Techno-Economic Analysis of DME Production from Indonesian Brown Coal: A Preliminary Plant Design

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Abstract

This article presents the preliminary plant design and techno-economic assesment of Dimethyl Ether (DME) production from coal. As the world's third largest coal producer, Indonesia faces challenges in using low rank lignite due to its high moisture content, wgich limits direct combustion efficiency. The plant was designed to produce 210,000 tons of DME per year, supporting national effort to reduce LPG imports and improve energy security. The calculation include mass and energy balances, equipment sizing, and enviromental considerations suh as CO2 emissions management. Economic evaluation demonstrate project feasibility, with an internal rate of return of 24.28%, a payback period of 3.46 years, and a net present value of 39.60 million USD. Sensitivity analysis shows profitability is highly sensitive to DME price variations. Further research issyngas recommended to develop effective carbon capture strategies and evaluate lifecycle emissions to enhance DME production more enviromentally friendly and sustainable.

Keywords: *Coal gasification, DME production, Indonesian brown coal, Techno-Economic Analysis*

Abstrak

Artikel ini menyajikan desain awal pabrik dan penilaian tekno-ekonomi produksi Dimetil Eter (DME) dari batubara. Sebagai produsen batubara terbesar ketiga di dunia, Indonesia menghadapi tantangan dalam penggunaan lignit berkadar rendah karena kandungan kelembapannya yang tinggi, yang membatasi efisiensi pembakaran langsung. Pabrik ini dirancang untuk memproduksi 210.000 ton DME per tahun, mendukung upaya nasional dalam mengurangi impor LPG dan meningkatkan ketahanan energi. Perhitungan mencakup neraca massa dan energi, perancangan peralatan, serta pertimbangan lingkungan seperti pengelolaan emisi CO_2. Evaluasi ekonomi menunjukkan proyek ini layak, dengan tingkat pengembalian internal sebesar 24,28%, periode pengembalian modal selama 3,46 tahun, dan nilai bersih sekarang sebesar 39,60 juta USD. Analisis sensitivitas menunjukkan bahwa profitabilitas sangat dipengaruhi oleh fluktuasi harga DME. Penelitian lebih lanjut disarankan untuk mengembangkan strategi penangkapan karbon yang efektif dan mengevaluasi emisi siklus hidup untuk mendukung produksi DME menjadi lebih ramah lingkungan dan berkelanjutan.

Kata kunci: *Analisis Tekno-Ekonomi, Batubara merah Indonesia, Gasifikasi batubara, Produksi DME*

1. Imtroduction

Dimethyl Ether (DME) is a potential fuel for transportation and domestic purposes. It has favourable characteristics as fuel, including lower emissions and a high cetane number. It has similar characteristics to LPG (Liquid Petroleum Gas), making it a promising candidate as an LPG substitute [1]. It has been reported that household stoves can function with an LPG mixture containing 20% DME [2]. Due to its potential, the Indonesian government has developed a scenario to reduce LPG import by utilizing DME.

DME can be synthesized from natural gas, crude oil, coal, biomass, or any carbonaceous feedstocks. Indonesia is the world's third-largest coal producer, with a total production of 725 million tons, accounting for 8.3% of global production. Among the total coal production, 20.2% is classified as low-rank coal, also known as brown coal [3]. The significant moisture content in this coal reduces its effectiveness as a power source, leading to a lower market price compared to other coal types. Its widespread availability offers great potential for DME production, which is still limited in Indonesia [4]. This project is driven by the goal of designing a coal-based DME production plant. The establishment of such a plant would support the growing need for clean energy, as DME burns with lower emissions compared to conventional fuels, owing to its higher hydrogen-to-carbon ratio [5][6].

Recent studies highlight advances in DME production from syngas and CO_2 [7][8]. In the study conducted by [9] reviewed next-generation catalytic systems improving efficiency and reducing emissions. However, studies specific to Indonesian lignite and local economic conditions are scarce. Moreover, lifecycle carbon impacts and integration with CCS remain underexplored, underscoring the importance of this research.

This study presents a techno-economic analysis of DME production from Indonesian brown coal. It outlines the flow diagram along with the overall material and energy balance of the preliminary plant design. The economic feasibility of the plant was assessed through capital and production cost calculations, profitability analysis, and sensitivity analysis.

2. Methodology

Based on the literature, several methods have been developed to produce dimethyl ether (DME), including direct synthesis from synthesis gas [9], synthesis from CO_2 [7], and methanol dehydration [8]. These processes have been extensively developed and modified to improve their process efficiency. Based on their performance, the synthesis of DME from syngas was selected as the main process of this preliminary study.

The final process flow diagram for DME synthesis from syngas was developed using Microsoft Visio to provide a comprehensive visual representation of the process. Mass and energy balance were accurately calculated for each unit operation to determine the required raw materials and utility consumption based on the planned production capacity.

Additionally, the plant location was determined by evaluating critical factors such as production capacity, feedstock availability, transportation infrastructure, and market accessibility, ensuring optimal operational and economic feasibility.

Capital cost estimation was perform using the bare module cost method, which incorporates the costs of equipment and associated infrastructure. Indirect costs were also considered, including the supervision fees, contractor fees, contingency allocations, and working capital investment necessary to initiate production. The annual production costs were estimated as the total of manufacturing expenses such as raw materials, labors, utilities, and local taxes, combined with general costs, including distribution expenses, administrative costs, and research and development activities [10].

A comprehensive profitability was conducted using financial indicators such as cumulative cash flow, return on investment (ROI), payback period (PBP), internal rate of return (IRR), and net present value (NPV). Sensitivity analysis was performed to evaluate the financial resilience of the project under different economic conditions. ROI was calculated as the ratio of net annual profit to total capital investment, serving as a key indicator of investment efficiency. The Pay Back Period (PBP) represented the duration required to recover the initial capital investment. The Internal Rate of Return (IRR) considers the time value of money by evaluating the outstanding balance of unrecovered investment at the end of each year throughout the project operational period. Finally, Net Present Value (NPV) was determined by discounting cumulative cash flows to present value at the end of the plant’s operational period, using the designated discount rate [10].

The following assumptions were justified to improve scientific data:

a. Coal price was based on 2024 Indonesian average lignite contract prices (USD 42,26/ton) [6]
b. Conversion efficiencies were derived from operating Chinese plants with similar capacities [4]
c. CO2 treatment assumed excess CO2 removal via Selexol process.
d. Equipment costs were updated using the Nelson-farrar index [10]

3. Result and Discussion

3.1. Process Description

The block flow diagram of the selected process is illustrated in Figure 1.

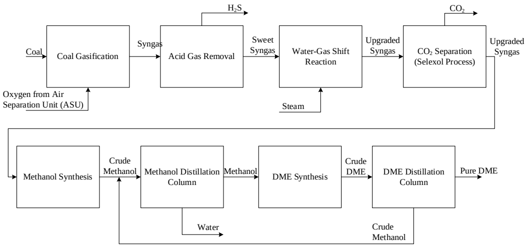


Figure 1 Block Flow Diagram of DME production from Indonesian brown coal.

Figure 1 illustrates the process beginning with coal gasification, in which coal reacts with oxygen at elevated temperatures to produce syngas, a mixture comprising hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), and other minor components. The syngas then undergoes a purification stage to remove impurities and adjust its composition.

In the subsequent stage, the syngas was directed through an acid gas removal unit, where sulphur compounds such as hydrogen sulphide (H_2S) were eliminated using a ZnO adsorption column. This step was essential to prevent catalyst poisoning in the downstream process. The purified syngas was then sent to a water-gas shift (WGS) reactor, where carbon monoxide reacts with steam to generate additional hydrogen and carbon dioxide, thereby enhancing the efficiency of methanol synthesis. Excess CO_2 was removed via the Selexol process, ensuring the syngas composition was suitable for methanol production. The methanol synthesis reactor then converts hydrogen and carbon monoxide into methanol (CH_3OH) using a copper-based catalyst. This exothermic reaction occurred under high pressure, requiring cooling systems to maintain optimal reaction conditions. The resulting crude methanol was subsequently distilled to remove water and impurities, ensuring a high-purity product for DME synthesis.

In the final stage, the purified methanol undergoes dehydration over an alumina catalyst in the DME synthesis reactor, producing dimethyl ether (CH_3OCH_3) at moderate temperature and pressure. The resulting mixture, containing DME, unreacted methanol, and water, were processed in a DME distillation column. High-purity DME was recovered at the top, while methanol and water were separated and recycled for further use.

3.2. Material and Energy Balance

Mass and energy balance calculations were conducted using data from coal based DME production plants in China. The Shenyang Ningxia Coal Group operate with a production capacity of 210,000 tons per year, while Shanxi Lanhua Clean Energy has a capacity of 140,000 tons per year. The production capacity of 210,000 tons per year (equivalent to 26.61 tons per hour) was selected for this study, based on the availability of coal feedstock in the vicinity of the proposed plant site. The mass and energy balance were calculated using the parameters listed in Table 1. Materials balance results for each process stage are illustrated in Figures 2 though Figure 9. The composition was calculated based on the general mass and energy balance equations are presented in Equation (1) and (2).

Mass balance equation :

$$\Sigma \mathrm{m}_{in} - \Sigma \mathrm{m}_{out} + m_{gen} - m_{con} = \frac{dM}{dt} \qquad (1)$$

Energy balance equation :

$$\Sigma \mathrm{E}_{in} - \Sigma \mathrm{E}_{out} + Q - W = \frac{dE_{system}}{dt} \qquad (2)$$

Table 1.
Process Design Parameters for Mass and Energy Balance

Feedstock	Brown coal with dry composition (%-mass): 60.3% C; 27.24% O_2; 3.53% H_2; 0.59% N_2; 0.17% S; 8.17% Ash
Gasification	P 3 bar and T 920.58°C
Water-gas shift reaction	P 30 bar and T 250°C
Methanol synthesis	P 70 bar T 230°C
DME synthesis	P 10 bar T 250°C

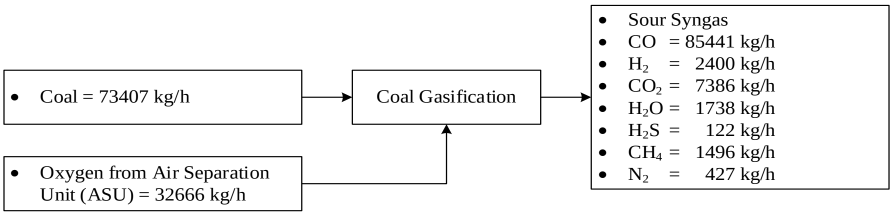


Figure 2. Material Balance on Coal Gasification Unit

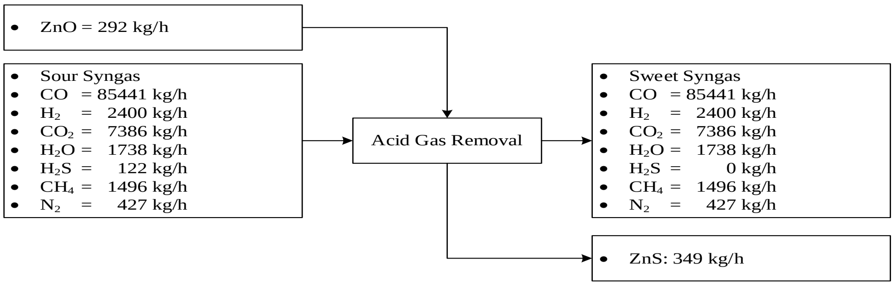


Figure 3. Material Balance on Acid Gas Removal Unit

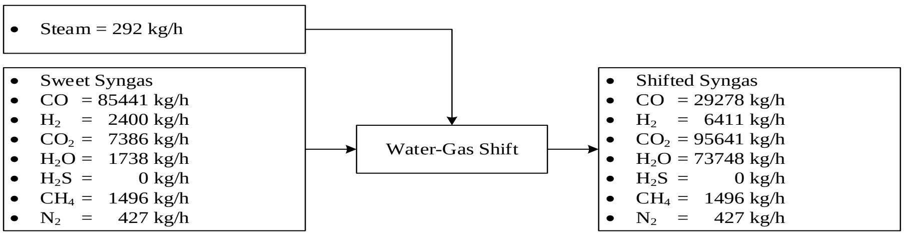


Figure 4. Material Balance on Water – Gas – Shift

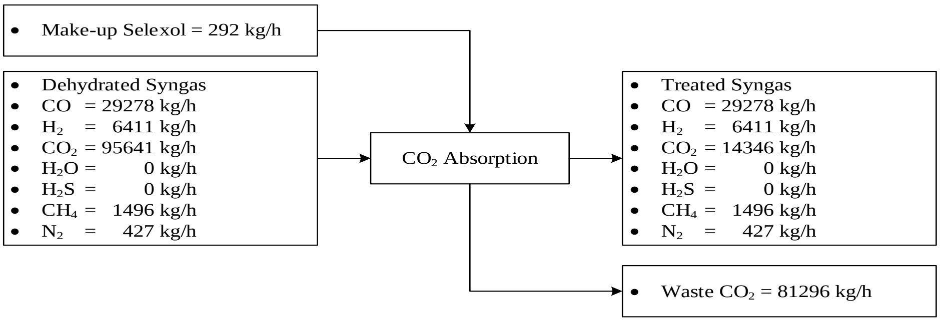


Figure 5. Material Balance on CO_2 Absorption

Figure 6. Material Balance on Mtehanol Synthesis

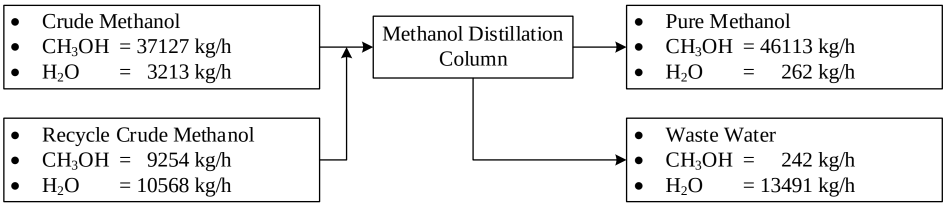


Figure 7. Material Balance on Methanol Distillation Column

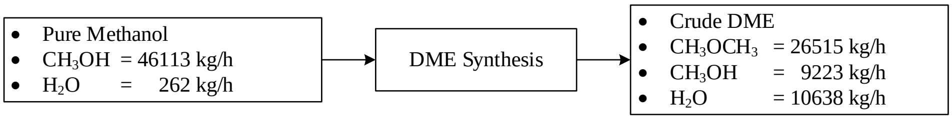


Figure 8. Material Balance on DME Synthesis

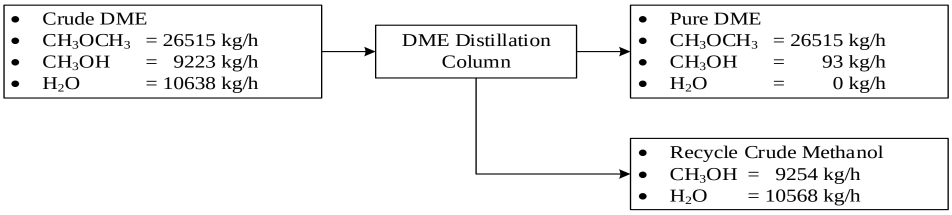


Figure 9. Material Balance on DME Distillation Column

The mass balance calculation indicated that producing 26.61 tons per hour (210,000 tons per year) of DME with 99.65% w/w purity requires 73.41 tons per hour (581,407 tons per year) of brown coal as feedstock. Energy balance calculations were carried out to determine utility requirements for equipment involving heat transfer. The energy balance for each unit operation was based on stream enthalpies, using a reference temperature of 25°C (298 K) and appropriate specific heat capacities. A summary of the plant's utility requirements is provided in Table 2.

Table 2.
Summary of the utility requirements of DME plant

1.	Coal for power plant	1,095	ton/h
2.	Natural gas for power plant	50,096	Scf/h
3.	Steam	300	ton/h
4.	Cooling water	4,333	ton/h
5.	Chilled water	1,918	ton/h
6.	Refrigerant (tetrafluoroethane)	962	ton/h

3.3. Economic Analysis

The capital cost estimation was performed using the bare module cost method. Base costs and correction factors for each process unit were obtained based on estimates using data from 2013 and adjusted for 2024 [10]. The equipment cost index values was projected using the *Nelson-Farrar* (NF) cost index [10], and the cash flow analysis was carried out based on the assumptions listed in Table 3. The total capital cost was determined by summing the total bare module cost of the main process and utility equipment with additional expenses, including site preparation, service facilities, contingencies, land, royalties, start-up, and working capital. A summary of the Total Capital Investment (TCI) calculation is presented in Table 4.

Table 3.
Assumptions Used in Economic Analysis

Plant Construction	2024
Duration of Construction	2 years
Operating Year	2026
Plant Lifetime	15 years
Operating Time	330 days/year with 35 days of maintenance
Capital Structure	20% equity, 80% debt
Debt Payback Period	8 years
Bank Interest	8.05%
Tax	22% from net income
Rate of Return Criteria	≥16%
DME Selling Price	800 USD per ton
Brown Coal Price	42.26 USD per ton

Table 4.
Total Capital Cost Summary

Cost	Definition / Formula	Value ($)
Total Bare Module Cost (C_{TBM})	Total bare module cost of main process equipments	158,623,927.47
Total Bare Module Cost Utilities (C_{alloc})	Total bare module cost of utility equipments	118,112,852.42
Cost of Site Preparation (C_{site})	10% C_{TBM}	15,862,392.75
Cost of Services Facilities (C_{serv})	5% C_{TBM}	7,931,196.37
Direct Permanent Investment (C_{DPI})	$C_{TBM} + C_{alloc} + C_{site} + C_{serv}$	300,530,369.01
Cost of Contingencies and Contractor Fee (C_{cont})	18% C_{DPI}	54,095,466.42
Total Depreciable Capital (C_{TDC})	$C_{DPI} + C_{cont}$	358,318,216.89
Cost of land (C_{land})	3% C_{TDC}	10,749,546.51
Cost of royalties (C_{royal})	1% C_{TDC}	3,583,182.17
Cost of plant startup ($C_{startup}$)	10% C_{TDC}	35,831,821.69
Total Permanent Investment (C_{TPI})	$C_{TDC} + C_{land} + C_{royal} + C_{startup}$	408,482,767.26
Working Capital (C_{WC})	15% CTPI	61,272,415.09
Total Capital Investment (TCI)	CTPI + CWC	469,755,182.35

Total Capital Investment (TCI) refers to the overall cost required to build and operate a plant until it begins production. As showed in Table 4, the calculation begins with determining the Total Bare Module Cost (CTBM), representing the cost of the main equipment and utilities. Additional costs for land preparation (Csite) and supporting facilities (CServ) are included to obtain the Direct Permanent Investment (CDPI). Contingency funds and contractor fees (CCont) are then added to calculate the Total Depreciable Capital (CTDC). The Total Permanent Investment (CTPI) is determined by adding land acquisition (Cland), royalties (Croyal), and start-up costs (CStartup) to CTDC. This results in a total capital investment (TCI) of $469,755,182.35.

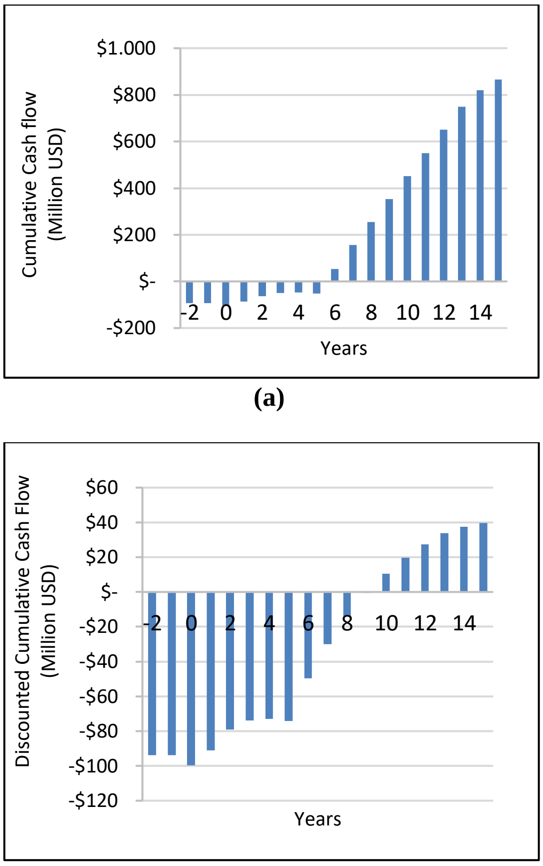
Production costs are categorized into fixed and variable components. Fixed costs are generally independent of production volume, while variable costs fluctuate based on production levels. As summarized in Table 5, the total production cost for producing 210,000 tons of DME per year from Indonesian brown coal is estimated at 67 million USD.

Table 5.
Total Production Cost Summary

Cost	Value
Variable costs	
Feedstock	$ 23,930,913.64
Utility	$ 6,319,624.08
Total Variable Cost	$ 30,250,537.73
Fixed Costs	
Operations	$ 2,334,555.98
Maintenance	$ 163,821.58
Operating Overhead	$ 148,926.29
Property Taxes & Insurance	$ 7,092,516.71
General Expenses	$ 1,527,442.76
Depreciation	$ 25,582,603.52
Total Fixed Cost	$ 36,849,866.83
Total Production Cost	$ 67,100,404.56

Variable costs include expenditures for raw materials and utilities. Fixed costs, which account for the largest portion of the total, amount to $25.582.603,52 and include operational expenses, maintenance, overhead, taxes and insurance, general administrative costs, and asset depreciation. These fixed costs are budgeted regularly to ensure uninterrupted plant operations.

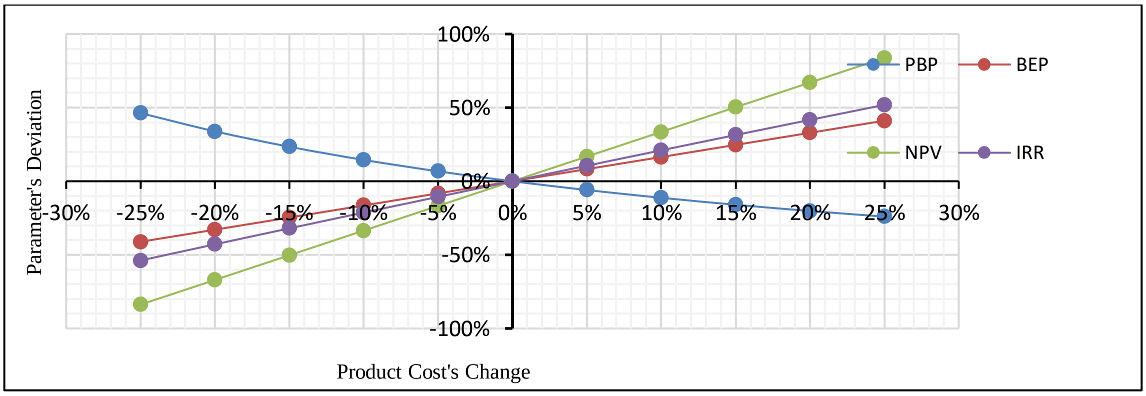
The total capital investment and production costs were used to estimate project cash flow, based on the assumptions outlined in Table 3. The cumulative cash flow is presented in Figure 10.a, while the discounted cumulative cash flow is presented in Figure 10.b**.**



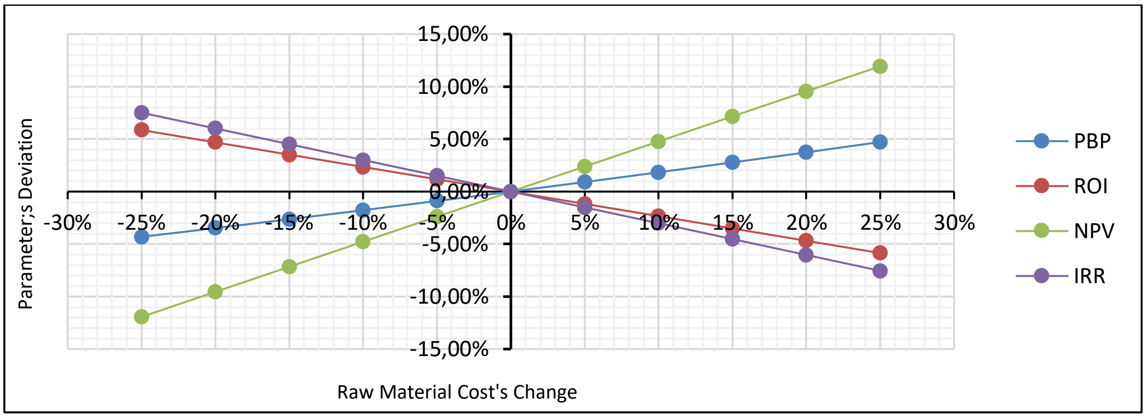
(a)

(b)

Figure 10. Cumulative Cash Flow Chart (a) cumulative cash flow, and (b) discounted cumulative cash flow



(a)



(b)

Figure 11. Sensitivity Analysis for (a) product cost changes and (b) feedstock cost changes

The spider plot in Figure 11 illustrates that profitability parameters are more responsive to fluctuations in product prices than to changes in raw material costs. For example, a 25% increase in raw material costs reduces the Return on Investment (ROI) below the 16% threshold, while a mere 5% decrease in product prices results in a similar decline in ROI. This indicates that the plant's financial performance is highly dependent on product price variations. Consequently, effective pricing strategies are crucial, as even small reductions in product prices can significantly impact overall profitability.

This plant supports Indonesian energy independence by utilizing underexploited lignite reserves. However, policy measures and carbon pricing have a significant impact on the project's feasibility. The integration of carbon capture and storage technology, along with the use of electricity from renewable energy sources, will improve environmental performance in line with global decarbonization trends [9].

3.4. Safety Consideration and Plant Location

Health and safety are critical aspects in any industrial plant. To ensure safe and secure plant operations, various safety devices are integrated into the process equipment. These include check valves on pump and compressor discharge lines to prevent backflow, as well as pressure relief valves installed on storage tanks, pressure vessels, and heat exchangers to protect against overpressure resulting from process disturbances or thermal expansion. All equipment containing hazardous liquids is clearly labeled, and essential control devices such as level, temperature, and pressure sensors are installed to maintain process variables within defined safe operating limits.

In terms of environmental protection, pollution prevention measures include the installation of gas ventilation systems designed to release exhaust gases containing CO_2 and CO in a controlled manner, ensuring that ground-level concentrations remain within permissible and environmentally safe limits. All wastewater generated by the plant is treated in a dedicated water treatment facility using activated sludge, in compliance with the maximum allowable discharge parameters set forth in the Indonesian Ministry of Environment Regulation Number 03 of 2010 concerning Wastewater Quality Standards.

The plant is strategically located in Peranap Regency, Indragiri Hulu, Riau Province, Indonesia**,** providing advantageous access to both the provincial capital and the national capital. The site is also surrounded by six coal producers, ensuring a reliable long-term supply of raw materials for continuous production.

4. Conclusion

The economic analysis confirms the financial feasibility of the proposed coal-to-DME plant with an annual production capacity of 210,000 tons, requiring 581,383 tons of coal. The profitability analysis yields an internal rate of return (IRR) of 24.28%, a payback period (PBP) of 3.46 years, and a net present value (NPV) of 39.60 million USD over a 15-year operational period. The total capital investment (TCI) is estimated at 469.76 million USD, with an annual production cost of 67.1 million USD. Sensitivity analysis indicates that profitability is more significantly influenced by product price fluctuations than raw material costs, underscoring the importance of effective pricing strategies. Given these results, further study should include detailed integration of CO_2 capture systems, comprehensive lifecycle emissions analysis, scale-up and pilot testing to validate the process, and evaluation of long-term market risks to ensure sustainable implementation.

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