Optimizing the Natural Gas Supply Chain Using Fundamental Engineering Economics Methods[1, 2]

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Abstract

Natural gas is a fossil fuel-generated deep underground containing small amounts of natural gas liquid and non-hydrocarbon gases. Due to its gaseous phase, the volume of natural gas needs to be considered in the distribution process. The capacity of natural gas reserves' production and distance from the gas field to consumer are both related to the cost of production; the smaller the gas reserves, the greater the production cost and the longer the distance the higher the cost per mmscfd.

This study will use the multi-attribute decision-making method to determine the most appropriate natural gas distribution model referring to the market priority listing. Besides that, the sensitivity analysis method will also be used in LCCA calculations to obtain the best economic parameters.

The result of this study is the highest natural gas price that can be accepted in Indonesia is US$ 6/MMBTU, and the most beneficial model for low-capacity natural gas is CNG, with the potential market that can be reached from a 300 km distance are city gas and power plant.

Keywords: Natural Gas, Gas Transportation, Value Chain, Gas Reserves, Market Clustering, Gas Pipeline, Compressed Natural Gas, Liquified Natural Gas, Sensitivity Analysis, Economic Evaluation, Multi-Attribute Decision

Introduction

"Energy is the ability to work out an action."1 If energy is seen from the source, Energy sources can be categorized as renewable or non-renewable. Renewable energy is an

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energy source that can be easily replenished, such as solar energy, geothermal energy, wind energy, biomass, and hydropower. Non-renewable energy is an energy source that cannot be easily replenished, such as hydrocarbon products, coal, and nuclear energy.

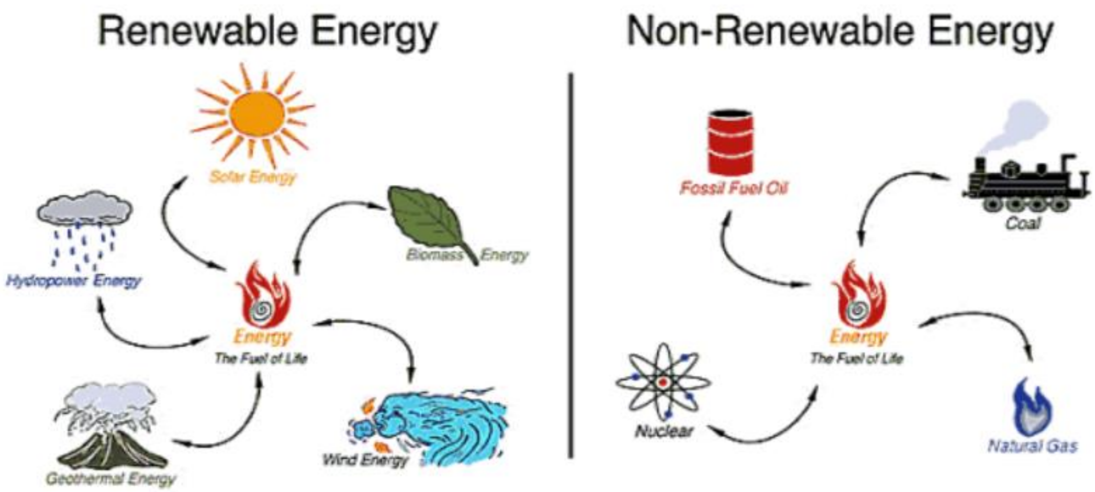

Figure 1. Renewable & non-renewable energy[2]

Global energy consumption has increased significantly since 1950; peak energy consumption in 2019 was 173,000 TWH with combined energy sources, as shown in the graph below.

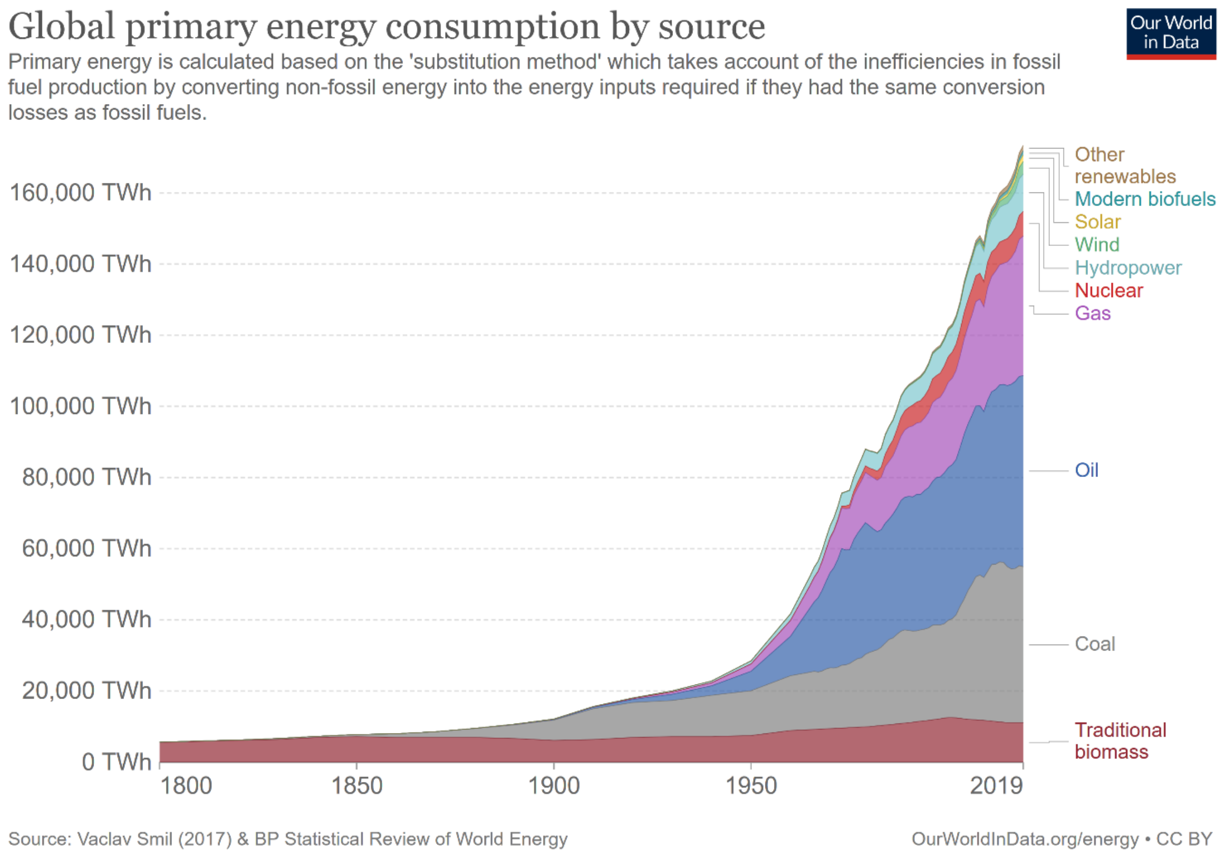

Figure 2. Global primary energy consumption by sources[3]

"Natural gas comes from reservoirs; mixed with crude oil is called associated gas, and from unmixed is called non-associated gas. Gas is separated in oil and gas collection facilities. The results are used as fuel, CNG, LPG, LNG"[4]. "After another record years, global demand for natural gas has grown until now, and driven by consumption energy for growing Asian economies, and supported by the continued development of the international gas trade." Natural gas is one of the primary energy sources in Indonesia, which has a vital role in supporting Indonesia's economic growth.

Indonesia's commitment to mitigate climate change has been strengthened by developing many policies, especially in the energy sector. Indonesia has set emission reduction and net-zero emission targets by 2060"[5]. During the transition period, natural gas can substitute dirtier fossil energy such as coal and oil before Indonesia can use renewable energy on a massive scale. "It is the cleanest burning conventional fuel, producing 45% less CO_2 emissions than coal and 30% less CO_2 emissions than oil when combusted"[6].

However, many gas reserves in Indonesia are scattered in various locations in Indonesia. The location of gas reserves is also not always close to industrial or economic centers, making it a challenge whether these gas reserves are possible to produce and can be accepted by the market at competitive prices. Moreover, natural gas, which has a much larger volume than other fossil fuels, requires special handling in determining the mode of transportation to consumers.

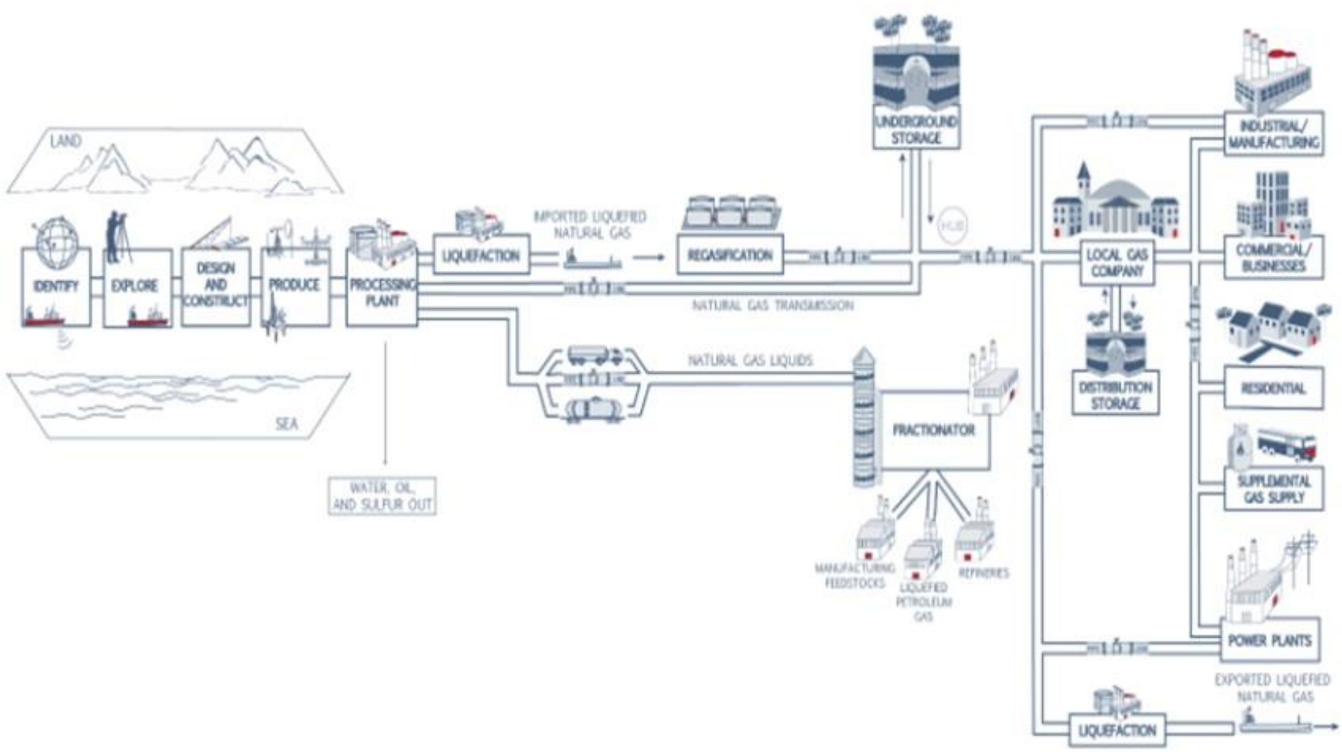

Figure 3. The natural gas supply chain[7]

The various natural gas supply chain can drive energy prices. Several factors shift the price of natural gas, including transportation modes, distance from the production site to the consumer, the natural gas content, and the capacity to be transferred to the consumer. Brito, D. L., in his paper, showed a comparison of Middle East pipelines and LNG cost transportation graphic.

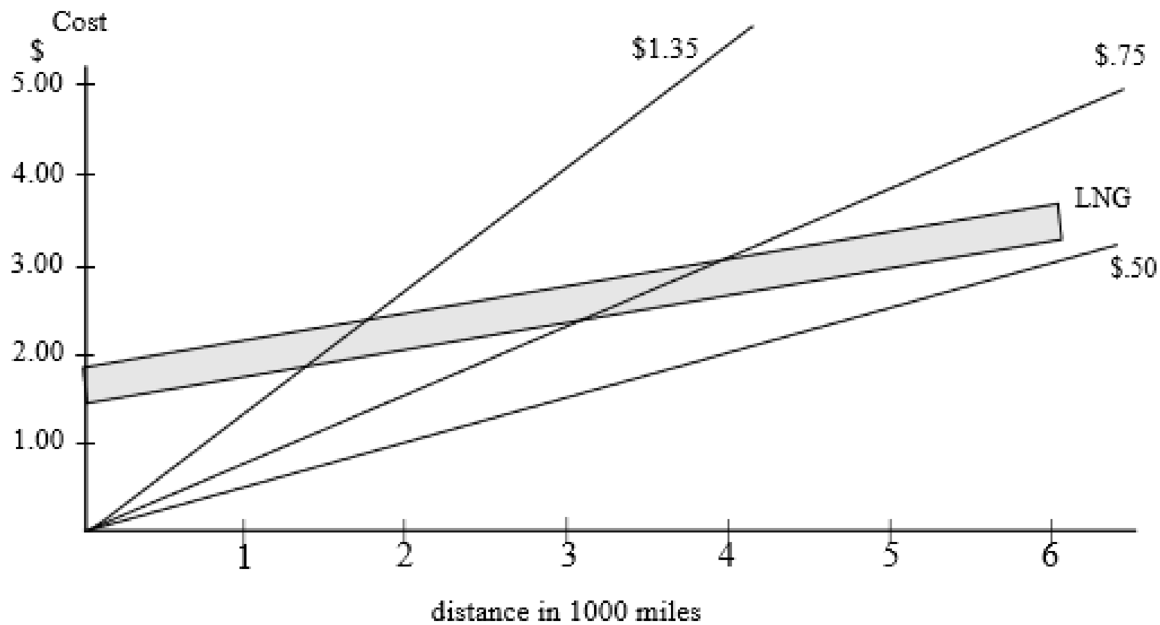

Figure 4. Comparison of pipelines and LNG cost transportation[8]

Based on the Ministry of Energy and Mineral Resources data, Indonesia's total natural gas reserves are 142.72 TSCF, 100.36 TSCF is proven reserves, and 42.36 TSCF is potential reserves[9]. The distribution of Indonesia's gas reserves is shown in the following graph:

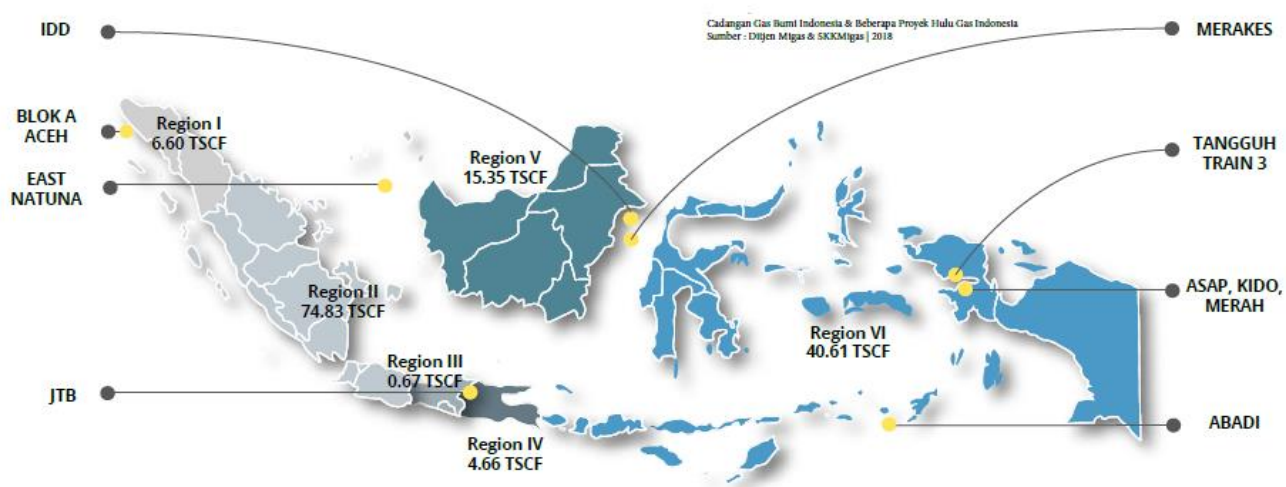

Figure 5. Indonesia gas reserves

This paper uses the island of Kalimantan as the location for a case study where based on gas balance data from the Ministry of Energy and Mineral Resources, the total gas reserves in Kalimantan are 15.35 TSCF. More specifically, data was taken from a gas field with relatively tiny gas reserves, namely the Kerendan gas field in Central Kalimantan province, with gas reserves based on exploration results of 458 BSCF"[10]. The reason for choosing this location as the object of study is that there are various gas market segments ranging from the city gas, petrochemical industry, power plant, and mining industry. The New National Capital, which is currently under construction and is targeted to start operating in 2024, is a potentially good market for city gas.

The author will discuss three main parts of this paper, namely:

1. Value chain components and drivers of the business model.
2. Market clustering in the near gas field
3. AACE class V estimate or Level 1 cost estimate for Economic valuation

"Level 1 cost estimate is intended to help management decide on several possible alternative solutions to a problem or opportunity, which might be the most cost-effective. Generally speaking, costs alone are not the determining factor but some combination of factors. For this level of the cost estimate, the most commonly used tools/techniques are Capacity Factored, Parametric Modelling, Expert Judgement, or other "Top Down" methods. There is little or no scope defined for this level of the cost estimate, and the cost estimator needs to be able to document, explain or justify a mean number with an acceptable range of accuracy between +100% to -50%"[11].

This paper will use sensitivity analysis, a financial model that determines how the target variable is affected based on changes in other variables called input variables. This model is also known as what-if or simulation analysis. Sensitivity analysis is a way to predict the outcome of a decision given different variables. Analysts can determine how variable changes affect results by creating a specific set of variables"[12]. The financial model for each scheme of gas transportation is affected by various variables, including the distance from the gas field to the consumer, transportation routes (land or sea), and production capacity, which depends on the targeted market segment.

A multi-attribute decision is another method that is used in this paper. "Multi-Attribute Decision Making where purely financial decisions alone are not sufficient, with the growing importance of Corporate Social Responsibility (CSR) and "Sustainability" more and more, we are seeing the use of MADM methods, which will be shown here using a simplistic yet effective case study and is a method everyone would be wise to master, as it is becoming the more commonly used analysis method."[13]

In this paper, the author wants to research and find answers to the following questions:

1. Potential market around gas reserves
2. The price of natural gas that each consumer is willing to accept
3. What variables affect investment & operational costs in the natural gas supply chain
4. Supply chain scenarios that meet the gas industry hurdle rate in Indonesia

Methodology

One of the essential steps that need to be done in conducting scientific research is methodology. A right and structured methodology are beneficial in doing high-quality scientific research. An illustration of the developing methodology is shown in the graphic below:

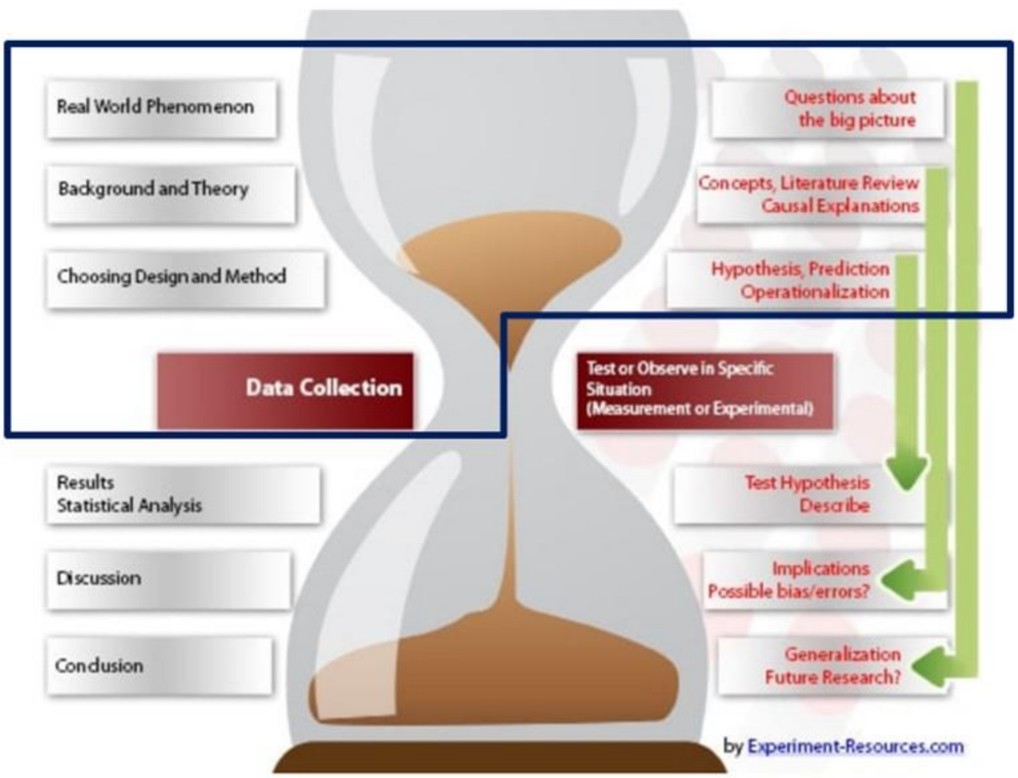

Figure 6. Steps of the Scientific Process[14]

Each methodology of scientific work must have 4 points that need to be explained in detail:

1. **Problem recognition** is a clear description of the fundamental problems found; this process is followed by the Narrowing Down the Research Paper Question stage to detail it into more core problems.
2. **Development of the Feasible Alternatives** is a verification process using other researchers to review the results by replicating the experiment and testing its validity which aims to prepare various alternative options.
3. **Development of the Outcomes and Cash Flows for each alternative** provides an entirely accurate description of the technique and equipment used to collect data.
4. **Selection of a Criterion (or Criteria)** explains how the raw data is compiled and analyzed.

Problem Recognition, Definition, and Evaluation

Natural gas is a fossil fuel-generated deep underground. Natural gas contains small amounts of natural gas liquid (NGL, also a hydrocarbon solution) and non-hydrocarbon gases such as nitrogen, carbon dioxide, hydrogen, and water vapor. Natural gas contains various compounds, and the main component of natural gas is methane, a compound with a carbon atom and four hydrogen atoms (CH4).

Due to its gaseous phase, the first problem is that the large volume of natural gas needs to be considered in the distribution process. For illustration, the conversion rate of one barrel of crude oil has the same energy as about 6,000 cubic feet of natural gas[15]. The second problem, natural gas found in each gas field has different reserves. The smaller the natural gas reserves in one gas field is a problem because the production costs are not linear with the existing gas reserves (the smaller the gas reserves, the greater the production cost per mmscfd). The third problem is that natural gas reserves that have been found need to be distributed to consumers, where the distance between the gas field and consumers varies greatly. The longer the distance from the gas field to the consumer, the higher the cost.

Based on the three main problems above, the objective of this paper is to research and find answers to the following questions:

1. Potential market around gas reserves
2. The price of natural gas that each consumer is willing to accept
3. What variables affect investment & operational costs in the natural gas supply chain
4. Supply chain scenarios that meet the gas industry hurdle rate in Indonesia.

Development of the Feasible Alternatives

A value chain is a business model that explains all activities needed to create a product or service[16]. When producing goods, a value chain comprises the steps that involve bringing a product from conception to distribution and everything in between, such as procuring raw materials, manufacturing, and marketing activities. The value chain of natural gas can be seen in the image below. (on next page)

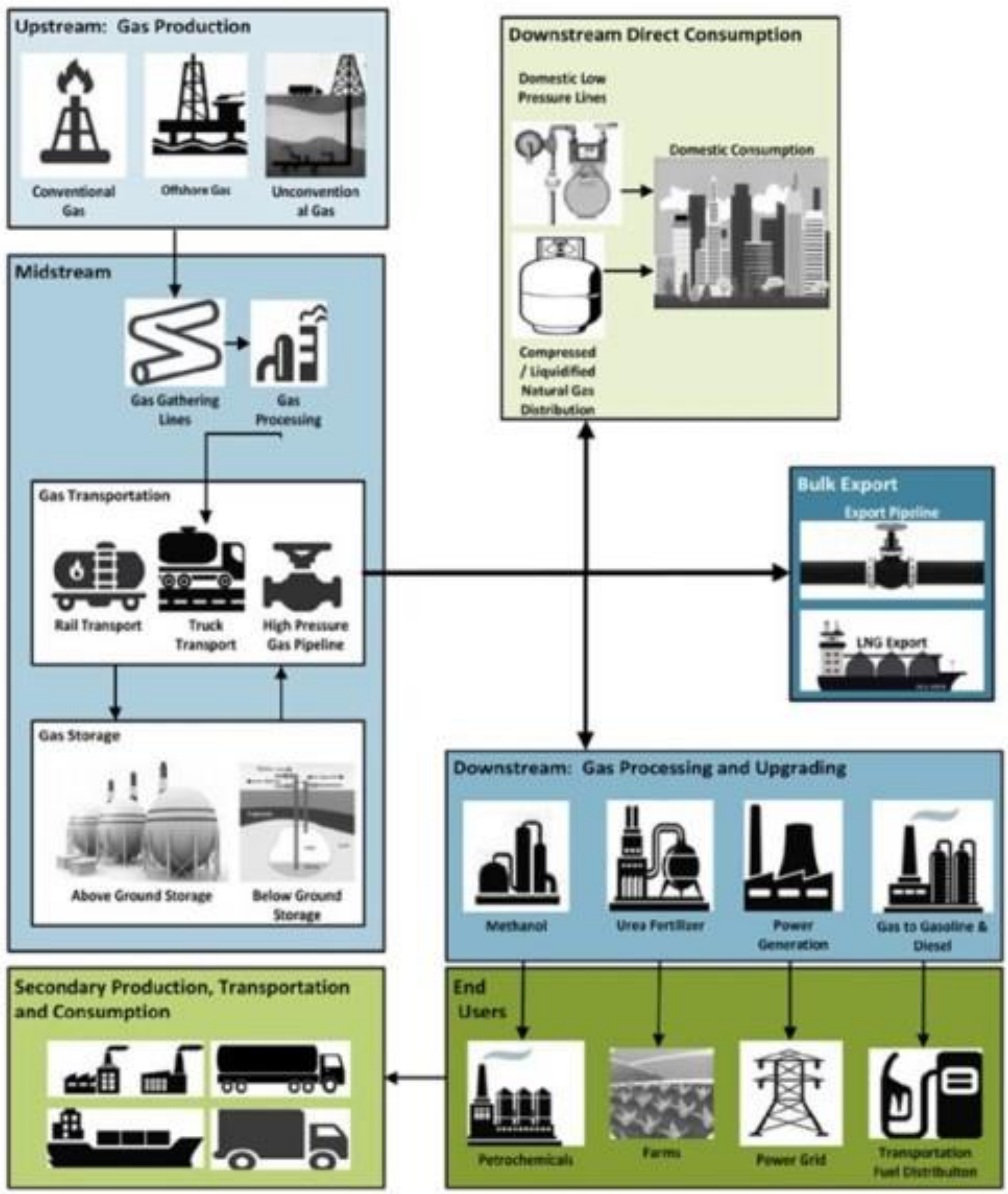

Figure 7. Value chain of natural gas[17]

Based on figure 7. We can determine aspects that affect the natural gas business:

1. Distribution

The natural gas distribution pattern is divided into the gas pipeline, LNG, and CNG.

a) Gas pipeline

Gas pipelines deliver natural gas to the consumer. Gas pipelines can be connected between regions, islands, and countries, with the ideal distance for a gas pipeline being about 0-600 nautical miles or 0.1 to 1000 km. The ideal gas flow volume is about 0 to 1000 mmscfd. Pipelines are the easiest method for natural gas distribution. But gas pipeline will be a problem if it is not connected to the pipeline around an oil and gas field. More analysis is needed to connect potential gas to existing pipelines.

b) LNG

Liquefied natural gas (LNG) is a natural gas phase that has been cooled to a liquid state at about -260^o Fahrenheit or -162^o Celcius for shipping and storage[18]. Natural gas volume in the liquid form is about 600 times smaller than its volume in the gaseous state. It is possible to transport natural gas to places pipelines do not reach using LNG. LNG distribution to consumers can use several modes of transportation, including ships, rail transport, and trucks.

c) CNG

Compressed natural gas (CNG) is natural gas compressed to high pressure to lower the volume. At standard temperature and pressure, the density of natural gas is around 0.7 kg/m^3 to 0.9 kg/m^3, depending on the composition. This compression is between 180 kg/m^3 and 215 kg/m^3[19]. CNG is generally stored in high-pressure cylinders of varying types and construction. CNG is not the same as LNG, which LNG has been turned into a liquid and must be at minus temperatures. While CNG is under higher pressure, it occupies less volume than ordinary natural gas (although it occupies more volume than LNG).

2. Market Segment

Natural gas consumers are divided into several classifications, including:

a) Petrochemical Industry
Natural gas in the petrochemical industry is divided into two uses: raw material and fuel gas. Petrochemical industries that require natural gas include fertilizer & oil refinery.

b) Power Plant
The need for natural gas in power plants is fuel for steam generators.

c) Basic Industry
The basic sector is an industrial category consisting of companies discovering, developing, and processing raw materials. This sector includes mining and metal refining companies, chemicals, and forestry products[20]. The need for natural gas in the basic industry is a source of fuel and electricity.

d) City Gas
Natural gas in the city gas cluster is used for cooking and water heaters. In Indonesia, the energy source commonly used for those activities is LPG (Liquified Petroleum Gas).

Development of the Outcomes and Cash Flows for each Alternative

After analyzing the value chain of natural gas, the expected outcome is to get The Life Cycle Cost for multiple scenarios. Life Cycle Cost Analysis (LCCA) is a method for assessing the total cost of facility ownership[21]; companies should count all costs of acquiring, owning, and disposing of. LCCA is useful when project alternatives that fulfill the exact performance requirements but differ from initial and operating costs have to be compared to select the one that maximizes net savings.[22]

In engineering practice, the term life-cycle cost is often encountered. Life cycle cost considers all the costs related to a product, structure, system, and service during its life span. The life cycle begins with identifying the economic need or want (the requirement) and ends with retirement and disposal activities. The life cycle is illustrated in Figure 8. below.

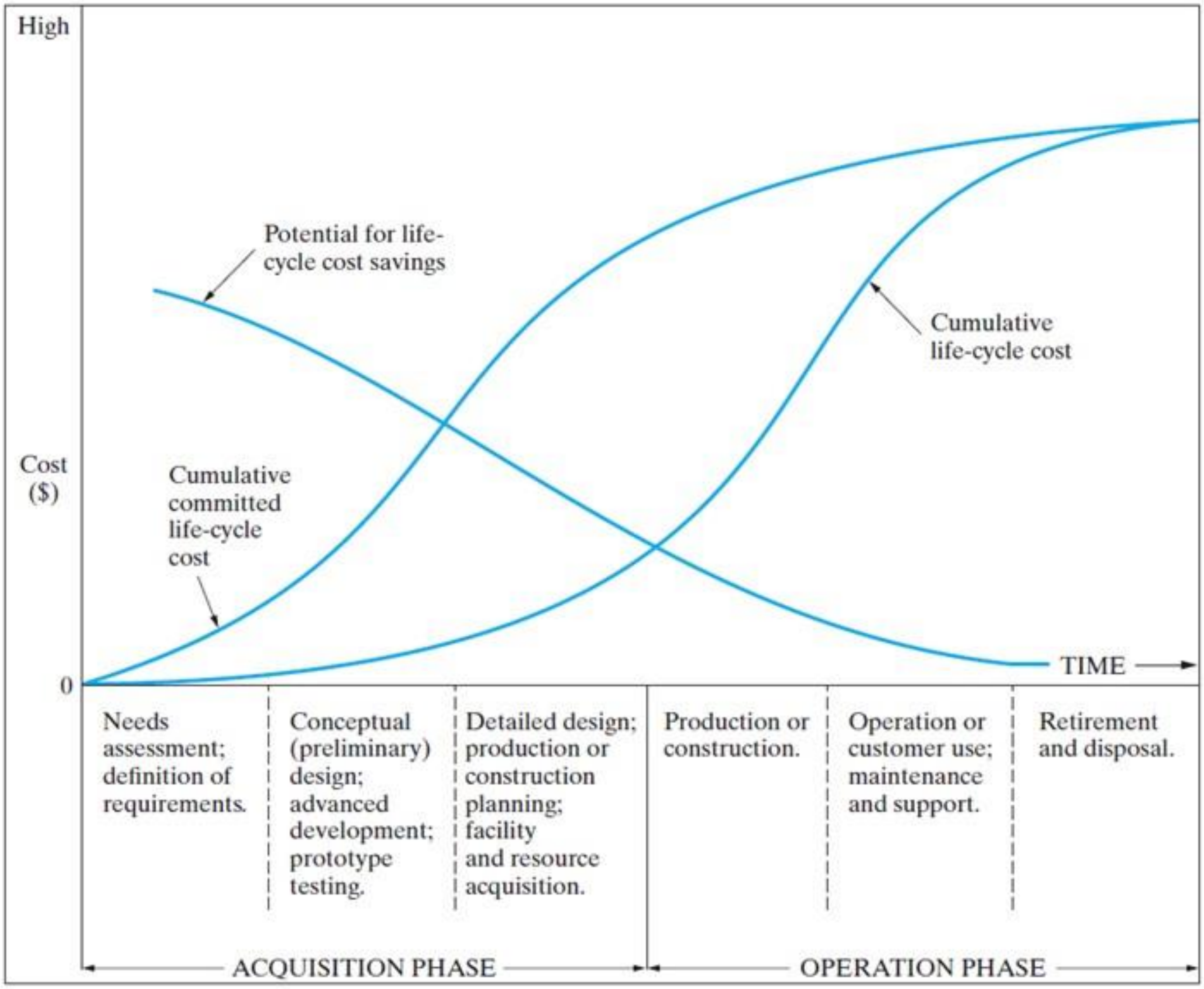

Figure 8. Life Cycle Phase and Their Relative Cost[23]

It is necessary to identify the business assets correctly before executing a project to perform a comprehensive LCCA calculation. Five categories of Organizational Business Assets are[24]:

- Physical Assets (plant, equipment, tools, etc.)
- Financial Assets (cash and near-cash instruments)
- Human Assets (people)
- Knowledge or Information Assets (proprietary designs, cost information, productivity information)
- Intangible Assets (organizations brand image or reputation)

An asset can be physical (tangible), such as cash, tools, machinery, inventory, land, and buildings, or Intangible like an enforceable claim against others, accounts receivable, copyright, patent, trademark, lease, or an assumption, such as goodwill.
Business assets that appear on the owner's balance sheet are usually categorized by their ease of cash conversion.

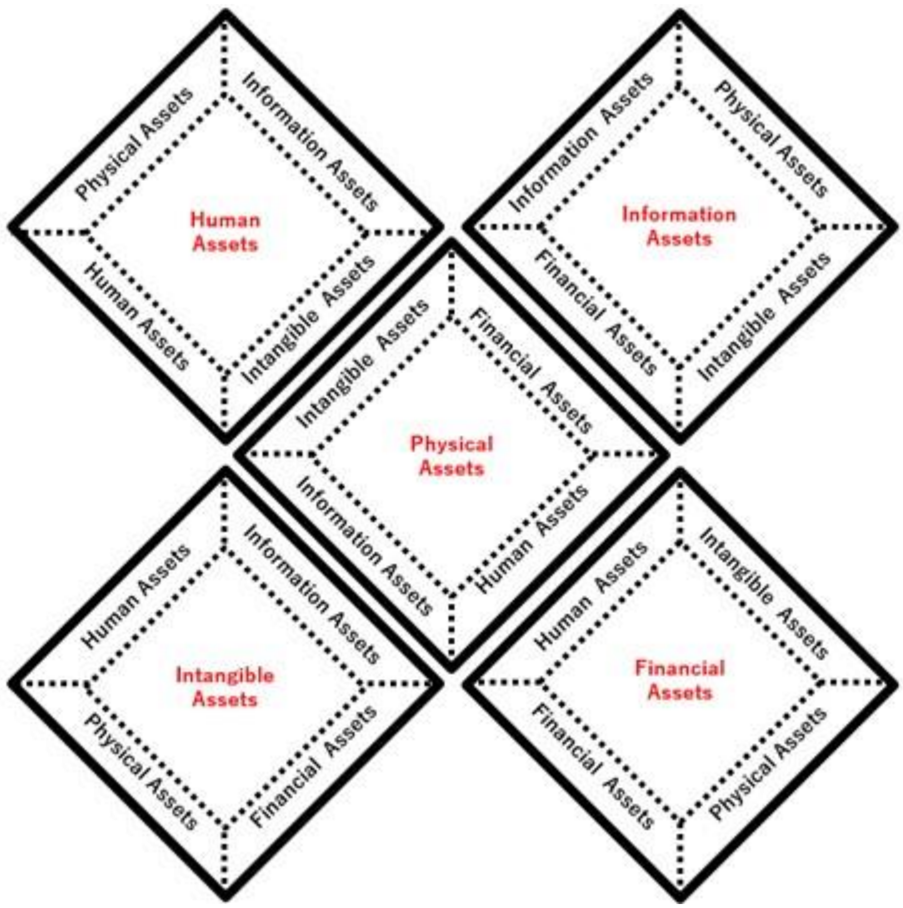

Figure 9. The balance sheet of business assets[25]

All parameters of business assets must be clearly defined, and their needs to be calculated both as capital expenditure and operational expenditure.

Selection of a Criterion (or Criteria)

The multi-attribute decision-making method will be used in this paper to determine the most appropriate natural gas distribution model referring to the market priority listing. Besides that, the sensitivity analysis method will also be used in LCCA calculations to obtain the best economic parameters. The parameters that will be used as a reference for the economy added value are Internal Rate of Return and Net Present Value.

Combining the two methods will recommend the most appropriate natural gas distribution model with the highest economic value. The complete process of selection criteria is shown in the chart below:

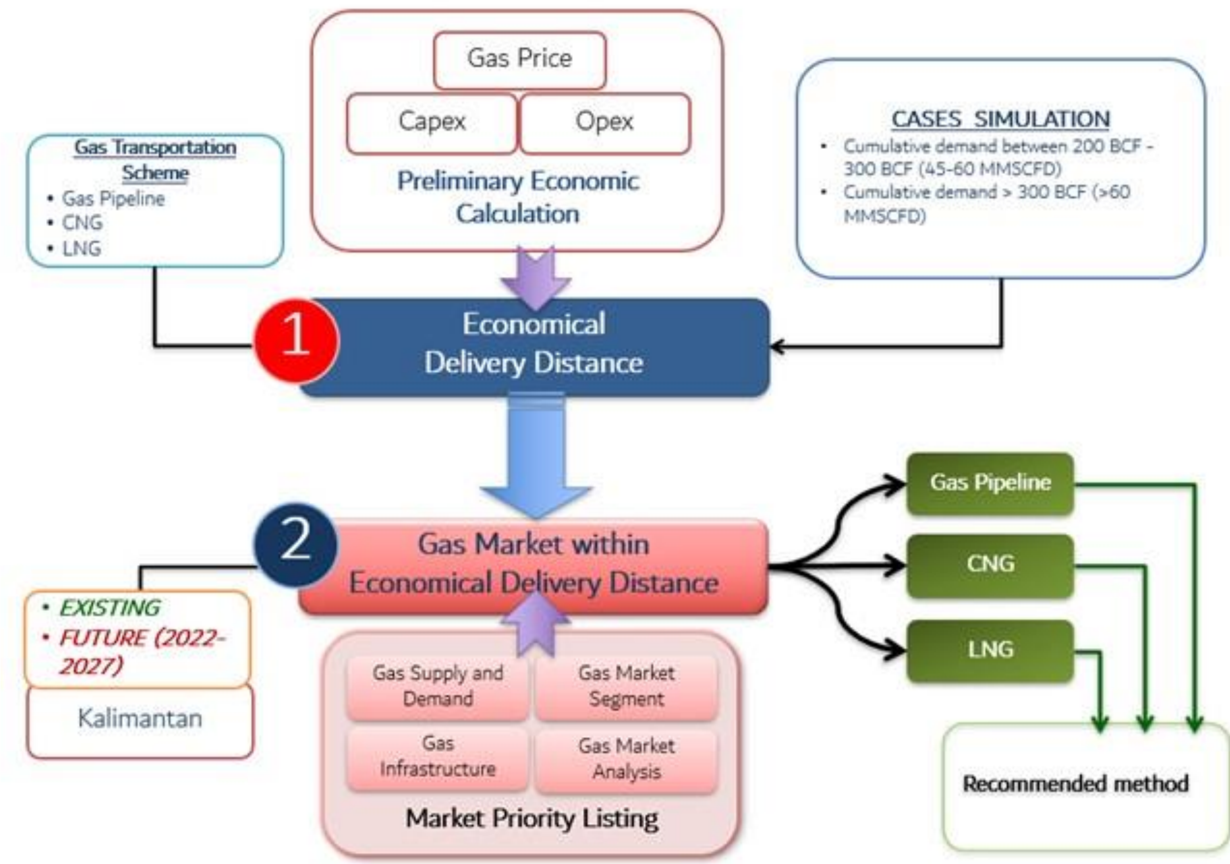

Figure 10. Selecting criteria for natural gas distribution[26]

Project Life, Years	20	EPC, Years	3	Loan, %	30	Project Finance Variables
Loan Interest, %	8	Loan Tenor, Years	10	Grace Period, Years	2	
Source Gas, Btu/Scf	1100	CO2, % Mole	2	LPG Extracted, %	0	Project Business & Commercial Variables
LPG in Source Gas, % Mole	0	Source Gas Pressure, Kg/cm2.	33	No. Of Regas Hub	1	
Process Driver	Gas Turbines	Power Plant	Gas Turbines	No. Of Satellites	1	
Source Gas, US$/mmBtu	0	Sales Gas, US$/mmBtu	6	Source & Plant Land, US$/Sq. m	100	
Refrigerant Prep. Unit	Yes	Market Gas, Kg/cm2.G	20	Receiving Land, US$/Sq. m	50	

Pipeline (Onshore), 000 $/inch-mile	120	Compressor (Onshore), 000 $/HP	3	Project Cost Database
AGRU, 000 US$/mmScfd	335	LNG Liquefaction, 000 US$/mmScfd	500	
Head Truck, 000 US$/Unit	250	LNG Tank Unit Price (FB), US$/m3	1000	
LNG Semi Trailer, 000 US$/FEU	50	Gas Well Unit, 000 US$/unit	5800	

Figure 11. Small gas transport economic variable and database

The data in figure 11[27] is used as a reference for the basis of economic evaluation. The hurdle rate on economic evaluation refers to the MARR in Indonesia for the oil and gas industry sector (distribution), which is 12%.

- **Market Priority Listing**
  Natural gas market clustering is carried out in areas with a radius of 300 and 500 km: power generation, refinery & petrochemical industry, basic industry, and city gas.

Findings

Analysis and Comparison of the Alternatives

1) Preliminary Economic Evaluation

This preliminary economic evaluation simulation is limited to production capacities of 30,45,60 and 75 mmscfd and distance to the consumer of 300 km & 500 km. A preliminary economic evaluation will present four parameters: Capex, Opex, NPV, and IRR.

The following are the results of the preliminary economic evaluation for natural gas production in the Central Kalimantan region:

i) Capital Expenditure (Capex)

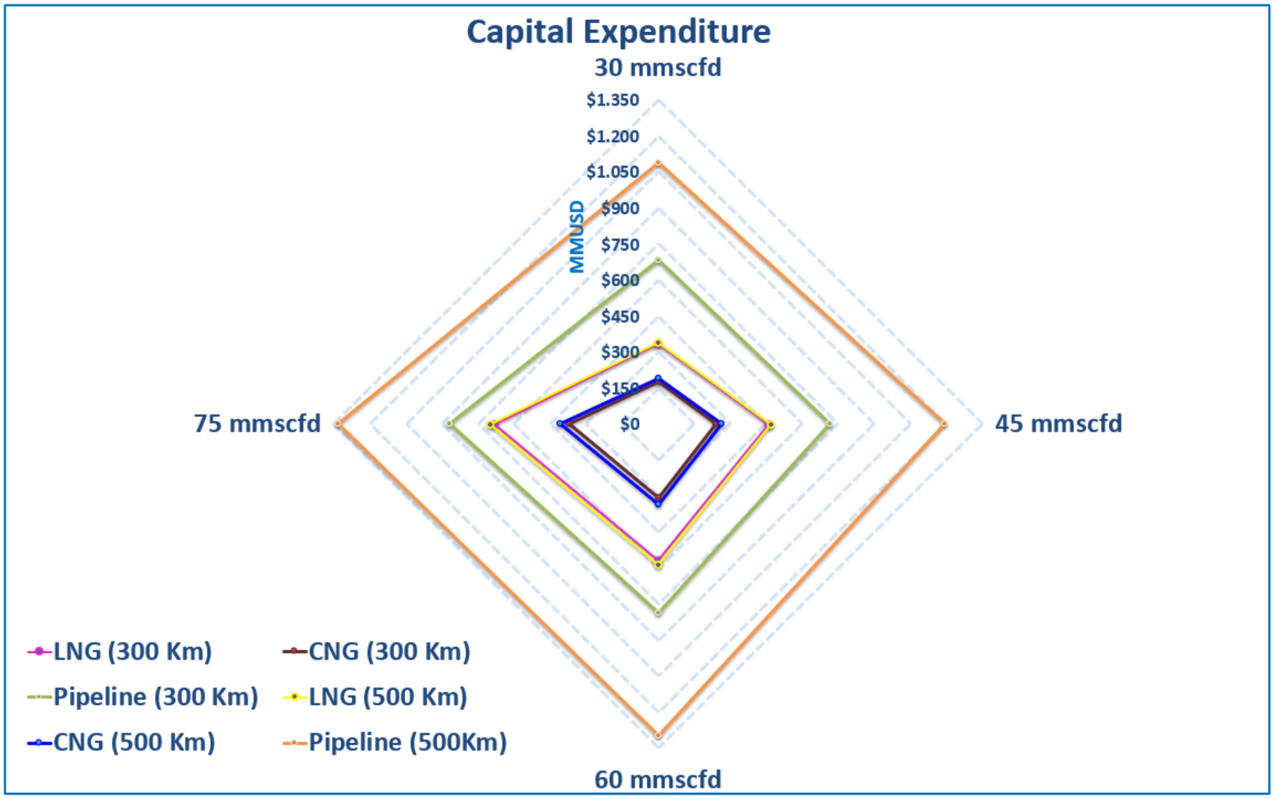

Figure 12. Capital expenditure for all scenarios

Based on the economic evaluation simulation, the largest capital expenditure is the pipeline distribution scenario with a capacity of 75 mmscfd, and the distance to the consumer is 500 km. In comparison, the smallest capital expenditure is the CNG distribution scenario with a capacity of 30 mmscfd, and the distance to the consumer is 300 km. In general, the components that cause high capital expenditure for pipeline distribution are land acquisition for Right of Way and procurement of pipe material & its installation. For LNG capital expenditure, the component that has the most influence is the LNG plant. In contrast, the CNG capital expenditure component has the most influence on the procurement of the trucking system.

ii) Operational Expenditure (Opex)

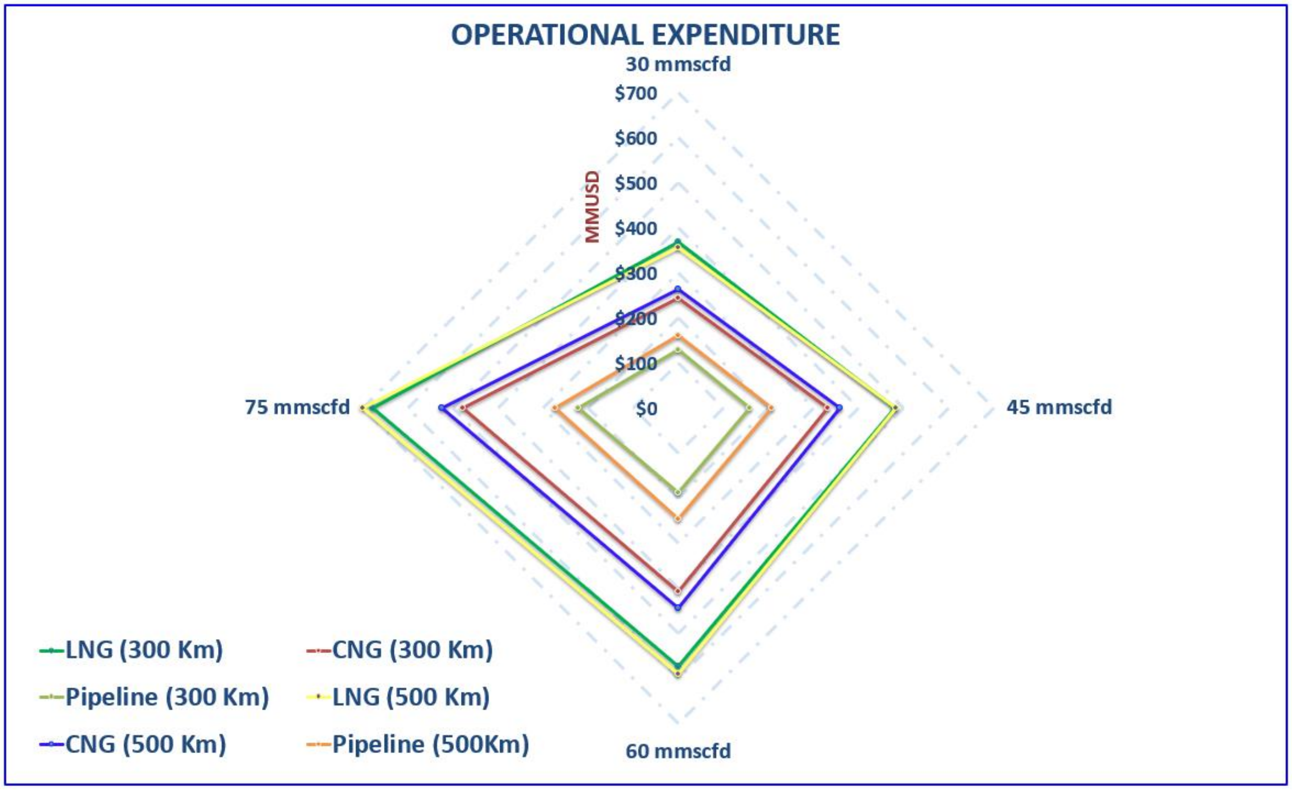

Figure 13. Operational expenditure for all scenarios

Based on the economic evaluation simulation, the most significant operational expenditure is the LNG distribution scenario with a capacity of 75 mmscfd, and the distance to the consumer is 500 km. In comparison, the smallest operational expenditure is the pipeline distribution scenario with a capacity of 30 mmscfd, and the distance to the consumer is 300 km. In general, the component that causes the high operational expenditure for LNG distribution is the operating cost of the LNG plant. For the distribution of CNG, the element that has a tremendous effect is the operational trucking cost, while for the pipeline scenario, it is the operating cost for pipeline transportation.

iii) Net Present Value (NPV)

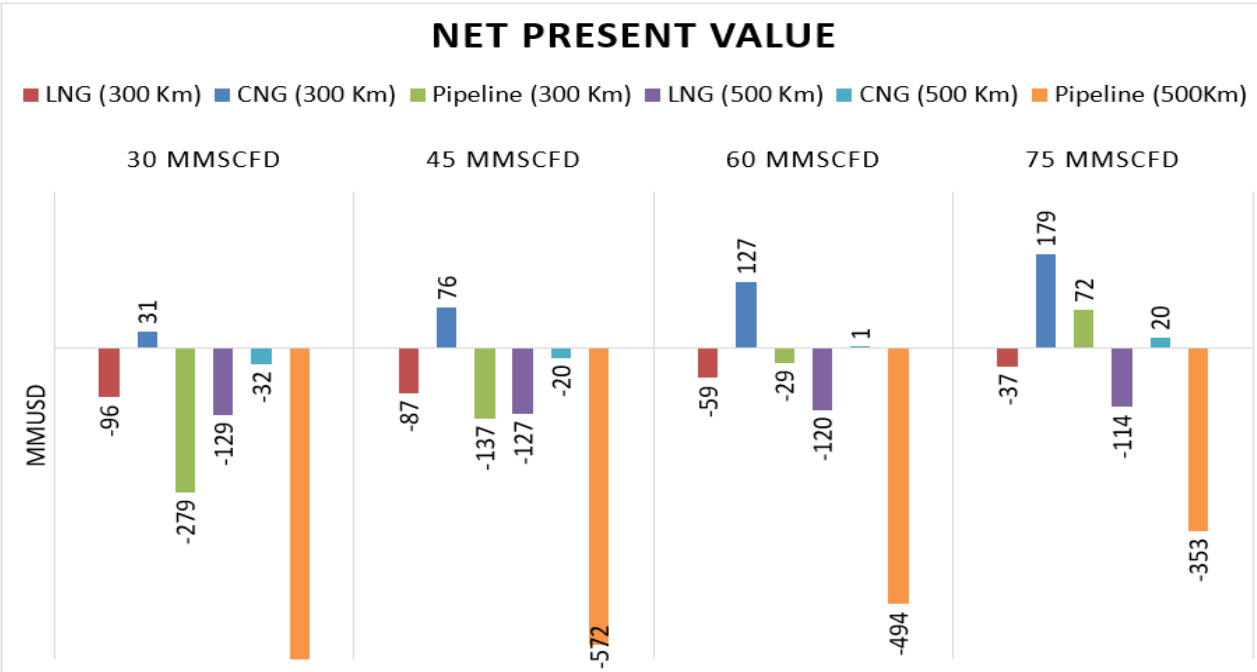

Figure 14. Net present value for all scenarios

Based on the economic evaluation simulation, the only positive net present value is the CNG scenario with a distance of 300 km for all capacity variations. A positive NPV is found in the 75 mmscfd pipeline scenario with a distance of 300 km and the CNG 75 mmscfd with 500 km. The amount of Capex and Opex in each scenario, when compared to revenue, causes the majority of negative NPV.

iv) Internal Rate of Return (IRR)

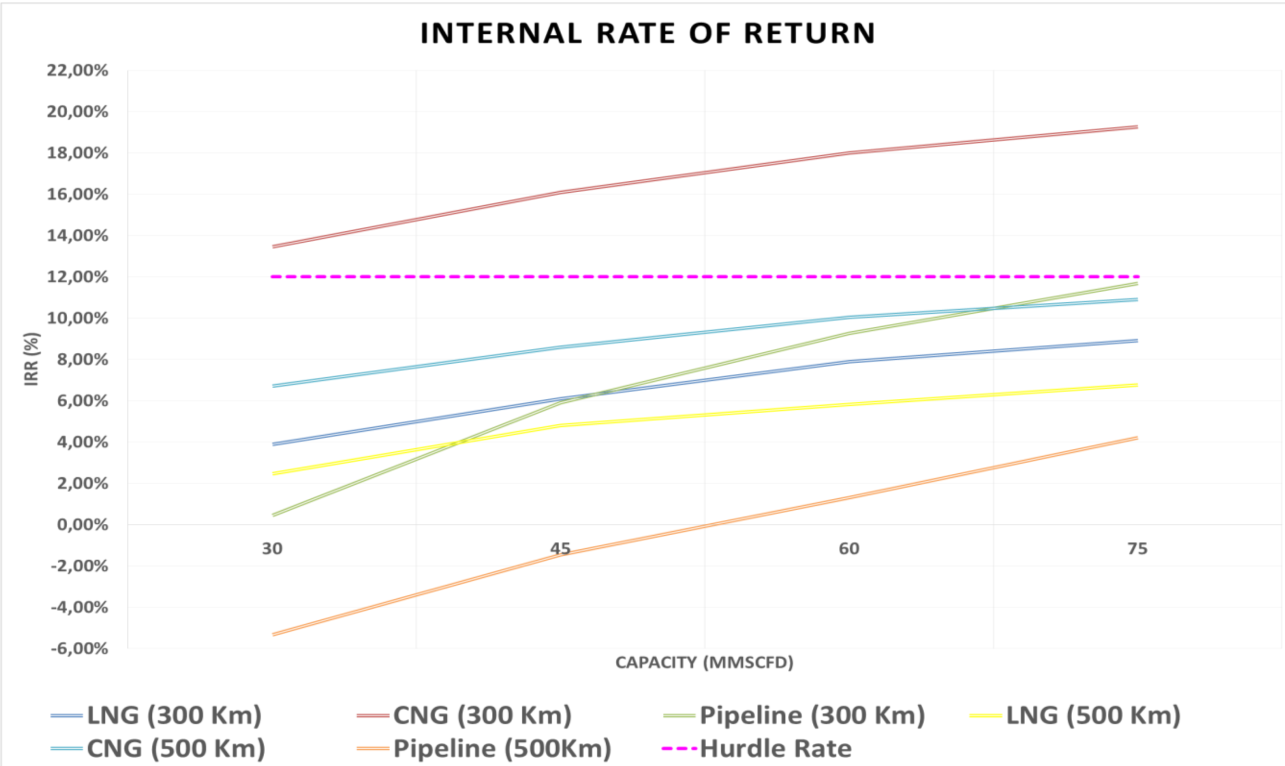

Figure 15. Internal rate of return for all scenarios

Based on the simulation of economic evaluation, the internal rate of return, which has a value above the hurdle rate, is the scenario for 300 km CNG with all capacity variations.

2) Market Priority Listing

- **City Gas Segment**

In the city gas cluster, the potential market is evaluated based on four existing big cities in Central, East, and South Kalimantan and one new city, which will become the new capital city of Indonesia located in East Kalimantan. The potential capacity for natural gas consumption in these five cities is 117.80 mmscfd.

Table 1. City Gas Potential Capacity Demand[28,29,30,31,32,33]

No	City	Population	Consumed gas per capita (mmscfd)	Potential capacity (mmscfd)
1	Balikpapan	688.318	0,00004	27,53
2	Samarinda	827.994		33,12
3	Palangkaraya	266.020		10,64
4	Banjarmasin	662.320		26,49
5	Ibu Kota Negara (IKN)	500.000		20,00
	Total	**2.944.652**		**117,80**

- **Power Plant Segment**

In the power plant segment, data is obtained from the long-term plan of PT PLN Persero as the sole distributor for electricity in Indonesia. The distribution and location of the power plant can be seen in the figure below:

Figure 16. Power Plant location in Kalimantan Island[34]

The capacities of all power plants in Kalimantan are as follows:

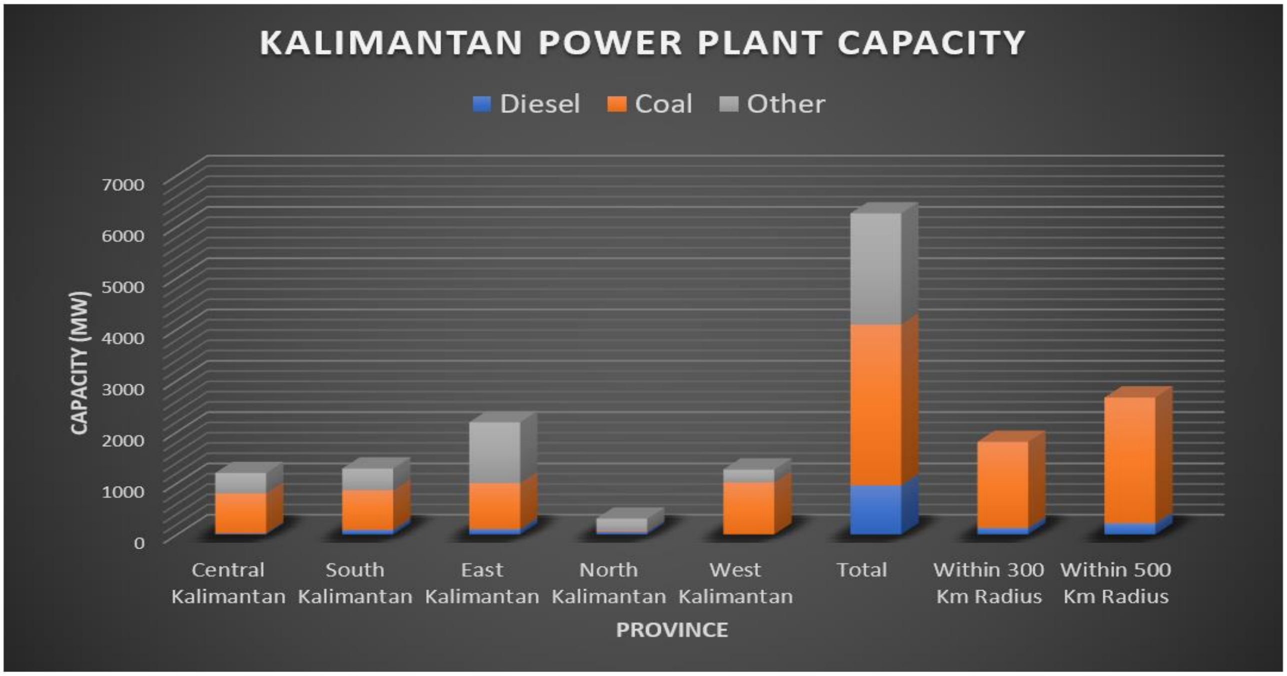

Figure 17. Power Plant Capacity based on Energy Sources[35]

There is a +/- 4100 MW power plant that uses coal and diesel fuel or equivalent to 690 mmscfd natural gas of the total installed capacity. For a power plant at a radius of 300 km, there is a potential substitution fuel to natural gas of 303 mmscfd. For a power plant at a radius of 500 km, there is a possible substitution in the amount of 448 mmscfd gas equivalent.

- **Basic Industry Segment**

In the basic industrial sector, the total energy consumption still using diesel is as follows:

Table 2. Basic Industry Energy Consumed

No	Type of Industries	Gas equivalent (mmscfd) - 2021
1	Food Industries	3,012
2	Beverage	0,005
3	Wood and Product of Wood	6,619
4	Furniture	0,000
5	Basic Metal	0,006
6	Fabricated Metal	0,000
7	Other Transport Equipment	0,019
8	Repair and Installation of Machinery and Equipment	0,022
9	Rubber and Plastic	0,009
10	Printing	0,001
11	Wearing Apparel	0,000
12	Leather	0,005
13	Chemical and Chemical Product	0,172
14	Other Non-metallic Mineral Product	0,051
	Total	**9,92**

The basic industry above is spread across various regions on the island of Kalimantan, with the most significant consumption being the wood industry; the majority are located in Central Kalimantan.

- **Petrochemical Segment**

For the petrochemical segment, data is obtained from the six largest industries in East Kalimantan with a total consumption of natural gas as shown in the figure below:

Table 3. Natural Gas Demand for Petrochemical Industry[36,37]

No	Company	Natural Gas Demand mmscfd
1	Badak NGL	3.150
2	PKT	270
3	KMI	71
4	KPA	71
5	KPI	53
6	Balikpapan Refinery	141
Total		**3.755**

Most natural gas needs have been supplied by existing natural gas producers for the petrochemical industry.

Selection of the Preferred Alternatives

Based on the economic evaluation above, the most profitable distribution model is CNG, with a maximum radius of 300 km with a capacity of 75 mmscfd.

The market segment for CNG within a 300 km radius can be seen in figure 21. below:

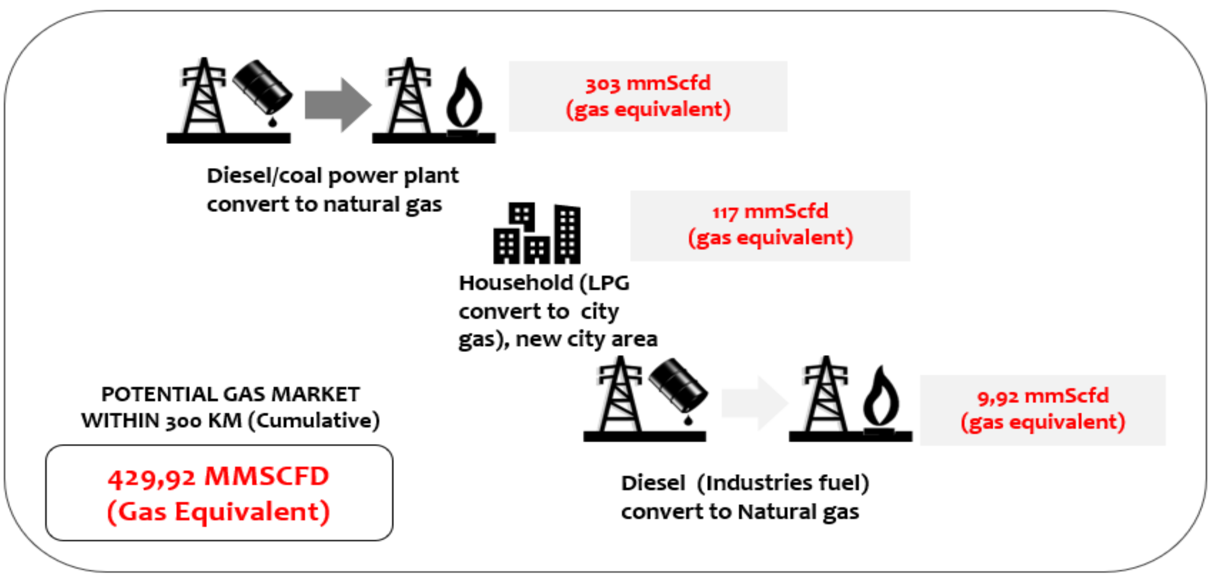

Figure 18. Potential Gas Market Segment

Based on the available potential gas market segment, city gas is a sector that can be prioritized. "The new capital area of the Republic of Indonesia (IKN), which is targeted to start operating in 2024,"[38] is the area with the most potential. Natural gas producers have the convenience of penetrating the market from the Indonesian government, and this is following IKN's vision to become a green city. Natural gas is suitable as an energy source in the household sector.

Another sector with great potential as a natural gas market is replacing power plant fuel from coal or diesel with natural gas. Converting coal or diesel power plant is also in line with the Indonesian government's policy of reducing carbon gas emissions and reducing coal-based plant operations[39].

Performance Monitoring and Post-Evaluation of Results

Based on the results of this case study, there are two potential markets for small natural gas capacity, namely the city gas segment and the power plant segment. It is necessary to carry out a more in-depth analysis, including the readiness of infrastructure from consumers and regulatory support from the government to realize the use of cleaner fossil energy to realize sales to these two sectors.

Conclusions

1. **What is the Potential market around gas reserves?**
   There are two potential markets around gas reserves: the city gas segment for the new capital city and the converted power plant.

2. **How much is the price of natural gas that each consumer is willing to accept?**
   As the regulation of the Republic Indonesian President No. 121/2020 "*Perubahan Atas Peraturan Presiden Nomor 40 Tahun 2016 Tentang Penetapan Harga Gas Bumi*" set the price of natural gas at the receiving point of natural gas users (plant gate) with the highest price of US$ 6/MMBTU.

3. **What variables affect investment & operational costs in the natural gas supply chain?**
   In this case study, several variables affect Investment & Operational costs for the natural gas supply chain, which are:
   a) Investment cost

   i. Land Acquisition
   ii. Equipment such as equipment in plant, pipe, truck.
   iii. Proprietary design costs, especially for LNG Plant
b) Operational cost
   i. Fuel for trucking transportation
   ii. Fuel for LNG/CNG Plant
   iii. Human capital to operate all business schemes

4. **What kind of supply chain scenarios meet Indonesia's gas industry hurdle rate?**
   Due to gas reserves located far from the coast, it is not possible to use ship transportation. In addition, another factor is the relatively low production capacity which makes transport using pipelines and LNG unprofitable. This case study's most suitable supply chain scenario is Compressed Natural Gas delivered by truck to the consumer.

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