NATURAL GAS AS PETROLEUM FUEL SUBSTITUTION: ANALYSIS OF SUPPLY-DEMAND PROJECTIONS, INFRASTRUCTURES, INVESTMENTS AND END-USER PRICES

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Abstract

The petroleum fuels (PF) subsidy has long burdens the government spending, and discourages less expensive energy usage such as natural gas (NG). Exporting NG and importing the more expensive PF products cause financial losses to Indonesia. The lack of NG infrastructure is the main hurdle in maximizing domestic NG usage and so does the perception of its high investment costs burdening government spending and pushing the NG transportation cost up. This study calculates the required NG infrastructure and its investments for several levels of PF substitutions up to 2030. To balance the NG demands, the supply from each field and its corresponding infrastructures needed was calculated and optimized using non-linear programming with generalized reduced gradient method to calculate the lowest transportation cost for the consumers. The study shows with a favorable return on investments attractive to private investors, the NG prices can still be put much lower than PF prices, allowing subsidy, import and production cost savings in many sectors. Furthermore, the highest level of substitution scenario needs only US$ 2.07 billion a year investment, very low compare to the current US$ 14.17 billion a year PF and electricity subsidy.

Keywords: alternative energy, gas supply-demand, infrastructure cost, oil substitution, optimization

1. Introduction

Unlike Indonesia, many countries both NG exporters and importers subsidized its NG price [1], to encourage the less expensive NG usage which has 50%-60% lower prices than that of PF. An estimated of US$ 10.37 billion a year net-export losses occurred due to exporting NG and importing the more expensive PF [2]. From 2006 to 2010, the PF subsidy for transportation and electricity subsidy (mostly due to PF usage) have reached a total average of US$ 14.17 billion a year or about 15% of Indonesian government spending [3], quite a significant amount.

In the energy sector, Indonesia has adhered to a PF subsidy policy, first adopted in the 1950s. Such a subsidy policy has been workable as long as Indonesian PF demand remained lower than the volume of oil actually produced and allocated for the Indonesia government. The economic reality is that Indonesia became a net oil importer in 1997*;* therefore the policy has to be reconsidered [2].

Studies show that excessive energy subsidy resulted negative impacts in many fossil fuels producer countries. The subsidy burdens the government spending, lowers the country income, distorts the national economy, discourages alternative energy infrastructure investment/usage, encourages excessive subsidized energy usage (because its low price), and in turn increases the country environmental vulnerability. Furthermore the subsidy is off target. Although, many agree that reducing the energy subsidy is not an easy task [1,4-7].

A study in Greece estimated an increase up to a staggering 3% in its gross domestic products (GDP) due to PF substitution with NG. This eight year NG transmission pipeline and distribution networks project was budgeted for US$ 2 billion in constant 1992 prices [8].

NG vehicles adoption dramatically increased in many countries, such in Pakistan, India and Bangladesh [9]. According to Yeh [10], there were three main reasons for a country to encourage such direction. *First,* lower air pollutions, especially in big and highly populated cities. *Second,* minimum investment required because the availability of the NG infrastructure, *Third,* to lower the dependency on expensive imported PF. Whereas, on the consumers side the less expensive NG fuel at the filling stations (40%-60% less expensive than PF) is the main factor for the consumers to switch to NG fuel in compressed natural gas (CNG) state.

Except for Italy which already developed, Engerer and Horn suggested the market penetration of natural gas as vehicle fuel should be promoted in Europe. European governments have developed incentives (e.g. tax reductions) to foster natural gas vehicles. However, the focus is on hybrid technology and the electric car, which, however, need further technical improvement. In contrast, the use of natural gas in conventional engines is technically mature [11]. For example, Toyota Prius Hybrid (gasoline) and VW Passat TSI EcoFuel (CNG) have similar long mileage, about 21 km per litre of gasoline (litre equivalent for CNG engine), however the CNG vehicle fuel cost about half that of the more complex gasoline hybrid car [12-13]. Additional NG imports to Europe can be avoided by further improvements of energy efficiency that will also reduce PF consumption.

Other lower price alternative fuel to PF is coal (lowest price among fossil fuels, mainly for power generation), but it is not preferable because it has the highest CO_2 emissions compare to that of PF or NG. And its emissions becomes the highest of the three fossil fuels in Indonesia, surpassing that of PF in 2008 and climbing at a rate of 20 Mt CO_2 per year whereas the combined PF and NG rate climbs only at 8 Mt CO_2 per year [14].

Therefore, the Indonesian government should encourage less expensive alternative fuels, such as NG to replace PF to lower the amount of subsidies, imports and production costs, which can accelerate its economic growth. However, the lack of NG infrastructure in Indonesia is the main hurdle in maximizing domestic NG usage and so does the perception of its high investment costs burdening government spending and pushing the NG transportation cost up, diminishing its low price advantage over PF; considering Indonesia consist of thousands of islands and its energy demand centers are far away from its supply sources.

This study analyzes Indonesia NG supply and demand projections, the required infrastructure and its investments for several levels of PF substitutions up to 2030. With a favorable return on investments attractive to private investors, the study will show whether the NG still hold the price advantages over PF at several crude oil price levels. It is hoped, the study can be used for determining the national energy, subsidy, financial and economy policies.

2. Methods

To obtain the NG infrastructure investment amount, schedule and transportation costs up to 2030, a comprehensive energy demand projections is required to see the overall picture. This includes energy demands such as coal and renewable energy in all sectors as well as NG for non-energy and export. Exclude the bio-mass energy demand. This study focuses in three dominant energy consuming sectors: industry, transportation and electricity. The electricity sector includes all electricity demand from other sectors. Using substitution scenarios the total yearly NG demands for each sector can be determined.

Unlike energy demand projections from Indonesia's Ministry of Energy and Mineral Resources [15] and Permana *et al.* [16], this study also projects Indonesia into eight regional energy demands, so both regional and national demands are taken into consideration in determining regional NG supply projections and its infrastructure requirements.

NG demands were balanced by certain amount of supply from every possible methane source fields in Indonesia through its corresponding infrastructures linking its end users (regions). The supply is mainly from current conventional NG and in the future from Coal Bed Methane (CBM) sources. An optimization using non-linier programming will determined the amount of production from each field and its corresponding infrastructures to ensure it provides the lowest mid-stream transportation costs to the consumers. Because majority of consumptions located in Java, optimization can be focused only on infrastructures delivering NG to and within Java.

Several pre-calculated infrastructures with several capacities have to be calculated first in order the optimization can be executed. It is a trial and error scheme with engineering judgment involved where the resulted infrastructure capacity should not be far from its pre-calculated capacity. The pre-calculated infrastructure has to be separately optimized, for instance whether to choose one large diameter size pipeline or two smaller size pipes for a certain flow rate and distance in combination of the needed compressors.

In comparison to most pipeline network optimizations such as Romø *et al.* [17] and Stoffregen *et al.* [18], they have more comprehensive constrains such as mass balance and pressure. Whereas this study is aim to minimize mid-stream transmission cost/toll fees while maintaining certain return on investment on NG infrastructures (pipelines, LNG plants and receiving terminals), their objectives were to minimize fuel consumption and maximize gas flow. Midthun *et al.* [19] optimization includes more comprehensive social and economic objectives such as maximizing social, consumer and producer surpluses. However, unlike this study the optimizations only apply to pipeline network systems.

Energy Supply and Demand Projections. Each fuel type demand projection is a function of energy demand in each sector (industry, transportation or electricity) and GDP [20] as shown in:

$$D_n = D_{n-1}(1+\alpha) \quad (1)$$

$$\alpha = \varepsilon_{Historical}\alpha_{GDP} \quad (2)$$

$$\varepsilon_{Historical} = \frac{\alpha_{Historical}}{\alpha_{GDP.Historical}} \quad (3)$$

where D_n is the fuel demand in a sector in year n, α is its demand growth projection, α_{GDP} is its GDP growth projection and $\varepsilon_{Historical}$ is its fuel elasticity demand in a sector. $\varepsilon_{Historical}$ is calculated from the average 2000-2007 elasticity. Regional energy demand is calculated using its regional GDP, but using the national elasticity demand for each sector due to the lack of regional data.

Historical production, consumption and GDP data were taken from official Indonesian sources [21-24]. The Indonesia GDP growth assumptions are as follows: 2008-2012: 4.5%; 2013-2017: 5.5% and 2018-2030: 6.5%.

NG field supply projection is related to its demand projection and its predicted reserve lifetime. CBM supply projection is taken from CBM Prospect [24].

Substitution Scenarios. NG demand is also dependent on the amount of switching/substitution from other fuel, in this case PF. The following are four PF substitutions to NG scenarios. *Scenario-1* or base scenario, assumed to be no switching between fuels, constant in fuels proportion usage up to 2030 as in 2007 proportions. In *Scenario-2* referring to the *contracted demand* in the Indonesian Gas Balance 2009-2020 [25], a 15% increase compare to 2007 NG usage proportion in the electricity sectors, applied between 2015 and 2030, lowering the PF demand. Whereas only a 5% increase is applied to the industry sector. *Scenario-3* is Scenario-2 plus a gradual 25% substitution increase of PF (subsidize gasoline and diesel fuel) to NG in the transportation sector. A 6% substitution in 2015, gradually increase to 25% in 2024 and stays in this level up to 2030. *Scenario-4* is Scenario-2 plus a gradual 45% substitution increase of PF to NG in the transportation sector. A 6% substitution in 2015, gradually increase to 42% in 2024 and stays at 45% between 2027-2030. Only in Scenario-3 and 4 additional supply of CBM were added, due to their higher demands.

In the electricity sector, in replacing diesel fuel with NG, the replacement power plants predicted to consume 23.13 MMSCFD to generate 1000 Mwh electricity in a year. PT Indonesia Power and PTPJB power plants consumption in 2007 is made as a reference [23].

Natural Gas Transportation Cost. NG transportation cost depends on its infrastructure type, capacity, investment amount and repayment scheme. The lower its capacity the higher its transportation cost, as describe in the following second order polynomial equation:

$$c = e + f v + g v^2 \quad (4)$$

Where c is the transportation cost (USD/MMBTU) for an infrastructure, v is the total volume (MMSCFD) of NG that went through the infrastructure. e, f, and g (constant, no unit) are regression results of the infrastructure.

Pipeline investment estimates were taken from the current PGN Tbk projects [26]. Cost US$ 35,000 per km-inch for onshore pipelines and US$ 50,000 per km-inch for offshore pipelines. An estimated of US$ 2,300 per horsepower for the compressor cost.

In calculating e, f, and g using regressions, the LNG plant and receiving terminal investment estimate is calculated using the *exponential method* [27], with the base investment of US$ 756 million for an *LNG plant* with 3.34 mtpa capacity and US$ 200 million for its tanker harbor. Cost US$ 360 million for the regasification/receiving terminal with 3.75 mtpa capacity [28].

LNG tanker transportation cost is calculated using Henry Lee formula [29]:

$$c_{tanker} = 7 \times 10^{-5} \times L + 0.102 \quad (5)$$

Where c_{tanker} is the transportation cost (USD/ MMBTU) and L is a round trip distance (Kilometer)

CNG transportation cost is estimated at US$ 1.79 per MMBTU [30]. Assumptions in calculating infrastructure investments is shown in Table 1 [26].

Optimizing Transportation Cost. To minimize NG mid-stream transportation cost to Java, the following objective function is applied:

$$Z = \min \sum_{i=1}^{m} q_{ij}c_{ij} \qquad j = 1,\ldots,n_i \quad (6)$$

With the following constraints:

Regional demand:

$$\sum_{i=1}^{m} q_{ij} = D_i \qquad j = 1,\ldots,n_i \quad (7)$$

Infrastructure capacity:

$$\sum q_{ij.vol.through.k} \le C_k \qquad k = 1,\ldots,o \quad (8)$$

Table 1. Infrastructure Investment Assumptions

	Infrastructure Type		
	Pipeline	Liquefaction	Regasification/CNG
Equity/Loan Ratio	30/70	30/70	30/70
IRR (%)	12	14	14
Payback duration (year)	8	6½	6½
Operation cost as percentage of fix asset (%)	2	4	1
Cost of money per year (%)	8	8	8
Loan duration (year)	8	8	8
Depreciation of fix asset (year)	10	8	8
Corporate tax (%)	30	30	30
Inflation per year (%)	5	5	5
Own use (%)	1	11	1
Construction duration and cost distribution	3 years, Year-1: 30%, Year-2: 50%, Year-3: 20%		

Production capacity:

$$\sum q_{ij.vol.originated.from.p} \le S_p \qquad p = 1,\ldots,s \tag{9}$$

Where:
Z = Total transportation cost (USD per day)
q_{ij} = Demand volume region i supplied by a series of infrastructures j (MMSCFD)
c_{ij} = Transportation cost region i supplied by a series of infrastructures j (USD/MMBTU)
m = Number of regions (unit)
n_i = Number of infrastructure series linking region i (unit)
o = Number of infrastructure linking Java (unit)
D_i = Region i external demand (MMSCFD)
C_k = Infrastructure k supply capacity to Java (MMSCFD)
S_p = Field p supply capacity to Java (MMSCFD)
s = Number of gas fields (unit)

These non-linier programming equations are solved using Microsoft Excel with optimization add-on called SOLVER. It uses the *generalized reduced gradient* (GRG) method to reach the optimum solution [31].

The optimization allocates the production volumes from each field, fulfilling each region demands through a certain series of infrastructures (pipelines, LNG receiving terminal, tankers and LNG plants) in such a way that the total yearly NG transportation reached the minimum cost.

Because the optimization is only within a year, a synchronized infrastructure across multi-years has to be performed using the planner/engineering judgments. If for instance in a year Center Java was supplied by the pipeline from East Java and the next year the program choose the opposite pipeline from West Java, an additional or modified constrain(s) have to be imposed in such a way that resulted a technical and economical sensible decision.

Like most non-linier programming methods, it is easy to be trapped in local optimum solutions. To be able to reach a global optimum solution, several initial q_{ij} values have to be tried into the optimization program. An engineering judgment has to be applied as well. The same judgment has to be use in determining the infrastructure configuration.

It is predetermined that the largest demand in Java (west region) is supplied by pipelines from Sumatra and East Natuna. The second largest demand (east region) is supplied by pipelines from East Kalimantan. LNG from East Kalimantan, Papua, Maluku and Sulawesi can supply east or west part of Java as well as the north part of Sumatra (excluded from optimization). Central part of Java has the lowest demand and supplied from the east or/and west regions of Java through pipelines (Figure 1).

Estimated Petroleum Fuel and Natural Gas Prices. The equations are calculated as follows:

$$Pp_{Intl} = P_{CO} \times F_{PT} / 159 \tag{10}$$

$$Pg_{Intl} = (P_{CO} / F_{OG} + P_{GT}) / H_{Val} \tag{11}$$

Where Pp_{Intl} is the average international petroleum fuel price and Pg_{Intl} is the equivalent international NG price (both inclusive their average transportation cost in USD/L). P_{CO} is the ICP crude oil price (USD/BBL). F_{PT} is the processing and transportation factor (1.341 for gasoline and 1.427 for diesel fuel correlated from current ICP and PERTAMINA retail prices). F_{OG} is the Oil-Gas Price conversion factor between ICP and Indonesian exported piped natural gas price (8.674 MMBTU/BBL on average between 2006-2008). P_{GT} is the natural gas transportation cost (USD/MMBTU). H_{Val} is the heating value of petroleum fuel (30.28 for gasoline and 27.29 for diesel fuel in L/MMBTU).

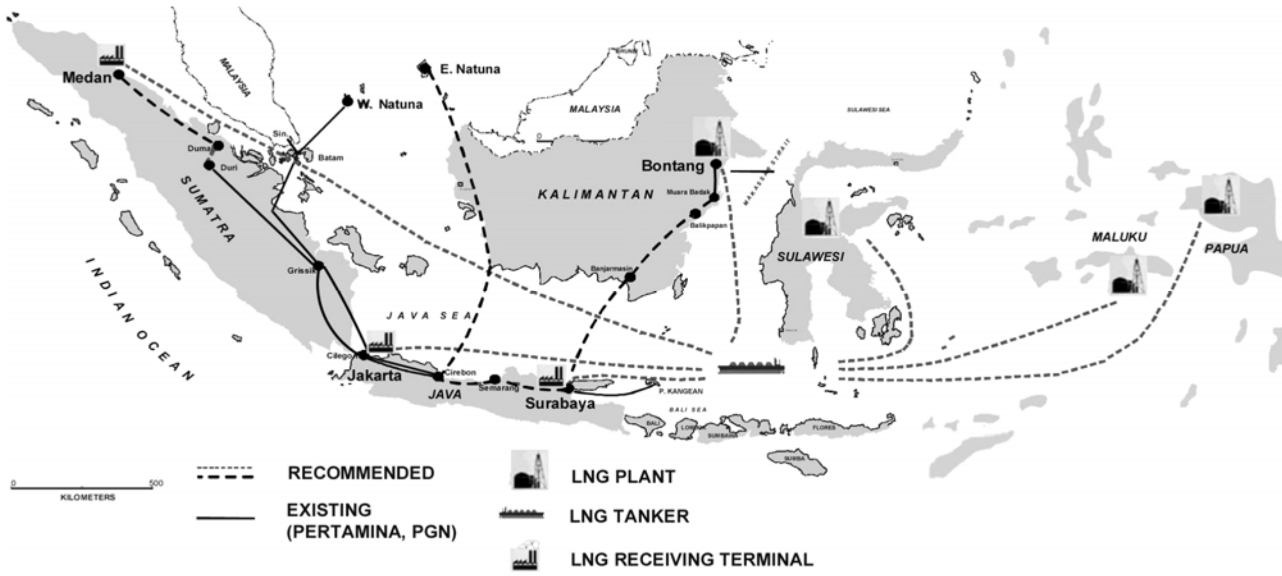

Figure 1. Natural Gas Pipelines/Main Transportation Route

3. Results and Discussion

Supply-Demand Projections. As less NG export is predicted [25], the projected Scenario-1 national NG demand looks decreasing at first, as shown in Fig. 2. The external Java NG demand shown in Fig. 3, Java demand projections minus local productions, looks constantly increasing without the influence of the decreasing NG export. These demand figures are used as constrains in the optimization.

The base scenario of Ministry of Energy and Mineral Resources demand projection [15] was much higher as the GDP growth assumptions were 7.2% between 2015 and 2030. Whereas Permana *et al.* [16] base demand projection was similar despite a lower GDP growth assumption (5.5% between 2008 and 2030), but with different projection methodology.

The differences will not affect the end results of this study, which is the NG affordability compares to PF. Furthermore, the additional investment cause by the differences can be drawn from the relation between NG demand and the required investment in this study.

Even though the optimization applied only to Java, the supply-demand balance is performed nationally. Table 2 shows the supply side, the production of each NG field in Indonesia supplying all demands including NG for export. In Scenario-4 due to the large demand increase, all Papua NG production is allocated for domestic usage in 2030.

Supply volumes from each field to each demand region in Java with the associated infrastructures used can be seen in Table 3 (Scenario-4 as an example).

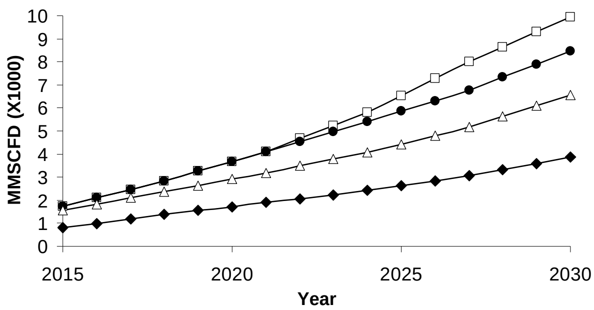

Figure 2. National Natural Gas Demand Projections, Scenario 1 (♦), 2 (Δ), 3 (●) and 4 (□)

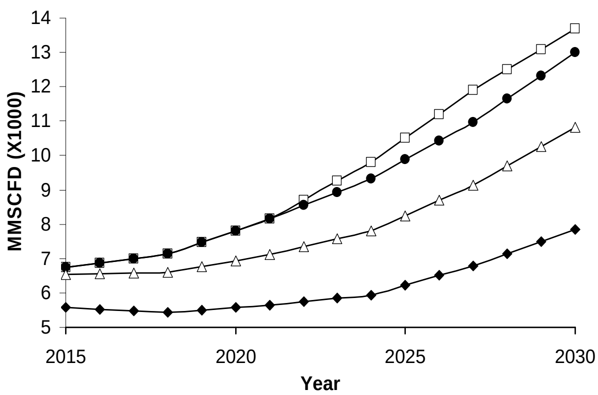

Figure 3. External Java Natural Gas Demand Projections, Scenario 1 (♦), 2 (Δ), 3 (●) and 4 (□)

LNG imports can fill domestic supply deficiencies; it can even reduce the investment cost (see further discussion below).

Infrastructures. From figures in Table 3 the infrastructures capacity, cost and construction schedule can be derived as shown in Table 4 (next page). The infrastructure details can be seen in Table 5.

LNG receiving terminal in East Java will result a higher transportation cost, if built in the early years. And even higher if the East Kalimantan pipeline is built at the same time, which will cause both infrastructures slow in reaching their full capacity. Except if the LNG is planned to fuel a large fleet of vehicles or other similar schemes.

Due to the assumption that no CBM is supplied in Scenario-2, the more expensive LNG sources from East Indonesia came sooner to Java. While in Scenario-3 it gives higher priority to the less expensive CBM sources from Middle and South Sumatra as well as East Kalimantan (Table 4, Scenario-2 & 3 are not shown).

As seen in Fig. 4, Scenario-2 is a stepping stone to the higher scenarios. The Indonesian government policy seems to follow Scenario-2 as can be seen in the 2009-2020 Indonesia Gas Balance [25]. However, the current actual NG infrastructure construction progression is more towards Scenario-1. This means Java could encounter shortage of NG for its power plants in the future. If the less expensive coal continuously increased with larger proportion, greater environmental damages would be expected.

Investments. A US$ 0.54 billion a year natural gas mid-stream infrastructure investment is still required to maintain the current mix/proportion of energy usage (Scenario-1). With an additional of US$ 0.52 billion a year investment, 21.95 million kL per year diesel fuel can be substituted in the electricity and industry sectors (Scenario-2). Another US$ 0.25 billion a year investment, enable additional 17.29 million kL per year

Table 2. National Natural Gas Supply Projections (MMSCFD)

Field Production	Scenario-1		Scenario-2		Scenario-3		Scenario-4	
	2015	2030	2015	2030	2015	2030	2015	2030
Reg 1, Riau & Natuna Island	551	2593	1083	3500	1290	3700	1290	3700
Reg 1, NAD/Aceh	128	171	162	248	166	266	166	279
Reg 1, Sumatra-north	87	172	51	166	72	281	72	365
Reg 2, Sumatra-mid-south	1714	1683	1708	2087	1725	2022	1725	2092
Reg 3, Java-west	362	68	362	68	362	68	362	68
Reg 4, Java-central	91	142	158	142	158	142	158	142
Reg 5, Java-east	407	302	407	302	407	302	407	302
Reg 6, Kalimantan-east	1177	1581	1536	1651	1504	1661	1504	1661
Reg 7, Sulawesi-central	16	64	16	64	16	384	16	384
Reg 7, Sulawesi-south	13	54	13	410	13	90	13	90
Reg 8, Papua	1034	1021	1034	1652	1034	1610	1034	1602
Reg 8, Maluku-south				534				534
Reg 2, CBM Sumatra-mid-south						1410		1410
Reg 6, CBM Kalimantan-east						1058		1058
Total	5580	7851	6530	10824	6747	12994	6747	13687

Table 3. Optimization Results: Supply Volumes from Each Field with the Associated Infrastructures

Scenario-4	Java-west-region							Java-central-region									Java-east-region MMSCFD					
Year	1) Sum 2) Btn 3) Gas	Nat Cb Gas	Kal JW LNG	Sul JW LNG	Mal JW LNG	Pap JW LNG	Total West Java	Nat Cb-Sm Gas	Kal Sb-Sm Gas	Kal Cb-Sm LNG	Pap Cb-Sm LNG	Mal Cb-Sm LNG	Kal Sm-Sb LNG	Pap Sm-Sb LNG	Mal Sm-Sb LNG	Total Central Java	Kal Sby Gas	Kal JE LNG	Sul JE LNG	Mal JE LNG	Pap JE LNG	Total East Java
2015	650	618	70	0	0	0	1338	121	0	0	0	0	0	0	0	121	283	0	0	0	0	283
2018	956	973	58	0	0	0	1987	227	0	12	0	0	0	0	0	239	607	0	0	0	0	607
2021	1100	1626	0	0	0	35	2761	385	0	0	35	0	0	0	0	420	922	0	0	0	0	922
2024	1612	2045	0	0	0	70	3728	355	175	0	0	0	0	152	0	681	1281	0	0	0	121	1402
2027	1464	3409	0	0	61	36	4970	98	75	0	260	142	0	314	126	1015	1587	0	0	205	231	2023
2030	2286	3101	82	0	0	656	6125	406	0	27	335	0	0	185	315	1268	1800	0	356	219	183	2558

Notes: 1) Sources: Sum = Sumatra, Nat = East Natuna, Kal = East Kalimantan, Sul = Sentral Sulawesi, Mal = South Maluku, Pap = Papua
2) Destination: Btn = Banten + West Java, Cb = Cirebon, JW = West Java, JE = East Java, Sby = Surabaya, Cb-Sm = Cirebon-Semarang PL, Sb-Sm = Surabaya-Semarang PL
3) Gas state at Java landing point

Table 4. Natural Gas Mid-Stream Infrastructures Capacity, Cost and Construction Schedule

Scenario-1 billion USD

Infrastructure	Capacity (mmscfd)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Natuna - West Java pipeline	2 X 1200				0.88	1.47	0.59							0.88	1.47	0.59				
East-Kal - East Java pipeline	900										0.61	1.02	0.41							
Cirebon - Semarang pipeline	400										0.08	0.14	0.06							
LNG Recv Term West-Java	250	0.22																		
LNG Recv Term East-Java	250				0.04	0.11	0.07													
Total Cumulative		0.22	0.22	0.22	1.14	2.72	3.37	3.37	3.37	3.37	4.07	5.22	5.68	6.56	8.03	8.62	8.62	8.62	8.62	8.62

Scenario-4 billion USD

Infrastructure	Capacity (mmscfd)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Natuna - West Java pipeline	3 X 1200	0.88	1.47	0.59				0.88	1.47	0.59				0.88	1.47	0.59				
East-Kal - East Java pipeline	2 X 900	0.61	1.02	0.41					0.61	1.02	0.41									
Cirebon - Semarang pipeline	400	0.08	0.14	0.06																
Semarang - Surabaya pipeline	400										0.10	0.17	0.07							
SSWJ I & II compressor exp	650→1100				0.05	0.08	0.03													
Pipa SSWJ III	1200								0.28	0.47	0.19									
LNG Plant Papua expansion	534							0.41	0.68	0.27										
LNG Plant Maluku-south	534																			
LNG Plant Sulawesi	356													0.47	0.78	0.31				
LNG Recv Term North-Sumatra	250																0.37	0.62	0.25	
LNG Recv Term West-Java	250+2X500	0.04	0.11	0.07										0.11	0.18	0.07	0.11	0.18	0.07	
LNG Recv Term East-Java	3 X 500	0.22									0.11	0.18	0.07	0.11	0.18	0.07	0.11	0.18	0.07	
Total Cumulative		1.84	4.57	5.68	5.73	5.80	5.83	7.12	10.15	12.50	13.30	13.64	13.78	15.33	17.93	18.96	19.54	20.51	20.90	20.90

Table 5. Natural Gas Infrastructure Details

Infrastructure	Capacity (mmscfd)	Capacity (mtpa)	Length (km)	Diameter (inch)	Compr. (hp)	Investment (mil. USD)
Natuna - West-Java pipeline	1200		1400	42	149,693	2931
East-Kal - East-Java pipeline	900		1100	42	30,000	2033
Cirebon - Semarang pipeline	400		250	32		280
Semarang - Surabaya pipeline	400		300	32		336
SSWJ I&II compressor expansion	650→1100 mmscfd				65,217	150
SSWJ III pipeline	1200		466	42	65,217	788
LNG Plant Papua expansion	534	4.00				1355
LNG Plant Maluku-south	534	4.00				1555
LNG Plant Sulawesi	356	2.67				1234
LNG Recv Terminal	250	1.87				220
LNG Recv Terminal	500	3.75				350

of petroleum fuel in the transportation sector can be substituted (Scenario-4, Scenario-3 is not analyze further because it's insignificant difference to Scenario-4). However, about US$ 0.77 billion a year additional investment has to be invested if the downstream distribution network is mainly consist of CNG. Less investment needed if more pipeline distribution network will be built. Therefore for a total of US$ 2.07 billion a year investment, 39.24 million kL per year of petroleum fuel can be substituted.

The above investment is small compare to the current energy subsidy; US$ 8.90 billion a year in PF (subsidizing around 38 million kL per year PF) and US$ 5.27 billion a year in electricity. Since private investor is aimed to fund the investment, the government can put its resources to support the substitution in other areas, such as subsidizing CNG converters for public transport vehicles, lower taxes on NG vehicles/engines and other supporting policies.

As mentioned above, importing LNG will lower investment cost, only 9% to 13% of total project capital expenditure according to Jensen [32], about 18% in this study, without the LNG tanker investment taken into account. Although, importing LNG will lower net-export as well which negatively impact GDP. Nonetheless it is still financially and environmentally more beneficial than importing the more expensive PF.

The study shows that to bring 1000 MMSCFD to Java through pipelines cost US$ 2.38 billion, whereas through LNG receiving terminals cost only US$ 0.66 billion, but at the expense of higher transmission cost as seen in Table 6.

End-User Prices. The projected NG prices are linked to crude oil prices, just as in most part of the world. Brown and Yücel [33] even saw that there was evidence linking NG price movements in Europe and North America, at least in the long-term.

Due to the current recession the NG price in U.S. is lower in 2010 despite the oil price averaging US$76/BBL. The wellhead, electric power and industrial NG prices were more like that of year 2001-2003 where the oil price between US$20 and US$30/BBL, and much lower if inflation is taken into account. However commercial and vehicle NG prices were about twice as high. The prices are even much higher for residential usage. Indicating the NG prices in these sectors were linked to oil prices [34].

The NG transportation cost strongly tied to its capital expenditures, less to crude oil prices (Table 7), whereas PF processing and transportation cost mainly linked to (certain percentage of) crude oil prices. Table 8 shows NG export prices using Eq. 11 plus the highest, lowest and average transmission cost from Table 7; and PF prices using Eq. 10.

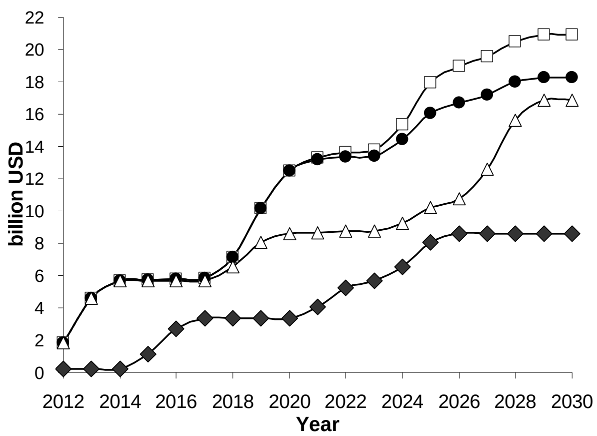

Figure 4. Cumulative Infrastructure Investment, Scenario 1 (♦), 2 (Δ), 3 (●) and 4 (□)

Table 6. Mid-Stream Transmission Cost (USD/MMBTU)

Infrastructure	Cost
Natuna-Cirebon Pipeline	1.54
East Kal-Surabaya Pipeline	1.35
Papua-West Java LNG	3.02
Papua-East Java LNG	2.93
East Kal-West Java LNG	2.16
East Kal-East Java LNG	2.09

Table 7. NG Scenario-4 Mid-Stream Average Transmission Cost (USD/MMBTU)

Year	Crude Oil Price (USD/BBL)		
	60	80	100
2015	2.37	2.39	2.40
2018	1.72	1.73	1.73
2021	1.74	1.74	1.74
2024	1.76	1.77	1.79
2027	1.95	2.00	2.04
2030	2.11	2.17	2.23

Table 8. NG Prices plus Transmission Costs and PF Prices

	Crude Oil Price (USD/BBL)		
	60	80	100
	(USD/MMBTU)		
Export	6.92	9.22	11.53
Ex+Hi_Trans	9.29	11.61	13.92
Ex+Lo_Trans	8.64	10.95	13.26
Ex+Av_Trans	8.86	11.19	13.52
	(USD/Litre)		
Gasoline	0.5060	0.6747	0.8434
Diesel Fuel	0.5385	0.7180	0.8975

In the industry and electricity sectors, as seen in Table 9, with lower transportation cost the potential savings are significant (37% to 46%). It is assumed; only mid-stream transportation costs were applied in these sectors.

The downstream distribution cost of US$ 1.79 per MMBTU, using CNG trucks, mother and daughter stations, is expensive compare to that of U.S. (Table 12). However, applying this figure the potential savings in the transportation sector still between 25% and 41% (Table 10 and 11).

If the industry and electricity sectors apply the distribution cost(using CNG), the savings become between 25% and 39%, the same Table 11 figures as in the transportation sector.

According to Yeh [10], the percentage price figures in Table 10 and 11 should be 60% or less to attract voluntary switching, considering the high CNG converter cost and short return on investment expectation. As mentioned earlier, the converter subsidy would help break such barrier to entry, more significantly at the lower crude oil price points. Or apply some NG subsidy which is common in many countries [1].

The above savings have not taken the efficiency factor into account.

Therefore, with a favorable return on investments attractive to private investors as shown in Table 1, the NG prices can still be put much lower than PF prices, allowing subsidy, import and production cost savings in many sectors.

Table 9. NG USD per Liter Equivalent Price and Its Percentage to Diesel Fuel Price in the Industry and Electricity Sectors

	Crude Oil Price (USD/BBL)		
	60	80	100
NG End User Hi	0.3405	0.4253	0.5102
NG End User Lo	0.3165	0.4012	0.4859
NG End User Av	0.3246	0.4100	0.4953
NG_Hi / Diesel Fuel	63%	59%	57%
NG_Lo / Diesel Fuel	59%	56%	54%
NG_Av / Diesel Fuel	60%	57%	55%

Table 10. NG USD per Liter Equivalent Price and Its Percentage to Gasoline Price in the Transportation Sector

	Crude Oil Price (USD/BBL)		
	60	80	100
NG End User Hi	0.3660	0.4425	0.5189
NG End User Lo	0.3444	0.4207	0.4971
NG End User Av	0.3517	0.4286	0.5055
NG_Hi / Gasoline	72%	66%	62%
NG_Lo / Gasoline	68%	62%	59%
NG_Av / Gasoline	69%	64%	60%

Table 11. NG USD per Liter Equivalent Price and Its Percentage to Diesel Fuel Price in the Transportation Sector

	Crude Oil Price (USD/BBL)		
	60	80	100
Total Price-Hi	0.4061	0.4909	0.5758
Total Price-Lo	0.3821	0.4668	0.5515
Total Price-Avg	0.3902	0.4756	0.5609
NG_Hi / Diesel Fuel	75%	68%	64%
NG_Lo / Diesel Fuel	71%	65%	61%
NG_Av / Diesel Fuel	72%	66%	62%

Table 12. NG Transportation Cost Comparison, Average Constant Price 2000 (USD/MMBTU)

	Indonesia	United States (historical)		
	(future)	Industry	Electric	Transp.
Transmission	1.57	1.10	0.79	1.36
Distribution	1.54			0.77

Table 12 shows comparison to U.S. NG average transmission and distribution cost [34] calibrated using U.S. Consumer Price Index at year 2000 constant price. The city gate price is the point between the transmission and distribution segment in the transportation sector. More pipeline network is required to lower the distribution cost.

4. Conclusion

The optimization results are highly dependent on the projections / assumptions of the supply source locations and their reserve / production capacities. The optimization will prioritize the less expensive supply sources first which usually can be reached by pipelines.

It is important for Indonesia to follow the Scenario-2 first; in order the electricity and industry sectors can as much as possible use the less expensive NG replacing PF. Increasing the NG proportion in electricity sector is a must, in order to avoid blackouts in Java and to compensate for the increasing less environmental friendly coal fuel for power plants.

The highest level of substitution scenario needs only US$ 2.07 billion a year investment, very low compare to the current US$ 14.17 billion a year PF and electricity subsidy. Since private investor is aimed to fund the investment, the government can put its resources to support the substitution in other areas, such as subsidizing CNG converters and other supporting policies. Further study is needed to lower and optimized the downstream transportation cost.

With a favorable return on investments attractive to private investors, the NG prices can still be put much lower than PF prices, allowing subsidy, import and production cost savings (25% to 46%) in many sectors. Further study is needed to calculate the savings and its impact to Indonesian macro economy.

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