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COST ANALYSIS AND ECONOMIC EVALUATION FOR THE FABRICATION OF ACTIVATED CARBON AND SILICA PARTICLES FROM RICE STRAW WASTE

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Abstract

The purpose of this study was to evaluate economic feasibility on the fabrication of activated carbon and silica particles from rice straw waste. Several economic evaluation parameters were analyzed for informing the potential production of valuable material from rice straw, including gross profit margin, internal rate return, payback period, net present value, and so on. The result showed that the production of activated carbon and silica particles from rice straw waste is prospective. The engineering analysis for converting 20 kg of rice straw waste per batch shows the total purchased equipment cost of USD 4,900. Adding the Lang Factor, the total investment cost should be less than USD 22,000. This value is relatively economical (i.e., project needs less investment fund) for degrading 67 tons per year or 1344 tons per 20 years of project. Compared to the total amount of degraded rice straw waste, the value will be only about 16 USD per ton. Indeed, this is not expensive for accessing a problem solver in degrading one ton of rice straw waste. To ensure the feasibility of the project, the project were estimated from the ideal condition to the worst cases in the production, including labor, sales, raw material, utility, as well as external condition (i.e., tax and subsidiary).

Keywords: Activated carbon, Economic evaluation, Feasibility study, Rice straw waste, Silica particles,

1. Introduction

Rice straw waste has been known as one of the biggest problems in agricultural countries [1]. Since the rice straw is a byproduct of rice, the existence of rice straw relates to the production of rice. Rice straw is part of the rice plant (See Fig. 1). Rice straw is obtained after the grain and the chaff have been removed. Rice straw is the largest part of a rice plant consisting of stems, leaves, and stalks of rice, in which this part usually un-utilized for consumption [2]. Increases in the production of rice have direct impact to the existence of high amount of rice straw waste [3].

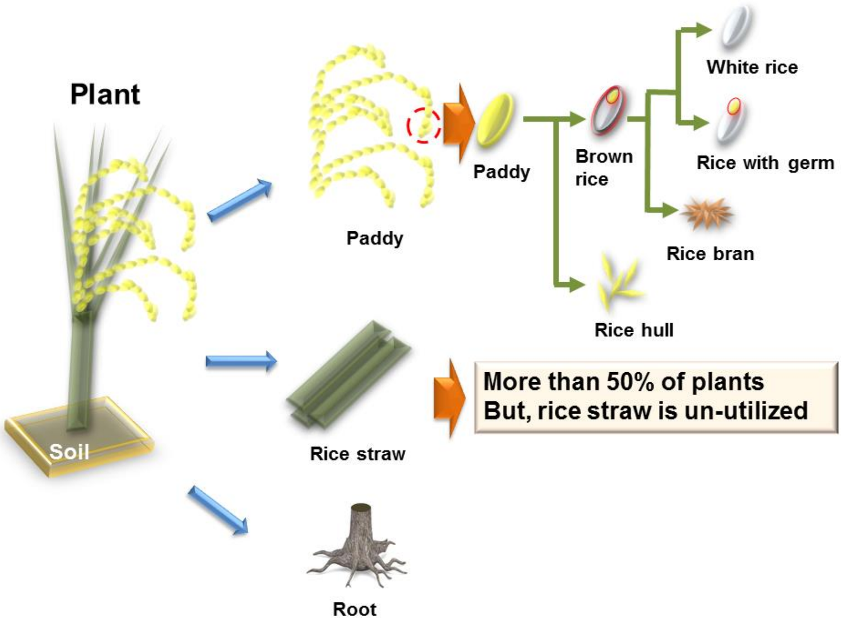


Fig. 1. Illustration image of parts of rice plant [2].

Many strategies have been proposed to reduce the existence of rice straw waste, from the use of traditional method to the application of advanced technology. In the traditional method, the rice straw is burned in an open field [1]. Indeed, although the burning rice straw can reduce the amount of waste, open field burning causes crisis, meeting with severe pollution issues [4]. Then, for some cases, traditional method also utilizes rice straw as roofing and packing material, feed, fertilizer, and fuel source [5]. Although the direct utilization of rice straw waste in traditional method is effective, the strategies still remain problems, specifically when facing the large amount of rice straw. To address the traditional method, implementation of advanced technology has been suggested, i.e., fermentation technology to gain ethanol [3], biogas production [6], isolation of the silica component [7], production of activated carbon [8, 9], etc. Although the implementation of advanced technology is prospective, there are still questionable, specifically for the scaling-up process. The current reports are typically applicable in limited uses (i.e., lab scale process), and there is no information regarding the economic evaluation on the feasibility conversion of rice straw waste into valuable product in commercial scale.

In previous studies [10-12], several methods for the production of silica and carbon material from rice straw waste have been reported, informing the prospect for the conversion of rice straw into valuable materials. Here, the purpose of this study was to evaluate economic feasibility on the fabrication of activated carbon and silica particles from rice straw waste. Several economic evaluation parameters (i.e., gross profit margin (GPM), internal rate return (IRR), payback period (PBP), cumulative net present value(CNPV), break-even point (BEP), break-even capacity

(BEC), return on investiment (ROI), and profitability index (PI)) were analyzed for informing the potential production of valuable material from rice straw. Then, the economic parameters were tested by changing various economic conditions, such as labor, sales, raw material, utility, as well as external condition (i.e., tax and discount rate).

2. Theoretical Production of Silica and Activated Carbon Particles from Rice Straw Waste

Figure 2 shows the synthesis route for the production of silica and activated carbon particles from rice straw waste. To ensure the processing steps, the process flow diagram is also presented in Fig. 3.

Based on these figures, at least there are 11 processing steps involving the conversion of rice straw waste. The raw materials required for the production process are rice straw waste, basic solution (e.g., sodium hydroxide (NaOH)), water, and acidic solution (e.g., hydrochloric acid (HCl)). Detailed information for the production of silica and carbon particles are reported in references [10-12].

The processes involved the following steps (see Figs. 2 and 3). Initially, the rice straw waste is burned (step 1). Indeed, this burning process creates energy that can be used for other processing equipments. The burned rice straw waste was grinded using a commercially available crusher/grinder (step 2), and the product was then put into the extractor (step 3). In the same time, NaOH was diluted (steps 4 and 5), and the diluted solution was mixed with rice straw waste in the extractor (step 6). After the extraction process, the solution was separated by filtration (step 7), in which this creates two routes: (i) silica (steps 9-14) and (ii) carbon powder (steps 8, 15, and 16).

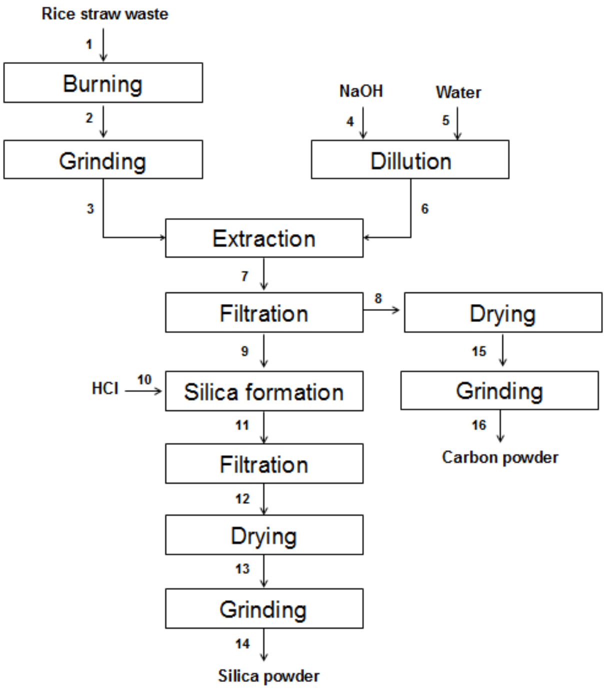


Fig. 2. Production of silica and activated carbon from rice straw waste.

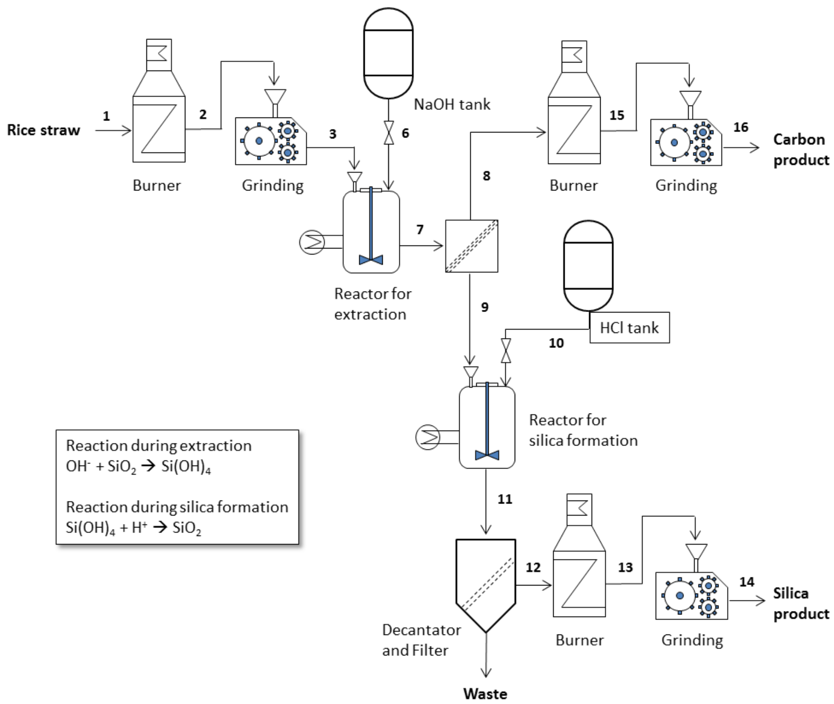


Fig. 3. Process flow diagram for the production of silica and activated carbon from rice straw waste.

In the case of silica powder route (steps 9-14), the following processes are conducted: silica formation process (step 9; by contacting the silica solution with HCl), filtration (step 11; to collect the formed silica), drying process (step 12; to enrich silica concentration), and grinding (step 13; to produce silica particles using ball-mill process). Next, regarding the carbon powder product (steps 8, 15, and 16), only two steps are required: drying process (step 8; to remove solvent) and grinding process (step 15; to create activated carbon particles). Finally, the final products (i.e., silica (from step 14) and carbon (step 16)) are put into the packaging step.

3. Research Method

The present method used several data based on the average price in commercially available products in online shopping web to guarantee the current price of the materials. All data were calculated using a simple mathematical analysis. To confirm the economic evaluation of this project, several economic evaluation parameters were used: CNPV, GPM, PBP, BEP, BEC, IRR, ROI, and PI. Then, when evaluating feasibility, various conditions were tested, including changing of raw material, sales capacity, labor condition, interest rate, etc.

In addition, several analyses were conducted to support the economic analysis in regard to calculate energy and mass balances: Thermo Gravity Differential Thermal Analysis (TG-DTA, DTG 60A TA 60 WS, Shimadzu Corp., Japan; operated at 5°C/min with 200 mL/min of carrier gas (oxygen gas)), Atomic Absorption Spectroscopy (AAS, Varian Spectra 240 FS, Varian Inc., Califonia).

4. Results

4.1. Energy and mass balance analysis

Prior to analysis energy and mass balance in the project, TG-DTA with AAS analysis was conducted (Fig. 4). The result showed that the mass reduction was obtained with the additional temperature.

Based on TG-DTA analysis, the mass decreased slightly when applying temperature until 250 C. The mass of ash is more than 80%. However, further additional heat treatment results in the more gradually to 40% (when temperature of between 250 and 300C) and 20% (for temperature of between 300 and 600C). The best condition to get the conversion of organic component in the rice straw waste into carbon is 200°C (See left image in Fig. 4). This is also verified by the appearance of black powder after the burning process (see photograph images panelled in the right-down in Fig. 4). Further heat treatments (higher temperature process) are not effective since it requires more heating energy and produces lower amount of carbon component.

To make the further estimation easier, the balance was predicted based on 1 kg of rice straw waste. The calculation was conducted based on the process discussed in Figs. 2 and 3 using the following assumptions:

i. Compositions of carbon and silica components in the ash were 20 and 70%, respectively, based on TG-DTA and AAS analysis results in Fig. 4.
ii. Mass ratio of NaOH and SiO_2 used for the complete removal of silica component from the burned rice straw was 0.40, based on reference [12].
iii. Moles of HCl and silica component in the silica formation rate were equal, based on reference [12].
iv. Conversion rate for the silica formation process was 80%.
v. All NaOH and HCl chemicals were consumed completely. No by product from these chemicals was created.
vi. Losses in the all mechanical grinding process (e.g., crusher and milling), filtration, and drying were 10%.

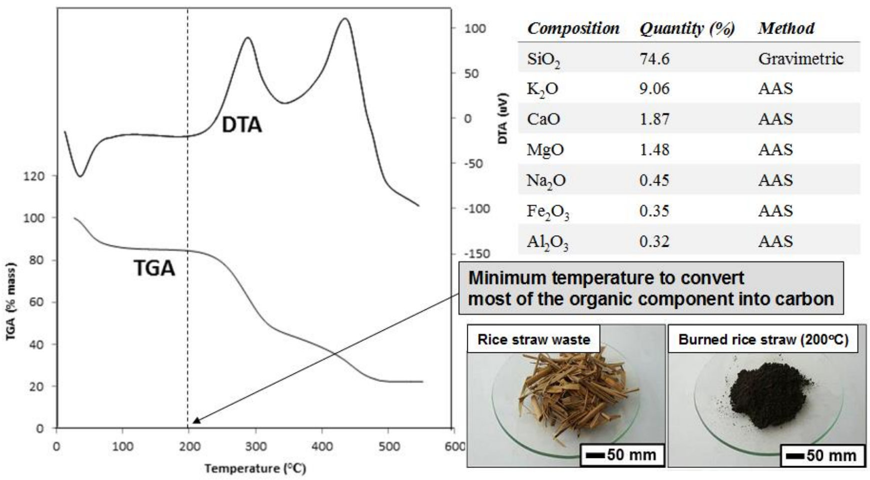
Based on the balance analysis, for converting 1 kg of rice straw waste, the amounts of NaOH and HCl (33%) were silica and activated carbon particles were 0.05 kg and 0.15 L, respectively. Water used for dilution must be at least 1.26 L. Finally, the silica and activated carbon particles generated in the process were 0.05 and 0.16 kg, respectively.

4.2. Economic evaluation

To ensure the economic analysis, several assumptions were used. This assumption is required to analyze and predict several possibilities happening during the project. The assumptions are

i. All analyses used USD using currency of 1 USD = 10,000 IDR.
ii. Based on commercially available prices, the price of NaOH, silica, and carbon were 0.60; 5; and 5 USD/kg, respectively. The price of HCl (33%) was 0.30 USD/L. All materials were approximated based on the stoichiometry [13].

iii. The price of equipment with its process condition is fixed based on the commerically available equipment (See Table 1). Other supporting fees (e.g., start up, instrumentation, electrical-related component) were neglected.
iv. The Lang Factor was used for analysing the total investment cost (TIC) [14]. (See Table 2) The calculation showed that the TIC of this project is about four times of the total equipment cost.
v. TIC was prepared at least into two steps. The first step is 40% in the first year and the second step is the rest (during the construction of the project).
vi. The manufacturing cost is changeable and predicted from the beginning of the project. The estimation of manufacturing cost is shown in Table 3.
vii. Land is purchased. Thus, the cost of land was added in the beginning of the plant construction and re-gained in the end of the project.
viii. Depreciation was estimated using the direct calculation [14].
ix. One cycle of the process (the process from putting rice straw waste step into gaining carbon and silica particles) requires 6 hours. Since one-year project contains 300 days (assuming holiday is an off-day production), the maximum total production per year was 3,360 processing cycles.
x. To simplify the utility system, the unit of utility can be described and converted as an electricity unit, such as kWh [15]. Then, the electricity unit is converted into cost by multiplying with standard minimum electricity cost. The utility cost was 0.15 USD/kWh [16].
xi. The total wage of labor per processing cycle was 3.21 USD [17].
xii. The discounted rate is 15% annually.
xiii. The income tax is 10% annually.
xiv. The length of the project operation is 20 years.



Composition	*Quantity (%)*	*Method*
SiO_2	74.6	Gravimetric
K_2O	9.06	AAS
CaO	1.87	AAS
MgO	1.48	AAS
Na_2O	0.45	AAS
Fe_2O_3	0.35	AAS
Al_2O_3	0.32	AAS

Fig. 4. TG-DTA analysis result of the rice straw waste. Insert table is the AAS result of the burned rice straw. Insert photograph images are photograph images of rice straw waste before and after burned at 200°C [10-12].

Table 1. Price of equipment and the process condition. All the prices as well as apparatus information are adopted from current available apparatuses in online shopping web.

No	Equipment	Price (USD)	Electricity (Watt)	Temp (°C)	Process time (h)
1	Oven (for rice straw waste)	200	800	200	4
2	Oven (for silica)	200	800	200	2
3	Oven (for carbon)	200	800	200	2
4	Filtration (for silica enrichment)	100	0		0
5	Filtration (for carbon enrichment)	100	0		0
6	Dillution tank (for silica formation)	200	100		1
7	Extraction polymer tank (for isolation of silica)	200	500	60	1
8	Silica Formation Polymer Tank	200	100		1
9	Storage Polymer Tanks (for raw materials and product)	1,000			
10	Grinding (for rice straw waste)	500	1000		1
11	Grinding (for silica)	500	1000		1
12	Grinding (for carbon)	500	1000		1
13	Water system	1,000	100		2
	Total purchased equipment	4,900			

Table 2. Lang factor for estimating total investment cost. Table was adopted from reference [14].

Component	Factor
Total Plant cost (equipment)	
Purchased Equipment	1.00
Piping	0.50
Electrical	0.10
Instrumentation	0.20
Utilities	0.50
Foundations	0.10
Insulations	0.06
Painting, fireprofing, safety	0.05
Environmental	0.20
Building	0.08
Land	0.50
Total Plant cost (management services)	
Construction, engineering	0.60
Contractors fee	0.30
Contigency	0.20
Starting-up fee	
Off-site Facilities	0.20
Plant start-up	0.07
Working capital	0.20

Table 3. Factor for estimating manufacturing cost [14].

Component	Factor	
Labor-related cost		
Payroll overhead	30%	Of labor
Supervisory, misc. labor	25%	Of labor
Laboratory charges	12%	Of labor
Capital-related cost		
Maintenance	6%	Of plant cost
Operating supplies	1.75%	Of plant cost
Environmental	2.25%	Of plant cost
Local taxes, insurance	4%	Of plant cost
Plant overhead cost	3%	Of plant cost
Depreciation	5%	Of plant cost
Sales related cost		
Packaging	1%	Of sales
Administration	2%	Of sales
Distribution and marketing	2%	Of sales
Research and development	1%	Of sales
Patents and royalties	1%	Of sales

4.2.1. Ideal condition

Figure 5 shows the CNPV with various economic evaluation parameters (e.g., GPM, PBP, BEP, break even capacity, IRR, ROI, and PI) in the normal condition. Analysis showed that the conversion of rice straw waste into silica and activated carbon particles are prospective, shown by the excellent and promising economic evaluation analysis.

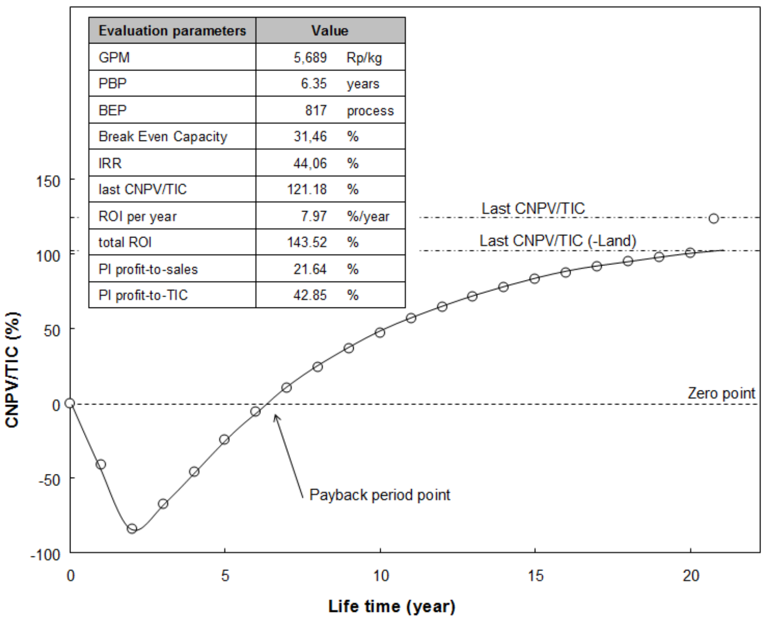


Fig. 5. CNPV with various economic evaluation parameters in the ideal condition.

4.2.2. Changing raw material, sales, labor, and utility

The first analysis for evaluating the project is analysis of GPM under various raw material and sales conditions (Fig. 6). This analysis is estimated by subtracting the cost of product sold (revenue) with the cost of raw materials [14]. The result showed a positive correlation between sales and GPM, while the raw material has opposite relation. In short, producing more sales has a direct impact to the successful project (profitable), whereas problems in raw materials influence the sustainability of the project. Based on the analysis, both raw materials (i.e., NaOH and HCl) have similar impact to the GPM. In the case of sales, the most influence parameters are found for activated carbon.

In addition to raw material and sales, other factors influence the economic condition of the project are labor and utility (See Figs. 7 and 8). This figure describes about the evaluation of PI as a function of sales, raw material, labor, and utility.

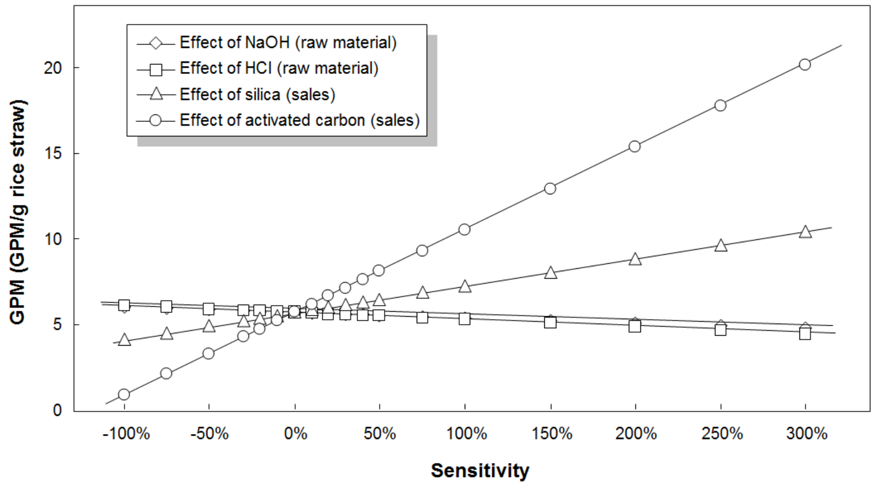


Fig. 6. Effect of changing raw material and sales cost on the GPM.

In the case of raw material and sales, similar trend with the above GPM analysis in Fig. 6 is found. The sales factor has a positive correlation to the GPM, whereas the raw material, labor, and utility have a negative impact.

In the case of PI for profit-to-sales (Fig. 7), the sales has an exponential-curve impact to the PI value. The PI value changed from -220 to 80%. This result replies that the decreases in the sales have a direct influence on the profit, especially in the variation of sensitivity between -100 and 30%. However, further increases in the sales have not affected to the profit since the increases in sales relate to the change in variable cost. Thus, the sales must be optimized to get optimum profit. The next impact that influences greatly is labor condition, in which the PI varied between -50 and 50%. In the case of raw material and utility, increases in these costs have less significant impact compared to the sales and labor condition (The PI varied between -10 and 30%).

In the case of PI for profit-to-investment (Fig. 8), relatively straight-linear curves were obtained for all parameters. In short, producing more sales has a direct impact to the successful project (profitable), whereas problems in raw material, utility, and labor must be considered as other influencing parameters for the sustainability of the project. Based on the dominancy of parameters, the most dominant is problems in the sales, followed by labor, utility, and raw material.

To ensure the impact of sales, labor, raw materials, and utility parameters on the profit, analysis of BEP was conducted (Fig. 9). Variation of these parameters from -100 to 300% gives perception the feasibility of the project, shown by the dashed area (for the non feasible project) and the clear area (for the feasible project).

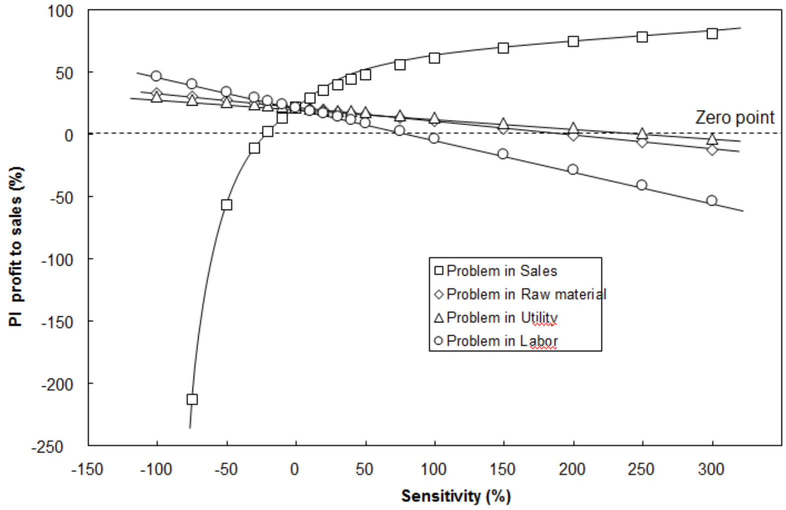


Fig. 7. Analysis of PI profit to sales as a function of sales, raw material, utility, and labor.

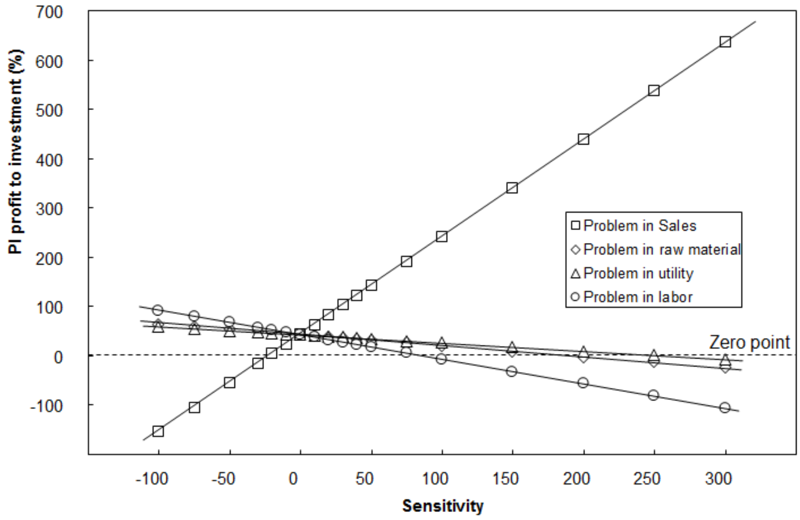


Fig. 8. Analysis of PI profit to investment as a function of sales, raw material, utility, and labor.

To clarify the impact of the parameters on the BEP, evaluation in the specific range was conducted (in the range of between -100 and 300%), shown in the inserted image in Fig. 10. As shown in this figure, improvement in sales has a good correlation with the decreases in BEP. On the contrary, labor, raw materials, and utility has an opposite impact compared to the sales. The result showed that the project will be possible when conducting the parameters in the specific range. Specifically, this condition is strict for sales (> -50%) and labor (< 100%), whereas other parameters (raw material and utility) are typically adaptable. In short, when there is a decrease in the sales down to more than -50% and/or an increase in the labor cost to more than 100%, the project is relatively not feasible to be done.

Since labor, utility, and raw material are included in the variable cost, analysis of CNPV curve and PBP based on the change in the variable cost is evaluated (Fig. 10). The analysis result showed that the variable cost plays important role to the profitability of the project, in which decreases in the variable cost influence directly to getting high value for final CNPV. Indeed, this also influences the PBP value to be decreased (shown in inserted figure in Fig. 10). In short, the lower variable cost would be effective for generating more profit. However, for the case in the increases in variable cost, the project will be getting lost. From the figure, the maximum changes in variable cost to sustain the project must be less than 120%. Then, when the production uses higher than 120% of the variable cost, the minimum PBP can not be obtained and will create the unprofitable project.

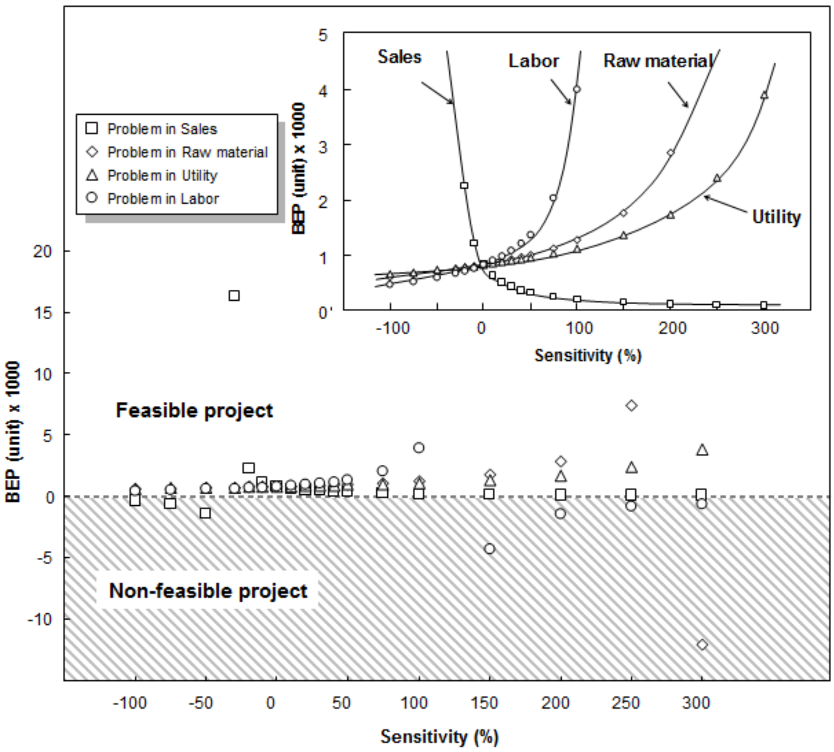


Fig. 9. Analysis BEP as a function of sales, labor, raw material, and utility. Insert image is the analysis of BEP in the specific range (between -100 and 300%)

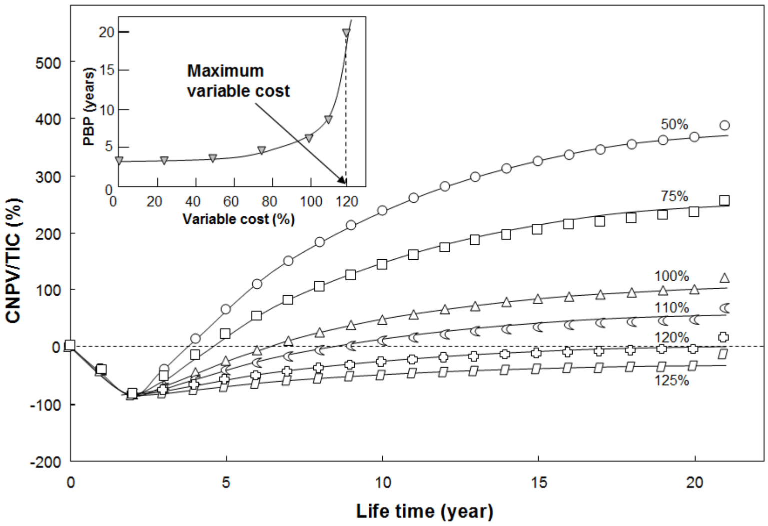


Fig. 10. CNPV curve in accordance to life time of the project with various variable costs. The insert graph is the PBP calculation based on variable cost.

4.2.3. Changing production capacity

Analysis of CNPV for gaining the minimum requirement of capacity is shown in Fig. 11. As shown in this figure, the CNPV can predict in detail when the project starts to be profitable. This graph also can estimate the PBP of the project (as shown in the insert figure).

The result showed that the capacity plays important role to the profitability of the project. Decreases in the capacity influence directly to the final CNPV. Indeed, this also influences the PBP value. From the figure, the minimum capacity to sustain the project must be more than 60%. In short, the use of capacity of less than 60% will create the unprofitable project.

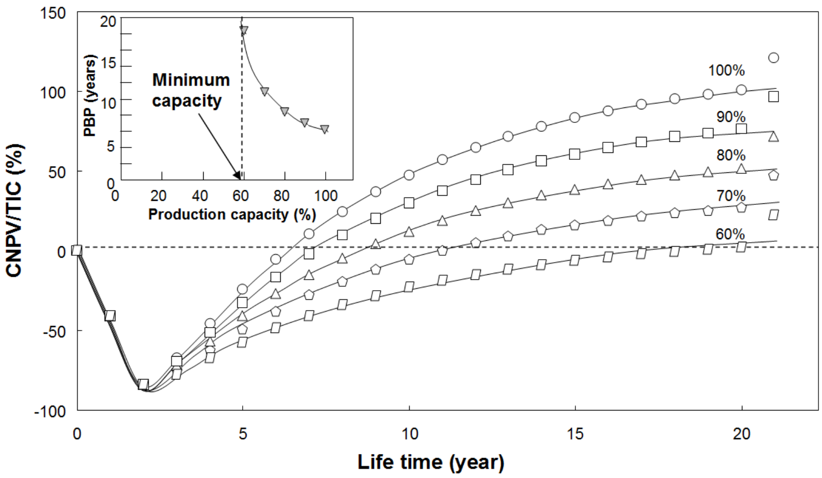


Fig. 11. CNPV curve in accordance to life time of the project with various production capacities. The insert graph is the PBP calculation based on production capacity.

4.2.4. Impact of external condition

For predicting the successful project, economic condition in the country where the project is conducted is one of the most influencing external parameters. This relates to a financial charge or other levy imposed upon a project by a state or the functional equivalent of a state to fund various public expenditures. The impact of economic condition in the country can form a tax or a subsidiary from the government itself.

Figure 12 shows a CPNV curves with various taxes and subsidiaries. The insert image is the PBP obtained with various taxes. As shown in the figure, initial condition (from 0 to 2 years of the project) of the CNPV under various taxes was identical. This is because these years relates to the construction of the project. The effect of tax on the CNPV can be obtained after the project established (from 2 years). The more taxes added to the project (shown by clear dots; from 0 to 65%) results in the less benefits obtained. Indeed, these benefits relate to the PBP of the project. Based on the PBP analysis, the maximum tax to get BEP (the point at which neither a profit nor a loss in the project) is 65%. The change in the taxes to more than 65% creates failure in the project.

In addition to tax, investigation about "negative tax" (shown as solid dots) was also presented. This negative tax means that the additional charge given by government as a subsidiary cash for the project. In short, when government gives 50% subsidiary, the graph in Fig. 12 is shown as -50%. Based on the graph, when the more additional subsidiary is applied, the more benefits can be obtained. However, we found that the subsidiary is not impact too much in the project since the PBP is about 5 years (confirmed by almost straight line in the insert graph in Fig. 12 in the dashed area).

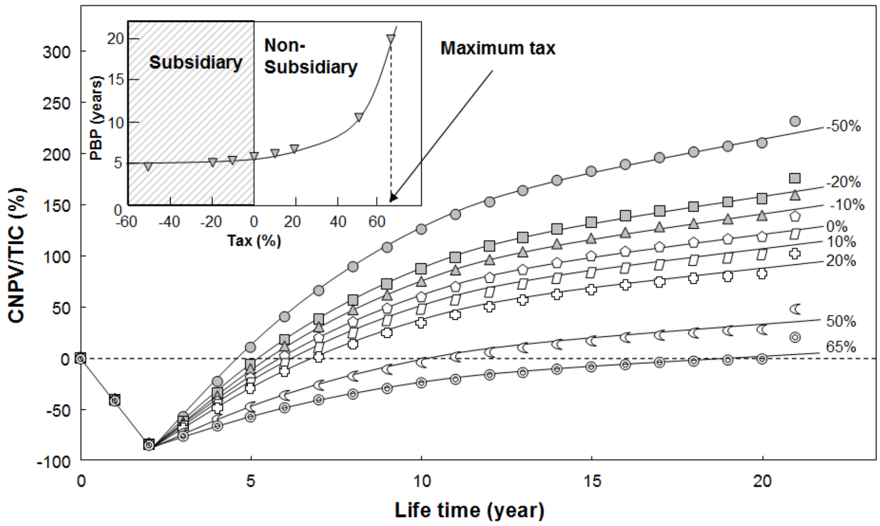


Fig. 12. CNPV curve in accordance to life time of the project with various taxes. In the figure, the solid dots are when government gives subsidiary, whereas the clear dots are when government asks tax. The insert graph is the PBP calculation based on tax (the clear area relates to tax, and the dashed area corresponds to subsidiary from government).

5. Discussion

5.1. Engineering perspective

The result from engineering point of view confirmed that the project is promising. Since the equipment to support the process can be from commercially available devices/apparatuses, the scale-up production up to 20 kg of rice straw can be done with no problem.

By calculating the project with 3,360 times of processing cycle per year, the suggested scheme is prospective to consume rice straw waste of more than to 67 tons per year. Indeed, when calculating the total project that reached to the 20 years of project, the project can handle rice straw waste of 1344 tons.

Further, the analysis regarding the total equipment cost for converting 20 kg of rice straw waste per batch requires the total purchased equipment cost of USD 4,900. Adding the Lang Factor, the TIC was less than USD 22,000. This value is relatively economical (i.e., project needs less investment fund). Compared to the total amount of degraded rice straw waste, the value will be only about 16 USD per ton. Indeed, this is not expensive for accessing a problem solver in degrading one ton of rice straw waste.

5.2. Economic analysis

Based the above analysis, the project under ideal condition is prospective. However, when there is a change in the economic circumstance, the project for the fabrication of activated carbon and silica particles is profitable only in the specific economic condition. In short, if the project is conducted in the circumstance that is out of the specific economic condition, the project will be loss. Detailed explanation of the specific condition is in the following:

i. The change in the cost of raw material must be less than 200%. Both raw materials (i.e., NaOH and HCl) have equal impact. Compared to other factors, the impact of these raw materials is relatively less due to their fewer amounts in use.
ii. Sales must be maintained in the range of higher than -50%. When the cost of sales is down more than -50%, the project will be failure. From the type of sales, carbon has more impact than silica, making the carbon to be the main influencing parameters for project sustainability. The fundamental reason for the great impact from carbon compared to silica is because the amount of carbon is almost three times than that of silica.
iii. Labor cost must be maintained to have less than 100%. This cost can be decreased by applying technology to alternate the use of labor.
iv. Utilization has less impact to the project. This is because the utility (specifically electricity) can be re-generated from the process itself, such as energy gained from burning the rice straw waste.
v. Tax has impact to the project profitability. The tax must be estimated clearly since the maximum tax for sustaining the project must be less than 65%.
vi. Subsidiary from government improves the sustainability of the project. However, the impact of subsidiary is less than that of tax

In addition to the economical prospect, analysis of the attractive of the project must be done. In short, although the GPM, the BEP, and the BEP showed positive value, other economic parameters (e.g., PBP, ROI, IRR, PI and final CNPV) give negative prospectives. The project seems to be unattractive perspective for industrial investor. This perspective is based on the Indonesian standard capital market. To simplify the discussion, analysis in the ideal case was conducted in the following.

The PBP analysis showed that the investment will be turn over after more than 5 years. Compared with the standard capital market's PBP, the result showed the uncompetitive condition. The investment of less than 25000 USD within 5 years is considered too long period. The standard Indonesian capital market for USD 25000 usually promotes PBP of about 1-2 years.

The negative decision was also found for ROI analysis that shown about 8%. This implies that investing fund of 100 USD generates additional benefit of 8 USD. Indeed, this profit is relatively unattractive, compared to the bank interest and capital market. Local capital market in Indonesia should be at least 10% of profit per year, in which 2.50% of it was usually used for *Zakat*.

In the case of final CNPV, the final value seems to be high enough for 20 years of project. However, when calculating per year, this CNPV is relatively less. This is also strengthened by relatively less value for PI. Indeed, this typical long term investment will be unattractive for investor.

Other parameter is IRR that determined the IRR value of 44% for 20 years. Rough calculation of IRR per year gives relatively low outcome that reached about 2%. This responds the IRR can be categorized to be unpromising, creating conflict against Indonesian local bank interest of about 5-6% [18].

In addition, none of new novelty in the engineering process is shown in this study. However, the new idea in this study is to give information and knowledge on the feasibility for the rice straw production. Based on the above results, although the process for converting rice straw waste is incompatible to be applied in industry, other perspective must be re-considered. The conversion of rice straw waste is prospective for solving environmental issue; thus, constructing this project is inevitable and must be done in the agricultural countries. Indeed, to maintain this project, the financial support has to be obtained, which can be from either government or industrial social responsibility.

6. Conclusion

Based the above analysis, the project in the conversion of rice straw waste into activated carbon and silica particles is prospective from engineering point of view. This analysis is also supported by cost analysis of economic parameters that presents positive value. Analysis of the several sensitivity parameters is also done, shown several condition boundaries to get profitable. However, the economic perspective shows opposite results. In short, the process for converting rice straw waste is unattractive for industrial investor. However, since the present project is one of the prospective methods for solving rice straw waste issues with relatively less investment fund, constructing this project is inevitable. Whether giving profit or not, the project must be done in the agricultural countries. As a consequence, to maintain this project, the financial support has to be added, which can be from either government or industrial social responsibility.

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