Optimization of LNG Logistics System to Meet Gas Supply at Gresik LNG Receiving Terminal

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Abstract. The construction of Gresik LNG receiving terminal is aimed to fulfil the 109 MMSCFD (0.87 MTPA) gas requirement for combined-cycle power plant (PLTGU) Jawa-3 which is integrated with LNG Gresik Terminal. There are several potential LNG plants in Indonesia and abroad that can be the source of gas for Gresik LNG Terminal. Each of these LNG plants has varying gas price and distance to Gresik. The modelling of the LNG logistics system for Gresik LNG Terminal was built to illustrate the LNG supply chain from the LNG plants to Gresik LNG Terminal and several supply scenarios will be proposed. The built model is linear and optimized by using linear programming. Linear programming involves the determination of objective functions, decision variables and constraints. The optimization of the logistics system aims to obtain the cheapest gas supply cost for Gresik LNG receiving terminal. The result shows that the cheapest gas supply cost is obtained through direct supply scenario with gas source from domestic and abroad with combination of delivery from Bontang equal to 0.34 MTPA (40 %) with 12 shipments, Tangguh equal to 0.26 MTPA (30 %) with 9 shipments, and Bintulu Malaysia equal to 0.26 MTPA (30 %) with 9 shipments.

1. Introduction
The installed capacity of power plants in Java-Bali electrical system by the end of 2015 is 33,825 MW consisting of various types of power plants. Gas-fired generation composition in 2015 is 24.8 % and in 2025 it is projected to be 29.4 %. One of the gas-fired power plant development projects included in the Power Plant Development Project Plan (RUPTL) 2016-2025 as well as the 35,000 MW Project is combined-cycle power plant (PLTGU) Jawa-3 with a capacity of 800 MW which is located in Gresik East Java [1]. Gas for power plant fuel is taken from LNG terminal which is integrated with PLTGU Jawa-3. The LNG source for Gresik LNG Terminal is obtained from various LNG plants which are located around Gresik. LNG is transported from an LNG plant to Gresik LNG Terminal using a tanker. Several scenarios for the selection of LNG supply sources and optimization of the logistics system are required to obtain the most optimal results in terms of technical and economic. Most existing supply chain design and optimization studies rely on centralized models [2]. All the decisions can be implemented successfully to pursue a single objective for gas supply chain optimization [3]. The linear programming approach involving multiple stakeholders with uncertainties is also successfully applied for natural gas supply chain optimization [4]. Based on these results, the linear programming is an appropriate approach for optimizing the LNG supply chain in our study.
2. Methods
The steps taken in conducting research on logistics system optimization to fulfill gas supply in Gresik LNG Terminal are: data collection, system boundary determination, logistic supply chain calculation, objective function determination, decision variable, constraints and optimization calculation using Solver from Microsoft Excel software.

2.1. LNG carrier selection
The volume gas required for power generation in Terminal Gresik is 109 MMSCFD or equivalent to 0.87 MTPA of LNG. The LNG carrier selection that will be used to send LNG from the liquefaction plant to the LNG Receiving Terminal is influenced by the condition of the port waterway where the terminal is located. The influential factors are the depth of the waters where the ship is leaning and the ship maneuvering area available in the waterways. The Gresik LNG Receiving Terminal is located at the APBS (West Surabaya Watershed) which has a water depth of 13 m and a turning radius of 900 m [5], so that the LNG carrier used should not have a draft exceeding 13 m and a rotating radius of the ship is not exceeding 900 m.

2.2. Logistics chain modelling
In this study the LNG supply chain under review is from a liquefaction plant, transported by an LNG carrier and an LNG receiving terminal as shown in Figure 1 below.

![Figure 1. LNG supply chain model](image)

The economic model or LNG project structure under consideration is the merchant model with the LNG supply chain cost calculated starting from the LNG price at the liquefaction plant where the upstream gas exploration and production costs as well as the liquefaction costs of the gas are considered as the cost of gas supply from the production region to the point at the nearest port of the liquefaction plant. Furthermore, transportation costs are calculated on the basis of the chartering a vessel scheme and the subsequent chain cost of LNG regasification at LNG Gresik receiving terminal and gas distribution to PLTGU Jawa-3.

2.2.1. Calculation from production region cost
In general the LNG price, production region cost, \( C_P \) is formulated by equation 1 below [6]. LNG price is FOB (free on board) price.

\[
C_P = A \cdot P_O + B \tag{1}
\]

For domestic gas purchase contracts, \( P_O \) refers to ICP (Indonesian crude price), while for LNG purchase contracts in Asia and Australia generally refers to JCC (Japan crude cocktail) or Brent crude oil price. A and B are coefficients with certain values that have been previously set.

2.2.2. Calculation of transportation cost
LNG shipments from liquefaction plant to destination LNG receiving terminals are carried out using LNG carrier in the form of tanker ships using charter a vessel schemes. LNG shipping cost from liquefaction plant to LNG receiving terminal by using time charter, \( C_T \) can be formulated by the following equation:
Transportation cost consists of 2 components, that is:
1. Fixed cost, $C_{\text{fixed}}$ which is the charter cost.
2. Variable cost, $C_{\text{variabel}}$ which consists of 4 components:
   a. Fuel cost. Ships with a capacity of 160,000 m$^3$ with steam propulsion require fuel of 0.15 % boil-off LNG per day plus fuel oil of 48.1 tonnes of HFO per day while ships with DFDE propulsion require 0.10 % fuel LNG boil-off per day;
   b. Port charge, consisting of an unloading cost of € 16,988 per ship (fixed cost) and € 35 per GWh (variable cost) when using a third party port facility;
   c. Insurance, which is 12 % of operating costs;
   d. General cost, which is 16 % of operating costs.

The LNG delivery method used in this study is single round. In this method, LNG shipments from each liquefaction plant use different ships and each LNG plant will use one ship for one purpose. To find out the ship's round trip time, LNG carrier capacity used and storage tank volume at LNG receiving terminal is calculated using equations developed by Nikolaou [7].

2.2.3. Calculation of regasification cost
The cost of LNG regasification at the LNG receiving terminal, $C_R$ is formulated by the following equation:

$$C_R = CAPEX + OPEX$$

Regasification cost consists of 2 components, that are:
1. Investment costs (CAPEX), the average for onshore LNG terminal in 2015 is US$ 242 per tonne, 2016 is US$ 334 per tonne, 2017 is US$ 212 per tonne and estimated for year 2018 is US$ 285 per tonne [8];
2. Operational cost (OPEX), influenced by regasification technology used and assumed 4 % of CAPEX [9].

After each cost in each chain is calculated, the total cost of the overall gas supply is formulated by the following equation:

$$C = C_P + C_T + C_R + C_D$$

The cost of gas distribution, $C_D$ can be ignored due to the position of power plant integrated with the LNG terminal so that the equation 4 above becomes:

$$C = C_P + C_T + C_R$$

2.3. Determining objective functions of the model
The illustrations of the problems in this study are shown in Figure 2 below.
The objective function to minimize the total cost of gas supply from the LNG plant to the LNG (Z) terminal is as follows:

\[
Z = \sum_{1 \leq i \leq m} \sum_{1 \leq j \leq n} \sum_{1 \leq t \leq T} C(i, j, t) X(i, j, t)
\] (6)

The total cost of gas supply, Z (US$) is a function of the entire gas supply chain cost, C (US$ per MMBtu) and the amount of LNG shipped, X (MMBtu).

2.4. Determining decision variable
The decision variable is a variable that can be changed and controlled in order to produce the desired result. In this study the decision variable is:

\[ X_{i,j,t} \]

is a variable showing the ability of LNG delivery (LNG volume delivered) by source \( i \) to delivery destination \( j \) within certain period of time \( t \), where \( i = 1, 2..., m \), \( j = 1, 2..., n \) and \( t = 1, 2..., T \).

2.5. Determining constraints
The decision variable is the objective function to be optimized to get the optimum result is limited by the following constraints:

a. The uncommitted capacity of the supply source (liquefaction plant), \( a \) is at least equal to the amount of LNG delivered, \( X \):

\[
\sum_{j=1}^{n} X_{i,j} \leq a_i
\] (7)

b. The LNG terminal’s regasification capacity, \( b \) is at least equal to the amount of LNG delivered, \( X \):

\[
\sum_{i=1}^{m} X_{i,j} \leq b_j
\] (8)

c. The gas consumption rate, \( q \) is at least equal to the terminal regasification capacity, \( b \):

\[
b_j \geq q_{c,j}
\] (9)

d. The number of LNG shipments with LNG carriers sent from source \( i \), \( F_{\text{actual}} \) must not exceed the maximum number of per year that the LNG carrier can carry, \( F_{\text{max}} \):

\[
F_{i,\text{actual}} \leq F_{i,\text{max}}
\] (10)
e. X value should not be negative:

\[ X_{i,j} > 0 \quad \forall i, j \]  

(11)

2.6. Logistics supply scenario

The logistics supply scenarios under review is the combination of direct supply of gas sources at domestic and abroad with a long term contract of 20 years. In this scenario gas sources for Gresik LNG Terminals are obtained from domestic liquefaction plants: Bontang, Masela and Tangguh coupled with a liquefaction plant from abroad: Withnell Bay in Australia, Pluto in Australia, Gorgon in Australia, Lumut in Brunei and Bintulu in Malaysia. The gas supply quotas from each of the above plants are assumed as shown in Table 1 below.

| No. | Liquefaction Plant | Distance Miles | Allocation for PLN Bcf/year | LNG Price US$/MMBtu | Remark                |
|-----|--------------------|----------------|-----------------------------|---------------------|-----------------------|
| 1   | Bontang            | 573            | 15.91                       | 7.88                |                       |
| 2   | Tangguh            | 1,290          | 12.53                       | 8.05                |                       |
| 3   | Masela             | 925            | 32.71                       | 8.40                |                       |
| 4   | Withnell B         | 985            | 26.41                       | 9.73                |                       |
| 5   | Pluto              | 986            | 13.50                       | 9.73                |                       |
| 6   | Gorgon             | 1,006          | 19.16                       | 9.73                |                       |
| 7   | Lumut              | 1,382          | 10.60                       | 8.40                |                       |
| 8   | Bintulu            | 1,495          | 14.85                       | 8.05                | Operation in 2026     |

2.7. Key assumptions

The key assumptions used as the basis for calculating the gas supply cost are as follows:

1. The price of crude oil refers to the estimated price of Brent crude up to 2050 issued by the EIA (US Energy Information Administration);
2. The LNG carrier’s charter rate for the Asian market is 80,000 US$ per day with a capacity of 160,000 m³ with a 5-year contract and the charter rate is assumed to increase by 10% every 5 years;
3. Average carrier LNG velocity of 10.5 knots with steam propulsion steam type;
4. LNG carrier fuel prices for diesel oil type of IFO 380 is 382.5 US$ per tonne and fuel prices from boil-off gas is 8.40 US$ per MMBtu. The increase in fuel prices follows crude oil prices;
5. The fuel consumption LNG carrier with capacity 160,000 m³ is 145 tonnes per day LNG equivalent, is a combination of LNG boil-off and diesel oil type IFO 380;
6. LNG boil-off by 0.15% per day and heel cargo at 4% of shipload. Cargo heel is required to keep the LNG storage tank in storage compartment cool until the vessel returns to its original location.

3. Result and Discussion

3.1. LNG carrier selection

To make a single voyage from all liquefaction plant to Gresik LNG Receiving Terminal requires 1 unit of vessel with capacity of 65,000 m³, whereas when using a vessel with a capacity of 27,500 m³ requires 2 units of ships, except from Bontang liquefaction plant requires 1 unit of ship and from Bintulu liquefaction plant requires 3 units of ship. As depicted in Figure 3, transportation cost is directly proportional to the mileage of ships and ships with larger capacity having smaller transportation costs than smaller capacity vessels.
Figure 3. The relationship among the shipping distance, vessel capacity and transportation cost

3.2. Gas supply cost

The calculation is based on the use of LNG carrier with capacity of 65,000 m³. The selling price of LNG (FOB price) and the price of IFO 380 oil diesel in the period 2019 - 2038 are adjusted to the crude oil price according to Brent crude oil price estimation data for the period of 2016 - 2050 issued by EIA (US Energy Information Administration). From the table, the lowest gas supply costs are obtained from the Bontang liquefaction plant, followed by the Tangguh liquefaction plant, the Bintulu liquefaction plant in Malaysia, the Masela liquefaction plant, the Lumut liquefaction plant in Brunei and the last liquefaction plants in Australia. The smallest gas supply cost is obtained from the Bontang liquefaction plant because it has the cheapest FOB LNG price and the closest delivery distance, followed by Tangguh and Bintulu. The largest gas supply cost is obtained from a liquefaction plant in Australia because although transportation costs are lower than Tangguh, Lumut and Bintulu but are unable to cover higher LNG (FOB) prices. The LNG (FOB) price of the liquefaction plant is the largest component of gas supply cost, which is about 86 % on average, followed by LNG regasification cost component at LNG receiving terminal of 9 % and last 5 % transportation cost component.

Gas supply costs follow world crude oil price, especially in LNG price from liquefaction plant and transportation cost. The relationship between the cost of gas supply and the reference crude oil price is shown in Figure 4. It shows that the increase in gas supply costs is proportional to the crude oil price.
3.3. Result of optimization gas supply

From the optimization result obtained gas supply to Gresik LNG Receiving Terminal as follows:

- **2019**
  The Gresik LNG Receiving Terminal starts to operate gradually and the gas requirement of 9.97 Bcf is fully met by Bontang refinery with 7 shipments;

- **2020 – 2038**
  The Gresik LNG Receiving Terminal is fully operational and gas supply is obtained with a combination of supply from Bontang liquefaction plant of 15.79 Bcf per year with delivery 12 times per year, Tangguh liquefaction plant of 11.84 Bcf per year with delivery of 9 times per year and Bintulu liquefaction plant of 11.84 Bcf per year with shipment 9 times per year.

The total cost of gas supply for 2019 - 2038 is shown in Table 2.

**Table 2.** The results of gas supply optimization for Gresik LNG Receiving Terminal for long-term contracts

| Year | Crude Oil $/bbl | Supply Cost Mio $ | Year | Crude Oil $/bbl | Supply Cost Mio $ | Year | Crude Oil $/bbl | Supply Cost Mio $ |
|------|----------------|-------------------|------|----------------|-------------------|------|----------------|-------------------|
| 2019 | 56.3           | 71.63             | 2026 | 87.5           | 468.16            | 2033 | 97.2           | 515.62            |
| 2020 | 70.0           | 383.97            | 2027 | 88.7           | 473.79            | 2034 | 98.7           | 524.78            |
| 2021 | 77.4           | 418.96            | 2028 | 90.3           | 481.60            | 2035 | 99.9           | 530.11            |
| 2022 | 80.5           | 434.02            | 2029 | 91.8           | 490.26            | 2036 | 100.3          | 532.24            |
| 2023 | 82.9           | 445.35            | 2030 | 92.8           | 495.06            | 2037 | 102.8          | 543.86            |
| 2024 | 84.5           | 454.18            | 2031 | 94.9           | 504.73            | 2038 | 103.9          | 549.29            |
| 2025 | 85.7           | 459.79            | 2032 | 95.8           | 509.32            |      |                |                   |
4. Conclusion
The minimum gas supply costs are obtained under the direct supply scenario of the domestic liquefaction plant plus the supply from abroad liquefaction plant. This is because the uncommitted capacity of the domestic liquefaction plant is not able to meet the gas requirements for PLTGU Jawa-3. The minimum gas supply cost is obtained with the following supply combinations:

- Bontang liquefaction plant: gas shipments of 15.79 Bcf or 40% supply and shipped 12 times per year;
- Tangguh liquefaction plant: gas shipments of 11.84 Bcf or 30% supply and shipped 9 times per year;
- Bintulu liquefaction plant: gas shipments of 11.84 Bcf or 30% supply and shipped 9 times per year.

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