THE POTENTIAL OF METHANOL AS AN ALTERNATIVE MARINE FUEL FOR INDONESIAN DOMESTIC SHIPPING

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SUMMARY

This analysis aims to provide insight and to explore the future usage of methanol as an alternative marine fuel for domestic ships in Indonesia. An overview of potential application, analysis of resources availability, and stakeholder readiness on the topic are provided; related challenges are also identified and further examined. The potential performance of methanol as a fuel is discussed and evaluated via two different perspectives (the ship-owner perspective and the government one) through case studies of two passenger ships owned by the shipping company Pelayaran Indonesia (PELNI): MV. Labobar and MV. Gunung Dempo. As ship-owners tend to look very closely at the economic aspects, a feasibility study is performed by developing a combinatorial scenario approach based on the combination of economic measures of merit (NPV and payback period) along with a technical scenario (main-pilot fuel set-up); the variables included in the calculation are: ship age, ship productivity, and macro-economy conditions. Regarding the government perspective, the main issues are environmental protection and policy compliance. These issues are evaluated by examining six emission types (NOx, SOx, CO2, CH4, N2O, and PM). Additionally, since there is a trade-off situation in government subsidies between the government and ship-owner interests, an optimisation and sensitivity analysis is performed by utilizing a combinatorial scenario model to determine optimum methanol price and external variables influencing the decision to support further use of methanol in the Indonesian market. An important finding was that Indonesia has certain advantages/drives to introduce methanol as a marine fuel. However, methanol competitiveness is mainly dependent on ship productivity and the price difference between methanol and marine diesel oil (MDO). Additionally, policy analysis (through an optimisation approach) could be one of the government options in order to determine the optimum condition in establishing methanol as a marine fuel. Finally, short, medium, and long term recommendations are also provided as the basis for future consideration.

1. INTRODUCTION

Indonesia has recently experienced a significant increase in energy consumption: from 598,106 mBOE in 2008 to 868,581 mBOE in 2018; this translates into an annual increase of 3.11% for the specific time-frame (Indonesia's Ministry of Energy and Mineral Resources (ESDM), 2018). Meanwhile, this country is still very heavily dependent on fossil fuels and non-renewable energy supply, considering that approximately 40.75% of the necessary resources are supplied by fuel oil (ESDM, 2018). In any case, increasing fossil fuel consumption, declining refinery production, and limited of new discovery of oil reserves resulted in a change of the import ratio of oil products and crude oil, where Indonesia's oil import dependency is approximately 35% (Suharyati *et al*, 2019). By using the assumption of the reverse-production ratio of non-renewable energy in 2017, then, oil is foreseen to be depleted in 10 years and natural gas will run out in 49 years (Pratama *et al*, 2018). This condition could lead Indonesia into becoming a net-energy importer and highly vulnerable in terms of national energy security.

Meanwhile, the transportation sector is the largest fuel oil consumer in Indonesia, holding a share of around 390.996 mBOE, or 87% of the total fuel oil consumption (ESDM, 2018). Furthermore, the wider shipping industry in the country is expected to grow significantly in the future, especially when factoring in the new policy from the Indonesian government which concentrates on port infrastructure development and domestic shipbuilding to support the vision of Indonesia's global maritime nexus.

Nevertheless, an increase of fuel oil consumption for serving maritime transport needs will also contribute to an increase of green-house gasses (GHG) emissions and further downgrade the quality of air (Ölçer *et al*, 2018). At the same time, high demand, volatility of oil price, and more stringent environmental regulations could also create disturbances in the normal conduct of shipping operations. Since maritime transport is the backbone of economic development in Indonesia, it is necessary for the Government to address and encourage the utilization of sustainable solutions for energy transition and incorporated initiatives in its future energy policies.

One solution could be the introduction of methanol as a marine fuel. Sustainability of feedstock provides methanol with an advantage over other alternative fuels, since it can be used both as a transitional marine fuel and future sustainable option. Unfortunately, in the wider literature and projections (Sugiyono *et al*, 2016; Prasodjo *et al*, 2016), Methanol has not yet been acknowledged as a promising future alternative fuel in Indonesia.

2. EXAMINING POSSIBLE FEEDSTOCK OF METHANOL AND METHODS OF PRODUCTION

Methanol is commonly referred to as wood alcohol (or, methyl alcohol), with the chemical formula of CH3OH.

For reasons of convenience (terminology used in the market), it is quite often abbreviated as MeOH (Olah *et al*, 2006). Methanol can be produced from fossil based resources (non-renewable), or via materials/resources that are considered as renewable and sustainable, such as wood, biomass, sewage, and even from CO2 (Bromberg & Cheng, 2010).

There are three basic steps commonly used to produce methanol, namely synthetic gas (syngas) production, syngas to methanol conversion, and distillation or purification of effluent. The sources of synthetic gas can be natural gas, coal, biomass, crude oil, or other carbon based sources. Despite this, the industry still prefers natural gas or methane as the feedstock, since the production cost, energy consumption, and impurities are considerably lower than all the other available options (Bozzano & Manenti, 2016). Indonesia has many potential feedstock-possibilities, either from fossil or renewable resources to facilitate methanol production. The fact that methanol can be produced from various alternatives is making it initially suitable as a transition option and subsequently as a "future sustainable" alternative fuel to effectively serve the country's needs.

2.1 FOSSIL RESOURCES

2.1 (a) Coal

Coal can be used for steam power generation; it can also be utilized as a potential methanol feedstock. Methanol can be produced from coal through gasification to produce synthesis gas and then followed by methanol synthesis and purification. Moreover, this type of production will consume 1,42-1,59 ton of coal per ton of methanol (Zhen & Wang, 2015). In addition, Indonesia has abundant coal resources, considering that this country is one of the biggest coal producers in the world (Hasan *et al*, 2012). In 2015, coal production was 126,61 billion tons, with an additional 32,26 billion tons kept as reserves (BGI, 2015).

2.1 (b) Natural Gas

Methanol production using natural gas in Indonesia has commercially started in 2000 by Kaltim Methanol Industry (KMI), with a production capacity of 600.000 ton per year. In the production of methanol, KMI has been using steam reformer and low-pressure synthesis methanol technology. Approximately 750-1300 m3 of natural gas were consumed to produce one ton of methanol and this volume is highly depending on the maturity of the technology used (Shen *et al*, 2012). Furthermore, in order to increase efficiency, the methane slip during the steam reforming processing is processed by using the partial oxidation method (KMI, 2015).

According to ESDM data, the country's total natural gas reserves in 2015 reached to 150,39 TSCF. The largest reserves are in Natuna (with 50,48 TSCF) and then in West Papua (with a total of 23,90 TSCF). Moreover, Indonesia has other potential natural gas resources, such as shale gas and coal-based methane (Prasodjo *et al*, 2016). Even though this country is rather rich in natural gas resources, the domestic absorption of natural gas is still relatively low (Sugiyono, 2016). Utilization of methanol as a marine fuel could certainly take advantage of these available resources and at the same time create a business opportunity.

2.2 RENEWABLE RESOURCES

2.2 (a) Industrial Waste

Indonesia is one of the biggest crude palm oil (CPO) producers in the world (Nizami *et al*, 2017; Winrock, 2015). The CPO Industry produces a lot of solid waste, such as empty fruit bunches, fibres, and shells, as well as pome (Sugiyono *et al*, 2016). According to Goenadi *et al* (as cited in Sugiyono *et al*, 2016), every ton of palm oil fruit will produce 180 kg of fibres and shell, and 600-700 kg pome. Decomposition of pome in anaerobic condition may produce biogas containing 50-75% of methane that can potentially be used as a methanol feedstock (Winrock, 2015). In addition, the sugar industry has potential to be utilized as a methanol feedstock because of available by-products such as molasses, bagasse, and leaves of cane tops (Sugiyono *et al*, 2016; Batidzirai, 2012). Another industry of interest is the pulp and paper one, which is creating by-products of non-condensate gas that can be used as bio-methanol feedstock (Sugiyono *et al*, 2016).

2.2 (b) Municipal Waste

With the population of more than 250 million, Indonesia has a problem of municipality waste. One of the solutions is to transform this waste into a source of energy. Through the process of sanitary landfill and anaerobic digestion, municipality waste can produce methane as methanol feedstock (Sugiyono *et al*, 2016). However, the concept of utilizing biomass to be converted into energy is not popular in Indonesia and the technology that is needed must be imported from outside; also, the culture of citizens sorting out their rubbish to facilitate further process is relatively new and low.

3. CHALLENGES IN IMPLEMENTATION

3.1 EXISTING REGULATIONS ON METHANOL AS A MARINE FUEL

For the time being, the existing requirements and standards of marine fuel (regulated by ESDM) only cover fossil fuel and biodiesel. Moreover, Directorate General of Sea Transportation (DGST) has not developed the related regulations for ships using low-flashpoint fuel yet. On the positive side, Biro Klasifikasi Indonesia (BKI) (as the only classification society that has received full authority from the Government) has already established the necessary regulations for methane-fuelled vessels, based on the International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF code). However, these regulations need to be amended to include provisions considering other low-flashpoint fuel, including methanol. According to the IGF Code, “In the meantime, for other low-flashpoint fuels, compliance with the functional requirements of this Code must be demonstrated through alternative design”. This means that if the Government does not have any prescriptive rules for other low-flashpoint fuel applications (including methanol) then the ship design has to be approved as an alternative design, through risk assessment. Although BKI has developed the guidance for risk evaluation for an alternative arrangement, the Indonesian Administration does not possess such regulations. Cooperation between both institutions is highly needed for the success of the implementation of methanol as marine fuel in Indonesia.

There is also an absence of regulations regarding authorization, standardization, and certification of ship bunker suppliers in Indonesia. Currently, BKI and DGST are working together to establish a scheme to maintain the quality of marine fuels and to promote the availability of domestic fuels based on MARPOL Annex VI Regulation 18. Since this standardization is still an on-going process, additional types of alternatives fuels, such as methanol, can be considered.

3.2 TRAINING AND COMPETENCY

Despite its potential advantages as a new alternative fuel technology, the application of methanol as a marine fuel may confer risks to personnel on-board the vessel. There is also the possibility of mishandling by the crew due to unfamiliarity or lack of training. It is important to keep in mind that there might be a reluctance to use new fuel systems by “traditional” seafarers. There is no maritime institute in Indonesia with the necessary facilities providing appropriate training and certification of proficiency based on the IGF Code and the Standards of Training, Certification and Watchkeeping for Seafarers (STCW).

To overcome the above challenges, the Maritime Administration needs to establish a compact training module, which consists of a theoretical and a practical program based on the STCW Convention Part A-V/3 regarding “Mandatory minimum requirement for the training and qualification of master, officers, rating, and other personnel on ships subject to the IGF Code”. Moreover, the concerned shipping company must ensure the familiarization of the crew on-board by having appropriate exercises/drills according to the ISM Code, especially on the use of personnel protection equipment (Dalaklis, 2017).

3.3 COORDINATION AMONGST ALL STAKEHOLDERS

In 2014, the Indonesian government established the “Coordinating Ministry of Maritime Affairs” that coordinates and synergizes 4 different other Ministries (Ministry of Transportation, Ministry of Fisheries, ESDM, and Ministry of Tourism). However, duties are merely on coordination, whilst there is no authority-obligation on providing a strategic maritime energy roadmap and policy making that is associated with all the respective Ministries and Institutions (Menkomar, 2015).

Indeed, establishing a National Energy Policy and introducing methanol as an alternative energy source in the country’s maritime transport industry requires effective coordination amongst stakeholders and preferably should not only be handled by the Ministry of Transportation. According to the regulation of the ESDM No.45/2005, regarding the standards and quality and supervision of various fuels that are marketed domestically, the authority to manage and standardize the quality, technical provision, and availability of marine fuels lies on the Ministry of Energy and Mineral Resources. However, the Ministry of Transportation requires the data of fuel availability and quality to comply with the respective MARPOL Annex VI requirements. In addition, the strategy to introduce methanol as fuel into maritime industry should also include the ship conversion activity.

3.4 SUPPLY, DEMAND, AND LOGISTIC

Total supply of methanol in Indonesia in 2014 was around 450.000 tons, and it was mainly produced from KMI (DIKH, 2016). Considering that KMI has the capability to produce methanol up to 600.000 tons, there is an opportunity to increase its production if the market can absorb this. According to the market projection from the Ministry of Industry, in 2020 the total methanol demand in Indonesia will reach 2,4 mta (DIKH, 2016).

Currently, 80% of methanol demand in this country is derived from the formaldehyde and Olefin industry as chemical product (KMI, 2015). Moreover, the feedstock of methanol production mainly from fossil feedstock i.e natural gas.

Even though methanol can be an energy resource, there is no establishment of such a market. Developing methanol as a marine fuel in Indonesia can improve absorption and even create a totally new energy market in relation to the maritime industry (see Figure 1).

Nevertheless, establishing this new market requires enormous efforts and stiff cooperation among all the stakeholders, which are located within different sectors.

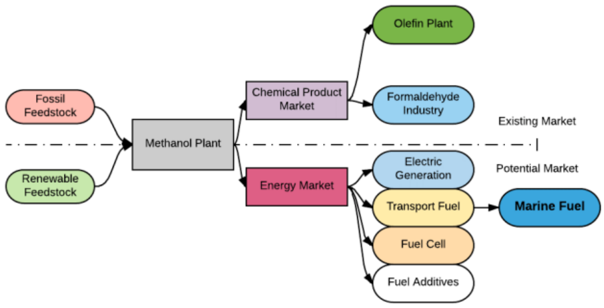


Figure 1: Existing and Potential Market of Methanol in Indonesia (Priyanto, 2017).

On the other hand, as Indonesia is an archipelagic country, the logistic channels need to be established according to the market assessment in the targeted island. There are three options for methanol distribution: small-scale chemical tanker, ISO-tank container, or by truck. Small-scale vessel or ISO-tank container can be used for delivering methanol in long distances from the producer or to large consumer islands; trucks can be used for short distances/near-by islands. In addition, to improve the future market, it is necessary to provide sufficient fleet of methanol tankers, to meet the demand.

3.5 INFRASTRUCTURE

To maintain the supply-chain and the availability of methanol as a marine fuel, infrastructure in designated ports will be needed (Andersson & Salazar, 2015). Currently, the existing methanol infrastructure is used for supplying the chemical industry: the main port for loading belongs to KMI with a capacity of 30.000DWT and most unloading is taking place in the PT. Siam Maspion Terminal.

Since methanol has liquid properties in atmospheric pressure, there are similarities with existing marine fuels (HFO, MDO, MGO) in the infrastructure of bunkering, distribution, and storage. However, since methanol is a low-flashpoint fuel, there are certain minor modifications necessary, in case the existing marine fuels infrastructure is chosen for supporting the specific fuel option. In addition, at the beginning of methanol implementation, there is no real need to have the new infrastructure in place, since the bunkering process can be performed by using the "truck to ship" method (Methanol Institute, 2017).

4. ENVIRONTMENTAL AND TECHNO-ECONOMIC ANALYSIS

Introducing methanol as a marine fuel in the Indonesian market requires investments and clarity in the national strategic energy and transport roadmaps, for instance a government subsidy system. If the provisions to support this application have not been established in advance, implementation can be significantly hampered (Buhaug *et al*, 2009). In order to understand the feasibility to what extent methanol can be introduced to the market, a techno-economic and policy-making analysis is performed via the case study of two passenger ships owned by Pelayaran Indonesia (PELNI).

The analysis has been divided into two perspectives: the ship-owner and the government prospective. Typically, ship-owners look at the economic aspects and benefits, such as Net Present Value (NPV) and the payback period. On the other hand, the government rather considers the optimum support to the market, including subsidies, as well as compliance with established regulations.

4.1 SHIP-OWNER PERSPECTIVE

From the ship-owner perspective, retrofitting an existing ship is preferred than building a new one, since they are emphasizing on economic considerations (Aronietis *et al*, 2014). Moreover, market conditions such as over-supply, volatility of oil price, and stringent regulations can make a ship-owner more cautious to invest in new ships. Therefore, in order to understand the effectiveness of methanol technology investment on main engine and which ship is possible to be retrofitted, a case study of technology investment behavior towards the ship revenue has been performed on two PELNI passenger ships: MV. Labobar and MV. Gunung Dempo.

4.1 (a) Case study of PELNI passenger ship

MV. Labobar is a T-3000 type that is capable of loading up to 3000 passengers, while MV. Gunung Dempo is a T-2000 type (see Table 1). Both of them are 2-in-1 ships which are capable of loading both passengers and cargo. PELNI also employs the T-1000 type. However, the last one is excluded from the case study since the estimated conversion cost is based on a passenger ship with 10-25 MW main engine.

Table 1: Ship particular of MV. Labobar and MV. Gunung Dempo (Santoso, 2017; BKI, 2017)

No	Parameter	Labobar	Gunung Dempo
1	Type	T-3000 (2-in 1)	T-2000 (2-in 1)
2	Passenger	up to 3000	up to 2000
3	Container Cargo	up to 28 TEUS	up to 98 TEUS
4	Deadweight Tonnage (DWT)	4238	3482
5	Gross Tonnage (GT)	15136	14017
6	Lenght of All (LoA)	146.3	147
7	Year of Built	2004	2008

There are three major cost variables and one benefit variable in this economic study, namely "capital cost", "opportunity cost", and "operational cost" as cost variables and "earning" as benefit:

- Capital costs are the investment or fixed costs incurred in the engine conversion activity including the shipyard cost, procurement of equipment, and retrofitting cost. In this study, all parameters in capital costs were incorporated into a single cost as the function of cost/kW.
- Opportunity cost is the loss of revenue due to the retrofitting activity. A retrofitting activity conducted in a shipyard will result in loss of revenue associated with a certain trip. However, the opportunity cost is reduced due to idle fuel cost (which is unused during the retrofitting period). Moreover, in this study this cost is incorporated to the Capital expenditure (Capex), which is represented by the following formula: Capex = Capital cost + Opportunity cost – Total idle fuel cost
- Operational cost is the cost that arises during main engine operation, including operation-maintenance costs and fuel costs. The operational cost increases year by year because it goes hand in hand with the inflation. For main engine fuel cost, it is calculated as follows:

$$\text{Fuel Cost}_{\text{methanol}} = [\text{Price}_{\text{methanol}}] \times [\text{\% of methanol}] \times [\text{Fuel Consumption}_{\text{MDO}}] \times \frac{\text{LHVMDO}}{\text{LHVMethanol}}$$

Where:
Lower Heating Value MDO = 42,8 MJ/kg
Lower Heating Value Methanol = 20,1 MJ/kg

$$\text{Fuel Cost}_{\text{MDO}} = [\text{Price}_{\text{MDO}}] \times [\text{\% of MDO}] \times [\text{Fuel Consumption}_{\text{MDO}}]$$

$$\text{Total Fuel Cost} = \text{Fuel Cost}_{\text{MDO}} + \text{Fuel Cost}_{\text{Methanol}}$$

- The benefit is the saving for the ship-owner due to operating with methanol. It is represented by the difference in fuel cost that included in the earning before taxation and depreciation (EBTD) as the following formula: EBTD = Revenue – Operational Cost

4.1 (b) Scenario and assumption

In order to identify investment behaviour of methanol, two scenarios have been considered:

- The composition of methanol as main fuel and MDO as pilot fuel. Referring to previous research, Srivastava (Srivastava, 2016) used M-85 (85% methanol - 15% distillate fuel) for the respective scenario calculation. According to Laakso (Laakso, 2017), the use of oil fuel as pilot fuel was lower compared to the methanol as main fuel, but the difference might be related to methanol properties used in the specific ship. Since the use of methanol as marine fuel is relatively novel, the situation might improve in the future. In this study, the scenario of the composition of methanol as main fuel and MDO as pilot fuel will be M-80, M-85, M-90, and M-95. Moreover, as a comparison, the scenario of 100% MDO will also be calculated.
- The percentage of methanol price compared to MDO. It is difficult to determine the pattern of fuel price since the issue of pricing is rather volatile and very unpredictable. However, price history can be used to estimate the future behavior of methanol and MDO price. According to the methanol-MDO price history from 2004-2016 (see Table 2), the highest percentage was 73,02% in 2004, and the lowest was 43,69%. Almost the percentage of methanol over MDO was in 40-60%, hence those percentages range with interval 2% is used as the basis of the scenario. Furthermore, the MDO price in 2016, USD 460,74/tons or Rp 6.136.596,06/tons, is used as the basis of the techno-economic calculation and combinatorial scenario analysis.

Table 2: Percentage of methanol-MDO price history from 2004-2016 (Clarkson, 2017; Bunkerindex, 2017)

Tahun	MDO bunker prices, Singapore ($/tons)	Methanol Price ($/tons)	% Methanol : MDO Price
2004	372.50	272	73.02%
2005	576.00	260	45.14%
2006	645.00	420	65.12%
2007	670.63	300	44.73%
2008	919.50	500	54.38%
2009	566.25	280	49.45%
2010	638.25	325	50.92%
2011	926.00	470	50.76%
2012	972.75	425	43.69%
2013	902.94	470	52.05%
2014	869.06	420	48.33%
2015	498.69	315	63.17%
2016	460.74	275	59.69%

In addition, there are certain assumptions required to perform the calculations:

- The ship maintenance costs remain similar when comparing “before” and “after” the conversion. As methanol is considered as a clean fuel compared to fossil oil fuel, the lifetime of lubricating oil and major spare parts remains equivalent at the same energy efficiency and output as of a diesel engine (Stojcevski, 2014);
- The cost for methanol conversion is taken as 300 EUR/kW as an assumption. According to Stefenson (2014), the cost for methanol conversion was around 300 EUR/kW for Stena Germanica. Moreover, retrofitting costs from diesel into methanol-diesel fuel have been evaluated to be 250-350 EUR/kW for large engines around 10-25 MW (Andersson & Salazar, 2015);
- The average exchange rate used is Rp.13319/USD and Rp.14630/EUR (Bank of Indonesia, 2017);
- The conversion started in the year-end of 2016;

- Depreciation was taken as straight line. This means that the invested methanol technology cost is uniformly reduced through the remaining lifecycle of the ship.

4.1 (c) Combinatorial scenario analysis of NPV calculation

Net Present Value (NPV) represents to what extent a project will increase a company's value. NPV calculated based on the following formula:

$$NPV = \sum_{t=0}^{n} \frac{CFt}{(1+r)^t} - \text{Capital cost}$$

Where r is the project's risk-adjusted of capital cost or discount rate, n is remaining economic life, and CFt is the net cash flow at time t that is calculated as EBTD – (Tax x EBT).

NPV is considered as one of the best criteria for investment decisions from a company perspective. When the positive NPV is obtained in a project calculation, it will add value to the company and vice-versa (Brigham & Ehrhardt, 2011)

Next, one of the examples NPV calculations of MV. Labobar, with combinatorial scenario of 40% methanol price to MDO and 95-5% composition methanol-MDO, is provided:

$NPV_{(40\%;95\text{-}5)}$ = [$NPV_{year\ 1}$] +...[$NPV_{year\ t}$] – [Capital Cost]

Where,

$CF_{year\ 1}$ = EBTD – 15% EBT
= [Rp26,135,414,969.409] – [15% x Rp21,649,080,001.65]
= Rp22,888,052,969.161

$NPV_{year\ 1}$ = $CF_{year\ 1}$/ (1+ 0.08)1
= Rp22,888,052,969.161/ (1.08)
= Rp21,192,641,638.112

The other NPV is calculated as above until the end of economic life of ship.

$NPV_{(40\%;95\text{-}5)}$ = [Rp21,192,641,638.112]+.....+ [Rp10,997,383,736.250]–[Rp80,754,029,420]
$NPV_{(40\%;95\text{-}5)}$ = Rp199,376,909,066.557

Another NPV calculation with combinatorial scenario is calculated based on the above steps, both for MV. Labobar and MV. Gunung Dempo.

Figure 2 demonstrates the scenario analysis of NPV of MV. Labobar in specific criteria. The investment needed for retrofitting a ship is feasible at any composition of methanol-MDO, when the percentage of the methanol price toward MDO does not exceed 52%. On the other hand, investment in methanol technology in MV. Gunung Dempo is feasible at any scenario as shown in Figure 3, as all of the NPVs at any scenario (relating to MV. Gunung Dempo) are positive.

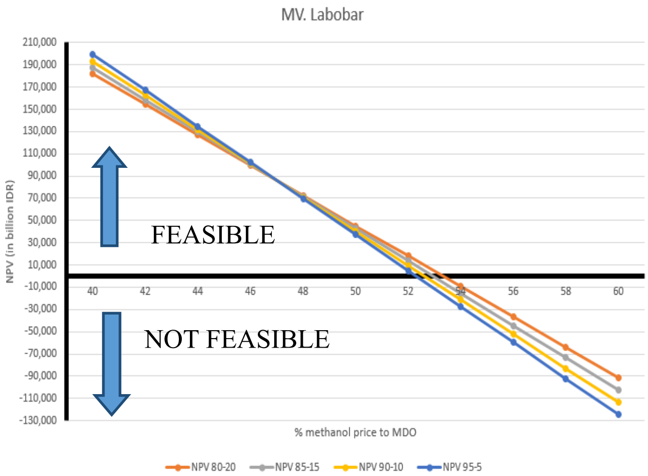


Figure 2: Scenario analysis of NPV-percentage of methanol composition-percentage of methanol price on MV. Labobar case.

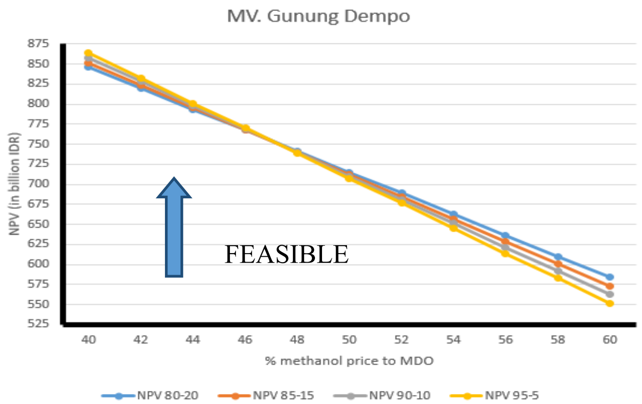


Figure 3: Scenario analysis of NPV-percentage of methanol composition-percentage of methanol price on MV. Gunung Dempo case.

From figures 2 and 3, in which the changing behavior of NPV towards the percentage of the methanol price is given, it can be seen that the improvement of the payback period is directly proportional to the increment of methanol composition as main fuel up to 46% of the methanol price to MDO. However, from 48% above the trend, the situation will be the other way round.

4.1 (d) Combinatorial scenario analysis of discounted payback period calculation

Together with NPV, the payback period is one of the most suitable criteria that has to be considered in an investment analysis. The discounted payback period is the time required when an investment (or, capital cost) is recovered from the operating cash flow and indicated with a positive payback rate. In this study, the payback rate is calculated from discounted cash flow or present value (PV) toward capital cost. The payback period position is in between positive and negative cumulative discounted cash flow (Brigham & Ehrhardt, 2011). For the remaining period after the last negative payback rate, it is calculated as Present value of the first positive payback rate divided by 12, then multiplied with the number of months, which gives the first positive value when added to the last negative payback rate.

Next, one example of the NPV calculation of MV. Labobar, with a combinatorial scenario of 40% of the methanol price to MDO and 95-5% composition methanol-MDO, is provided:

First positive Payback rate = [year of last negative payback rate (in year 4)] + [PVpositive/12 x 1 month]
= (-Rp706,164,030.81)+(Rp18,145,354,158.192/12 x 1)
= Rp805,948,815.70

Therefore, the payback period for these specific scenarios is 4.1 or 4 years and 1 month. Another determination of the payback period with the combinatorial scenario is calculated based on the above steps, both for MV. Labobar and MV. Gunung Dempo.

More importantly, PELNI does not use a corporate maximum payback time limit in technology investments for ships in decision-making processes (Santoso, 2017). Therefore, Table 3 in this study is employed as an analysis tool in order to determine how feasible methanol conversion is for a shipowner, where the colour also represents the payback time.

Table 3: Colour level of payback period of investment

No	Colour Level	Description
1	Highly Recommended	The payback time is ≤ 1/4 of remaining life cycle of the ship, **and** NPV is ≥ 3/2 of capital cost
2	Recommended	The payback time is 1/4<x≤1/2 of remaining life cycle of the ship, **and** NPV is 1≤x<3/2 of capital cost
3	Not Recommended	The payback time is 1/2<x≤3/4 of remaining life cycle of the ship, **and** NPV is 1/2≤x<1 of capital cost
4	Not Feasible	The payback time is > 3/4 of remaining life cycle of the ship, **and** NPV is < 1/2 of capital cost

Table 4 represents the combinatorial scenario analysis of the discounted payback period of MV. Labobar in the applied scenarios. When examining the associated results, retrofitting of MV. Labobar is highly recommended at any methanol composition when the percentage of the methanol price compared to MDO is 40%. Moreover, it is also advisable to retrofit at instances when the methanol price is up to 46% compared to MDO. However, when looking back to 2016 conditions, in the case that the percentage of methanol over MDO was 59.69% and also by factoring in the revenue condition of MV. Labobar, there is the conclusion that converting the ship into methanol as fuel is not feasible in any scenario from a ship-owner's perspective.

The condition might be changed if the ship-owner can improve the revenue, for instance by improving container cargo capacity (MV. Labobar is a 2-in-1 ship, passenger and container cargo), or getting subsidies from the government for willingness to implement green technology (this will be discussed in the government perspective below). In addition, the payback period changed with the percentage of methanol price. Up to 46%, the improvement of the payback period is directly proportional to the increment of methanol composition as main fuel. However, from 48% the trend will be the opposite way.

Table 4: Combinatorial scenario analysis of payback period-percentage of methanol-percentage of methanol price on MV. Labobar case.

Methanol %	Methanol (USD/ton)	80-20	85-15	90-10	95-5
40	184	4.5	4.3	4.2	4.1
42	194	4.11	4.10	4.9	4.8
44	203	5.8	5.7	5.6	5.5
46	212	6.7	6.7	6.6	6.6
48	221	7.11	8	8.1	8.1
50	230	10	10.4	10.7	10.10
52	240	13.8	14.6	15.5	16.7
54	249				
56	258				
58	267				
60	276				

Table 5 represents the combinatorial scenario analysis of the discounted payback period of MV. Gunung Dempo in the stated scenarios. Retrofitting of MV. Gunung Dempo is possible in all applied scenarios. Eventhough MV. Gunung Dempo is smaller than MV. Labobar in terms of size and passenger capacity, MV. Gunung Dempo can gain higher revenues from cargo than MV. Labobar. It can be concluded that, from a ship owner's perspective, the decision of retrofitting a ship to running on methanol also depends on how "productive" the specific ship is.

Table 5: Combinatorial scenario analysis of payback period-percentage of methanol-percentage of methanol price on MV. Gunung Dempo case.

Methanol %	Methanol (USD/ton)	80-20	85-15	90-10	95-5
40	184	1.1	1.1	1.1	1
42	194	1.1	1.1	1.1	1.1
44	203	1.1	1.1	1.1	1.1
46	212	1.2	1.2	1.2	1.2
48	221	1.2	1.2	1.2	1.2
50	230	1.3	1.3	1.3	1.3
52	240	1.3	1.3	1.4	1.4
54	249	1.4	1.4	1.4	1.4
56	258	1.4	1.5	1.5	1.5
58	267	1.5	1.5	1.6	1.6
60	276	1.6	1.6	1.6	1.7

4.2 GOVERNMENT PERSPECTIVE

Ensuring welfare for people and compliance with regulation for all maritime stakeholders is under the government's considerations, while developing business in the maritime sector. In the first attachment of the Presidential Regulation No. 16 of 2017 on Indonesian

Maritime Policy, it is stated that the challenge in developing maritime countries is to build inter-regional connectivity and to optimize sea transportation to eliminate social and economic disparities and to facilitate the movement of people, goods, services, and capital. On the other hand, the efforts to increase maritime activities will have negative environmental impacts. Therefore, the government needs to make an effort through robust measures and policies, such as market-based intervention and regulations, to help stakeholders in improving their capability to comply with "green regulations". One indicative form of market-based intervention is by providing subsidies when applying green technology within the maritime sector (UNEP, 2008).

In this section, the impact of methanol technology implementation on improvement of environmental protection and policy compliance will be evaluated. Furthermore, an optimisation and sensitivity analysis will be conducted to measure to what extent the government can provide subsidies to support green technology implementation by shipping companies

4.2 (a) Environmental analysis and compliance

An environmental benefit analysis was conducted for the MV. Labobar and MV. Gunung Dempo in order to understand to what extent the application of methanol can reduce emissions generated during the annual operation of the ships. Moreover, a compliance analysis was also performed to understand to what extent the implementation of methanol as marine fuel can satisfy future environmental regulations.

There are six emission types to be analysed, namely NOx, SOx, CO_2, CH_4, N_2O, and Particulate Matter (PM). The emission calculation is based on a one-year operation of the main engine and auxiliary engine in sailing and berthing conditions. For the case study, the basic formula to calculate the emission factor and total emission follows the concept of IMO's 3rd GHG Study (Smith, 2014) and expanded as per fuel characteristics and ship operations, as follows:

$TE = ES + EP$
ES or EP $= EM/E + EA/E$
$E_{M/E} = ((\%\ Methanol \times EF_{Methanol}) + (\%\ MDO \times EF_{MDO\ M/E})) \times P \times t \times T \times LF$
$E_{A/E} = EF_{MDO\ A/E} \times P \times t \times T \times n \times LF$
$EF_{MDO} = EF_{reference} \times SFOC_{M/E\ or\ A/E}$
$EF_{Methanol} = EF_{reference} \times LHV \times SFOC_{M/E}$

Where:
TE = Total emission (tons/year)
ES = Emission during sailing (tons/year)
EP = Emission during berthing (tons/year)
EF = Emission factor (g pollutant/kWh)
P = Total operated engine power (kW)
T = Average time of sailing or berthing (hours/trip)
T = Number of trips annually
LF = Average load factor
LHV = Lower heating value (MJ/kg fuel)
SFOC = Specific fuel oil consumption (g fuel/kWh)
M/E = Main engine
A/E = Auxiliary engine

Next, one of the examples of NOx emission calculations of the main engine MV. Labobar with 80-20 fuel composition scenario is provided:

$P_{M/E}$ = 9000 x 2 kW
$t_{sailing}$ = 198 hours/trip
$t_{berthing}$ = 0 (Main engine is off during berthing)
T = 24
LF = 0.8
LHV = 20.1 MJ/kg fuel
SFOC = 175 g fuel/kWh

$EF_{MDO} = EF_{reference} \times SFOC_{M/E}$
$= 0.05684$ g/gfuel x 175 gfuel/kWh
$= 9.947$ g/kWh

$EF_{Methanol} = EF_{reference} \times LHV \times SFOC_{M/E}$
= [0.28 g/MJ] x [20.1 MJ/1000 gfuel] x [175 gfuel/kWh]
= 0.9849 g/kWh

$E_{M/E\ sailing} = ((\%\ Methanol \times EF_{Methanol}) + (\%\ MDO \times EF_{MDO\ M/E})) \times P \times t \times T \times LF$
= [(80% x 0.9849) + (20% x9.947) tons/kWh] x [18000 kW] x [198 h/trip] x [24 trip/year] x [0.8/1000000 g]
= 190.0486 tons/year

$TE_{NOx\ M/E}$ = 190.0486 tons/year + 0
= 190.0486 tons/year

Another emission calculation is calculated based on the above formula; both MV. Labobar and MV. Gunung Dempo depend on various parameters that create the respective operational scenario.

Table 6 demonstrates that methanol has a clear advantage in terms of less fuel emission content compared to MDO. Even SOx, CH_4, and N_2O have zero value. Unlike the auxiliary engine of the two passenger ships, the emission factors for the main engine of MV. Labobar and MV. Gunung Dempo remains similiar since they have the same type of engine with the same SFOC, but with a different number of cylinders.

Table 6. Emission factors of MV. Labobar and MV. Gunung Dempo

Emission	Methanol (g/kWh)	MDO (g/kWh)		
		M/E	A/E Labobar	A/E Gunung Dempo
NOx	0.9849	9.947	10.7996	10.5154
SOx	0	0.462	0.5016	0.4884
CO_2	242.7075	561.05	609.14	593.11
CH_4	0	0.0105	0.0114	0.0111
N_2O	0	0.02625	0.0285	0.02775
PM	0.01512525	0.1785	0.1938	0.1887

There are four (4) significant pollutants in the internal combustion engine, particularly in a diesel engine; CO_2, NOx, SOx, and PM. The other pollutants, CH_4, and N_2O are combined with SOx and PM in Figure 4 since their value is relatively low. CO_2 and NOx are separated to create a clear picture, since their value is much higher compared to the other pollutants.

4.2 (b) N_2O, CH_4, SOx and PM analysis

According to Figure 4, N_2O and CH_4 have the lowest emissions compared to the other pollutants. The application of 80% methanol as main fuel in the main engine of MV Labobar and MV Gunung Dempo can reduce total emissions to 59.65% compared to 100% MDO in the main engine (see Table 7). Subsequently, by increasing the composition of methanol by 5%, 4.5-4.7% of the emission reduction compared to the previous methanol percentage will be acquired. The reduction of SOx and PM is following the same trend. However, the reduction of PM was slightly lower since methanol as fuel emits some PM despite the zero SOx emission factor. This is because the source of PM is not only associated with the sulphur conversion during the combustion process (IMO, 2016)

Table 7. The percentage of total emission reduction of SOx-CH_4-N_2O-PM for MV. Labobar and MV. Gunung Dempo

	% reduction SOx, N_2O, CH_4		% reduction PM	
	Labobar	G.Dempo	Labobar	G.Dempo
100% MDO	-	-	-	-
M-80	59.65%	62.66%	53.62%	56.33%
M-85	64.09%	67.33%	57.69%	60.61%
M-90	68.54%	72.00%	61.76%	64.88%
M-95	72.98%	76.68%	65.83%	69.16%

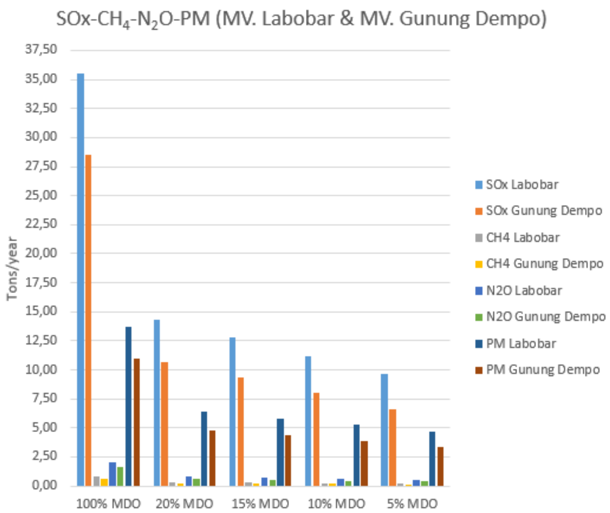


Figure 4. Total emission value of SOx-CH_4-N_2O-PM for MV. Labobar and MV. G. Dempo

Currently, Pertamina's MDO products, which are marketed in Indonesia, have complied with national and IMO regulations with a maximum sulphur content of 1.5% m/m (Pertamina, 2009). This means that by using 100% MDO on board MV. Labobar and MV. Gunung Dempo, the ships still comply with the 3.5% m/m limit required in MARPOL Annex VI (chapter III-regulation 14). However, according to the new regulation of SOx and PM set-up by IMO, at the beginning of January 2020 the SOx and PM limit will be 0.5% m/m. Based on Figure 5, by using 100% MDO, neither of the ships will comply with this limit. Interestingly, using methanol as marine fuel in all the scenarios will help to satisfy the maximum limit of SOx and PM.

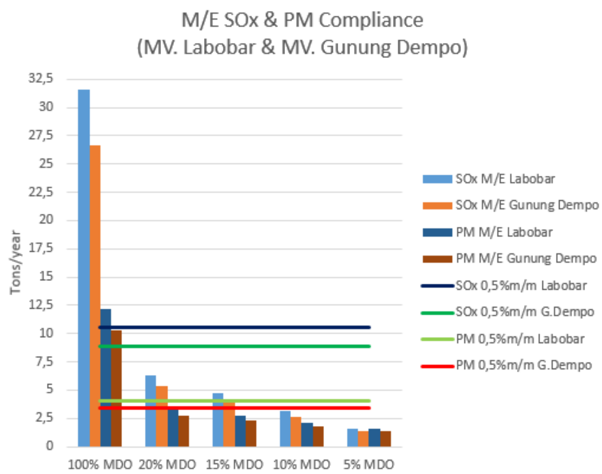


Figure 5: M/E SOx and PM value for MV. Labobar and MV. G. Dempo.

In addition to assisting in the compliance to the IMO's regulations, the application of methanol as a marine fuel can help the government commitment to protect the domestic environment from acidification, acid rain, and human health problems caused by SOx-PM pollution.

4.2 (c) NOx analysis

Table 8 presents the improvement of total NOx reduction due to methanol fuel application compared to 100% MDO application on MV. Labobar and MV. Gunung Dempo. The 50-60% reduction can be achieved just by using 80% of methanol as main fuel; the reduction will gradually increase with more methanol in the fuel composition.

Table 8. The percentage of total NOx reduction for MV. Labobar and MV. Gunung Dempo

	% reduction NOx	
	Labobar	G.Dempo
100% MDO	-	-
M-80	57.5%	60.08%
M-85	61.1%	63.84%
M-90	64.7%	67.59%
M-95	68.3%	71.35%

From Figure 6, it can be seen that both main engines of MV. Labobar and MV. Gunung Dempo fulfil the IMO NOx code Tier I that is applied for ships constructed after 1 January 2000, as they were built in 2004 and 2008. Even though the

Tier II and III will not be imposed on these ships, an analysis for future regulation compliance can be done out of interest. For Tier II, the NOx emission value of the main engine is below the threshold for both MV. Labobar and MV. Gunung Dempo. Moreover, it will be difficult for ships of the same type and characteristic as MV. Labobar and MV. Gunung Dempo to comply with Tier III without applying measures to reduce NOx content. Implementing methanol technology will help the aforementioned ships achieve compliance of Tier III considering that the use of methanol is reducing NOx emission. However, not all of the scenarios resulted in NOx emissions below the Tier III threshold (see Figure 6). The possible scenarios for the ships were M-85, M-90, and M-95.

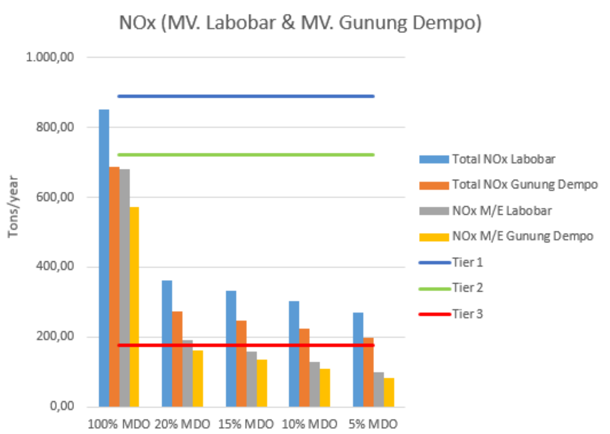


Figure 6: Emission value of NOx for MV. Labobar and MV. G.Dempo.

4.2 (d) CO_2 analysis

Total emission value of CO_2 from MV. Labobar and MV. G. Dempo can be reduced by at least 28-30%, or 12,477 tons, annually by applying M-80. The reduction will gradually increase with a higher methanol composition (see Figure 7). This reduction is possible because methanol has a lower carbon factor (carbon content 0,3750 and carbon conversion factor 1,375 t-CO_2/t-fuel) compared to other fuels, even LNG (carbon content 0,75 and carbon conversion factor 2,750 t-CO_2/t-fuel).

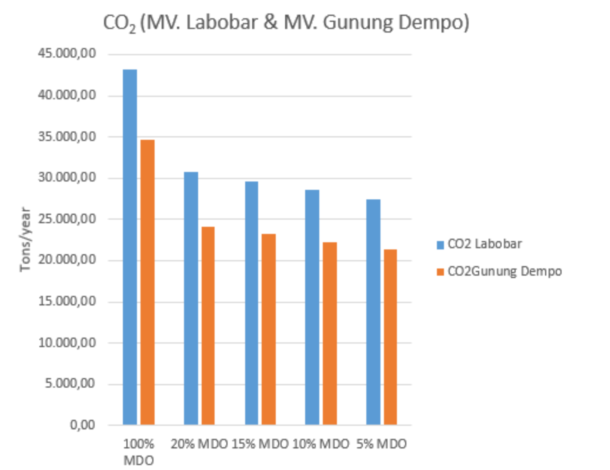


Figure 7: Total emission value of CO_2 from MV. Labobar and MV. G. Dempo.

Both of the ships are existing ships; hence, the Energy Efficiency Operational Indicator (EEOI) will be used to evaluate and quantify the energy efficiency improvement in the ship operations. Since PELNI has not implemented the so-called Ship Energy Efficiency Management Plan (SEEMP) yet, the EEOI used here is the average EEOI on an annual basis (multiplying the annual fuel consumption with the carbon factor then divided by the gross tonnage of the passenger ship and the average of the voyage annually). Table 9 shows that applying M-95 can achieve 1.54925x10-05 tonsCO_2/tonsNmiles or 36.45% of CO_2 reduction for MV. Labobar and 1.09174x10-05 tonsCO_2/tonsNmiles or 38.28% of CO_2 reduction for MV. Gunung Dempo.

Table 9. The percentage of total CO_2 reduction and EEOI for MV. Labobar and MV. Gunung Dempo.

	% reduction CO_2		EEOI (tons CO_2/tons.Nmiles)	
	Labobar	G.Dempo	Labobar	G.Dempo
100% MDO	-	-	2.43796E-05	1.769E-05
M-80	28.89%	30.33%	1.73368E-05	1.23239E-05
M-85	31.41%	32.98%	1.6722E-05	1.18551E-05
M-90	33.93%	35.63%	1.61072E-05	1.13863E-05
M-95	36.45%	38.28%	1.54925E-05	1.09174E-05

Unlike the Energy Efficiency Design Index (EEDI), EEOI is not mandatory but only recommended by the IMO. Nonetheless, the result of EEOI per individual ship will provide the overall picture to the maritime stakeholder, especially the government, on how well the CO_2 reduction effectiveness of the applied technology is. As shown in Figure 7 and Table 9, methanol as marine fuel is effective in reducing CO_2 and could be one of the respective government strategies to support the implementation of MARPOL annex VI chapter 4 that is already ratified by Indonesia.

4.3 MARKET-BASED INTERVENTION

Prior to establishing and stipulating a subsidy policy for methanol as a marine fuel, the government needs to have at its disposal data that demonstrates how a shipping company can improve its market share when the government interferes with subsidies. Also, the government needs to know to what extent the subsidies, in terms of quantity and condition, can interfere with the market. By an optimisation approach, the government can acquire the necessary information. Moreover, the identification of which variables have the greatest influence on the policy-making on alternative fuel selection can also take place.

In this study, an optimisation is conducted by using the OptQuest-Crystal Ball in the techno-economic model of MV. Labobar to achieve the above objectives. MV. Labobar model is selected as the basis of the optimisation model because of the result gap between each payback time and NPV is wider than MV. Gunung Dempo. Hence, it will be easier to recognize the trend.

4.3 (a) Optimisation model

There are four (4) important components that have to be identified in the optimisation model: assumptions, decision variables, optimisation objectives, and constraints. The explanation of these components are provided below:

a. Assumptions contain an unpredicted value or are beyond internal control (Oracle, 2013). In this model the assumption variable was set as follows:
   - Total Revenue is set as normal distribution with mean value according to the total revenue in 2016.
   - Engine conversion cost is set as triangular distribution with minimum cost at 250 EUR/kWh and maximum cost at 350 EUR/kWh according to the Methanol Institute report (Andersson & Salazar, 2015). The likeliest is set up at 300 EUR/kWh based on the assumption in the techno-economy calculation.
   - The MDO price is set as normal distribution with a mean value according to the price in 2016.
   - The inflation is set as triangular distribution with minimum inflation of 4% and maximum 6% according to the regulation of the Ministry of Finance.
   - The exchange rate is set as normal distribution with a mean value at Rp. 13.319/USD.

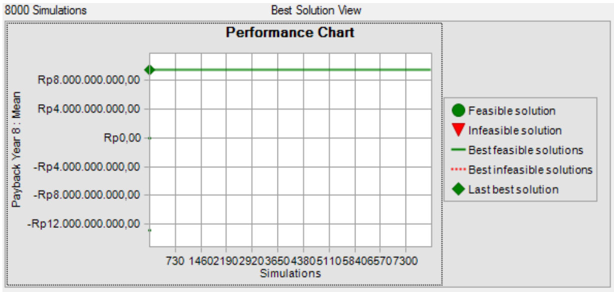
b. Decision variables are the variables that can be controlled internally (Oracle, 2013).
   - Percentage of methanol price compared with MDO price as the function of government subsidies. The variable is set at 43.49 as lower bounds and 73.02 as higher bounds. This value comes from the highest and lowest of the price percentage of methanol over MDO from 2004 to 2016.
   - Percentage of methanol composition is set based on the scenario in the techno-economy calculation; between 80 to 95% with a 5% interval

c. Optimisation objectives are set at year eight (8) as maximizing mean of payback/return rate. Based on Table 4, it can clearly be observed that the boundary between recommended (light green) and not recommended (yellow) payback period is around 6-8 years.

d. Constraints are the restrictions of the decision variables (Oracle, 2013).
   - The main engine dual fuel (methanol-MDO) will be determined as close as to when using 100% MDO. This means that the fuel cost is close to the business-as-usual cost of the shipping company, as the minimum standard.
   - The payback/ return rate after year 7 (seven) must be positive.

4.3 (b) Optimisation and sensitivity analysis

From Figure 8, it is shown that the optimum decision from the government's perspective is to maintain the price of methanol to 47% or less to MDO.



Best Solution:

Objectives	Value
Maximize the Mean of Payback Year 8	Rp9.358.244.849,12

Requirements	Value

Constraints	Left Side		Right Side
'Labobar (conversion economy)'!G7 >= 'Labobar (conversion economy)'!C7	66397860083,3...	>=	66352964545,1...
'Labobar (conversion economy)'!K28 >= 0	55960821266,523	>=	0

Decision Variables	Value
% methanol composition	0,85
% methanol price	47,00

Figure 8: OptQuest-Cristal Ball optimization result

According to Table 2, the percentage of methanol price compared to MDO for 2016 was 59.69%. Therefore, in order to support the introduction of methanol as a green technology and a sustainable marine fuel into the market, the government needs to subsidize the methanol by 12.6%, or USD 58/tons of methanol, or Rp 610.28/liter.

Moreover, from this study, it can be suggested that the government should support M-85 technology in the first introduction when the market condition is as in 2016. In addition, since the methanol technology in the maritime business is relatively novel, there are opportunities to improve the technology and advancing the product. Further, with time and a massive implementation, the price will be dropped and the government subsides can be reduced.

There are also several external factors influencing a government decision to give subsidies based on the assumptions that have been made. Therefore, a sensitivity analysis was also conducted during the optimisation. From Figure 9, it can be concluded that the most influential external variable on government decision-making is the condition of the economic market uptake, represented in the total revenue by 52.7%. The exchange rate and the MDO price had almost the same influence, 25.2%, and 21.9% respectively. However, the engine conversion cost and the inflation had a smaller effect.

In general, the result of the sensitivity analysis is logically acceptable since the government does not want to impose any new technology that can disrupt the maritime industry, for instance an exorbitant price of technology or a sluggish maritime business market. The MDO price is also considered as an external factor that can change the government decision. For instance, when the price of MDO becomes higher, the government will try to find a solution to maintain its maritime business such as introducing alternative fuels or even subsidizing the use of certain fuels.

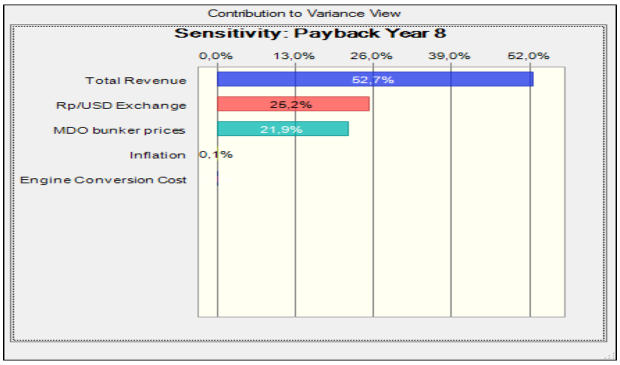


Figure 9: Sensitivity analysis of external factor for payback year-8

4.3 (c) Verification

A simple verification was made by manually calculating the fuel cost of the main engine of MV. Labobar for each methanol composition scenario. Figure 10 demonstrates that the position of the 47% line was the same as the 100% MDO line; this means that the fuel cost of the methanol as a main fuel with various compositions will be close to the fuel cost of a business-as-usual condition of the shipping company. From the government perspective, 47% was the optimum price of methanol where the optimum subsidies can maintain the market and keep the shipping company making profits as usual.

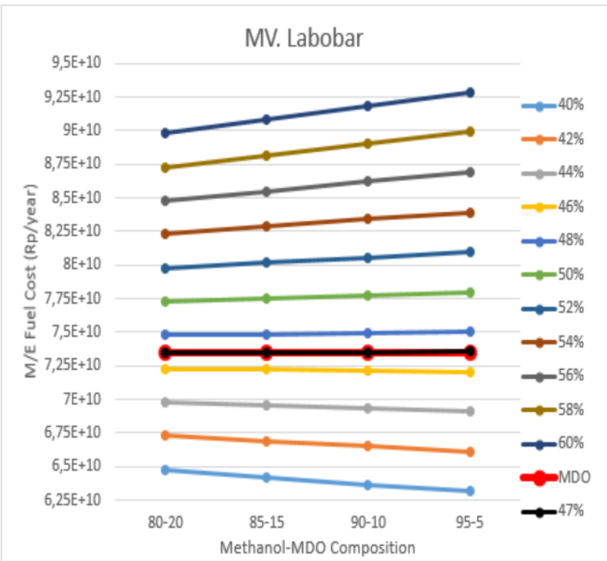


Figure 10: Verification of the optimisation result based on fuel cost

From the ship owner's perspective, the percentage was the minimum price of methanol to decide on investment of methanol technology on the fleet, with a favourable payback period. By inputting the scenario in methanol price to 47% with a composition of 85-15 in the techno-economic calculation, some economic criteria could be then defined. The payback period can be achieved in 7 years and 3 months, with the positive NPV Rp86,057,237,977.600. When the criteria are plotted to Table 4, then the position will be between the light green and yellow area; this means that these criteria are the minimum for the shipping companies to maintain their profit in the business-as-usual scenario and in the case the application of methanol is introduced.

4.4 DISCUSSION

"Competitiveness" of methanol as a marine fuel generally depends on ship productivity and the price differences between methanol and MDO. Considering the different results of techno-economic calculations in the feasibility investment of MV. Labobar and MV. Gunung Dempo, this means that the model should be applied separately to each individual ship. The result can not be generalized as the reference for other passenger ships, since it may vary depending on the revenue gained (profit), engine size, maintenance cost, cargo capacity, and remaining economic life of each passenger ship.

However, the trend of the combinatorial scenario analysis for both ships can be considered as the reference for other passenger ships, since there are similar trends and an interesting relationship between NPV, payback period, percentage of price, and percentage of methanol price to MDO. The payback period and NPV for each percentage of methanol composition are sensitive to the percentage of the methanol price. Up to 46% of the methanol price to MDO, the improvement of payback period and NPV are directly proportional to the increment of methanol composition as main fuel. At the same time, around 48% above the trend, the situation will be the opposite. These results can be considered as the indicative strategy for ship-owners to select the "right" operational option when dealing with the current market situation. When the price of methanol is close to or above 48% of the MDO price, then the lowest set-up methanol composition (80% methanol-20% MDO) can be operated to maintain the profit and payback time.

In terms of regulation compliance, running with dual-fuel methanol propulsion significantly reduces related emissions. Generally, as seen from Tables 6-9, the higher methanol composition used as a main fuel, the higher emission reduction is achieved. Further, most of the scenario can comply with the recent and upcoming regulations, particularly MARPOL Annex VI. Therefore, from the policy compliance point of view, the application of methanol as a marine fuel is feasible to get government support since it will help the government commitment to protect the domestic environment from negative impacts to the environment and human health caused by pollution from ships.

Decision-making and policy analysis using optimisation can be performed as one of the government approaches in determining the optimum point and condition to introduce and establish methanol as a marine fuel. The optimum point that the government should maintain is the methanol price at 47%. The MDO price has a similar trend in the combinatorial scenario analysis from the ship-owner's perspective. Moreover, from the sensitivity analysis result, it is evident that three main external variables that have to be taken into account in the policy-making are: market situation, methanol price and exchange rate. The complete work of this research can be found in the first author's MSc dissertation conducted at the World Maritime University (Priyanto, 2017)

5. CONCLUSIONS

Domestic ships are one of the most important means of transport to connect the numerous islands in an archipelagic country like Indonesia. A certain number of the domestic ships, particularly passenger ships are assigned to deliver services in uncompetitive commercial areas. Unfortunately, the vast majority of the current passenger ships are dependent on fossil fuel, and therefore vulnerable to fluctuations of fuel oil prices. In order to promote a sustainable and more "environmental friendly" shipping market, methanol fuel can be a very promising option for Indonesia. Abundant potential feedstock with availability of methanol producers and existence of relevant infrastructure in the country under discussion have all been identified within the context of the analysis in hand. As already highlighted, running with dual-fuel methanol propulsion significantly reduces ship's emissions to air. In the emission calculations previously performed, most of the scenarios can comply both with the recent and upcoming regulations, particularly with those of MARPOL's Annex VI.

Subsequently, an economic analysis was performed by using a techno-economic model based on case studies of two passenger ships owned by PELNI: MV. Labobar and MV. Gunung Dempo. The combinatorial scenario approach, which is the combination of economic measures of merit (NPV and payback period) with the technical solution scenario (main-pilot fuel set up), effectively provides a broader overview for ship-owners not only to determine the feasibility of the investment in methanol technologies, but also to determine which ships are "eligible" for retrofitting and what scenarios of engine set-up should be operated on-board the ship based on ship age, ship productivity (for instance: revenue, cargo and passenger troughput, operational or utilization time), as well as current and long-term market conditions.

It was found that the competitiveness of methanol application is mainly dependent on ship productivity and the price differences between methanol and MDO. Productivity of passenger ships was represented with revenue; it can be improved by modifying and improving container cargo capacity (MV, Labobar is a 2-in-1 ship, passenger and container cargo), or by introduction of "green technology" subsidies as a market-based intervention by the government.

However, there is a trade-off situation in the market-based intervention. Ship-owners tend to get high income by collecting as many incentives as possible, while the government needs to provide subsidies that are based on a limited state budget. Therefore, an optimisation approach was developed and performed by utilizing the combinatorial scenario model; hence, the optimum methanol price was evaluated. The optimisation result revealed that the optimum price of methanol was when the percentage of methanol price compared to MDO was 47%. That is the optimum percentage where the fuel costs are close to the bussiness-as-usual condition (100% MDO). Moreover, it could be the reference for the government to target a percentage by providing subsidies for the market to be maintained and to help the shipping company maintain profits as if they had been operating their vessel with MDO.

Providing support for methanol as a marine fuel could increase domestic methanol production and also encourage its use in other industrial sectors. Methanol hopefully can fulfil the energy transition needed since the oil reserves in Indonesia are for the time being steadily decreasing. However, there are several issues that must be addressed and considered:

- In the short term, an initiative should come first from the government with a national policy including financial support, such as subsidies to allow the stakeholders to develop sustainable energy strategies ranging from model to full-scale experiment. This is important for gaining the trust of those shipping companies that do not want to take the "unnecessary" risk. The government also needs to stimulate further research on this issue by academic institutions, engine manufacturers, methanol producers, and various other parties involved into developing the market for methanol as a marine fuel. Moreover, in order to bring clarity regarding the legal basis, the government should work together with classification societies to develop safety regulations for domestic passenger ships running on methanol.
- In the medium term, the government should develop a rigid energy policy, as well as a national strategic roadmap that includes methanol as one of the alternative fuels for transportation, particularly marine transport needs. The policy and strategic roadmap need to consider an incentives scheme, allocation of methanol fuel supplies, an inter-ministerial coordination framework, and explicit responsibilities for each party involved. In addition, Indonesia still has abundant resources of coal and

natural gas that have not yet been absorbed by the domestic and international market. Therefore, it would be favourable to increase methanol production using coal and natural gas in the medium term of the energy transition.

- In the long term, considering Indonesia has ample waste as renewable feedstock resources, such as plantation waste and municipal waste, it would be favourable to shift the methanol feedstock from natural gas and coal into the more sustainable feedstock. Further, utilization of these resources could help the environment by reducing emissions and even creating a circular economy.

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