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Research Paper

Resin-based Brake Pad from Rice Husk Particles: From Literature Review of Brake Pad from Agricultural Waste to the Techno-Economic Analysis

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Abstract

A brake pad is the most crucial component in motorized vehicles. Many ways have been done and reported on how to prepare resin-based brake pads, but information relating to the economic analysis of resin-based brake pads on a large-scale production is still rare. This study aimed to report a literature review of brake pad production from biomass and agricultural wastes, optimal design of brake pad, and techno-economic analysis of resin-based brake pad production from rice husk. In the techno-economic analysis, we focused on engineering and economic perspectives. Engineering analysis was conducted by calculating the mass balance in the resin-brake pad production process. To support the analysis, economic parameters including gross profit margin (GPM), payback period (PBP), break-even point (BEP), cumulative net present value (CNPV), profitability index (PI), internal rate return (IRR), and return on investment (ROI) were calculated to predict the feasibility of project under ideal condition. We also calculated the techno-economic analysis for the worst cases in the project, calculating the internal problems (i.e., raw materials, sales, utility, labor, employee, fixed cost, variable cost, and production capacity) and the external issues (i.e., taxes and subsidiaries). Based on the engineering evaluation, the resin-based brake pad project is prospective. From economic evaluation, GPM, PBP, BEP, CNPV, PI, and ROI showed positive results, indicating that the project is potential for the large-scale production. This work has demonstrated the importance of the projects for further development and can be used as a reference for further production of brake pads made from agricultural waste.

Keywords: Engineering perspective, Feasibility study, Resin-based brake pad, Techno-economic analysis.

1. Introduction

A brake pad is one of the most important parts of the vehicle [1]. A brake is a system that works to control, retard, and stop the rotation of the machine in the vehicle. The working principle of the brake is by converting kinetic energy into heat by rubbing the disc (brake disc) with brake pads when the two components contact. When the vehicle is driving at a high speed, the brake pad plays a very important role because it supports the safety of drivers and passengers. The performance of the brake pad depends on the quality of the brake pad, such as friction materials used in the process of brake pad production [2]. Based on the manufacturing process, brake pad, including particulate composites consisting of reinforcement and binding materials (matrix). The reinforcing material consists of dispersed particles evenly distributed in the matrix which acts as a binder, thus producing a compact structure [3,4].

Based on the type of matrix material, the brake pad can be made from metallic, semi-metallic, and non-metallic materials [5,6]. Generally, the asbestos friction material-based brake pad is widely available commercially at low prices and guarantees the durability of the brake pad. However, the result of friction powder in the form of small particles is very dangerous for human health due to asbestos content. The use of asbestos is avoided because of its carcinogenic properties [7]. Therefore, a brake pad supported by asbestos-free materials is inevitable.

Recently, many studies have developed brake pads based on non-asbestos organic material (NAO) through the utilization of agro-industrial wastes such as rice husk [2], sawdust [8], palm shells [9], periwinkle shells [10], cocoa beans [11], corn husks [12], and seashells [13]. The use of agricultural waste promotes good strategies not only in increasing economic value but also in solving environmental issues [10,11,14-17]. These organic wastes are at the center of attention. Direct disposal of organic agricultural waste into roads, rivers, and plantations can cause new problems in the environment like accumulation of garbage, destroying scenery as well as bringing bad smells [18-20]. Along with the development of innovation and technology that is quite fast, researches on utilization of organic materials as composites brake pad have been studied and carried out. Hybrid composite is one method used in the manufacture of brake pads with strong, natural, easy to recycle, and cheap characteristics [21,22].

Our previous study [2] succeeded in fabricating the brake pad from rice husk as a friction component under room temperature and without additional heat and pressure. Here, the purpose of this study was to report a literature review, optimal design, and techno-economic analysis of resin-based brake pad production from rice husk. The techno-economic analysis was done based on our previous studies in evaluating many materials [23-36].

Rice husk was selected and used as a filler material in the brake pad because rice husk has ceramic-like behavior as a consequence of silica content (about 15%) and organic content (about 75% cellulose, hemicellulose, and lignin) [37]. The detailed composition of the rice husk is explained in

Table 1. Based on

Table 1, among agricultural waste, the most contained chemical in the rice husk is silica [14,38]. Silica is the main mineral of rice husk ash although some components are also found such as potassium, sodium, magnesium, calcium, iron, phosphorus, and other elements in much smaller amounts [39]. This makes rice husk is prospective for reinforcing components since it will have excellent performance in toughness dan flame retardant. Therefore, rice husk is considered as an organic filler element in a polymer resin to create organic-inorganic composite material [40]. In addition, rice husk was selected as a filler material because the rice husk is one of the agricultural products that abundant and inexpensive material that considerably reduce the composite manufacturing cost [19]. The utilization of rice husk as a composite reinforcement is considered to increase the stiffness of the composite [2], but it can also reduce the strength and strain of the composite due to the low interfacial bond between the rice husk and the polymer resin [41,42]. However, the low interfacial bond between rice husk and polymer resin can reduce the strength and strain of the composite material [41,43,44].

Many studies mentioned strategies in manufacturing brake pads. However, studies discussing the techno-economic analysis especially for the production of brake pads are rarely found.

Table 2 summarizes the current process for the production of brake pads using alternative materials from biomass as natural reinforcing agents for strong substitutes for asbestos-based friction materials.

Table 1. Chemical composition in agricultural waste [33]

Type	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Silica (%)	Other components (%)	Total (%)	Silica content in ash
Corncob	42.5	32.5	15	10	< 1	100	> 60*
Rice Husk	36	26	21	17	< 1	100	90-93
Rice Straw	44	20	20	16	< 1	100	65-75
Sugarcane bagasse	38	27	22	9	4	100	70-96

*Note: some reports showed less than 60%

Table 2. Current processes for producing brake pads using the utilization of biomass

Type of agricultural waste as a reinforcing component	Supporting components	Results	Refs
Bamboo	• Aluminum oxide • MgO • Epoxy resin	Bamboo is promising as a reinforcement of brake pad material since bamboo composition have good effect for mechanical properties of brake pad which have a wear rate value of 0.9612x10^{-8}g/mm^2 and have hardness value of 91.8 HRR.	[1]
Coconut and Bamboo	• MgO • Al_2O_3 • Epoxy Resin	• Brake pad made from bamboo has a temperature resistance of 251.53°C, a hardness of 37.14 HRB, a wear rate of 0.323 mm^3 / N.mm, and a friction coefficient of 0.454 with a mixed composition of 29% of coconut, 40% of epoxy, 6% of MgO, and 25% of Al_2O_3. • The coconut fiber-reinforced composite mixed with 20% of natural fiber, 46% of epoxy, 6% of MgO, 28% of Al_2O_3 has a temperature resistance of 250.56°C, a hardness of 44.10 HRB, a wear rate of 0.242 mm^3/N.mm, and a coefficient of friction of 0.46. • The wear rates and the coefficient of friction of the two composite brake pads are relatively the same as the commercial ones. However, it is slightly smaller than commercial brake pads.	[45]
Coconut Fibre	• Aluminum • Graphite • Zirconium Oxide • Silicon Carbide • Titanium Oxide • Aluminum Oxide • Hexamethyltetra mine • Phenolic resin	Coconut fiber particles with suitable composition, homogeneous particle size, and homogeneous distribution on the brake pad improve the physical and mechanical properties of the brake pad.	[46]
Banana Peel	Phenolic Resin	• Too much binder composition causes brake pads made of banana peels to have a low wear rate. • However, an increase in the resin composition of the banana peel leads to an increase in the mechanical properties (i.e., strength, hardness, and coefficient of friction) of the brake pads.	[6]
Palm Kernel Fiber (PKF)	Epoxy Resin	• The PKF reinforcement and a small amount of binder give the brake pads a low wear rate. • However, the addition of reinforcing material composition (PKF) increases the compressive strength of the brake pad.	[47]
Maize Husk	Epoxy Resin	The mechanical properties (i.e., wear rate, hardness, compressive strength, thermal conductivity, and	[48]

Type of agricultural waste as a reinforcing component	Supporting components	Results	Refs
		tensile strength) of the brake pad decreases as a maize husk composition increase.	
Cocoa Beans Shells (CBS)	Epoxy Resin	The compressive strength and hardness of the brake pads increase as the composition of CBS as a reinforcing material decreases.	[11]
Palm ash	• Polychlorinated Biphenyls • Phenolic Resin	The compressive strength and wear properties of the brake pad increase as palm ash content increases.	[49]
Saw-Dust	Epoxy Resin	• Brake pad density, compressive strength, and hardness reduce as improving sawdust composition. • Saw-dust particles with sizes of 100 μm have the potential to be used as a substitute for asbestos-based brake pads.	[50]
Groundnut Shells	Phenolic Resin	• Increases in the compressive strength of the brake pad are from increases in phenolic resin • Decreasing the composition of groundnut shells increases the compressive strength density of the brake pad.	[51]
Rice Husk	• Bisphenol A-epichlorohydrin • Cycloaliphatic amine	• Rice husk particles are evenly distributed in the brake pad resulting in a compact brake pad structure. • Brake pads prepared with different rice husk particle sizes have different pore characteristics as well. A brake pad with a large rice husk particle size produces a large number of porous surface characteristics. Meanwhile, brake pads with small rice husk particle sizes produce smooth surface characteristics with few pores. • A brake pad that has good mechanical characteristics is a brake pad with a small rice husk particle size. • Brake pads with large, medium, and small particle sizes have hardness values of 0.238; 0.173; 0.144 MPa, sequentially. • All brake pads that have been prepared have the same relative coefficient of friction as conventional brake pads.	[2]

The main idea of this study is to find the best and optimal conditions for the fabrication of products [29], which can minimize the use of raw materials. Information for the large-scale production from all perspectives and parameters is important. Thus, to support the analysis, several economic parameters such as gross profit margin (GPM), payback period (PBP), break-even point (BEP), cumulative net present value (CNPV), profitability index (PI), internal rate return (IRR), and return on investment (ROI)) in the ideal condition and the worst cases of the project were calculated. Indeed, this can predict the economic condition of the brake pad project. The worst case is applied to predict non-ideal conditions by changing the sensitivity of the ideal condition calculations and calculating costs based on internal (i.e., raw materials, sales, utility, labor, employee, fixed cost, variable cost, and production capacity) and external problems (i.e., taxes and subsidiaries) during the production process. These analyzes are essential to obtain information regarding the profitability of the process [29,52].

2. Literature Review

2.1. *Current studies about techno-economic analysis*

Table 3 summarize current studies about techno-economic analysis. This analysis is important for comparing current strategies on gaining feasibility studies of some projects. The literature review can bring analysis and give suggestions for understanding what kind of previous reports that can be adopted and innovated [53,54].

Table 3. Current studies about techno-economic analysis

Material	Product	Results	Refs
$FeCl_3$, $FeSO_4$, H_2O, and NaOH.	Magnetite (Fe_3O_4) product obtained 456 kg/year via co-precipitation method	• The scaling-up process was possible using commercially available and inexpensive apparatuses.	[55]
Zinc acetate dihydrate, sodium hydroxide, ethanol, and distilled water.	ZnO nanoparticles produce around 18 tons/year via the co-precipitation method.	• An analysis of total equipment costs requires a total cost of 11480 USD and TIC must be less than USD 50980. • TIC and equipment costs are relatively economical, and the project requires fewer investment funds.	[56]
Cobalt ion and Cetyltrimethylammonium bromide (CTAB)	Cobalt nanoparticles were successfully produced as much as 171,072 kg/year via the chemical reduction method	• The analysis results show that the synthesis of Co nanoparticles from cobalt (II) chloride hexahydrate is profitable. • The technical analysis explains that the preparation can be improved using currently available technology.	[36]
Silica from agricultural wastes (i.e., rice husk, rice straw, corn cob, sugarcane, bagasse)	• Silica production from rice husk is 360,000 kg/year. • Silica production from rice straw is 352,000 kg/year. • Silica production from bagasse is 180,000 kg/year. • Silica production from corn cob is 135,000 kg/year.	• Agricultural wastes (i.e., rice husk, rice straw, bagasse, and corn cob) 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.	[33]
TiO_2 Nanoparticles	• 12 tons/year via liquid-phase process	• The project under ideal conditions is feasible.	[34]
Rice Straw	• Carbon particles generated in the process were 168 kg/year. • Silica particles generated in the process were 537 kg/year.	• The process for converting rice straw waste is unattractive for the industrial investor.	[8]
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 kg-1 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.	[57]
Cassia fistula plant extract	• The production of zinc oxide nanoparticles is 250 kg ZnO nanoparticles per day with a total equipment cost of 21,450.00 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.	[58]
Larch wood waste	• Production for pilot scale and industrial-scale processes with different extractor capacities,	• The lowest production cost for one kg of phenolic compounds was obtained for the process of extractor capacity of 350 L (daily	[59]

Material	Product	Results	Refs
	ranging from about 12 to 1200 kg of wood material per day.	production capacity of 1200 kg), operating at 300 °C and of 221.32 ± 19.26 USD/kg.	

Some researchers have done techno-economics but there are limitations in explaining agricultural waste. Further, although many reports explaining researches on rice husks for silica [60] an carbon fabrication [61,62], rice straws for carbon and silica particle fabrication [63,64], corn for bioplastics [42,65], sawdust for energy [66], palm for plasticine and brake pad production [9,47,49], larch wood waste for the production of phenol compounds [59], and indeed all discussed discussed agricultural waste, no one has focused on materials and their economic feasibility that can be used in a realistic application to the market, such as brake pads. Therefore the brake-pad techno-economy analysis is important.

2.2. *Calculation of economic evaluation*

Several basic inputs for economic evaluations were used:

1) Raw materials are the main components needed in the production process. This raw material will be converted into a final product that is worth selling or generating profit.
2) Sales are activities or actions related to the product sales process.
3) Cost includes several parameters, including:
   a) Utilities are supports to sustain projects.
   b) Labor cost is an indicator that measures the degree of correlation between wages, productivity, and hourly output minus inflation.
   c) Manufacturing costs are costs associated with the cost of the production process.
   d) Production costs consist of
      - Fixed cost is the cost required to build the project.
      - Variable costs are costs required to maintain the process in the factory.
      - Depreciation is an action prepared to maintain production maintenance.
      - Total Purchasement Cost (TPC) is the cost to estimate the equipment needed for the process to run. TPC only estimates the price of the tool without taking into account other costs.
      - The Investment Cost (TIC) is the initial cost that must be provided at the beginning of production.

To calculate the economic evaluation, the Lang Factor was used to calculate the estimated total investment cost and the estimated manufacturing cost. **Table 4** and **Table 5** show the Lang Factor for estimating total investment cost and estimating manufacturing cost, respectively [29]. To predict project feasibility, several economic analysis parameters were taken into accounts, such as GPM, PBP, BEP, CNPV, PI, IRR, and ROI, which were calculated based on the ideal condition and the worst condition. Prediction in the worst condition was done by changing the sensitivities parameters based on internal (i.e., raw materials, sales, utility, and variable cost) and external problems (i.e., taxes) during the production process.

1) GPM (USD/Pack) was obtained from the difference between sales revenue and the Cost of Goods Sold.

$$GPM = \sum_{t=1}^{t} (S.\eta - RM)PC.Q.t \quad (1)$$

where *S* is the total sales, *RM* is the total raw material, *PC* is the production capacity, *Q* is the capacity of raw material inputted and applied in the process (kg/h), *t* is the production time, and η is the efficiency of the conversion.

2) PBP (year) was calculated based on the lifetime point when CNPV/TIC reaches zero.
3) BEP (pack) BEP was calculated by dividing the total fixed costs associated with production and revenue per individual unit minus the variable costs per unit.
4) IRR (%) was calculated through equation 1 as follow:

$$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_o \quad (2)$$

where C_t, *r*, *t*, and C_o are the net cash inflow during the period of time, the discount rate, the number of time periods, and the total initial investment cost, respectively.

5) NPV is calculated by multiplying cash flow and discount (equation 3).

$$NPV = \sum_{t=1}^{tr} \left(\frac{R_t}{(1+i)^{tr}}\right) \quad (3)$$

where *Rt* is the net cash inflow subtracted by outflows during a single period of *tr*, *i* is the discount rate that could be earned in alternative investment, and *tr* is the project time (year).

6) CNPV (%) was calculated by calculating the Present Value (PV) of the total expenditure per year. NPV could be obtained by multiplying cash flow with the discount factor.
7) ROI (%) was calculated by dividing the return or net profit by the amount of funds invested and then multiplied by one hundred.
8) PI (%) was calculated by dividing sales and manufacturing costs difference with sales (profit to sales) or investment (profit-to-TIC).

Table 4. Lang factor for estimating Total Investment Cost (TIC) from Purchasement Cost (PC) [29]

Component	Factor		Cost
PC (EQUIPMENT)			
Purchased Equipment	1.00	$	13,574.51
Piping	0.50	$	6,787.26
Electrical	0.10	$	1,357.45
Instrumentation	0.20	$	2,714.90
Utilities	0.50	$	6,787.26
Foundations	0.10	$	1,357.45
Insulations	0.06	$	814.47
Painting, fireproofing, safety	0.05	$	678.73
Yard Improvement	0.08	$	1,085.96
Environmental	0.20	$	2,714.90
Building	0.08	$	1,085.96
Land	0.50	$	6,787.26
Subtotal 1		$	45,746.10
PC (MANAGEMENT SERVICES)			
Constructions, engineering	0.60	$	8,144.71
Contractors fee	0.30	$	4,072.35
Contigency	0.20	$	2,714.90
Subtotal 2		$	14,931.96
Total PC (=equipment + management service)		$	60,678.06
TPC (=Total PC - Land)		$	8,144.71
STARTING-UP FEE			
Off-site facilities	0.20	$	2,714.90
Plant strart-up	0.07	$	950.22
Working capital	0.20	$	2,714.90
Subtotal 3		$	6,380.02
TIC (=TPC + Starting up fee)		$	14,524.73
TIC-Land		$	7,737.47

Table 5. The factor for estimating total Manufacturing Cost (MC) [29]

No	Item	Factor			Cost per year
	Total Life Time	**20**	**years**		
1	Raw Materials			$	1,488,474.90
2	Utilities			$	984.24
3	Loan Interest	7%	of loan		
4	Operating Labor			$	31,680.00
5	**Labor-related cost**				
	a. Payroll overhead	30%	of labor	$	9,504.00
	b. Supervisory, misc. labor	25%	of labor	$	7,920.00
	c. Laboratory charges	12%	of labor	$	3,801.60
6	**Capital related cost**				
	a. maintenance	6%	of (TPC-land)	$	464.25
	b. Operating supplies	1.75%	of (TPC-land)	$	135.41
	c. Enviromental	2.25%	of (TPC-land)	$	174.09
	d. Depreciation	5.00%	of (TPC-land)	$	386.87
	e. Local taxes, insurance	4%	of (TPC-land)	$	309.50
	f. Plant overhead cost	3%	of (TPC-land)	$	232.12
7	**Sales related cost**				
	a. Packaging	1%	of sale	$	17,325.00
	b. Administration	2%	of sale	$	34,650.00

c. Distribution and marketing	2%	of sale	$	34,650.00
d. Research and development	1%	of sale	$	17,325.00
e. Patents and royalties	1%	of sale	$	17,325.00
Total Manufacturing Cost			$	1,665,341.99

3. Method

In this study, we evaluated the feasibility of the project from engineering and economic perspectives. Based on an engineering perspective, resin-based brake pads from rice husk were fabricated under room temperature and without additional heat and pressure on a large scale using commercially existing apparatuses based on our previous literature [2]. The raw material was calculated based on mass balance during processing. In the economic evaluation, several assumptions were used based on equipment specifications, raw material/ chemical prices, utility systems, and equipment costs, where these prices are seen from several e-commerce sites, such as Alibaba, Amazon, Tokopedia, etc. This data was then processed, used, inputted, and computerized in the calculation of economic feasibility analysis. Economic evaluation analysis was carried out by applying two calculation conditions, namely in ideal and not ideal conditions (by changing several variables: raw material prices, utilities, labor, and sales capacity). Then, the calculations used for the economic feasibility analysis were adopted from the literature [29].

4. Results and Discussion

In this study, a feasibility analysis is used to assess the feasibility of producing resin-based brake pads from an economic and engineering perspective. The engineering perspective was used to assess the project of resin-based brake pads production by simulating the process in large-scale production using commercially available apparatus. In economic evaluation, we used several assumptions to assess the project such as the price for raw material, utility system, and equipment cost. These data were used and included in the calculation for economic analysis.

4.1. Resin-based braked pad production process

Raw materials used for the resin-based brake pad were rice husks as reinforcement, bisphenol A-epichlorohydrin, and Aliphatic cyclo amine. The production was based on our previous literature [2]. Rice husk was used as the main reinforcement for the brake pad. To produce rice husk particles, rice husk was cut into small pieces and dried in the sun for 3 days. To get the homogeneous and specific particle size of rice husk with particle size in the range of 250-500 µm, the sieving process was conducted. After that, the resin-based brake pad was made by mixing the rice husk, 100 mL of polyester resin as a matrix, and 10 mL of catalyst. The prepared resin-based brake pad mixture was then poured into a silicone mold (with silicon dimension is 4 x 1 x 3 cm) and dried at room temperature without not exposed to sunlight for one day. After the brake pad dried, the brake pad was sanded to remove the resin effect on its surface. The engineering process design of the experimental method is shown in **Figure 1**.

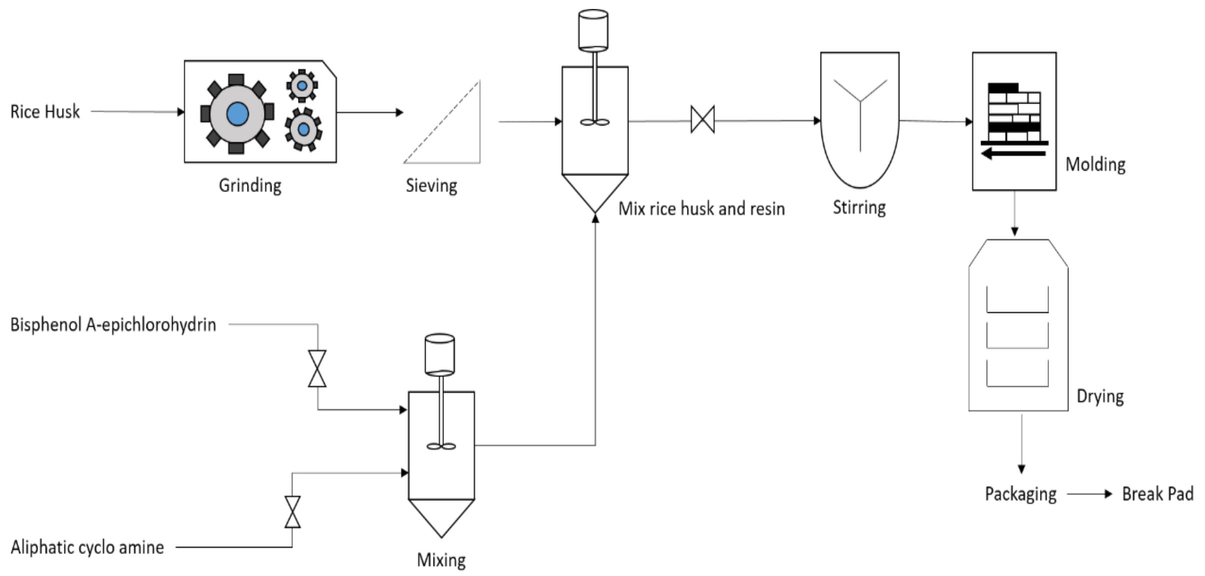

Figure 1. The engineering process design of the resin-based brake pad production

4.2. *Energy and mass balance*

Several assumptions were used to calculate the mass balance in the production of resin-based brake pads on a large scale. The assumptions are as follows:

1) The cost of equipment and raw materials that support the production process were obtained from commercially available online markets such as alibaba.com, tokopedia.com, and bukalapak.com.
2) The composition of rice husk, bisphenol A-epichlorohydrin, and Aliphatic cyclo amine were 243.75; 206.25; and 206.25 kg, sequentially.
3) There are no byproducts because all chemicals are consumed perfectly.
4) The temperature for resin-based brake pad production was at room temperature.
5) The final product was resin-based brake pad material only.
6) The production process of resin-based brake pads is 1 cycle per day.

Based on the results of the mass balance analysis, one producing cycle for one day produces 18,750 pieces of brake pads with the dimension of length, height, and weight of 4 x 1 x 3 cm. Under ideal conditions, the project can be scaled up to 264 cycles in a year. As a result, production the project capacity is 4,950,000 pieces. The detailed amount of raw materials needed in the production is described in **Table 6**.

Table 6. Detailed mass balance

No	Materials	Ton/year
1	Rice husk	64.35
2	Bisphenol A-epichlorohydrin	54.45
3	Amina siklo alifatik (Epoxy hardener EPH 555)	54.45

4.3. *Assumption used*

Several assumptions were used to evaluate the economic perspective of the resin-based brake pad project from rice husk:

1) USD unit price is used. Conversion from USD to Rupiah is 1 USD = 15000.
2) Resin-based brake pad from rice husk sell for 1 USD/pc.
3) All raw material used during the production is calculated by stoichiometry calcculations.
4) The rice husk is free of charge.
5) The discount rate and income taxes are 15% and 10%, respectively.
6) The cost of a utility system is 0.10 USD/kWh
7) The number of productive days of labor in one year is 300 days.
8) The number of labors is 15 people where the salary of each worker for one day is 8 USD/Day/person.
9) Lang Factor is used to estimate TIC conditions and project production costs (see **Table 4** and **Table 5**) [29].
10) The project takes place in the purchased underground. Therefore, the land is calculated as the initial cost of project

development which will then be recovered after the project is running.

11) The project operating for 20 years.

Total manufacturing cost (TMC) calculation was done by taking into account the cost of raw materials, utilities, loan interest, operating labor, labor-related costs, capital-related costs, depreciation, and sales-related costs. These costs were determined in advance by their annual characteristics as follows:

1) Plant Cost (PC), $ 60,678.06;
2) Total Plant Cost (TPC)-Land, $ 8,144.71;
3) Total Invesment Cost (TIC), $ 14,524.73;
4) Raw materials cost, $1,488,474.90;
5) Utilities cost, $ 984.24;
6) Loan interest, $ 0 (without bank loan);
7) Operating labor, $ 31,680.00;
8) Selling price per year, $ 1,732,500.00; and
9) The production process will be carried out for 20 years (depreciation = 1/20 TPC).

After obtaining the cost information above. The TMC value was estimated as shown in **Table 7**. The TMC value is the sum of raw materials, utilities, loan interest, labor, and labor-related costs, capital-related costs, depreciation, and sales-related costs. Detailed information for the raw materials, utilities, packaging are presented in **Table 8**, **Table 9** and **Table 10**, respectively. Detailed information for the fixed cost is presented in **Table 11**. Other information used is variable cost information including costs of raw materials, utilities, labor and sales as shown in **Table 12**.

Table 7. Total manufacturing cost (TMC) calculation

Component	Factor		Cost	
Raw Materials			$	1,488,474.90
Utilities			$	984.24
Loan Interest	0.07	of loan		
Operating Labor			$	31,680.00
Labor-related Cost			$	21,225.60
Capital-realated Cost			$	1,315.37
Depreciation	0.05	of (TPC-land)	$	386.87
Sales-related Cost			$	121,275.00
TMC			$	1,665,341.98

Table 8. Details of the price of raw materials used per year

No	Items	Unit (tons) per year	Cost per year
1	Rice Husk	64,350	$ 4440.15
2	Bisphenol A-epichlorohydrin	54,450	$ 882,906.75
3	Aliphatic cyclo amine (Epoxy hardener EPH 555)	54,450	$ 601,128.00
Total			$ 1,488,474.90

Table 9. Detailed price of utilities used per year

No	Items	kWh	Cost per year
1	Grinding	9768	$ 973.56
2	Sieve Shaker	105,6	$ 10.68
Total			$ 984.24

Table 10. Detailed price of packaging per year

No	Item	Units	Cost per year
1	Plastik Zipper 4x6	4,950,000	$ 6,930.00

Table 11. Detailed information for fixed cost

No	Item	Units	Cost

1	BCA 500 liter water tank / toren T550	2	$ 84.18
2	Mechanical grinding powder	1	$ 8,000.00
3	Plastic jar 15 liters green leaf 0166	15	$ 46.58
4	VBENLEM automatic sieve shaker included 10 mesh + 60 mesh	15	$ 3,149.85
5	Silicone mold 4x3x1 cm	18750	$ 2,285.63
6	Mixer stick	15	$ 8.28
Total			$ 13,574.51

Table 12. Detailed information for variabel costs

No	Components	Cost per year
1.	Raw Materials	$ 1,488,474.90
2.	Utilities	$ 984.24
3.	Labor	$ 31,680.00
4.	Sales	$ 1,732,500.00

4.4. *Economic evaluation in ideal condition*

Figure 2 shows the CNPV/TIC curve against the lifetime for the resin-based brake pad project. Based on the ideal curve, the first three years of the project still show negative values for the CNPV/TIC parameter. The first two years of the project are still under construction. Several factors affecting this result included the variable costs, fixed costs, sales, depreciation, pre-tax profits, and income taxes that started to consider in the third year. In the third year, the production process has just started and there is no profit. The project starts to make a profit starting from the fourth year and continues to be profitable for up to 20 years. Based on the economic analysis under ideal conditions, the resin-based brake pad project is profitable and promising.

Table 13 presents the economic evaluation parameters including GPM, PBP, BEP, BEC, IRR, CNPV, ROI, and PI. Based on the economic evaluation parameter, all parameters show positive value. Although this project provides benefits. In short, GPM determines the profitability of the project. However, based on the IRR and PI profit-to-TIC parameters, the project seems to be lacking attractive to industrial investors. PBP analysis shows that the project can return the initial capital after 3.2 years. The time is short enough that the project is quite competitive. The BEP value indicates the minimum product that must be sold to cover the total production cost [67]. In this project, the minimum number of products that must be sold to make a profit is 150,175 pieces. IRR analysis shows an IRR value of 1.74% for 20 years which shows a very low level of investment for investors and is not promising for investors. The final CNPV/TIC analysis shows a relatively high positive yield over the 20-year project run. ROI analysis shows positive results with a value of greater than 14%. Compared to bank and capital market interest, the additional benefits are relatively attractive. Local environment capital market in Indonesia at least 10% of profit/year where 2.5% of it is usually used for zakat. PI analysis was calculated to identify the relationship between project costs and the impacts of the project. Profit-to-sale and profit-to-TIC analysis showed some positive results indicating that the project is profitable. Based on the analysis of economic parameters, many economic parameters show positive values which means the project is a perspective.

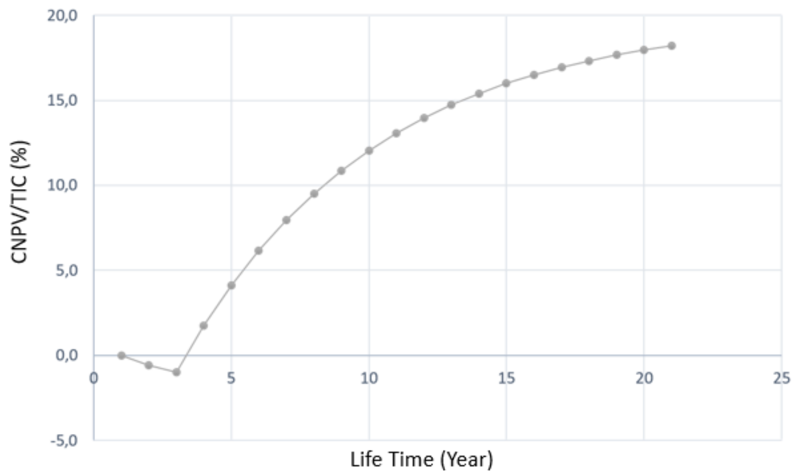

Figure 2. The CNPV/TIC curve against the lifetime for resin-based brake pad project

Table 13. Economic evaluation parameter

Economic Evaluation Parameter	Value
GPM (USD/year)	244,025.00
PBP (years)	3.20
BEP (pieces)	150,175.00
IRR (%)	1.74
Final CNPV/TIC (%)	18.21
ROI (% per year)	25.69
Total ROI	462.37
PI profit-to-sales (%)	0.04
PI profit-to-TIC (%)	4.62

4.5. *Economic evaluation in non-ideal conditions: Internal (raw materials, sales, utility, and variable cost) and external cases (tax)*

The first analysis carried out to evaluate the project of production brake pad made from rice husks was the GPM analysis using various conditions of variation cost or fluctuation cost in raw materials as shown in **Figure 3**. The analysis was carried out by estimating the reduction in the cost of goods sold (income) with the cost of raw materials [29]. The results showed that the raw material cost affects GPM. The price of raw materials used in the project affects the sustainability of the project. Based on the analysis, two raw materials that have the most influence on the project's GPM are Bisphenol A-epichlorohydrin and Aliphatic cycle amine. The aliphatic cyclo amine parameter has the most influence on GPM, followed by the bisphenol a-epichlorohydrin parameter. Rice husk has the least effect on sales. The analysis showed that the project can still survive and operate until the raw material cost reaches 300% of the estimated cost. Here, increases in raw material cost have a negative impact on GPM profit [52,68].

Figure 4 and **Figure 5** show the evaluation of PI as a function of sales, raw materials, and utilities. Figure 4 shows the PI analysis for profit-to-sales. The Sales Factor has an exponential curve impact on the PI value. The PI value has increased from -2 to 1.5%. These results indicate that a decrease in sales has a direct effect on the profit to be obtained [34], especially with a sensitivity variation range between -100 and 50%. The selling price is too low making the project unprofitable. However, a further increase in sales does not affect profit because the increase in sales is related to changes in variable costs [28,69]. Therefore, sales must be optimized to get optimal profits. The next factor that is very influential is the cost of raw materials. The raw material factor has a negative effect on the PI value. Raw materials have an impact on decreasing the PI value from 1.5 to -3% if the sensitivity cost of raw material continuously increases up to 300%. Raw materials have similar results to the results of the GPM analysis as shown in **Figure 3**. In terms of utility, this increase in costs has a less significant impact compared with raw material and sales factors to PI profit to sales.

The next analysis is about the PI value for profit-to-investment as shown in **Figure 5**. A relatively linear curve is shown by the sales parameter. Parameters of raw materials and utilities greatly affect the profitability of the project which will affect the sustainability of the project. The results of the analysis show that the cost of raw materials and utilities must be in accordance with the prices that have been previously set, namely the maximum increase of not more than 0%. Based on the dominance of the parameters that influence the profit-to-investment, the most dominant are raw materials, followed by utilities and sales.

Figure 6 shows the results of the analysis of variable cost variations. The results of the analysis show that if the variable cost price increases more than 100%, it will have a negative effect on the sustainability of the project (profit).

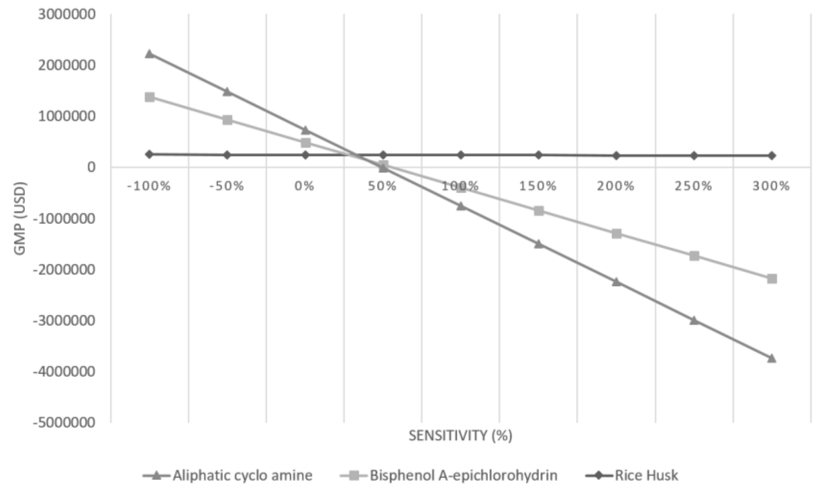

Figure 3. Effect of changing raw material on the GPM.

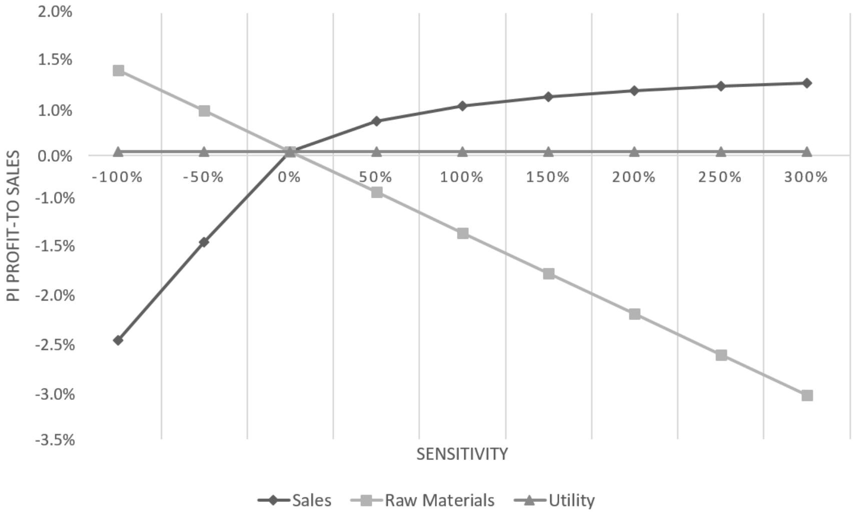

Figure 4. Analysis of PI profit to sales as a function of sales, raw material, and utility

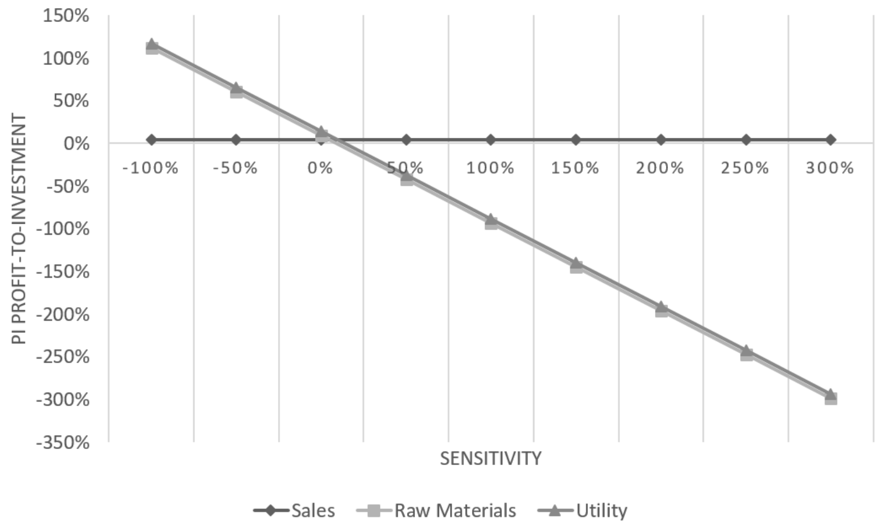

Figure 5. Analysis of PI profit to investment as a function of sales, raw material, and utility

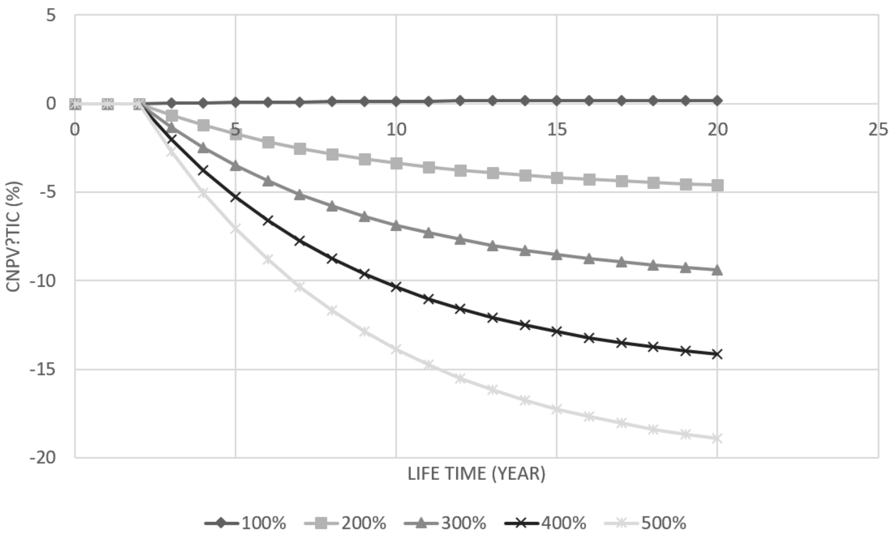

Figure 6. CNPV curve in accordance with the lifetime of the project with various variable costs

In addition to CNPV analysis based on variations in variable costs, in this study, a CNPV analysis of tax variations was carried out according to the time the project lasted for the next 20 years as shown in **Figure 7**. The CNPV graph shows that the greater the tax obtained, the more profit will be reduced and vice versa. A large tax of only 10% will increase the profits to be obtained, this is inversely proportional to when the tax received is 100%, the profits will decrease. If the tax received is more than 100%, the project will suffer a loss. Thus, the minimum tax charged to the project is 100%.

4.6. *Engineering perspective results*

Based on the results of the technical analysis, the resin-based brake lining project from rice husks is considered feasible to scale up using available and inexpensive equipment. The results showed that the project showed a relatively high TIC at $ 14524.73 with detailed costs as shown in **Table 4**. This is relatively inexpensive since all processes can be done using commercially available in the local market.

4.7. *Economic perspective results*

Based on ideal and non-ideal conditions in economic analysis, the resin-based brake pad project is promising. However, when the change in economic parameters happens as a non-ideal condition, there is a fluctuation in getting a profit from the project. In non-ideal conditions, the project only gets minimum profit. Based on the results of the study, we predict the economic conditions of this project are as follows:

a. The project will continue despite the increase in the price of raw materials (such as rice husk, Bisphenol A-epichlorohydrin, and Aliphatic cycle amine) of up to 50%. If the increase in the price of each raw material is greater than 50%, the project is not profitable.
b. Parameters that have the most influence on project profits are raw material and sales parameters. If there is a slight increase in the price of raw material parameters (up to +50% from the estimated raw material price), then the project is not profitable.
c. Therefore, the selling price must be increased to get the maximum profit. However, the selling price must also be optimized with the cost of production parameters. a slight decrease in the selling price (a decrease of -50% from the estimated selling price), then the project is not profitable.

From an economic perspective, the resin-based brake pad project from rice husks is promising because the value of economic parameters (such as GPM, PBP, PI to Sales, PI to Investment, and final CNPV) after economic analysis shows a positive value.

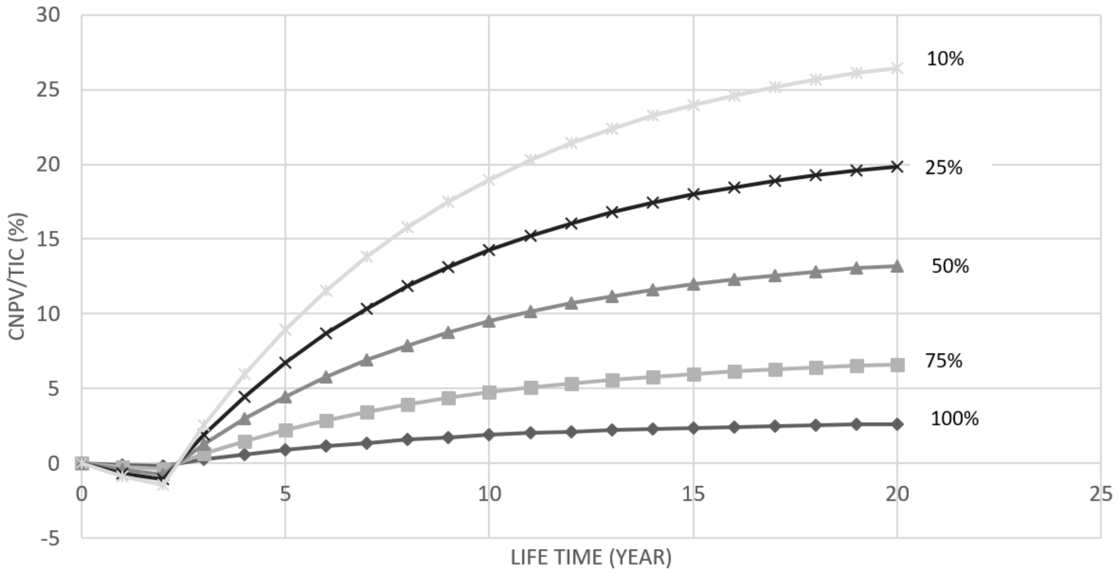

Figure 7. CNPV analysis of tax variations

5. Conclusion

Based on the results of the analysis that has been carried out, this study succeeded in analyzing and reporting the literature review, optimal design, and techno-economic analysis of the production of resin-based brake pads from rice husks. This resin-based brake lining project is viewed from a technical and economic perspective. This project is also a perspective for improvement. Based on the economic parameters in the economic evaluation, it was found that the best and optimal conditions for the production of brake pads were all parameters that showed positive values. However, the project is not attractive to investors due to the relatively small IRR value. Therefore, financial support from the government must be considered to maintain the sustainability of the project. The production process of resin-based brake linings involves the use of agro-industrial waste materials which can be a solution to the problem of agro-industrial waste treatment.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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