A Gas Infrastructure Pathways in East Java Using System Dynamic Approach

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Abstract. As a developing country, Indonesia has been consuming energy with 114 Million Ton Oil Equivalent (MTOE) and estimated that the demand for energy will increase up to 167.4 MTOE in 2050 by Indonesian Energy Ministry. It is also estimated that natural gas will play the role in fulfilling the energy demand in Indonesia. However, in utilizing the natural gas spread of the regions, Indonesia still lack of natural gas infrastructures. As natural gas infrastructures are playing a vital role on those problems, the condition of supply demand, capacity of infrastructure and the effectiveness of the route need to be adjusted and considered. In this study, system dynamic method is employed in order to forecast the supply and demand of natural gas in East Java Province. In addition, a simulation is carried out to optimize and simulate the scenario model of the natural gas infrastructure at certain time-year period. With the constraint and condition given to the system dynamics, a supply-demand condition in East Java area that mainly comes from electrical power generation, industry and household is assessed. Based on developed scenarios, the model is expected to fulfill the needs of natural gas in East Java. The possibility of establishing new LNG terminal in certain location or expanding the capacity of existing facilities are also considered in this study.

1. Introduction

Energy has become the most crucial element for every sector in human life for the last decades. Industries (Power Plant, Construction, Other Industries), Transportation, and Household are several core sectors that consume big amount of energy. Based on International Energy Agency (IEA), up until 2030 energy demanded by the world increase to 45% or 1.6% per year. In Indonesia for instance, in 2018 the total consumption of energy (without traditional biomass) is about 114 Million Tonnes Oil Equivalent (MTOE) with 40% on transportation sector, 36% on industrial sector, 16% on household sector, 6% for commercial, and 2% for other sector according to Indonesia’s Ministry of Energy [1], while in 2030 they forecasted that the total energy need will be around 200 MTOE. As we can conclude that the total need of world energy is increase significantly, the source of energy has been produced by many means of form. In Indonesia, the energy sources are form in oil, natural gas, coal and renewable energy sources. In 2050, Indonesia government has set a foresight that Natural Gas will be the biggest source energy (not including renewable energy) with 167.4 MTOE three times bigger than Indonesia can produce in 2018.

Natural Gas (NG) is a gas that came out from earth that contain methane as its main ingredient. This source of energy has been known as the cleanest, safest, and handiness. It has unique characteristics such as colorless, odorless and non-toxic. The use of natural gas is quite advantageous
because it has the lowest point in term of emission per released joule of energy comparing to other fossil fuel. About 20% of CO₂ dropped and 80% for NOₓ. Other point that contributing NG popularity is the price of produced energy. The cost includes not the only cost of the main gas but also the cost of the technology needed as well as the cost for other things necessary such as subsequent minimization of environmental impact, ecological fees and carbon credits. Additional point that our country, Indonesia, has is the quite excessively amount of natural gas resource, 142.71 trillion standard cubic feet (TSCF) and stated as the largest reserves in Southeast Asia. As the world demand big amount of gas to fulfil the energy needed, transporting this form of energy become the world spotlight. Many form and way of transporting this energy has been developed in the last several decades, contributing the worldwide demand for NG. Directly transferred with fixed network pipeline, compressing, and liquifying are several methods in transporting this form of energy. In Indonesia, directly and liquify method is quite prevalent with this matter, with 1.2 TSCF of export from total of 2.9 TSCF of production in 2018, was transferred using those two methods.

With the demand of NG in the form of LNG, the supply cannot always supply the amount needed. In Indonesia, even as government has stop the export of NG in any form gradually until 2035, it does not mean that the demand of domestic use in Indonesia will fulfilled completely. It sad to be said that despite the great amount of NG that Indonesia has, Indonesia has been forecasted that there will be no more new gas reservoir in 50 years. With 5.6% of economic growth as 2045 Indonesia’s vision see and 0.7% as Bappenas foresight in 2045, hard-dense scenario and optimization must be well planned, especially in big with superfast growth region such as East Java.

Blessing with many good resources of gas, WMO, Saka, and many others, East Java has the absence of data and strategy in overcoming future problems regarding supply - demand unmatch, especially in infrastructure condition. To overcome the condition and meet the needs, it is necessary to have the optimum scheme on natural gas distribution. In order to have an accurate solution, any historical and forecast data will be obtained and analysed, then the scenario will be simulated.

2. Methodology
In this study there are several scopes of discussion, the first is supply and demand condition in the current year. The supply and demand condition are needed in order to model the real condition in the real-world situation. After the model is built, a system dynamic simulation will be done. This system dynamic simulation aimed is to analyse the current and upcoming supply fulfilment and optimization.

2.1. System Dynamic.
System Dynamic is method that fits to determine a feedback behaviour of complex model that represent a real-world system which in each element is affected to the other. This system characteristic can cover the gap from previous method such linear model like regression with its circular structure. A group of researchers[2] did a research about natural gas supply and demand in China and the result is China have a gradually enlargement of demand condition which lead to a recommendation to increase the gas supply.

In other study, a policy analysis and fulfilment scenarios can be obtained by modeling the desired system using system dynamics. F. Daneshzand and others[3] analyzed the future natural gas supply demand condition in Iran, resulting new proposed policy regarding the export of natural gas and three scenarios to increase their effectiveness in fulfilling the gap between supply and demand. In more recent study, system dynamic has been applied in East Java condition. Kusuma[4] forecasted the natural gas balance in East Java, finding that East Java will face a deficit in the upcoming year despite of the new Teluk Lamong LNG Terminal. In her study[4], the proposed infrastructure is not simulated yet. In this study, based on the previous research, a system dynamic is use not only for forecasting the supply and demand condition but also simulating the infrastructure fulfilment scenario.

2.2. Regression
Sarstedt [5] stated that regression analysis is one of the most frequently used tools in market research. In the most basic form, regression analysis can help the user to analyse relationships between one independent and one dependent variable. In this study case we can use the connection between the
number of certain sectors with several years that the sector has been running. The Main benefit of using regression analysis are that it can:

- Indicate if independent variables have a significant relationship with a dependent variable
- Indicate the relative strength of different independent variables effect on a dependent variable
- Make predictions.

Since this study needed to make a several predictions on several sector of demand, we can use the basic of regression by knowing the relationship between years and the increase number of several sector. the Subsets to be used in the optimization must be assessed to ensure its feasibility.

\[ y = \alpha + \beta_1 x_1 + c \]  

(1)

The Equation no 1 is the most generally equation that been used for many problems. The represent the dependent variable, which is the variable you are trying to explain. The represent the constant (called intercept) of the regression model, and indicates what your dependent variable would be if all of the independent variables were zero. The independent variable is indicated by which indicates the regression coefficient of the independent variable x. This coefficient showed us the gradient of the line and is also indicated as the slope. The last notation is called the error (residual) of the equation. This error term is commonly used in study, and some other used residual as its term.

3. Data Recapitulation and Analysis of Demand Condition

East Java is one of Indonesia province that consume gas which stand above other provinces in term of the amount of gas consumed. As a gate for eastern Indonesia side, there is no surprise that East Java region hold up many sectors of economical matter to its optimal form. This matter not only stand for domestic need but others related island too. With more than 30 million of life living in East Java region, people life become the government concern in term of energy consumed, not included the other island that sustained by East Java energy supply. From what this research can gather, the needs of gas energy consumption can be diverse into household, electrical generation, and industrial consumption.

For household, PT Perusahaan Gas Negara has established the gas distribution pipeline across some of East Java region, and East Java has been consumed the gas as their daily basis ever since. As we can see in the Figure 1, these days, only several cities in East Java that facilitated with direct gas housing pipeline while the other still consuming gas in LPG form. Those cities are Surabaya, Sidoarjo, and Mojokerto. Even though at this very moment not all cities are provided with the pipeline facilities, there is no doubt that other cities will be facilitated soon. As the need keep increase then there is no stop on developing to fulfill the supply gap. In this research, the household consumption is defined as number of gas consumed by people live in East Java that diverse in every district. The number people live in every district will converted with the gas consumption of each person can consumed. The flow of population grow will also be forecasted using certain formula to obtain the closest prediction so the consumption of each year can be correctly obtained. And the 2016 – 2020 data of East Java population is used.

As East Java has that many people live in across the area, then the electricity generation must be in an excellent form, even more so for other island that still depended on East Java electricity like Bali for instance. At this moment, most East Java electricity generation units still managed by coal energy followed by gas energy. From the government vision, gas energy will soon be the main source of electricity generation, and because of that the demand of the gas will soon increase year by year. As for Electrical Generation stated in this research defined as the value of gas consumption that been consumed per Gas Based Electrical Generation units. The data will be provided from RUPTL[6]. The research only focused on the Electrical Generation Units that located in East Java. The data is already in gas consumption unit so there is no need to convert it.

In city gas program, transportation become one of the biggest points concerned. In Surabaya, one of the biggest cities in the province, is already establishing several infrastructures for gas
transportation. We can see several gas stations across the city to provide the city needs. For now, the gas station that owned by PT Perusahaan Gas Negara is used for public transportation such as the city bus, but in the future, it might use for public use. As for transportation demand, the definition for this research regarding the transportation consumption is the value of gas consumed by every district in East Java. The number of vehicles will convert with the equivalent number of gas needed per vehicles. In this research, the vehicles are divided into car and motorcycle that existed across all districts in East Java. The flow of vehicles grow will also be forecasted using certain formula to obtain the closest prediction so the consumption of each year can be correctly obtained. For base analysis, the 2015 – 2017 data of vehicles grow from Dishub [7] is used.

Figure 1. BPH Migas Distribution Gas pipeline map

In industrial matter, there is no doubt that gas come out as the major material needed for several industry. Normally the gas will be used as the source of boiler or heater, but that not rule out other possibilities. In East Java, the industry that consumed gas is categorized in to two type of industry, there are manufactural and non-manufactural industry. Across East Java, PT Petrokimia Gresik is the biggest consumer of all other industries and still that is not stopping other industries to increase the gas consumed in the upcoming future exceedingly the government vision on the industrial expansion. As for industrial demand, the definition for this research regarding the industrial gas consumption is the value of gas consumed by industries. The data has been obtained in MMSCFD unit per industry. The flow of industrial consumption growth will also be forecasted using certain formula based on government program to obtain the closest prediction so the consumption of each year can be correctly obtained. For base analysis, the 2018 data of industrial gas consumption from BPH Migas and KESDM [8] are used.

Table 1. Demand baseline value.

| Industry          | Transportation | Household | Electrical Generation |
|-------------------|----------------|-----------|----------------------|
| 2020              | 441,4426       | 14,598    | 3,48                 | 215,6                |
From all the data that have been gathered, we can conclude as we can see in Table 1. From Industry sector we have 441,4426 MMSCFD that we obtained big industry all over East Java. For Transportation sector, we have 14,598 MMSCFD for 2 city which are Surabaya and Gresik. The location is assumed by the condition of existed Gas Station owned by PGN.

While for Household sector, we consumed about 3,48 MMSCFD that we recap from several cities that are already facilitated by several gas company in form of gas pipeline. And for the last sector which is Electrical Generation, we obtained 215,6 MMSCFD as the baseline consumption value based on government development project. For all sector we can total all the demand sector and the result is 675,1206 MMSCFD.

4. Data Recapitulation and Analysis of Supply Condition

Having a tremendous amount of gas reserves with 142.71 trillion standard cubic feet (TSCF), Indonesia still have many large gas resources that are still undeveloped such as offshore East Natuna Block which hold 49.6 TSCF based on KESDM [8]. Indonesia gas resource area has been separates in several region.

![Figure 2. Indonesia region IV supply trend][8]

As Indonesia Ministry of Energy stated, Per January 2017, East java which known as the region iv has 4.66 TSCF of gas reserves[8]. Both are proven reserves with 2.54 TSCF and 2.12 TSCF of possible reserves. The ownership of this region is dominated by Kangean Energy Indonesia with 1.48 TSCF followed by Husky with 0.9 TSCF and PHE WMO with 0.53 TSCF. The rest 1.75 TSCF is divided into many reserves and ownership such as Pertamina EP, Cepu, and many more.

Indonesia has many gas fields that has been located and produced. The location is dispersed in many regions in Indonesia. The biggest one is located in Tangguh and operated by British Petroleum. Meanwhile, in East Java, despite of not having any liquification unit, they have several gas fields that so far handled the needs on East Java and Madura regions. The fields are located in Kangean, Sampang, West Madura offshore, Brantas and many others as we can see in Table 2.
### Table 2. Current Supply Condition

| No | Company                          | Field                      | Capacity | Units  |
|----|----------------------------------|----------------------------|----------|--------|
| 1  | Kangean Energy Indonesia         | Kangean                    | 201,77   | MMSCFD |
| 2  | PHE WMO                          | West Madura Offshore       | 140      | MMSCFD |
| 3  | Husky CNOOC Madura Ltd           | Madura Strait               | 100      | MMSCFD |
| 4  | Petronas (Bukit Tua)             | Ketapang                   | 35,43    | MMSCFD |
| 5  | SANTOS                           | Sampang Offshore           | 66,04    | MMSCFD |
| 6  | SAKA Pangkah                     | Pangkah                    | 23,96    | MMSCFD |
| 7  | Pertamina EP - Poleng            | Poleng                     | 14,44    | MMSCFD |
| 8  | LAPINDO                          | Brantas                    | 13,81    | MMSCFD |
| 9  | JOB Pertamina-PetroChina East    | Tuban                      | 1,97     | MMSCFD |
|    | Total Existing Supply            |                            | 597,42   | MMSCFD |
| 1  | PHE WMO                          | West Madura Offshore       | 11,42    | MMSCFD |
| 2  | Total Project Supply             |                            | 11,42    | MMSCFD |
| 1  | PHE WMO                          | West Madura Offshore       | 19,82    | MMSCFD |
| 2  | Total Potential Supply           |                            | 19,82    | MMSCFD |
|    | **Total Supply Region 4**        |                            | 628,66   | MMSCFD |

5. Modelling Approach

5.1 Causal Loop Diagram

The causal loop diagram is a representation of a conceptualization of the system dynamics model that will be built. Through causal loop diagram, system dynamics model that will be developed, is explained by showing the causal relationship between variables entered in the model before entering the stage of model development. By showing the big picture of each relationship between variables inside the system, a causal loop diagram might show us the hypothetical result of a system that modelled with system dynamic. In this study, the causal loop was created using VENSIM software.

![Figure 3. Causal Loop Diagram](image-url)
As we see in the Figure 3 above, there are four main sectors in demand section, those are Transportation, Power Generation, Industrial and household. Each of this sector has several relationships with variables. In Transportation sector the consumption will be related to the growth of the car each year and the percentage of car which used gas as their fuel. In this case we use 5% for the percentage of car gas based from KESDM [8] and data conversion from PGN for the gas consumption.

For Power Generation sector the consumption is connected with the growth of its consumption per year. The data obtained is already usable so there is no need to use any form of conversion. In this case we use the yearly consumption from PT PLN Persero[6]. While Industrial sector the consumption is related to the consumption of each industry and its growth. We use 1,1%/year for the growth as Neraca Gas Bumi[8] and BPH Migas stated. There is no need to make a conversion because the data is already in usable unit. For the last sector, household, the consumption is related to the growth of the population, the consumption rate, and the growth of the consumption each year. We need to make certain conversion from as Artana and PGN developed[9] because the data is not in usable unit. The consumption growth is depended to the population growth which we use regression analytical. For the percentage of the household that used gas line we assume it with 5700 household for mostly all district and city which currently don’t have the gas line, in the other hand we use PGN data resource for the city that already facilitated with the gas line.

In supply section, there are 3 main factor that are affect to the final supply. Those are Domestic Production, International Import and International Export. For Domestic Production, the variable connected is the production rate from each reservoir in East Java. The data is already in a usable form so there is no need to convert it. We use Neraca Gas Bumi [8] as the data source. For International import, we assume that there is no fulfilment from outside stated source. And for International Export, as the Indonesia government state that all gas production is used for domestic need only, so there is no export in this study.

Table 3. Simulation of demand growth scenario

| Industry          | Transportation                  | Household                                      | Electrical Generation |
|-------------------|---------------------------------|------------------------------------------------|-----------------------|
| 1,1%/yr           | 5% of vehicle growth in each    | 5700 households which later changed to         | RUPTL                 |
|                   | particular area                 | percentage according to the ratio of          |                       |
|                   |                                 | population in each particular region          |                       |

By having all the connection between each element, we can conclude it into some major scenarios. By looking to Table 3, we know that all sector will growth according to each constraint and parameters that already confirmed and obtained.

5.2 Stock-Flow Diagram

After making the causal loop diagram and knowing all the connection with all variables, the next step is to make the stock and flow diagram. Stock flow diagram is a concept from system dynamics model that functioned to represent the stock and flow of certain system. In this case we use stock flow diagram to know the current condition of supply and demand in East Java. We use POWERSIM software to built the model.

As we see in Figure 4, the transformation from causal loop diagram into stock flow diagram is complete. We have 4 major demand sectors, which each sector has their own unique constraint and relation to other variables. We can see too that there is no error in the simulation diagram which indicate each relation is already in acceptable formula. So, the simulation can be done with no error.

From that figure, we see in 3 of all the demand sector we divide the demand into several sub-model. The divided area is diverse according to Eks Keresidenan area that Indonesia used to run. The objective of categorizing the area of demand is to know which area is having the greatest number of demand so in the next study, fulfilment scenario will be analysed effectively.
From Figure 4, in the supply sector, there are many gas fields that currently existed in Java and outside Java, whether its already been producing or still waiting as a project. We set the time and capacity accordingly to the source, including when it starts, when it increased its capacity and when it stops. Other than that, we also add the newest receiving infrastructure in East Java, Terminal Teluk Lamong, and set its time and capacity accordingly to the source. We also made a scenario and balancing scenario in order to see the behaviour of the system when it faced with various scenario.

Figure 4. Stock Flow Diagram

6. Result and Conclusion

Figure 5. Demand and Production Condition
From a thorough of 12 year of simulation, we obtained gas consumption number for all sector that diverse from all area, production from all field in and out East Java in MMSCFD unit. As we see from figure 5, we know that if East Java gas demand is always increasing year by year, while the production rate, they may drastically grow in the early 2022 but drop down until the end of this simulation time frame. Then we know that East Java is facing a deficit condition in almost every year from 2020 – 2032 except in for early 2022 when suddenly the production number can overcome the demand.

The district/city that consumed gas more than others are Gresik, Sidoarjo, and followed by Surabaya. Those cities consumed large amount of gas in almost every demand sector. As Industry sector (retail) is the second-most generous sector in term of gas consumption, then Gresik, become the most gas consumed city with almost 120 MMSCFD and its because of the number of big industries consisted in Gresik region as we can see in the Figure 6. Following by Sidoarjo with almost 90 MMSCFD, while Surabaya is consuming almost 10 MMSCFD at the last year of simulation for industrial sector, but beat out other area in household sector and vehicle with almost 10 MMSCFD.

Based on Figure 5, we all know that we have to deal with the deficit condition. As stated prior to the simulation, we prepare 2 ways to overcame the deficit condition. We have ‘spot market’ as our way to overcome sudden/unhandled demand and new production infrastructure such as masela and Tangguh field that will provide almost 1000 MMSCFD in the upcoming years. With so many resources available to utilize, then we make an upgrade option for Terminal Teluk Lamong with capacity up to 600 MMSCFD. With those decision we see from Figure 7. that our deficit condition is solved.
By seeing the result of simulation, and knowing Gresik, Sidoarjo, and Surabaya are the most consumable area in East Java for couple of years ahead, the development of gas infrastructure in those area is a must to prevent any under-supply condition that can cause a chaos to other close area. This result can support the project of Teluk Lamong newest LNG infrastructure because of the location and demand condition, but a further study need to be done to obtained the best result.

7. Future Study
There are various rooms for improvement in broader scope of this study. After this research is done through some studies, there are some possible points of advancement that come into thoughts upon the writing of this document regarding the future direction of this research.

• Adding multiple scenarios regarding the demand situation.
• Adding the time and complexity of the simulation.
• Make a fulfilment scenario and simulate it to know the real result.
• Make it monthly scenarios so the delivery time and delay can be calculated so the result will be more accurate.

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