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A Techno-Economic Analysis of Utilization and Development Activated Carbon as Biomass-based Electrodes for Supercapacitor Device

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Abstract

Biomass-based activated carbon (AC) has been widely used as a supercapacitor electrode. Although there have been many studies that explain the potential of biomass as a material to produce AC as supercapacitor electrodes in performance through specific capacitance values and energy values, there have been no studies that discuss their potential from an economic point of view. Therefore, this study aims to use mission grass as a supercapacitor electrode to produce AC based on techno-economic aspects. There are several calculations, including the cost of production, break-even point (BEP), payback period (PP), net present value (NPV), and sensitivity analysis. Furthermore, it is necessary to include an estimate of cost component data to calculate the small-scale production target of 5,472 units/year. The results showed that cost of production of USD 1.83/unit with a selling price of USD 2.37, BEP at 3,538 units earned a gross profit, PP, and a positive NPV of USD 8,380, 5 years, and USD 8,768, respectively. According to sensitivity analysis, changes in selling price to BEP are considered the most sensitive. These implies that using mission grass as a supercapacitor electrode is beneficial.

Keywords: Activated carbon, Mission grass, Supercapacitor; Techno-economy

Introduction

Activated carbon ranges from carbon blacks to nuclear graphite, carbon fiber, and composites to graphite electrodes. Furthermore, its availability for industrial purposes is closely related to resources. Activated carbon is commonly used in industry, such as cigarette filters, petroleum refineries for separating gas mixtures through carbon molecular filters, and others [1]. The high absorption properties are used to overcome environmental pollution [2]. Activated carbon has high conductivity properties, adjustable pore size, large surface area, and physical stability [3]. This led to its wide application in some energy storage devices, such as lithium-ion batteries [4], capacitors [5], and supercapacitors [6]. Furthermore, the supercapacitor uses electrodes as its primary material to perform well. There are obstacles to preparing and producing electrodes, namely the expensive cost of materials and complicated processes. Therefore, several studies showed that biomass, such as activated carbon's primary material, has great potential as supercapacitor electrodes with low production costs and a simple manufacturing process [6]. Biomass used as supercapacitor electrodes includes miscanthus grass [7], pine sawdust [8], argan bark [9], rotten carrots [3], banana leaves [10], bamboo [11], pineapple leaf fiber [12], *averrhoa bilimbi* leaves [13], and mission grass [6]. Furthermore, they have a good performance with specific capacitance ranging from 130 - 293 F g^{-1}. Study was conducted on the use of this biomass. However, no study discussed the pre-plans for the industrial-scale production of biomass-based supercapacitors. Techno-economic analysis has been widely carried out on several productions of activated carbon for various functions, such as electricity generation and storage [14], as a carbon capture [15], and the bio-energy plants [16]. In another case, techno-economic analysis also used on several production for the energy conversion, such as the natural gas pyrolysis [17], and to produce methanol [18]. This study expands the usage of mission grass as a supercapacitor electrode based on techno-economic aspects within the estimation of small and medium industries in Indonesia. First, a business plan's economic value and feasibility are calculated using basic tools, such as the cost of production, payback period, and net present value (NPV) calculations [19]. In addition, the value of break-even points (BEP) and sensitivity analysis are also calculated. This aims to provide an overview of the projected cost of manufactured supercapacitors and the potential for developing mission grass biomass supercapacitors in the future industrial sector.

Materials and methods

Materials

The mission grass waste was collected as raw material from surrounding areas in Pekanbaru, Indonesia. The other substances obtained as auxiliary materials were potassium hydroxide (KOH) and sulfuric acid (H_2SO_4) [6].

Calculation of cost production

The cost of production is a set of costs consisting of the values of raw material, direct labor, and factory overhead [20]. It is calculated based on the cost component and estimation in small and medium industries using the following Eq. (1) [21,22]. The following cost data used can be seen in **Tables 1 - 3**.

$$\text{Cost of Production} = \frac{\text{RMC+LC+FOC}}{\text{Total Production}} \tag{1}$$

note: RMC = Raw Material Cost, LC = Labor Cost, FOC = Factory Overhead Cost

Table 1 Raw Material Costs.

Cost component	Needs/Year	Unit cost (USD)	Total cost (USD)
Mission grass	7 kg	-	-
Sulfuric acid (H_2SO_4)	1 bottle	6.4	6.4
Duck eggs (Separator)	12 item	0.19	2.30
Total		8.7	

Table 2 Factory overhead cost.

Cost Component	Total Cost (USD)
Electricity	1,152
Distilled water	38.4
Potassium Hydroxide (KOH)	28.8
Depreciation cost	272.3
Building rent	1,280
Packaging:	
Acrylic (122×244 mm)	96
Stainless steel sheet	224
Total	3,092

Table 3 Labor cost.

Labor Needs	Day Work	Fee (USD)	Total (USD)
2 labor days	240 days/year	6.4/Day	3,072
2 permanent employees	12 months/year	160/month	3,840
Total			6,912

Calculation of break-even point (BEP)

Break-even point (BEP) is the state in which income equals total cost, the point where profit equals zero (a business that does not profit and does not suffer losses). It consists of fixed cost, variable cost, and selling price [23]. Furthermore, it is calculated in units and rupiah using the following Eq. (2), [24].

1) BEP in Units

$$BEP = \frac{FC}{P - VC} \quad (2)$$

2) BEP in Dollars

$$BEP = \frac{FC}{1 - \frac{VC}{P}} \quad (3)$$

note: FC = Fixed Cost, VC = Variable Cost, P = Price

Calculation of payback period

The payback period is the time taken for capital or initial costs to return. It is calculated in terms of time (often years). An investment business or project is declared feasible when the payback period value obtained is smaller than the desired target [25]. Furthermore, it requires a cash flow based on the profit and loss projection from the estimated annual income during the 10 years assumed business duration, which is 10 years. The payback period is calculated using the following Eq. (4), [25].

$$\text{Payback Period} = n + \frac{a - b}{c - b} \times 1 \text{ year} \quad (4)$$

note: n = Last year where the cumulative amount cash flow has not covered the cost of the initial investment, a = investment cost, b = cumulative amount of cash flow at the year-n, c = cumulative amount of cash flow at the year-n+1

Calculation of net present value

NPV is calculated to determine when the value of investments made during the business period is good or bad. It requires several indicators such as cash flow, interest rate value, and discount factor. Furthermore, it is the difference between the present value of an investment and cash flow in the future. A business is believed to be feasible when NPV obtained value is positive and vice versa. This value is calculated using the following Eq. (5), [25].

$$NPV = \sum \frac{C_{Ft}}{(1+K)^t} - I_0 \quad (5)$$

Sensitivity analysis

A sensitivity analysis is performed to identify the factors influencing the changes in investment value and their effect on the cost of production and profit margin. These parameters include investment, cash flow, raw material, interest, and tax rates. Furthermore, the analysis is conducted by replacing the value of the changing parameters to determine their effect on the acceptability of alternative investments [25]. It also helps determine the most sensitive factors to change for appropriate decision-making.

Results and discussion

The production target of 1 set of supercapacitors is 450 units/month. Therefore, it is predicted to produce approximately 5,472 units/year. **Table 4** shows that the selling price of 1 unit of supercapacitor set based on mission grass stems is cheaper than those in the market branded Kamcap with a capacitance of 1.5 F and sold for USD 3.26 - USD 3.84 in one of the largest e-commerce in Indonesia. This implies that using mission grass biomass as the raw material of supercapacitor electrodes can compete with non-biomass electrodes. **Table 5** shows that the production target of 5.472 units obtained BEP of 3,538 units or a gross income of USD 8,380. This calculation was only based on fixed costs, variable costs, and selling prices. It implies that until 3,538 units are sold, the profit margin value covers the operational costs generated before reaching the profit point. Furthermore, the value of the 3,538 units, which is smaller than the production target in a year of 5,472 units, shows that BEP was obtained in the first year of sales.

Table 4 The component of cost of production.

Cost component	Total cost (USD)
Raw Material Cost	8.70
Factory Overhead Cost	3,092
Labor Cost	6,912
Total	11,433
Cost of Production	1.82
Profit Margin (30 %)	0.55
Selling Price/unit	2.37

Table 5 The cost component of BEP calculation.

Cost component	Total cost (USD)
Fixed cost	
Permanent employees	3,840
Depreciation cost	272
Building rent	1,280
Total	5,392
Variable cost	
Labor days cost	3,702
Raw material cost	8.7
Auxiliary cost	67.2
Electricity	1,152
Packaging	320
Total	4,620
Variable cost/unit	0.84
BEP (Dollar)	8,380
BEP (Units) = 3,538 units	

Payback period is calculated using an annual cash flow derived from projected profit-loss over an assumed business period of 10 years. Due to this fact, the revenue for the next 10 years is calculated by assuming an annual income increase of 5 %. **Table 6** shows the estimated annual revenue. Furthermore, the projected profit and loss from the income are also taken into account with the 15 % tax that has been arranged in UU HPP No. 7, 2021 (The law in Indonesia). **Table 7** shows the profit-loss projection among 10 years. The cash flow is then realized based on the projected net profit. Since it is not the same annually, it needs to be sought yearly considering the initial investment costs. **Table 8** shows the initial investment costs resulting from the necessary production equipment. **Table 9** shows payback period obtained over 5 years. Therefore, this company made a net profit in the 5th year, covering operational costs, taxes, and investment costs. This implies a good or worthy investment value [25] because payback period is obtained before the assumed business duration of 10 years. The interest rate value used in this study is based on the average Credit Base Rate of Conventional Commercial Banks for corporations issued by the Financial Services Authority of Indonesia in February 2022, which was 8 %. The data processing shows a positive NPV value of USD 8,320. This implies that the net present value for the next 10 years, when projected to the present, is considered good since the NPV value is > 0 [25]. The NPV calculation uses an interest rate of 8 % as follows in **Table 10**.

Table 6 Estimated annual revenue.

Year	Revenue	Value (USD)
1	Sales (75 %)	9,718
2	Sales (80 %)	10,204
3	Sales (85 %)	11,014
4	Sales (90 %)	11,662
5	Sales (95 %)	11,813
6	Sales (100 %)	12,958
7	Sales (105 %)	13,606
8	Sales (110 %)	14,253
9	Sales (115 %)	14,901
10	Sales (120 %)	15,549
	Total Average Revenues/Year	12,568

Table 7 Profit-loss projection.

	Year (USD)										Total (USD)	Average (USD)
	1	2	3	4	5	6	7	8	9	10		
Revenue	9,718	10,204	11,014	11,662	11,813	12,958	13,606	14,253	14,901	15,549	125,678	12,568
Operational cost	10,012	10,012	10,012	10,012	10,012	10,012	10,012	10,012	10,012	10,012	100,122	10,012
Profit before tax	(294)	192	1,002	1,649	1,800	2,945	3,593	4,241	4,889	5,537	25,556	2,556
Tax (15 %)	(44)	28.8	150.2	247.5	270	442	539	636	733	831	3,833	383
Profit	(250)	163.2	851.5	1,402	1,530	2,504	3,054	3,605	4,156	4,706	21,723	2,172

Table 8 Initial investment.

No	Production equipment	Cost (USD)
1	110 °C electric oven	640
2	Electric oven 250 °C	96
3	Ball milling machine	320
4	Hot plate	160
5	Furnace machine	2,048
6	Cyclic voltammetry test kit	832
7	Hydraulic press	384
8	Digital scales 500 g	4.10
9	Sieve	4.48
10	Paintbrush	0.58
11	Measuring cup	22.4
12	Vacuum cup	0.64
13	Litmus paper	38.4
14	Magnetic stirrer	2.82
15	Gas N_2	249.6
16	Gas CO_2	314.88
	Total	5,278

Table 9 Annual cash flow.

Year	Net profit (USD)	Depreciation (USD)	Cash flow (USD)	Cumulative cash flow (USD)
1	(249.84)	272.29	22.46	22.46
2	163.19	272.29	435.48	457.94
3	852	272.29	1,124	1,582
4	1,402	272.29	1,675	3,256
5	1,530	272.29	1,803	5,059
6	2,504	272.29	2,776	7,835
7	3,054	272.29	3,327	11,162
8	3,605	272.29	3,877	15,039
9	4,156	272.29	4,428	19,467
10	4,707	272.29	4,979	24,446
Payback period obtained during 5 years				

Table 10 Calculation of net present value.

Year	Cash flow (USD)	Interest rate (%)	Discount factor	Present value (USD)
0	(5,278)		1	(5,278)
1	22	8	0.9259	21
2	435	8	0.8573	373
3	1,124	8	0.7938	892
4	1,675	8	0.7350	1,231
5	1,803	8	0.6806	1,227
6	2,776	8	0.6302	1,749
7	3,327	8	0.5835	1,941
8	3,877	8	0.5403	2,095
9	4,428	8	0.5002	2,215
10	4,979	8	0.4623	2,302
Net present value				8,768

Figures 1 and **2** shows some adjustments to BEP (unit) using the following max and min 50 % change factors with a range of 10 %.

a. When fixed and variable costs decrease, BEP (Unit) increases.
b. When the selling price decrease, BEP (Unit) increase.
c. When fixed and variable costs increase, BEP (unit) increases.
d. When the selling price increase, BEP (unit) decrease.

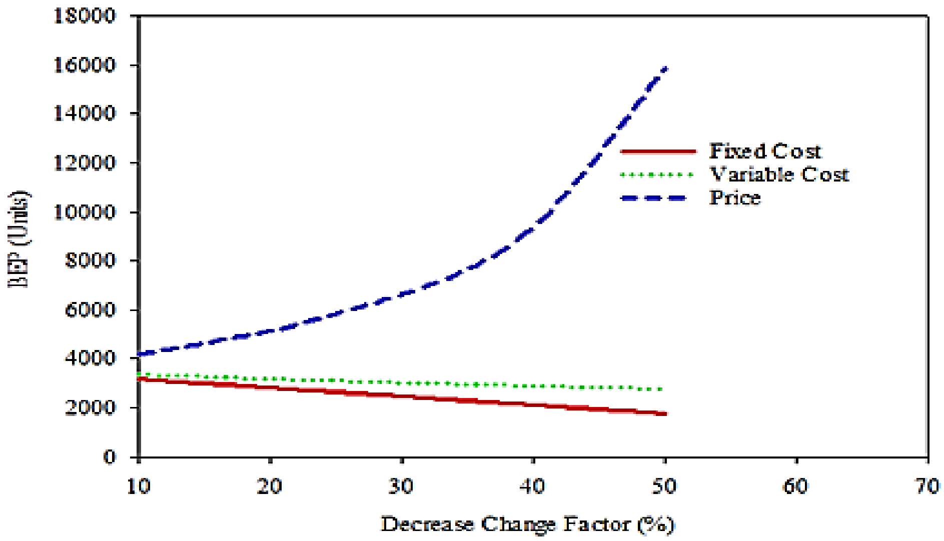

Figure 1 Decrease change factor to BEP (Unit).

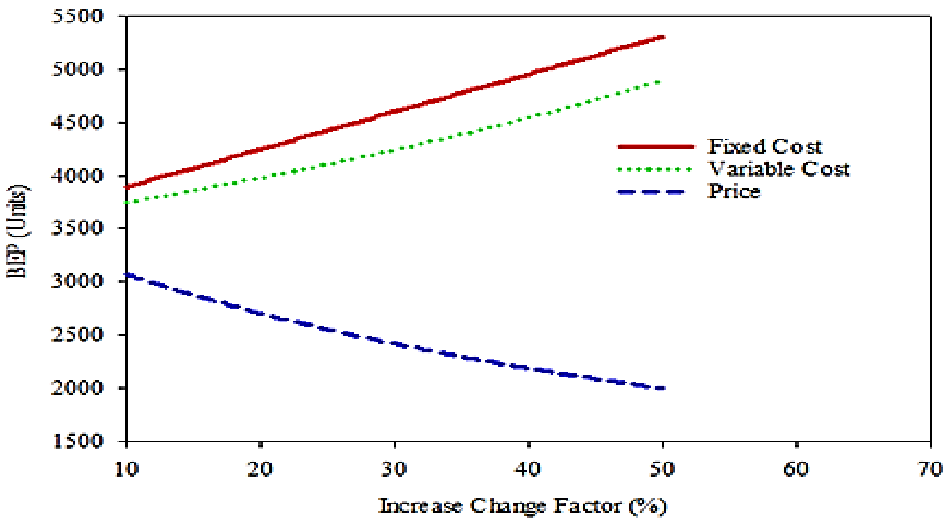

Figure 2 Increase change factor to BEP (Unit).

The adjustment is appropriate in Hudori's study [26]. Furthermore, the most sensitive factor in changing is that the selling price is viewed based on a chart that varies more significantly than fixed and variable costs. For example, BEP (unit) reaches 5,135 when there is a 20 % reduction in selling price and increases fixed costs by 50 %, which results in BEP (Unit) reaching 5,308 units. This implies that when the value exceeds the production target of 5,472 units yearly, then changes are not made because, in a business, it is expected that the obtained value should be smaller than the production target set. A sensitivity analysis is also conducted on the selling price with BEP (unit) as the change factor. The data processing results show that the value can reduce the selling price of supercapacitors to 50 %. For example, a BEP of 1,770 units produces a selling price of USD 3.89 with a fixed record using a profit margin of 30 %. This causes the selling price to be higher than competitor supercapacitors with a capacity of 1.5 F, which is at USD 3.26 - USD 3.84 in the market. Therefore, BEP (Unit) can be reduced and recommended by 30 and 40 % because the selling price value remains below other competitors. **Table 11** shows details of the changes from BEP to the selling price.

Table 11 Changes from BEP to the selling price.

Changes BEP (%)	Selling Price (USD)
0	2.37
−10	2.54
−20	2.75
−30	3.02
−40	3.38
−50	3.89

Conclusions

In conclusion, apart from the specific capacitance value and energy, the development of activated carbon using mission grass biomass as supercapacitors electrode can be potentially produced in small and medium industries considering various aspects of the economy. We conclude the cost of production, the desired profit margin, and the selling price obtained is USD 1.82/unit, USD 0.55/unit, and USD 2.37/unit, respectively. BEP in units and rupiah are obtained at 3,538 units, and when receiving a gross profit of USD 8,380, respectively. Payback period was calculated to be 5 years. This value is feasible because it is smaller than the assumed 10 years of business period. NPV with an interest rate of 8 % for 10 years also showed a positive value of USD 8,768. Several factors affect the value of this study. According to sensitivity analysis, the major factor is the selling price, where the reduction in its value from 10 to 50 % shows a significant change to BEP (Unit). Therefore, the recommended selling price reduction limit is approximately 30 and 40 %. Therefore, it is feasible and has a fairly high-profit value of USD 2,172/year based on profit-loss projections. The mission grass supercapacitors compete in the Indonesian market at USD 2.37/unit, which is lower than the selling price of other supercapacitors.

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