Technology selection of LNG receiving terminals in Gresik, East Java

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Abstract. Java, the centre of industry in Indonesia, needs fuel gas supplies to maintain production continuity. The addition of gas infrastructures in the form of Liquefied Natural Gas (LNG) receiving terminals can be an alternative to secure gas supplies. Such a terminal is planned to be built in Gresik, East Java. This paper aims to examine the most appropriate technology for LNG receiving terminals to be built in East Java by considering both technical and economic aspects. In this research, LNG receiving technology was selected based on the terminal location and selection of the regasification technology using the method Analytic Hierarchy Process. Moreover, economic and sensitivity analyses were also performed. Research findings suggest the land-based LNG receiving terminal with regasification technology in the form of shell and tube vaporizers as the most suitable LNG receiving terminal in Gresik, East Java. Land-based LNG receiving terminal establishment in Gresik, East Java is feasible as regasification costs 0.468 USD/MMBTU, the Net Present Value (NPV) amounts to 31943500 USD, the Internal Rate of Return (IRR) reaches 19.25%, the Benefit-Cost (BC) Ratio equals 1.23, and the Payback Period (PBP) is 3.4 years. The throughput required by the power plant generates the greatest sensitivity to IRR.

1. Introduction
The availability of natural gas for industrial fuel needs in Java as the centre for industry in Indonesia is an absolute requirement to maintain fuel gas supplies in order that production activities continue. In 2013 to 2028 there was an imbalance between natural gas supplies and demands, especially in East Java and Bali [1]. It is imperative to increase the number of gas infrastructures in the form of Liquefied Natural Gas (LNG) receiving terminals in order to maintain security of natural gas supplies.

This paper intends to examine the appropriate technology to be applied to the LNG receiving terminals to be built in East Java by taking the technical aspect and the economic aspect into account. The LNG receiving terminals to be selected are the land-based LNG receiving terminal (fixed onshore facility), the gravity-based structure LNG receiving terminal (concrete structure near the beach), and FSRU (Floating Storage Regasification Unit). As for regasification technology, those LNG receiving terminals will adopt Open Rack Vaporizer (ORV), Submerged Combustion Vaporizer (SCV), Shell and Tube Vaporizer (STV), Intermediate Fluid Vaporizer (IFV), and Ambient Air Vaporizer (AAV).

In this research, the LNG receiving technology was selected based on the location of the terminal and selection of the regasification technology using the method Analytic Hierarchy Process. The Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision Making System that was developed by Thomas L. Saaty in the 1970s [2]. This procedure has been widely applied in decision making. AHP
was used as a method to choose warehouse location, to choose an optimal corporate maintenance strategy and to make decisions about reverse logistics plans [3-5]. This decision support model will describe complex multi-criteria problems in a hierarchical arrangement. A hierarchy is defined as the representation of complex problems in a multi-level structure where the first level constitutes the goal, followed by the levels factors, criteria, sub-criteria, and so on up to the last level of alternatives [6].

2. Methods
The steps taken in this research were selecting technology for LNG receiving terminals as shown in Figure 1, that were comprised of: determining the case study, collecting technical data and data on the location for LNG receiving terminal construction in Gresik, selecting LNG receiving terminals based on location, selecting regasification technology, selecting scenarios and calculating sizes of the equipment, undertaking economic calculation and sensitivity assessment of the LNG receiving terminals, and drawing conclusions and suggestions.

![Figure 1. Research flow chart.](image_url)
on location, selecting regasification technology, selecting scenarios and calculating sizes of the equipment, undertaking economic calculation and sensitivity assessment of the LNG receiving terminals, and drawing conclusions and suggestions.

2.1. Analytic Hierarchy Process
The Analytic Hierarchy Process (AHP) method is used to select the LNG receiving terminal and regasification technology. The steps in the Analytic Hierarchy Process method are as follows: Defining the problem and the goal, Identifying the decision criteria, sub criteria and alternatives, Developing pairwise comparison matrices (the nine scale pairwise comparison is presented in Table 1) and calculating the eigenvalue and eigenvector and the consistency ratio of each pairwise comparison [6]. In the analytic hierarchy process, the construction of judgment matrix is the key in the whole analysis process, which determines the success or failure of the analysis process [7].

| Intensity of Importance of an Absolute Scale | Definition | Explanation |
|---------------------------------------------|------------|-------------|
| 1 Equal importance                          | Two activities contribute equally to the objective |
| 3 Moderate importance                       | Experience and judgement slightly favour one activity over another |
| 5 Strong importance                         | Experience and judgement strongly favour one activity over another |
| 7 Very strong or demonstrated importance     | An activity is favoured very strongly over another; its dominance demonstrated in practice |
| 9 Extreme importance                        | The evidence favouring one activity over another is of the highest possible order of affirmation |
| 2, 4, 6, 8 Intermediate values between the two adjacent judgements |

Table 2. Random index

| n   | RI  |
|-----|-----|
| 3   | 0.58|
| 4   | 0.9 |
| 5   | 1.12|
| 6   | 1.24|
| 7   | 1.32|
| 8   | 0.141|
| 9   | 1.45|
| 10  | 1.49|

The pairwise comparison matrix with n criteria is a nxn square matrix A, whose element $a_{ij}$ is the value of the comparison of $i^{th}$ over $j^{th}$ criteria, while the value of reverse comparison is denoted by $1/a_{ij}$. Matrix W is then constructed by dividing each column of matrix A by its column sum. The principle eigenvalue of the matrix ($\lambda_{max}$) is then calculated using the following equation:

$$AW = \lambda_{max}W$$

AHP assesses consistency from various aspects using a consistency ratio. The consistency ratio has to be less than 10 percent, otherwise the assessment needs to be revised [8]. The consistency ratio (CR) of each pairwise comparison is then calculated as:

$$CR = CI/RI$$

$$CI = (\lambda_{max} - n) / (n - 1)$$

Where CI is the consistency index and RI is the random index (see Table 2) [8]. The comparison is considered to have satisfactory consistency if $CR \leq 0.1$. 

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In the decision making process using the AHP method, the data to be processed consists of two types, namely quantitative data and qualitative data. The data is combined so that it can be used to calculate parameter assessments. Therefore, the quantitative data is changed to preference degree to simplify the calculation process. For all benefit attributes, the preference degree can be determined as follows:

\[ P_{rk} = \frac{2(V_{rk} - V_{k\min})}{(V_{k\max} - V_{k\min})} - 1 \]  
(4)

For all cost attributes, the preference degree can be determined as follows:

\[ P_{rk} = \frac{2(V_{k\max} - V_{rk})}{(V_{k\max} - V_{k\min})} - 1 \]  
(5)

Where \( P_{rk} \) is the preference degree, \( V_{rk} \) is the attribute values for the alternatives are calculated, \( V_{k\min} \) is the minimum attribute value from alternative, \( V_{k\max} \) is the maximum attribute value from alternative, \( r \) is the number of alternatives, \( k \) is the number of quantitative attributes. After obtaining a preference degree, entropy is calculated using a formula:

\[ \text{Entropy} = -\frac{1}{\ln(m)} \sum_{i=1}^{m} Y_i \ln(Y_i) \]  
(6)

Where \( m \) is the number of alternatives, and \( Y_i = \) preference degree value.

2.2. Analysis technical aspect

2.2.1. LNG receiving terminal. The type of LNG receiving terminal or alternative chosen is land based LNG receiving terminal, gravity based LNG receiving terminal, FSRU LNG receiving terminal. Data related to LNG receiving terminal technology consists of qualitative and quantitative data. Quantitative data can be divided into two types of attributes, namely cost attributes and benefit attributes. Cost attributes are all attributes that give effect to generating costs in the selection process. Otherwise, benefit attributes are all attributes that give a beneficial effect in the selection process. In this case the benefit attribute is the depth of the water because the greater the value the shorter the distance between the jetty and the terminal. While other parameters include the cost attribute. The quantitative data is converted into a preference degree to simplify the calculation process. Entropy calculation is done after obtaining a preference degree.

2.2.2. Technology of regasification. Data collected related to regasification technology is capital expenditure, operational expenses, operations and maintenance, environment, safety, limited conditions. This data is obtained from literature studies. The alternative chosen is an open rack vaporizer, intermediate fluid vaporizer, submerged combustion vaporizer, shell and tube vaporizer, ambient air vaporizer. Furthermore, the selection of regasification technology is carried out using the AHP method as is done when selecting LNG receiving terminal technology.

2.3. Economic calculation

After designing equipment specifications using process modeling software, economic calculations are carried out by estimating the total value of capital investment, estimating operational costs, calculating project feasibility. In this research, Guthrie’s method was used to estimate the value of total capital investment. The Guthrie method is done by determining the Free On Board (FOB) of each equipment. FOB is the price of equipment plus the cost of transportation to the port in the country producing the equipment. The price of the equipment FOB is multiplied by the bare module. Bare module is a comparison of other costs such as piping, instrumentation, concrete, and other costs against FOB. Multiplication between FOB and total bare module factor for each tool, each added to obtain a total fixed capital investment. Land, office, working capital costs are determined based on the ratio of fixed capital investment. The sum of all fixed capital investments and other costs will be the total capital investment. Total capital investment consists of fixed capital investment and variable costs.

\[ C_{TIC} = 1.18 \ (C_{TBM} + C_{site} + C_{buildings} + C_{offsite}) + C_{WC} \]  
(7)
Where $C_{TCI}$ is total capital investment cost, $C_{TBM}$ is total bare module cost, $C_{site}$ is site development cost, $C_{building}$ is building cost, $C_{wcap}$ is working capital cost approximately 15% $C_{TCI}$.

To get the total bare module cost, it is necessary to calculate the bare module cost component. The calculation is done using the following formulas, proposed by Meyers & Kime [9]:

- **Tank**

  $$C_T = F_M \exp[11.662 + 0.6104(\ln V) + 0.04536(\ln V)^2]$$  
  \hspace{1cm} (8)

  Where $V$ is tank volume, $F_m$ is 3.25 for stainless steel 314

- **Heat Exchanger**

  $$C = f_d f_m f_b C_b$$  
  \hspace{1cm} (9)

  $$C_b = \exp[8.821-0.30863(\ln A) + 0.0681(\ln A)^2]$$  
  \hspace{1cm} (10)

  $$f_d = \exp[-1.1156+0.9096(\ln A)] \text{ for fixed head}$$  
  \hspace{1cm} (11)

  $$f_m = 1.0305 + 0.07140(\ln A), \text{ pressure range = 300-600 psig}$$  
  \hspace{1cm} (12)

  $$f_m = 0.8603+0.23296(\ln A), \text{ SS316}$$  
  \hspace{1cm} (13)

  Where $A$ is Area, ft$^2$

- **Pump**

  $$C = F_M F_T C_b$$  
  \hspace{1cm} (14)

  $$F_M = 2 \text{ (SS 304 or 316)}$$  
  \hspace{1cm} (15)

  $$F_T = \exp[b_1 + b_2(\ln QH^{0.5}) + b_3(\ln QH^{0.5})^2]$$  
  \hspace{1cm} (16)

  $$C_b = 1.55 \exp[8.833-0.6019(\ln QH^{0.5}) + 0.0519(\ln QH^{0.5})^2]$$  
  \hspace{1cm} (17)

  Where $Q$ is flow, $H$ is head

After the investment costs are obtained, then an economic analysis calculation is performed to see whether the design of the regasification unit has been made economically feasible or not. The calculation is done by calculating the NPV value, IRR, payback period. In this study, the sensitivity analysis is done to see the effect of a cost component on the economic value of a factory. The analysis is done by changing the cost component to be bigger or smaller then comparing with changes in economic value.

The economic value used for sensitivity analysis can be IRR, NPV or payback period. In this study, sensitivity analysis will be made between the investment costs of the IRR and regasification capacity of the regasification costs.

### 3. Results and discussion

#### 3.1. Technical aspect

##### 3.1.1. Technology selection for LNG receiving terminal

This research was began with determining attributes or criteria for selection. Quantitative criteria includes the distance between the terminal and the power plant, regasification capacity, sea depth, land area, wave height, wind speed, currents. These data were obtained from Indonesia’s Meteorology Climatology and Geophysics Council. Qualitative criteria includes investment costs, safety, environmental impact, terminal flexibility, energy efficiency, and improvement to the regasification capacity obtained from literature studies. Afterwards, a pairwise comparison matrix was formulated for each alternative technology for each criterion. Then, a synthesis and normalization were carried out in such a way that the sum of all the factors was equal to 100%. The normalized factor turned into a weight. The sum of the weights multiplied generated a weighted sum factor. The consistency vector was obtained by dividing the weighted vector by its weight. The mean of consistency vectors generated a lambda. Then, this lambda was used to calculate the consistency index.

For the criterion investment costs, the calculation was undertaken by making pairwise comparison matrices. The pairwise comparison matrices of each alternative for the criterion investment costs were developed based on the scale proposed by Thomas Saaty by comparing alternatives based on Table 1. The investment costs for gravity-based LNG receiving terminals are around 20-50% of those of the

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land-based LNG receiving terminals [10]. FSRU-type LNG terminals have lower capital expenditure than that of land-based LNG receiving terminals [11]. The investment costs for gravity-based LNG receiving terminals are higher than those of FSRU-type LNG receiving terminals [12].

In relation to the criterion safety, the accident most likely to occur is a gas leak that may result in an extremely dangerous fire given the location of the LNG receiving terminals that is very vulnerable to explosion. The flash fire envelope of offshore terminals reaches 4000 m while that of onshore terminals reaches 2000 m [13]. This suggests that land-based LNG receiving terminals have a flash fire envelope range that is relatively lower than those of gravity-based LNG receiving terminals and FSRU-type LNG receiving terminals.

For the criterion environmental impact, FSRU uses boil-off gases as fuels, thus eliminating the risk of flare. The whole waste undergoes treatment, including chemical waste [12]. For the criterion terminal flexibility, the land-based LNG receiving terminals do not have any flexibility to move closer to the source of supplies or demands. Conversely, the FSRU-type LNG receiving terminals can move to approach the source of supplies or demands. Similar to the FSRU-type LNG receiving terminals, the gravity-based LNG receiving terminals can also be relocated but are relatively more difficult.

In terms of the criterion improvement to the regasification capacity, it remains feasible to increase the regasification capacity of the land-based LNG receiving terminals since they have a wider area compared to the gravity-based LNG receiving terminals and the FSRU-type LNG receiving terminals. The addition of vaporizers and tanks can be done to the land-based LNG receiving terminals. For the criterion energy efficiency, the addition of power plants and use of waste heat to make LNG evaporates can improve efficiency of the overall system [14]. After comparing each criterion based on the scale in Table 1, a synthesis and normalization were then carried out to calculate the weight and consistency. The consistency ratio generated was less than 0.1, meaning that the resulting calculation can be accepted. Then, matrix values were compared for each criterion with the following description: A = investment costs, B = safety, C = environmental impact, D = location-related flexibility, E = capacity improvement, and F = energy efficiency. Afterwards, a comparison was made for each criterion to determine which criterion has the greatest weight using the method Analytic Hierarchy Process.

Quantitative criteria includes the distance between the terminal and the power plant, regasification capacity, sea depth, land area, wave height, wind speed, currents, were calculated by converting quantitative data into degrees of preference then the entropy is calculated. This entropy is summarized with the results of qualitative comparisons of paired data. Because entropy of results is zero, it does not change the results of qualitative data. The sum of the quantitative data and the qualitative data was calculated as shown in Table 3. Based on the table, it is revealed that, compared to the other alternatives, land-based LNG receiving terminals are more compatible to be applied in Gresik, East Java because the highest value is 0.4.

| Factor | Weight | Land-Based | Gravity-Based | FSRU |
|--------|--------|------------|---------------|------|
| A      | 0.16   | 0.11       | 0.26          | 0.63 |
| B      | 0.30   | 0.59       | 0.25          | 0.16 |
| C      | 0.30   | 0.25       | 0.16          | 0.59 |
| D      | 0.04   | 0.14       | 0.09          | 0.77 |
| E      | 0.07   | 0.70       | 0.18          | 0.11 |
| F      | 0.13   | 0.59       | 0.25          | 0.16 |
| Total  | 0.40   | **0.21**   | **0.39**      |      |

3.1.2. Technology selection for regasification technology. This research was began with determining attributes or criteria for selection. The attributes chosen included: capital expenditure, operational expenditure, operation and maintenance (O & M), environmental impact, safety, and limitation. As for
the alternatives to be chosen were: open rack vaporizer, submerged combustion vaporizer, shell and tube vaporizer, intermediate fluid vaporizer, and ambient air vaporizer. The method adopted in the selection of regasification technology was Analytic Hierarchy Process.

Submerged Combustion Vaporizer, Shell and Tube Vaporizer, and Intermediate Fluid Vaporizer have lower capital expenditure compared to Open Rack Vaporizer. While Ambient Air Vaporizer has the highest capital expenditure (Tractebel Engineering SA, 2015). For the criterion operational expenditure, SCV has the highest operational expenditure compared to STV, IFV, and ORV. As for AAV, it has almost no operational expenditure [15]. The ways SCV are operated are more complex than the other types of vaporizer as it requires a balance between fuels and waste heat, and coordination with the department in charge of factory operations. ORV is simpler because it only requires additional sea water pumps and filtering systems [16].

AAV does not have any significant impact on the environment except fog. While ORV, SCV, STV, and IFV affect marine life [16]. In relation to the criterion safety, hydrocarbon leakage in ORV and AAV is discharged into the atmosphere at the lowest level, while in SCV, STV, and IFV, it is removed through a vessel [16]. For the criterion operating limitation, AAV’s performance depends on the weather [17]. Seawater temperature suitable for the operation of ORV is above 5° C [16]. For the criterion resume, environmental impact, safety, and operating limitation take priority. In the recapitulation of criteria, the value of CR <0.1 was generated, meaning that the calculation can be accepted. After collecting all the data, the sum was calculated as shown in Table 4.

Based on Table 4, it is revealed that the vaporizer technology chosen is the Shell and Tube Vaporizer that is deemed to be compatible to be applied in Gresik, East Java as it generated the highest value compared to the other alternatives. The advantage of using this vaporizer is that it is relatively more environmentally friendly and safer. In conclusion, selection of technology using Analytic Hierarchy Process chose land-based LNG receiving terminals as location-based terminal technology, and the shell and tube vaporizer as regasification technology.

Table 4. Cumulative value results.

| Factors          | Weight | ORV | SCV | STV | IFV | AAV |
|------------------|--------|-----|-----|-----|-----|-----|
| Capital Expenditure | 0.10   | 0.12| 0.41| 0.21| 0.21| 0.05|
| Operational Expenditure | 0.10  | 0.27| 0.11| 0.11| 0.11| 0.41|
| O&M              | 0.06   | 0.41| 0.11| 0.23| 0.11| 0.14|
| Environment      | 0.24   | 0.09| 0.09| 0.32| 0.18| 0.32|
| Safety           | 0.24   | 0.09| 0.18| 0.32| 0.32| 0.09|
| Limitation       | 0.24   | 0.09| 0.18| 0.32| 0.32| 0.09|
|                   |        |    |     |     | 0.13| 0.17|
|                   |        |    |     |     | 0.28| 0.24|
|                   |        |    |     |     | 0.18|     |

3.2. Capital expenditure and operational expenditure calculation

The method develop by Meyers & Kime can be used as an approach to capital expenditure calculation [9]. Specifications and capital expenditure are calculated for each equipment. Then, the total bare module cost is obtained. The total bare module costs generated are shown in Table 5.

If capital costs amount to 10%, life time is 20 years, and the regasification capacity is equal to 0.92 MTPA, then CRF is equal to 0.117. The capital expenditure of regasification amounts to 0.45 USD/MMBTU. The operational expenditure is equal to 4% of the capital expenditure, thus the operational and maintenance costs are 0.018 USD/MMBTU. Based on results of the calculation, it is revealed that regasification costs 0.468 USD/MMBTU. This amount is still reasonable as regasification usually costs less than 1 USD/MMBTU.
Table 5. Total bare module cost.

| Equipment                  | Total cost (USD) |
|---------------------------|------------------|
| LNG storage tank          | 80508566.44      |
| Shell and tube vaporizer  | 1949615.37       |
| LNG pump                  | 1790099.28       |
| Sea water pump            | 1199295.31       |
| **TOTAL**                 | **85447576.40**  |

Table 6. Total capital investment.

| Equipment                  | Total cost (USD) |
|---------------------------|------------------|
| C total bare module       | 85447576.40      |
| C site                    | 5126854.58       |
| C building                | 4272378.82       |
| C offsite                 | 4272378.82       |
| C contingency             | 8554757.64       |
| C contractor fee          | 1708951.53       |
| C working capital         | 8554757.64       |
| C land                    | 17089515.28      |
| C port                    | 1708951.53       |
| **TOTAL**                 | **136716122.20** |

3.3. Economic calculation and sensitivity

The installed capacity of the power plant is 800 MW. The power plant capacity factor is 70%. Specific fuel consumption is 0.01 MSCF/KWh. The cost for investment in LNG receiving terminals amounts to 136,716,122.20 USD. Regasification costs 0.468 USD/MMBTU. Revenues are calculated by firstly calculating the throughput needed by the power plant. The throughput required by the power plant is equal to 134.4 BBTUD and therefore the revenues amount to 22,958,208 USD. In this calculation, the financing scheme is 30% for government’s company and 70% for private companies. Calculating the cash flow, NPV amounting to 31,943,500 USD is obtained. Because the NPV is positive, it indicates that the project makes more money than the amount needed to pay off debts. From the cash flow calculation, IRR of 19.25% is generated. A positive IRR implies that this project is feasible.

![Figure 2](image-url) (a) Throughput sensitivity required by power plants and sensitivity of investment costs to IRR. (b) Sensitivity of the financing scheme to IRR.
The resulting BC Ratio is equal to 1.23. The benefit is greater than the cost, making this project worth doing. Calculation results show that the payback period is 3.4 years, meaning that the whole sum of money invested will be paid back after a lapse of 3.4 years. Sensitivity calculation aims to determine the change in results if the parameters are changed. In this case, sensitivity calculation carried out was the change in the throughput required by the power plant in connection with IRR, the effect of changes in investment costs on IRR, and the effect of changes in the funding scheme on IRR. Sensitivity was measured by setting changes in the throughput required by the power plant and investment costs were set at 50%, 100%, and 150%.

Based on Figure 2.a, it is evident that the greater the throughput needed by the power plant is, the greater IRR is. Revenues increase, which in turn result in an improved ability to repay loans. Moreover, changes in investment costs do not significantly affect IRR. Sensitivity measurement was performed by making adjustments to changes in the financing scheme, which were set to be at 20% (government): 80% (private), 30% (government): 70% (private), 40% (government): 60% (private), and 50% (government): 50% (private). From Figure 2.b, it can be seen that the smaller the portion of the financing scheme is for government’s company, the relatively larger IRR is. In fact, the difference in IRR between they each is relatively small, thus leading to the conclusion that it does have an effect but the resulting effect is minor.

4. Conclusion
Research findings suggest the land-based LNG receiving terminal with regasification technology in the form of shell and tube vaporizers as the type of LNG receiving terminal most suitable to be built in Gresik, East Java. The establishment of a land-based LNG receiving terminal in Gresik, East Java is feasible as regasification costs 0.468 USD/MMBTU, NPV amounts to 31943500 USD, IRR reaches 19.25%, the BC Ratio is equal to 1.23, and PBP is 3.4 years. The throughput required by the power plant generates the greatest sensitivity to IRR.

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