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Research article

Economic Feasibility of Dimethyl Ether from Oil Palm Empty Fruit Bunch as a Substitute for LPG in Indonesia

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Abstract

Oil palm empty fruit bunch (OPEFB) can be utilized as a feedstock for dimethyl ether (DME) production through the gasification route. DME has similar characteristics to liquefied petroleum gas (LPG). Therefore, it can be used as a substitute for LPG. Some research has been conducted on DME as a substitute for LPG from various aspects. However, little research was focused on the economic study of OPEFB-based DME as an LPG substitute and its contribution towards saving the LPG import budget. This study aims to find DME plant feasibility, and to assess its contribution to the LPG import budget reduction, especially in the Kalimantan region. The DME price at the depot is calculated based on the ex-factory price of DME, transportation cost, and depot fee. The OPEFB-based DME plant capacity is 994 t day^{-1} OPEFB, which produces 192 t day^{-1} DME. From an economic perspective, the net present value (NPV), internal rate of return (IRR), and payback period (PP) are USD 93.1 million, 17%, and 10 years, respectively, based on 30 years of plant life and USD 185.4 million investment. Only 57% of the DME-LPG mix can be distributed to fulfill Kalimantan region demand per year, while the savings on the import budget is USD 5.81 million y^{-1}. The OPEFB-based DME plant capacity and capital expenditure (CAPEX) are the most sensitive to perturbance, whereas OPEFB feed price is the least sensitive.

Keywords

DME;

economic analysis;

feasibility;

LPG;

savings

1. Introduction

Biomass is a potential renewable energy source, and currently, it contributes 14% of the world's energy needs [1]. One of the biomass types available abundantly in Indonesia is oil palm empty fruit bunch (OPEFB), which has the potential to be developed for biofuel production as an alternative to fossil fuels. About 23% of OPEFB waste is obtained from oil palm fresh fruit bunch (FFB)

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production, which can be used as raw material for making bio-pellets, biofuels, chemicals, and fertilizer [2]. So far, the OPEFB has only been used widely as mulch and compost [3].

OPEFB can be used as a feedstock for dimethyl ether (DME) production through the gasification route, producing syngas as the feedstock of the DME production process [4]. DME has similar characteristics to liquefied petroleum gas (LPG). Therefore, it can be used as an alternative to LPG [5]. The government of Indonesia, through RUEN (the general national energy plan) 2017, stated that it will use DME as a partial substitute for LPG, of which around 67% to 74% has been imported [6, 7]. Substituting LPG with DME for household applications is simple and easy because the facilities and infrastructure that support the distribution of LPG can be directly used to support the distribution of DME without any significant modifications [5]

Research on DME as a substitute for LPG has been conducted from various perspectives, including performance analysis, DME production simulation models, and techno-economic analysis [4-6, 8, 9]. Although many studies have been performed, the economic feasibility of OPEFB-based DME as an LPG substitute still seems unclear, and especially on its impact on the savings in the LPG import budget. One of the reasons is the lack of publications addressing this issue.

Parbowo *et al*. [4] found that the utilization of OPEFB as a raw material for DME production through the gasification route was feasible, with the price of the domestic LPG at the end-user used as a benchmark of DME ex-factory price. It was the first research on the techno-economic analysis of OPEFB-based DME plant construction. The OPEFB-based DME plant was feasible according to net present value (NPV) and internal rate of return (IRR) indicators. However, the equipment cost estimation and calculation method were not elaborated. Even though the OPEFB-based DME plant was feasible, this study did not estimate the savings to the LPG budget or LPG imports.

Anggarani *et al*. [5] studied the testing of the DME-LPG mix in various concentrations, and the focus was on evaluating heat consumption, flame stability, and fuel efficiency of the LPG-DME mix in a normal gas stove. DME concentrations in LPG were 5%, 10%, 15%, 20%, and 30%. Heat consumption increases once the DME concentration increases because DME has lower heat content than LPG. Fuel efficiency also increases once DME concentration increases. The flame is stable for the DME-LPG mixture at any concentration. This study concluded that a normal gas stove could be used. Still, to increase the concentration of DME in LPG, improvements to LPG stove design should be made, especially in terms of efficiency and heat consumption.

Muliahati *et al*. [6] studied the economic feasibility of a coal-based DME plant, and the production of the DME also followed the gasification route. The method for cost estimation was clearly described by using overnight cost estimation. In this study, not only DME plant feasibility was estimated, but also the feasibility of the additional DME storage tank was estimated. The DME plant and extra storage tank were feasible based on two feasibility parameters, NPV and IRR. The savings to the government budget estimated was also quite significant, at USD 388 million year^{-1}.

Marchionna *et al*. [8] studied the combustion of pure and mixed DME tests and showed that the ideal mix of DME was at 15% to 20%. This mixture brings a significant improvement over pure DME utilization. It was also concluded that the DME is relatively safe to handle and store, though frequent, flexible tube replacement is needed compared to pure LPG.

Tetrisyanda *et al*. [9] studied the techno-economic status of coal gasification plants with the derivative process to produce various strategic chemicals, namely DME, ammonia, LNG, and dimethyl carbonate. The project is feasible by having these multiple chemicals with an IRR value of 12.46% and NPV greater than zero. Despite its result, the method used was not clear in describing the technical aspects of the process in the plant, equipment cost estimation, and assumptions used in economic analysis.

The above reviews are summarized in Table 1. As summarized in Table 1, many studies of DME as LPG substitute have been conducted. However, the significant contribution of DME from OPEFB as an LPG substitute is still lacking. These studies are strategically important, especially in some Indonesian regions that have a high concentration of oil palm plantations. So far, there was only one study by Parbowo *et al*. [4], i.e. on the feasibility of DME production from OPEFB. No other study has ever been conducted to assess the impact of the DME using OPEFB. Therefore, this study was aimed to evaluate the feasibility of DME production using OPEFB as feedstock and to find the potential savings to the LPG consumption and the import budget. The utilization of OPEFB as the feedstock of DME production as an LPG substitute can also be implemented further in other countries in tropical regions with significant palm oil plantations.

This study used the OPEFB potential data from palm oil mills located in East Barito regency, Central Kalimantan Province, and its surrounding areas. The location selection was based on the planning of the Central Kalimantan government, who intended to develop East Barito as a special economic zone [10].

Table 1. Summary studies of DME as LPG substitutes

Author (s)	Raw Material of DME Production	DME Utilization as an LPG Substitute
Parbowo *et al*. [4]	OPEFB	This study focuses on the techno-economic study of the DME plant with LPG domestic selling price as the benchmark price. There was no LPG budget savings discussed in this study.
Anggarani *et al*. [5]	No information	Testing of DME-LPG mix in standard LPG stove by using DME-LPG mix. No economic analysis in this study.
Muliahati *et al*. [6]	Coal	An economic study based on an existing DME plant in Japan and the LPG selling price is utilized as the benchmark price of DME. The impact of LPG import budget savings is discussed in this study.
Marchionna *et al*. [8]	No information	Testing and simulation of DME-LPG mix in the standard gas stove using DME-LPG mix. No economic analysis in this study.
Tetrisyanda *et al*. [9]	Coal	Techno-economic study of coal-based DME and LPG prices is used as the DME price benchmark for economic calculation. No impact on the LPG savings was discussed.

2. Materials and Methods

There are four main steps in this study: (i) determination of OPEFB potential and production scenario, (ii) economic analysis, (iii) LPG budget savings, and (iv) sensitivity analysis.

2.1 Determination of OPEFB potential and production scenario

This study considers the palm oil mills located in East Barito, Central Kalimantan. East Barito, Central Kalimantan, is the outermost regency of Central Kalimantan that borders South Kalimantan and has a strategic position as one of the main routes from Central Kalimantan and West Kalimantan to the location of the new capital of Indonesia in East Kalimantan.

DME production facilities were assumed to be built in Tamiang Layang, Dusun Timur district, East Barito, Central Kalimantan. The OPEFB was collected from palm oil mills surrounding Tamiang Layang. The collection area of OPEFB was set at within a 100 km radius of the proposed DME plant location in Tamiang Layang. There are five palm oil mills within a 100 km radius of Tamiang Layang, as presented in Figure 1. There are two palm oil mills with a 60 t h^{-1} fresh fruit bunch (FFB) production capacity and one palm oil mill with a 45 t h^{-1} FFB. Also, there are two palm oil mills with a 30 t h^{-1} FFB. Palm oil mills typically run 24 h a day^{-1} and 7 days $week^{-1}$ for 328.5 days [11]. The OPEFB feed composition based on proximate analysis has 60% water content, 1.46% ash content, 34.84% volatile matter, and 3.71% fixed carbon [12].

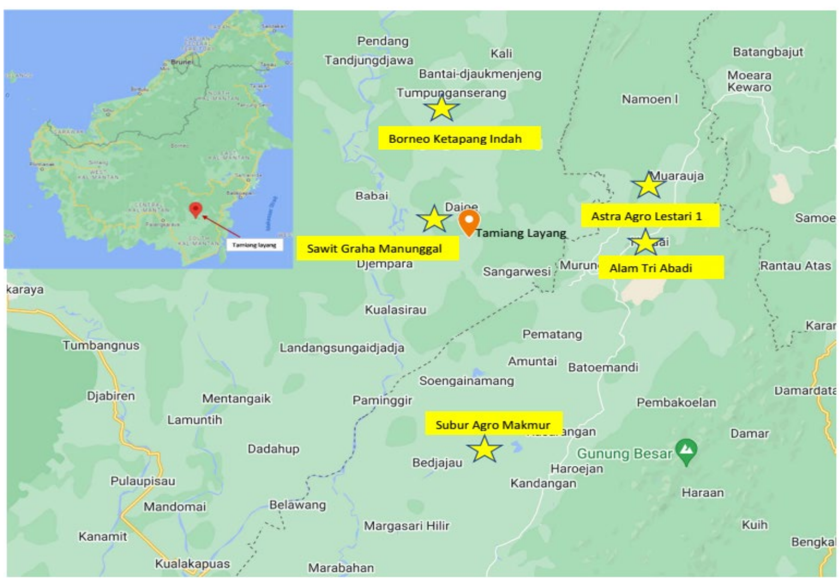

Figure 1. Location of palm oil mills in a 100 km radius of Tamiang Layang

2.2 Economic analysis

In economic analysis, the DME price, demand for household sectors, and the distribution scheme need to be considered. The standard blend ratio of DME to LPG is 1.5, as it was tried through the burning test with the same burning load [6]. DME can replace 20% of the LPG without modifying the stove [6]. The monthly demand for LPG is limited to household demand in Kalimantan, where

LPG's demand was at 46,205 t [13], which is expected to grow in the future. DME has similar characteristics to LPG, as shown in Table 2; hence the equipment to transport LPG can be used to transport DME, and its distribution scheme follows the LPG distribution scheme. DME from the plant was assumed to be transported to the existing LPG blending facility in Balikpapan, East Kalimantan, Indonesia.

Table 2. Properties of DME and LPG [6]

Property	DME	LPG (Mixture of Propane and Butane)
Chemical formula	CH_3OCH_3	C_3H_8 & C_4H_{10}
Molecular weight	46.07	58.13
Boiling point (°C)	-25	-42
Liquid density at 20°C (kg m^{-3})	660	490
Viscosity, 40ºC (cP)	0.18	0.1
LHV (MJ kg^{-1})	28.8	46

The capital expenditure (CAPEX) consists of DME plant and land costs. The DME plant cost calculation of the OPEFB-based DME plant was based on the direct synthesis process of biomass to DME, where the DME plant as reference was the biomass-based DME plant with a production capacity of DME at 392 t day^{-1} [14]. The DME plant cost of this OPEFB-based DME plant in East Barito, Central Kalimantan, can be found using equation (1) [15].

$$\text{Cost}_{\boldsymbol{d}} = \text{Cost}_{\boldsymbol{c}} \left(\frac{\text{S}_{\boldsymbol{d}}}{\text{S}_{\boldsymbol{c}}}\right)^{\boldsymbol{e}} \tag{1}$$

where d and c denote the equipment cost of the plant with capacity d (Sd) and c (Sc), and e is the scaling exponent. The scaling exponent value used is 0.7 for biorefinery projects involving solid phase and thru gasification routes [16].

The chemical engineering plant cost index (CEPCI) in equation (2) is used to update DME plant costs to the current year.

$$Cost_a = Cost_b \; x \; (\frac{CEPCI_a}{CEPCI_b}) \tag{2}$$

where a and b denote the most recent year (2021) and base year (2010), the annual values of CEPCI for 2010 and average 2021 are 550.8 and 776.3, respectively [17]. Since the DME plant taken as a reference was located in the Netherlands, the plant cost was also adjusted with the location factor. The location factor adjustments for the Netherlands and Indonesia are 1.23 and 0.89, respectively [15, 18]. Land cost in Tamiang Layang, East Barito, was also part of CAPEX. Based on an interview with several land owners, the average price of the land in Tamiang Layang, East Barito, was IDR 400 000 m^{-2} (USD 27.59 m^{-2}; based on the exchange rate of USD 1 = IDR 14,500). The CAPEX is validated using specific CAPEX and was used for comparison with other similar studies. Specific CAPEX is CAPEX per heating value of DME product, and the heating value is expressed in MW_{th} (the heating value of DME is 28.8 MJ kg^{-1} [6]).

Operational expenditure (OPEX) consists of variable cost (VC) and fixed cost (FC). VC depends on the operating hours of the plant. Hence, estimation of the plant running hours is essential. VC includes raw materials, catalysts, and utilities. FC are costs associated with labor costs, maintenance costs; insurance and taxes; all costs for the process; costs related to sales and marketing; research and development costs; and administrative costs. The personnel required to run the DME plant consist of 1 plant manager, 15 staff, three process engineers, and 41 operators [19]. The standard salary includes required taxes, pension, and overtime for each position obtained from the typical salary in Indonesia and minimum wages in the East Barito region [20]. Maintenance cost per annum was estimated at 2.5% y^{-1} of the investment cost [19].

The OPEFB-based DME price used as the DME ex-factory price was assumed to be the same as the LPG FOB Aramco price in June 2022, at USD 750 t^{-1} [21]. The price assumption was based on the use of OPEFB-based DME as an LPG substitute, and was also used in a previous study [4].

Another factor that affects the economic analysis is the price of the feedstock. OPEFB as feedstock is considered a waste and can be obtained from palm oil mills by considering handling and transportation costs. In this study, the price of the OPEFB is the price received at the gate of the DME plant; the price of OPEFB is IDR 157,900 t^{-1} or USD 10.9 t^{-1} [22, 23], and the transport cost was added at an average of IDR 37,900 t^{-1} or USD 2.61 t^{-1} for long distance transportation [23]. Therefore, the total price of OPEFB was USD 13.51 t^{-1}. The further assumptions used for economic analysis are presented in Table 3.

Table 3. Assumptions used in the economic analysis

Description	Assumed Value	Unit	References
Expected plant life	30	year	[24]
Depreciation (no salvage value)	straight-line depreciation		[24]
The interest rate for a loan	8	%	[25]
Tax rate	25	%	[6]
Construction period	30	months	[26]
Spending period	30	% for year 1	
	40	% for year 2	
	30	% for year 3	
Start-up time	6	months	[24]
Investment Scenario			
Internal equity	30	%	
Loan	70	%	
Revenue and costs during start-up			
Revenue	50	% of normal	[24]
Variable costs	75	% of normal	[24]
Fixed cost	100	% of normal	[24]
OPEX			
Utility Cost	8	USD DME^{-1}	[6]
OPEFB feedstock price	13.51	USD ton^{-1}	
Maintenance Cost	2.5	% of CAPEX	[19]
Admin and other costs	0.5	% of CAPEX	[6]
Exchange rate USD 1	14500	IDR	[27]

Net present value (NPV), internal rate of return (IRR), and payback period (PP) were used as indicators in the feasibility analysis of the OPEFB-based DME plant. NPV, IRR, and PP can be calculated by using equations (3), (4), and (5) [28, 29].

$$NPV = \left(\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}\right) - I \tag{3}$$

$$\left(\sum_{t=1}^{t=n} \frac{C_t}{(1+IRR)^t} - I\right) = 0 \tag{4}$$

$$PP = \frac{I}{AI} \tag{5}$$

where C_t is the net cash flow at time t, t is the time of cash flow, n is the lifetime of the OPEFB-based DME plant, i is the discount rate, and IRR is the discount rate that makes NPV equal to zero. PP is the payback period, and it is the most straightforward financial measure to determine the period required for the return on investment. I is the initial investment, and AI is the annual income. The discount rate or minimum attractive rate of return (MARR) in investing as a reference in calculating the NPV refers to the loan interest rate prevailing in Indonesia. In 2022, interest rates for investment used were 8% per annum from private banks in Indonesia [25]. The value of this interest rate was used as the desired expected return on the construction of the OPEFB-based DME factory.

2.3 LPG budget savings

Calculating the LPG import cost depends on the price of LPG (mixture of propane and butane) at the delivery point in Indonesia, usually called the LPG depot. The LPG depot serving the Kalimantan area is in Balikpapan, East Kalimantan. Therefore, the distance used for the transport calculation of the DME from the factory was between Tamiang Layang, Central Kalimantan, and Balikpapan, East Kalimantan, a distance of 320 km. The import price of LPG (LPG FOB Aramco price) became a reference for calculating budget savings. The import price of LPG was compared with the price of DME produced in East Barito at the Balikpapan depot. The saving was the difference between LPG and DME prices at the Balikpapan Depot. The LPG price at the depot can be calculated using equation (6), and the DME price at the depot can be calculated using equation (7) [6].

$$LPG\ P_{depot} = (BFAP\ x\ 58\% + PFAP\ x\ 42\%\ )\ x\ (1 + IC) + FC + DF \tag{6}$$

where LPG P_{depot} is the price of LPG at the depot, BFAP is the Butane FOB Aramco price, PFAP is Propane FOB Aramco price, IC is import constant at 1.88%, FC is freight cost, DF is depot fee.

$$DME\ P_{depot} = DME\ P_{factory} + LTC + DF \tag{7}$$

where DME P_{depot} is the price of DME at the depot, DME $P_{factory}$ is DME price ex-factory, LTC is the land transport cost, and DF is the depot fee.

2.4 Sensitivity analysis

A sensitivity analysis of selected factors on NPV was conducted in order to investigate the effect on the project economy feasibility of possible interfering factors in the economic evaluation result. There were four selected factors: variations of OPEFB price, plant capacity, DME price, and CAPEX.

3. Results and Discussion

3.1 OPEFB potential and production scenario

OPEFB waste is usually 23% of FFB processed [30]. Table 4 shows the potential OPEFB that can be collected daily from several palm oil mills within a 100 km radius of Tamiang Layang, East Barito, Central Kalimantan.

Table 4. OPEFB waste potential from East Barito Regency

Palm Oil Mill Capacity	OPEFB Waste	Number of Palm Oil Mill	Total OPEFB Waste (Eff = 80%)*
30 t h^{-1}	165.6 t day^{-1}	2	264.96 t day^{-1}
45 t h^{-1}	248.4 t day^{-1}	1	198.72 t day^{-1}
60 t h^{-1}	331.2 t day^{-1}	2	529.92 t day^{-1}

*OPEFB collection efficiency is 80% [4].

The total potential OPEFB that can be collected is 994 t day^{-1} or 41 t h^{-1}. As received, OPEFB collected has 60% moisture content, and with a dry ash-free (daf) base, the feedstock rate becomes 383 t day^{-1} or 16 t h^{-1}. According to Heryadi *et al.* [31], 1 t DME was produced for every 2 t OPEFB feedstock daf base. This ratio is applied to OPEFB biomass production, where 192 t day^{-1} of DME is made from 383 t day^{-1} OPEFB daf base input. Production time of POM is assumed to be 24 h day^{-1} and 7 days $week^{-1}$ [11, 32]. At 328.5 days, the DME produced is 63,072 t $year^{-1}$.

3.2 Economic evaluation

3.2.1 Capital expenditure (CAPEX)

It is assumed that an area of 30,380 m^2 is required for fuel storage, handling and drying, syngas plant, and DME production facility from syngas. This area assumption is based on the work of Huisman *et al*. [19] on land area requirements for DME plant based on biomass gasification. The CAPEX calculation of OPEFB DME plant is based on the 192 t day^{-1} DME. The CAPEX investment data for the OPEFB-based DME plant in East Barito are summarized in Table 5.

Table 5 shows that the land cost is only a tiny fraction of CAPEX at 0.45% of CAPEX, despite the large area needed to build the DME plant. The land cost varies and depends on where the DME plant was built, from 0.1% to 0.6% [4, 19]. The specific CAPEX of the OPEFB-based DME plant in East Barito is still within the range of other studies with the same production route.

Table 5. CAPEX of OPEFB-based DME plant

Description	Unit	Parameter Value	Reference
Base Scale	t-DME day^{-1}	392	[14, 19]
Base Cost*	million USD	299	[19]
DME plant capacity in East Barito	t-DME day^{-1}	192	
DME plant Cost in East Barito	million USD	185	
Land Cost	million USD	0.84	
CAPEX	million USD	185.84	
Specific CAPEX (per MW_{th} product)	million USD MW_{th}^{-1}	2.90	

* Base cost in 2010, the exchange rate was Euro 1 = USD 1.327

The study done by Parbowo *et al*. [4] shows that the specific CAPEX is USD 2.74 million MW_{th}^{-1}. In contrast, Larson *et al*. [33] and Kreutz *et al*. [34] show that the specific CAPEX is USD 2.91 million MW_{th}^{-1} and USD 2.97 million MW_{th}^{-1}, respectively. The specific CAPEX of the DME plant in East Barito is within the range of other studies' specific CAPEX.

3.2.2 Operating expenditure (OPEX)

OPEX of the OPEFB-based DME plant consists of OPEFB raw material cost, labor cost, maintenance and repair, utilities, depreciation, administration, and other expenses. The annual OPEX of the DME plant is shown in Table 6. It is shown that the yearly OPEX is USD 17.03 million, where the contribution from maintenance, depreciation, and raw material costs dominates.

Table 6. OPEX of OPEFB-based DME plant

Cost Type *	Cost Component	Cost per Annum (million USD)	Remark(s)
VC	Labor and direct supervisory cost	0.33	[20]
VC	Maintenance and repair	4.65	2.5% of CAPEX [19]
VC	Raw material cost	4.41	OPEFB waste
VC	Utilities (water, refrigeration, water treatment)	0.51	USD 8 per ton DME [6]
FC	Depreciation	6.20	Straight Line 30 years
FC	Administration and other costs	0.93	0.5% of CAPEX [6]
	Total variable cost	**9.90**	
	Total fix cost	**7.13**	
	Total operating cost	**17.03**	

*VC is a variable cost, and FC is a fixed cost.

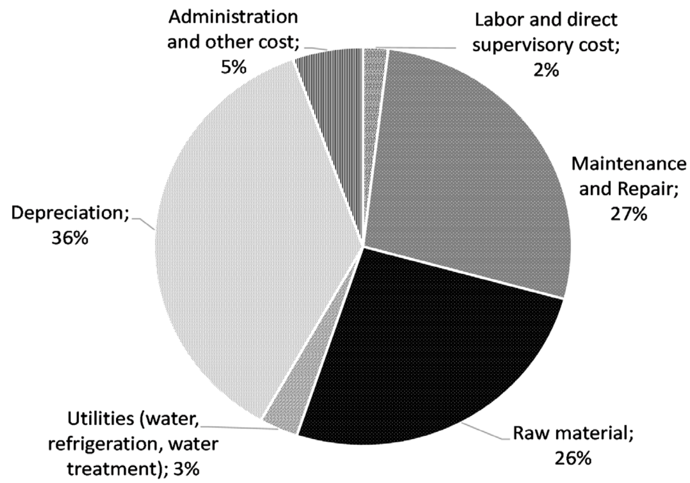

Figure 2. Break-down of OPEX OPEFB-based DME plant

As shown in Figure 2, the depreciation or cost related to capital is the most significant cost contributor to DME plant operation, followed by the maintenance and repair cost, raw material cost, administration, and other costs, utility cost, and labor cost. Other techno-economic or economic studies displayed a similar pattern, where the operating cost component related to capital was always dominant compared with other cost components [4, 19].

3.2.3. Economic feasibility

Economic feasibility was calculated using NPV, IRR, and PP. The results of the economic feasibility calculation are displayed in Table 7.

Table 7. Economic evaluation result

Parameter	Unit	Value	Remark
CAPEX	million USD	185.84	
OPEX	million USD y^{-1}	17.03	
Total revenue	million USD y^{-1}	47.30	
Loan payment	million USD y^{-1}	14.05	10 years loan of 70% CAPEX
NPV	million USD	93.10	
IRR	%	17	Equity IRR
PP	year	10	Payback Period

It is worth stating that NPV is positive and IRR is more significant than MARR (8%). These two indicators show that this OPEFB-based DME plant, in this context, is feasible to be built in East Barito, Central Kalimantan. Parbowo *et al*. [4] shows that the OPEFB-based DME plant can also feasibly be built in Riau Province, with a positive NPV and IRR value of 10% greater than MARR at 8%.

3.3 LPG import savings

A comparison of the OPEFB-based DME price and LPG at the depot was made to calculate the saving contribution of substituting LPG with DME at a maximum 20% DME mix into LPG. The DME price consists of the OPEFB-based DME ex-factory price, which follows the LPG FOB Aramco price, the transport fee from the DME plant to Balikpapan Depot in East Kalimantan, and the current LPG depot handling fee. The LPG price at the depot and the DME price at the depot are shown in Table 8. From Table 8, it is shown that the annual saving of the LPG budget by substituting LPG with DME in Kalimantan is USD 5.81 M. The budget saving mainly comes from transport cost savings. This budget-saving can be improved further by lowering the ex-factory prices of the DME without sacrificing the feasibility of the OPEFB-based DME plant. Utilization of pure DME as a substitute LPG is discouraged as pure DME has a lower heating value than LPG. Pure DME consumption is around 1.5 times LPG consumption per unit mass; therefore, the consumption of 100% DME reduces the savings obtained from substituting imported LPG with OPEFB-based DME. In contrast, a mixture of 20% DME with 80% LPG is encouraged as it gives a cooking efficiency of around 0.5% greater than pure LPG [35]. This higher cooking efficiency compensates for the low calorific value of DME, which in turn provides the budget saving per ton of LPG substituted, as shown in Table 8.

Table 8. Results of LPG import budget saving

Descriptions	Unit	Value	Remark
LPG			
Butane Aramco FOB price	USD t^{-1}	750	[21]
Propane Aramco FOB price	USD t^{-1}	750	[21]
LPG Aramco FOB Price	USD t^{-1}	750	60% Butane and 40% Propane
Freight cost (VLGC)	USD t^{-1}	105	[36]
Import constant (1.88%)		14	[6]
Depot fee	USD t^{-1}	22	[6]
LPG Price at Balikpapan Depot	USD t^{-1}	891	
DME			
DME ex-plant/factory price	USD t^{-1}	750	
Transport of DME to Depot per mT	USD t^{-1}	27	Based on [37], the transport cost is USD 0.083 km^{-1} t^{-1}
Depot Fee	USD t^{-1}	22	[6]
DME price at Balikpapan Depot	USD t^{-1}	799	
LPG demand of Kalimantan	t y^{-1}	554,460	[13]
DME produced from a plant in East Barito	t y^{-1}	63,072	
Import budget saving of LPG	USD t^{-1}	$92	
Import budget saving of LPG	million USD y^{-1}	5.81	

The DME produced in East Barito is only 11% of the total annual demand for LPG in Kalimantan, and if it is mixed with 80% LPG, it gives LPG – DME mix at 315,360 t y^{-1}. Only 57%

of the DME-LPG mix can be distributed to fulfill the demand for LPG in Kalimantan. From the total annual LPG demand in Kalimantan, the DME needed to meet the 20% mix of DME in LPG is 110,892 t y^{-1}. Other plants with the same capacity can be built near the Balikpapan depot, or existing plant capacity can be increased to cater to the annual DME demand in Kalimantan. By increasing the existing DME plant capacity, the production cost of OPEFB-based DME is lower, and more savings are attained.

3.4 Sensitivity analysis

A sensitivity analysis was performed concerning the variation in DME ex-factory price, the price of the OPEFB raw material, plant capacity, and CAPEX. The fluctuation in DME ex-factory price affected by the change in world LPG price needs to be analyzed since the DME ex-factory price is based on the LPG FOB Aramco price [21]. The fluctuation of the LPG FOB Aramco price in 2021 and 2022 is shown in Figure 3. Based on Figure 3, the lowest LPG price was USD 483 t^{-1} in May 2021, and the highest LPG price was USD 952 t^{-1} in April 2022. The average LPG FOB Aramco prices in 2021 and 2022 (contract price until November) were USD 687 t^{-1} and USD 743 t^{-1}, respectively. In 2021 the average price of LPG was 8.4% lower than the DME ex-factory price, while in 2022, the average LPG price was slightly lower 0.9% than DME ex-factory price. Therefore, due to the world LPG price fluctuation, the sensitivity analysis must also be carried out for DME ex-factory price. The sensitivity analysis was carried out for 10%, 23%, and 33% lower DME ex-factory prices. Figure 4 shows that the OPEFB-based DME plant is feasible if the DME ex-factory price is never lower than 23%. This 23% lower price corresponds with USD 575 t^{-1}, which must be maintained as the minimum price of DME sold from East Barito, Central Kalimantan.

Figure 4 shows the correlation of OPEFB price with the value of NPV. The DME plant is still feasible with a positive NPV. The NPV increases when the price of OPEFB decreases, and the opposite applies when the NPV decreases, the price of OPEFB increases. The correlation between NPV and the price of OPEFB is positive, as seen in Figure 4. The price of OPEFB at USD 6.76 t^{-1} corresponds with NPV at USD 79.76 million, the price of OPEFB at USD 13.51 t^{-1} corresponds with NPV at USD 61.36 million, the price of OPEFB at USD 20.27 corresponds with NPV at USD 42.96 million, and price of OPEFB at USD 27.02 corresponds with NPV at USD 24.58 million.

A sensitivity analysis was also carried out regarding variation in capacity. As the current capacity is running at 100% OPEFB feed, the sensitivity analysis was carried out for 20%, 25%, and 50% lower OPEFB feed. The DME plant is still feasible when the capacity is 20% and 25% lower. The NPV is negative when the capacity of the DME plant is 50% or lower, as seen in Figure 4.

Sensitivity towards the CAPEX was also evaluated, and the sensitivity analysis was carried out with 25% and 50% higher CAPEX. Sensitivity towards CAPEX was evaluated for inflation adjustment affecting the equipment price and other related costs during construction. Figure 4 shows that when CAPEX increases by 25%, NPV is still positive, and this means that the DME plant can still feasibly be constructed, while a 50% increase in CAPEX shows that the DME plant is not feasible as the NPV has a negative value. An increase in CAPEX to 25% corresponds with an NPV of USD 30.74 million, and an increase in CAPEX to 50% corresponds with an NPV of USD -31.61 million.

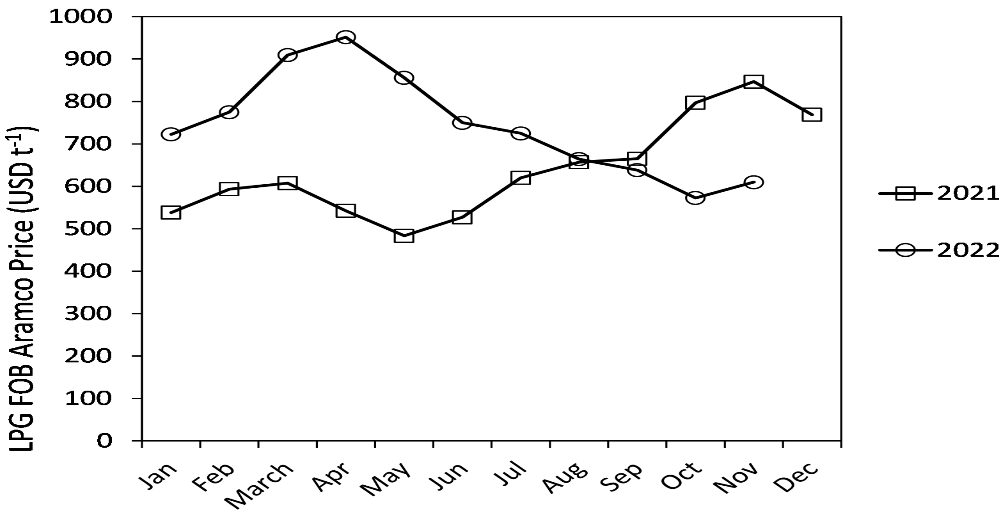

Figure 3. LPG FOB Aramco price trend

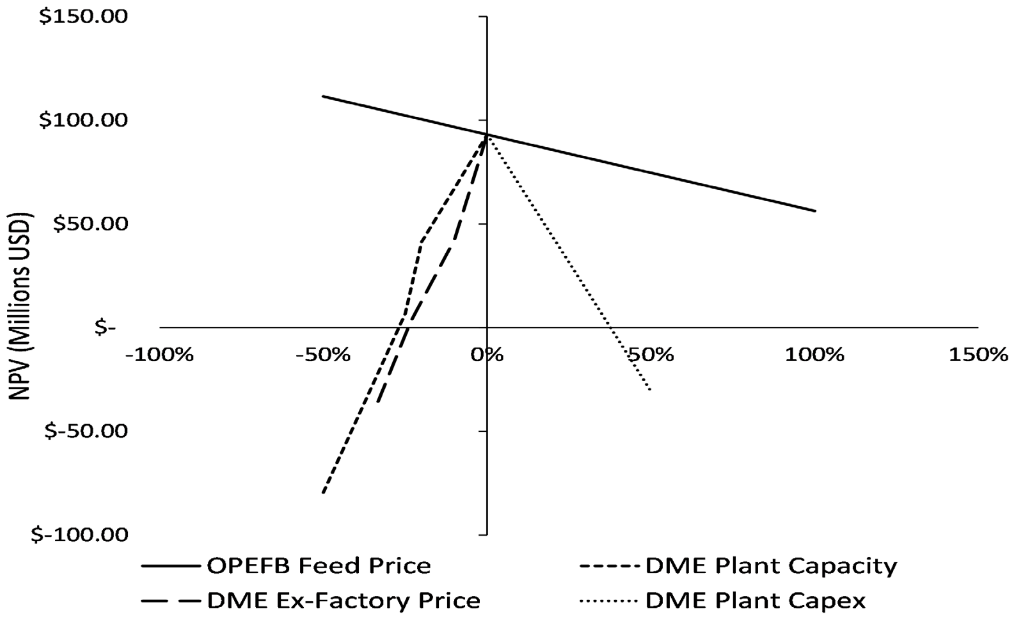

Figure 4. Sensitivity analysis result

3.5 Sensitivity analysis of parameters variation towards LPG budget saving

The saving of the LPG import budget is affected by the variation in DME price and plant capacity. In contrast, the variation of OPEFB price and CAPEX will not affect the budget savings as long as the DME selling price is maintained at a constant price. The savings of the LPG import budget versus the variation of DME price and plant capacity are summarized in Table 9. As displayed in Table 9, the budget savings are affected by the change in the DME price and the plant's capacity. Suppose the price of DME is higher following a high LPG price; then a more significant saving is obtained. Savings in the budget are also affected by the DME plant capacity. To get maximum savings regarding capacity, the DME plant must run at almost its total capacity.

Table 9. Sensitivity analysis result of DME price and capacity

Parameter	Saving of Import Budget (USD t^{-1} of LPG imported)	Total Saving (Million USD y^{-1})
DME Price		
750	92	5.81
675	91	5.72
575	89	5.60
Capacity		
100%	92	5.81
85%	92	4.94
75%	92	4.36

Further budget savings can be achieved by lowering the price of the DME ex-factory, which follows the price of LPG FOB Aramco. The reduction in the price of the DME ex-factory is made by paying attention to the feasibility aspect of the DME plant. Lower DME prices can be adjusted using a MARR benchmark lower than 8%.

4. Conclusions

This paper exhibits the economic aspects of the OPEFB-based DME plant and their implications for the import budget savings of LPG, especially for the Kalimantan region. Based on financial analysis, the OPEFB-based DME plant at 994 t day^{-1} of OPEFB feed with a yield of 192 t day^{-1}. DME can feasibly be built with an NPV of USD 93.1 million and IRR of 17%. Only 57% of the DME-LPG mix can be distributed to fulfill Kalimantan region demand per year, and the savings of the import budget are at USD 5.81 Million y^{-1}. This current OPEFB-based DME plant is still insufficient to cater to the demand for LPG-DME mix in Kalimantan; at least twice the current plant capacity is needed to fulfill 100% LPG-DME mix in Kalimantan. Based on the sensitivity analysis, the OPEFB-based DME plant capacity and CAPEX are the most sensitive to perturbance, whereas the OPEFB feed price is the least sensitive. The OPEFB-based DME plant capacity and DME price fluctuation affect the savings of the LPG import budget, where plant capacity has more impact than DME price. The OPEFB-based DME plant must continuously operate at or near maximum capacity to maximize the savings value.

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