% was increasing the PBP by one year.	[35]
Carbon nanoparticles	300,000 kg per year by the non-thermal plasma method	- The total cost for raw materials/year = 1,003,975.68 USD - The total cost for equipment/year = 17,041.67 USD - The sales in one year = 2,400,000 USD - The profit earned per year = 1,168,626.13 USD - CNPV/TIC reaching a value of 70.8 in year 13 and PBP corresponding in the 3rd year.	[36]
Cobalt nanoparticle	163,1232 kg per year by chemical reduction method	- The payback period is two years. - In ideal conditions, the project can reach 28800 cycles per year. - The IRR value shows 15% for years of project life. - Based on the final CNPV parameters and PI, the value is relatively high for projects with 20 years of lifetime.	[37]
Copper nanoparticles	1.5 kg per production with Rongalite as reducing agent	- In ideal conditions, the curve of CNPV/TIC (%) to a lifetime (year) decreased until the second year and increased in the 3rd to the 20th year. - The payback period is 2.2 years. - The highest profit is obtained when using 80% of the sales.	[38]
$LaCoCo_3$ nanoparticles	20,243 packs per year by co-precipitation method	- PBP analysis showed that investment could return the total initial expenditure after more than 4–6 years. - IRR analysis in ideal conditions showed the value of 51.84; 47.06; and 35.22%, respectively, for products with water, ethanol, and ethylene glycol solvents during 20 years. - ROI showed a negative result with a value of around 3–4% - The use of water as a solvent in $LaCoO_3$ nanoparticles is better than ethanol and ethylene glycol from an engineering and economic perspective.	[39]
MgO nanoparticles	180,000 kg per year by the physicochemical method	- PBP occurs in the third year. - One of the benefits of MgO nanoparticles is as an antimicrobial in the water filtration process. - Using 300 cycles per year can obtain 600 kg of MgO nanoparticles, magnesium hexahydrate is 3,846 t, and sodium hydroxide as much as 4 t with a total water solvent of 60,000 L. - The project is feasible to run.	[40]

Table 3: Current studies about techno-economic analysis (*Continued*)

Material	Product	Result	Ref.
Cashew nut shell briquettes	2,000 tons per year by the pyrolysis method	- The bio-briquettes are made from a pyrolysis process that is carried out in a simple batch-type reactor by heating using liquefied petroleum gas (LPG). - The 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%. - Cashew nut shell-briquettes can be sold at 1,052,878 USD/year. - The total production cost is USD 841,304 per year. - The net profit is USD 147,402 per year. - The investment rate is 23.55% - The payout time is 3.42 years. - The break-even point is 50.09%.	[3], [41]
Silica from agricultural wastes (i.e., rice husk, rice straw, corncob, sugarcane, bagasse)	Silica from rice husk, rice straw, bagasse, and corncob were 360; 352; 180; and 135 tons/year, respectively.	- Agricultural wastes (i.e., rice husk, rice straw, bagasse, and corncob) are perspective as silica raw material. - The engineering perspective shows that the project is easily operated, simply improved, and developed using technologies and apparatuses that are currently available and inexpensive equipment.	[24]
Rice Straw	Carbon particles and silica particles were 168 and 537 kg/year, respectively.	The process for converting rice straw waste is unattractive for industrial investors.	[42]
Waste date palm (*Phoenix dactylifera*) leaves	The production for the date palm leaf wax extraction estimated the lowest cost of manufacture (COM) at 3.78 EU/kg wax	Date palm leaves are an attractive raw material for the natural wax industry due to their low manufacturing costs, high wax yield, thermal properties of the extract, and abundant resources.	[43]
Cassia fistula plant extract	The production of zinc oxide nanoparticles is 250 kg of ZnO nanoparticles per day with a total equipment cost of 21,450 USD	- The investment will be profitable after more than three years. - This project can compete with PBP capital market standards because of the short investment returns. - The project is estimated from ideal conditions to the worst case in production, including labor, sales, raw materials, utilities, and external conditions.	[44]
Larch wood waste	Production for pilot scale and industrial-scale processes with different extractor capacities, ranging from about 12 to 1,200 kg of wood per day.	The lowest production cost for one kg of phenolic compounds was obtained for the process of extractor capacity of 350 L (daily production capacity of 1200 kg), operating at 300 °C and of 221.32 ± 19.26 USD/kg.	[45]
Brake pads from rice husk particles	The production capacity is 2,950,000 brake pad pieces per year with one production cycle per day.	- The project is feasible to run with a payback period of 3.20 years. - The ROI value is 25.69% per year. - The project is not promising for investors due to the low IRR value for 20 years (1.74%). - Raw material and sales parameters have the most influence on the project's profit.	[46]

Some researchers have done techno-economic analyses, but there are limitations in explaining agricultural waste. Many studies reported researches on rice husks for silica [47] and carbon fabrication [48], [49], rice straws for carbon and silica particle fabrication [50], [51], corn for bioplastics [52], [53], sawdust for energy [54], palm for the plasticine, and brake pad production [55], [56], larch wood waste for the production of phenol compounds [45], and rice husk for brake pads [46]. Most of the reports discussed

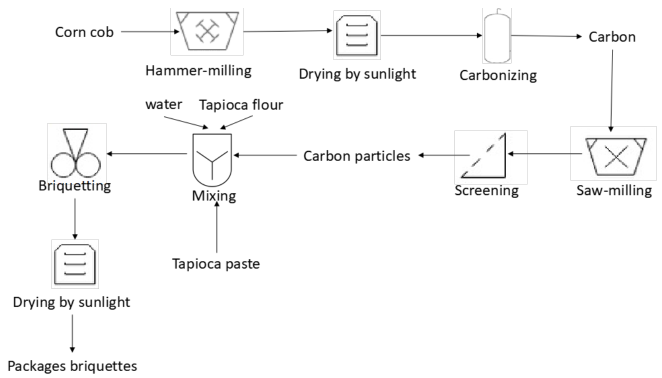

Figure 1: Process flow diagram for corncob briquette production.

agricultural waste, but fewer reports focused on materials and their economic feasibility, such as briquettes, which can be used in a realistic application to the market. Therefore the techno-economic analysis of briquettes manufacture is inevitable.

3 Method

3.1 *Literature study*

The literature study was carried out by searching articles on the Google Scholar database from 2010–2020 that inform the briquetting technique (i.e., non-binder briquetting and cold-press with a binder technique) and the techno-economic analysis, using the same searching method in our previous studies [57]–[59]. The keywords were briquettes, binder, briquetting, agricultural waste, carbonization, techno-economic analysis, particles, feasibility study, and economic evaluation. The main collected articles were regular articles (scientific reports). Proceedings and literature reviews were read, but they were not our main focus since regular articles give more up-to-date ideas and suggestions. When reading the articles, the first focus was abstract. If the abstract is good, the reading was continued to the main parts. On the contrary, when the abstract was out of topics, the in-depth reading was not done. The number of collected articles for the present topic was more than 100 articles, and the best articles were put as references.

3.2 *Production process of corncob briquettes*

East Java area in Indonesia is selected as the location for the corncob's supplier and the planned plant for this project since this area is the center of corn production in Indonesia [60]. The corncobs that are used are not from the specific variety and were collectively obtained as waste. This study also selected the cold-press technique with tapioca paste binder as the optimal design for the corncob briquette manufacture.

The process of making briquettes starts from crushing, continued by drying using sunlight and carbonizing the dried corncob powder. The resulting carbon is then crushed and sieved to form similar carbon particles, which is similar using our previous reports [61]. The carbon particles are then mixed with tapioca paste with a composition of 39:20 and molded using a briquetting machine. Tapioca paste is made by mixing tapioca flour and water with a 1: 10 composition. After drying in the sun, briquettes are ready for packaging. The process flow diagram for making corncob briquettes is presented in Figure 1.

3.3 *Economic analysis of corncob briquette production*

Several economic analysis factors were used to estimate project feasibility [62], including GPM, PBP, BEP, CNPV, PI, IRR, and ROI, which were calculated based on the ideal and non-ideal scenarios. Non-ideal scenarios' prediction was carried out by varying the sensitivity parameters based on internal factors (i.e., sales, raw materials, variable cost, and utility) and external factors (such as tax) during the manufacturing process.

The main calculations from the economic parameters are

1) GPM (USD per pack) was calculated by

subtracting sales revenue and the cost of goods that were sold.

2) PBP (year) was obtained using the lifetime point when CNPV/TIC value was zero.

3) BEP (pack) was computed by subtracting the variable costs per unit from the overall fixed costs connected with manufacturing and revenue per individual unit.

4) IRR (%) was calculated using Equation (1):

$$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_o \quad (1)$$

where C_T is the net cash inflow during the period of t; r is the discount rate, t is the number of periods, and C¬$_0$ is the total initial investment cost.

5) The value obtained from the net present value (NPV) at a specific is referred to as CNPV. The NPV was computed by multiplying the cash flows with a discount factor.

6) The return on investment (ROI; %) was computed by dividing the net profit by the amount invested and multiplying by one hundred.

7) The PI (%) was computed by dividing the difference between sales and manufacturing expenses by sales (profit to sales) or investment (profit-to-TIC).

The following assumptions were used in this study to analyze the production of briquettes made from maize cob waste on a broader scale:

1) The pricing equipment and raw ingredients for the briquette production process can be found on available online markets such as Bukalapak.com, Tokopedia.com, and Alibaba.com.

2) One kg corncobs could produce 500 g carbon.

3) The composition of tapioca flour and water to make tapioca paste was 1: 10.

4) The composition of carbon and tapioca waste for the briquette mixture was 39: 20.

5) The production did not use chemicals.

6) The final product was briquettes prepared from corncob waste.

7) The production process was one cycle per day.

8) The one-year project lasts 264 days.

9) Assuming utility costs are IDR 1,444 per kWh.

10) Income tax is 10% every year.

11) The project operation length was 18 years.

Based on the results of the economic analysis of corncob waste briquette production, a single production cycle for one day produces 1000 kg of briquettes. Under ideal conditions, production can be increased up to 264 cycles in a year with a production capacity of 264,000 kg of briquettes.

4 Results and Discussion

4.1 *Engineering perspective*

Corncob was used as the main material for the briquette, which is an alternative option to maize or corn-based agricultural waste product. The corncob was smashed into smaller pieces with a hammer mill, dried in the sun, and carbonized. The milling technique was required to reduce the amount of time needed to dry the corncob. The drying procedure, on the other hand, was used to eliminate any moisture from the corncob. The amount of water was kept to a minimum to speed up the carbonization process. Carbonization is the process of removing volatile compounds from a feedstock without or with a limited air supply [5]. Carbonization of biomass such as corncob has been reported as an effective way for increasing fixed carbon and heating value [63]. Equation (2) shows the carbonization mechanism. In this paper, carbonization was carried out by putting corncob in an electrical furnace at a temperature of 250 °C [24].

$$C_xH_yO_z + O_2 \rightarrow CO_2 + CO + C \quad (2)$$

Although corncob can be processed into briquette with no other process, the carbonization method was selected for the optimal briquette production design because:

1) It converted higher cellulose content material, enchancing mechanical properties [64].

2) The briquette created has a blue flame (high temperature) that lasted longer.

3) The carbonization increases the fixed carbon content, which improves the briquette's heating value [65].

4) The carbonization decreases the moisture content

5) The briquettes that are produced have lower air pollution emissions [66].

6) The briquettes that are produced do not leave a black mark on utensils

7) The briquettes have a lower specific fuel consumption, indicating better fuel efficiency

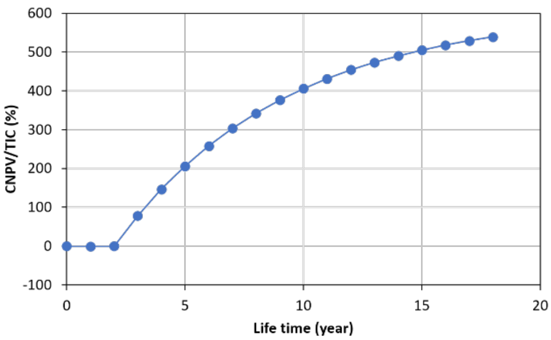

Figure 2: The CNPV/TIC curve as a function of a lifetime for the corncob briquette project.

To make a briquette, carbon could not produce significant attraction between particles, implying that a sticking or agglomerating agent was required. Therefore, the cold-press briquetting technique was selected with tapioca paste as the binder for the optimal design. Tapioca paste was obtained by mixing tapioca flour and water. Binder is used to mediating the bonding of carbon particles. It happened due to intermolecular hydrogen bonds between the starch components amylose and amylopectin, van der Waals forces, and mechanical locking caused by cold-pressing (briquetting) [10]. The briquetting process is done by a briquetting machine with a hydraulic press. The prepared briquettes are then dried under sunlight for few days. This procedure effectively prevents the abrupt moisture loss resulted in briquette cracks that typically occur while using an electrical furnace for drying. The briquettes are then ready to be packaged for sale.

4.2 *Economic evaluation*

4.2.1 Ideal condition

Figure 2 shows the CNPV/TIC curve against the duration of the corncob waste briquette project. Based on the ideal curve, the project's first two years still showed negative values since it was still in the construction stage. Several factors that influenced the result were variable costs, fixed costs, sales, depreciation, profit before tax, and income taxes calculated in the third year. The production process started in the third year and is already profitable and advantageous for the next 18 years. Based on the economic analysis under ideal conditions, the corncob waste briquette project is worthwhile and promising. The trend of the graph obtained was under ideal conditions as in our previous report [44].

Table 4: Economic evaluation parameter in ideal condition

Economic Evaluation Parameter	Value
GPM (USD/year)	1,725,240
PBP (years)	3.00
BEP (pieces)	284.72
IRR (%)	12.43
Final CNPV/TIC (%)	538.85
ROI (% per year)	740.26
PI profit-to-sales (%)	88.37
PI profit-to-TIC (%)	133.24

Table 4 presents the economic evaluation parameters of GPM, PBP, BEP, BEC, IRR, CNPV, ROI, and PI with positive analysis results, indicating an attractive project for industrial investors. For future discussion, the analysis in the ideal case is carried out as follows.

The GPM analysis is the first step in determining profitability in an economic review. GPM can calculate project efficiency in equipment use and raw material costs for producing and selling items. GPM calculates a value of 1,725,240 for this project, indicating that it is viable and practical. Although the results show that a chemical process is highly profitable, GPM cannot be employed directly because the project is based on other fundamental economic evaluations and manufacturing expenses [39].

According to the PBP analysis, the project will recover the initial investment after 3 years. Because of the short timeline, this project is relatively competitive compared to the traditional capital market PBP. In Indonesia, the normal capital market promotes PBP approximately 30–32 years for investments of 800,000 USD [39].

The BEP specified the minimum quantity of items sold to cover the total cost of production. In this project, the minimum product that must be sold to generate a profit is 284.72 pieces. These figures are within reach for Indonesian businesses interested in purchasing and using briquettes. Briquettes processed from corn stalk waste can be used for cooking fuel and domestic heating [67], [68].

The IRR for this project is 12.43 percent over 18 years, indicating a high investment rate and promising for investment. This result demonstrates that IRR was

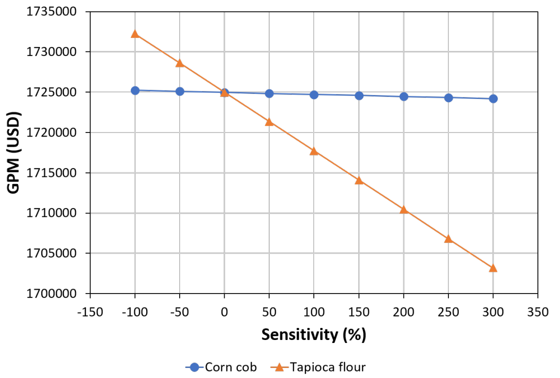

Figure 3: Effect of changing raw material on the GPM.

not in contradiction with the interests of Indonesian local banks, which are 5–6% [69].

Through the discussion above, the concept of generating briquettes from corncob waste demonstrates good and intriguing prospective engineering outcomes from economic analysis for industrial investors in Indonesia. However, other perspectives must be reconsidered.

4.2.2 Non-ideal condition: internal factors (raw materials, sales, utility, and variable cost) and external case (tax)

For the main raw materials of corncobs and tapioca flour, Figure 3 displays the analysis results to estimate the effect of decreasing raw material prices and selling expenses from –150% to 300% on GPM. According to the findings, GPM was affected by variations in sales of corncob briquettes. The rise in raw materials' price has a negative influence on GPM. Increased sales, on the other hand, make GPM more profitable (profitable). This means that growing sales results in profits while increasing raw materials results in losses for the project. Based on the analysis, when the sensitivity was changed, the GPM value of the corncob parameter did not show a significant change. Tapioca flour has the biggest impact on GPM fluctuations.

Another factor that can affect the economic condition of this project is the PI evaluation that includes sales, raw materials, and utilities. Figure 4 depicts the profit-to-sales PI analysis. The impact of the sales factor on the PI value follows an exponential curve with increases from –8% to 4%. These findings suggest that a rise in sales directly impacted profits, especially when the sensitivity variation ranges

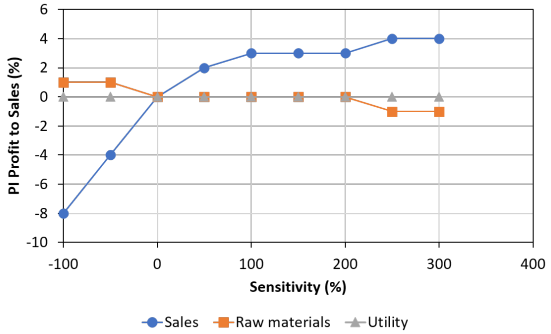

Figure 4: Analysis of PI profit-to-sales as a function of sales, raw material, and utility.

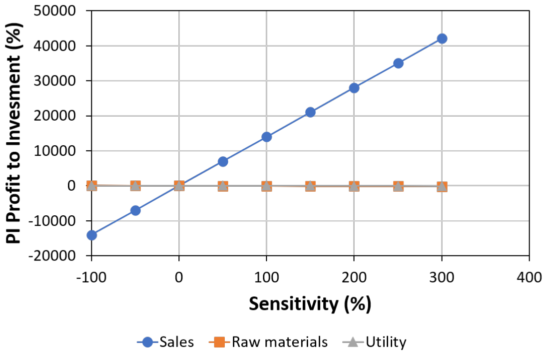

Figure 5: Analysis of PI profit-to-investment as a function of sales, raw material, and utility.

between –100 and 50%. Another factor that is important to consider is raw materials. The raw material element has a negative impact on the PI value, as seen by declines in the PI value from 1% to –1%. Figure 3 shows that raw materials have similar outcomes to those of the GMP analysis. From a utility standpoint, the cost increase has a minor impact than the increase in sales.

The PI value for profit-to-investment was also investigated, as shown in Figure 5. The raw materials and utility parameters show a relatively linear curve. The project's profitability is heavily influenced by sales factors, which impact the project's long-term viability. The study's findings showed that the cost of raw materials and utilities must be in line with previously established pricing, with a maximum rise of 0%. The factors that impacted PI value were sales, followed by raw materials and utilities.

The findings of the examination of variable cost variations are shown in Figure 6. The lower the CNPV/TIC number, the higher the variable cost. The CNPV/

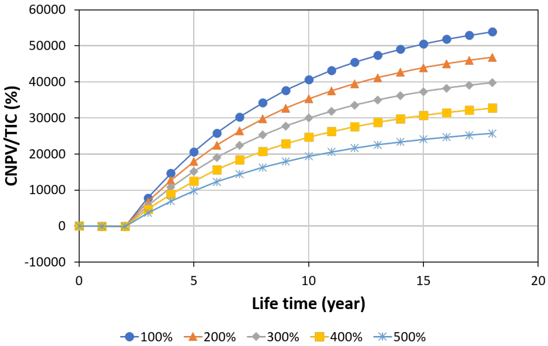

Figure 6: CNPV curve in accordance with the lifetime of the project with various variable costs.

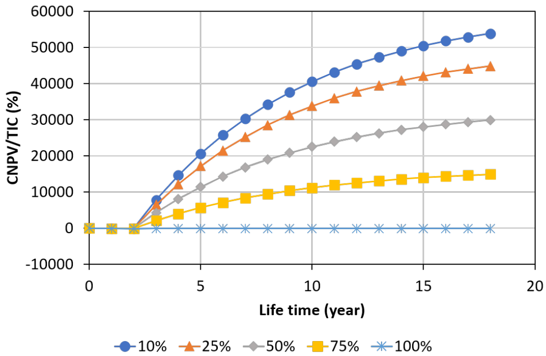

Figure 7: CNPV curve as a function of the project's lifetime with various taxes.

TIC score, however, remains positive with a sensitivity of 100–500 percent. Even with the 500 percent rise in variable cost rates, the project is still profitable.

In addition to the CNPV/TIC analysis based on variable cost fluctuations, a CNPV/TIC analysis of tax variations depending on the project's duration for the following 18 years was performed in this study, as shown in Figure 7.

The CNPV/TIC curve demonstrates that the higher the tax, the more profits are cut, and vice versa. A 10% tax will produce the highest profits, while a 100% tax will cause the project's failure. As a result, the tax burden imposed on the project must be less than 100%.

Corncobs briquettes' long-term viability will be assured as long as people continue to cultivate corn. In fact, from 1986 to 2017, Indonesian corn production increased by an average of 1.74% per year, resulting in total annual production of 2.39 million tons [70]. Since corncobs make up about 15–20% of the above corn residues (non-grain) [71], [72], approximately there were 478 million kilograms of corncobs produced per year. Furthermore, according to the economic study [60], corncob briquetting may be incorporated in supporting sustainable development to provide both energy and food safety, along with adaptability to reduce the adverse effects of climate change.

That is true that the project must be supported by the availability of raw materials, such as corncob. There are possibilities for the existence of companies or industries using corncob. However, the amount of corncob is large based on the above data, reaching 478 million kg/year. This makes the corncobs usually go to the disposal site without further use. Thus, this study can promote ideas for increasing economic value as well as give good problem-solving and new perspectives in the utilization of agricultural waste.

5 Conclusions

We successfully investigate the feasibility studies for the production of briquettes from corncob. Corncob is effective since it can create more energy than other types of agricultural waste containing more other components such as silica. From an engineering point of view, corncob briquette production is suitable for small-scale production and could potentially be scaled up because it uses affordable and readily available equipment. GPM, PBP, BEP, CNPV, PI, IRR, and ROI showed positive results in the economic evaluation, indicating that this project is prospectively developed in large-scale production for more than 18 years and that the payback period is 3 years. Tapioca flour has the greatest impact on the feasibility of the project, but corncob has none. Sales had the greatest impact on the PI value of profit-to-sales and profit-to-investment compared to raw material and utility prices. The project was still feasible even at a 500% of variable cost, and it demonstrated high endurance in the face of a rising tax rate. At a 100% tax rate, however, the project would be a failure. The results of this study can be used to assist sustainable development by providing both energy and food safety and resilience to reduce climate change's adverse implications.

Acknowledgements

This study was supported by RISTEK BRIN, Grant

Penelitian Unggulan Perguruan Tinggi, and Bangdos Universitas Pendidikan Indonesia.

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