

Feasibility of Natural Gas Supply from Russia to Korea

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Abstract

In this paper author calculates the price of gas for the planned gas supply project from Russia to Korea. That price includes: the gas production cost in the prospective gas fields in Russian East regions, gas pipeline transportation cost across Russia to the Pacific coast, and further gas transportation by gas pipeline through the Korean Peninsula or transportation of gas by tankers as liquefied natural gas (LNG), to the Korean consumers. It also includes expected minimum return rates of investment (hurdle rates).

Our calculations show that the estimated prices of Russian gas in Korea in 2010 US constant dollar during the period of the possible contract from 2017 to 2041 could be as follow: for PNG (pipeline natural gas) 12.91 \$/MBtu (468 \$/1000m³), and for LNG 13.22 \$/MBtu (479 \$/1000m³), which is rather competitive with the projected oil price between 18.37 and 25.79 \$/MBtu or 106 and 150 \$ per barrel of crude oil for the same period of time. This suggests that supplying Russian natural gas to Korea is cost effective in either PNG or LNG form.

Key Words : Gas supply cost, LNG, Gas pipeline, Energy cooperation, Northeast Asia, Korea

Jel Codes : Q48, P48, L95

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1. Introduction

For substantial strengthening of climate policy actions and since fossil fuels will remain the dominant sources of primary energy in the next decades, natural gas, having the lowest carbon emissions content per unit of energy relative to coal and oil, will play a key role in the energy policies worldwide [1]. The demand for gas has consequently significantly increased, especially in the Asia Pacific Region. China and India see the most rapid rates of gas share increase in their primary energy mix. At the same time Korea, Japan, and Taiwan heavily rely on liquefied natural gas (LNG) imports for their gas supplies from Malaysia, Brunei, Indonesia, Australia and the Middle East. On the other hand, Russian Eastern Siberia (RES) and Far East (RFE) regions (which are also part of the NEA) are rich with natural gas, oil and coal and considerably closer to the NEA consumers than the other gas producers. For instance, a possible onshore pipeline route from Russian port Vladivostok to South Korean port Samchuck is about 980 km and 690 km offshore respectively, while the distances between Korea and its other LNG suppliers are 4,140 km - from the closest producer- Brunei, and 13,800 km - from the farthest supplier - Qatar.

Moreover, Korea has a growing gas industry that is heavily dependent on imports and relies almost exclusively on importing gas in liquefied form. LNG imports account for nearly all of the Korean gas supply. Due to the high dependence on LNG imports from the Middle East producers (51% of the total LNG import) and unexpected disruption of gas supply from Indonesia such as the shutdown of the Arun LNG plant for several months [2], diversification of the Korean gas import sources became a very important matter for Korea, and one of

the preferable sources of alternative gas supply is Russia [3].

At the same time, Russia seeks to increase its presence in Asian markets [4], but the high cost of development of Greenfield gas deposits in RES and RFE regions and its associated long-distance transportation to the Asian gas markets made the supply of Russian gas to Korea economically inefficient [3]. The economics is becoming more favourable in the last decade because of the rapid increasing in oil prices and correspondingly in the gas prices.¹⁾ This makes gas production from the difficultly-accessible deposits in the RES and RFE regions more practical and also very attractive for sustainable development of the Russian Eastern part and for Northeast Asia as a whole.

This study developed the methodology for enabling the calculation of the minimum prices of gas supply from the RES and RFE regions to Korea. Specifically it determines the price of gas supply from the Chayanda oil and gas condensate field (OGCF) in the Republic of Sakha (RES) together with the gas from Sakhalin III gas fields offshore of Sakhalin Island (RFE), with gas transportation by pipelines across Russia to the Pacific coast (port Vladivostok) and further gas transportation from Vladivostok to South Korean consumers, by tankers as LNG, or, alternatively, by a land pipeline through the Korean Peninsula.

While there are several publications analysing the economic feasibility of Russian gas supply to Korea [5-6], including feasibility studies conducted by companies such as UKOS (Russia), BP (UK), Kogas (Korea) jointly with the government of Sakha Republic (RES) that worked in eastern Russian gas projects, the question of the Russian gas supply cost for Korea still remains open because of two reasons. First, because the previous works examined the different sources and therefore routes of gas supply to Korea [5] which are resulting in different

1) Since in all Korean long-term gas supply contracts the gas price is still linked to the oil price by the price formula.

level of final gas price. For example such as the gas supply from Kovykta field near Irkutsk city (RES) by 4,100 km gas pipeline to northeast China and Korea [5; 3]. Second, because the past studies were conducted under different economic assumptions of the gas supply projects, such as different levels of taxation, different field development schemes (production sharing agreements, concessions etc), as well as for different inflation and discount rates. The previous studies also employed the assessment of the economic feasibility of the project mostly by the Net Present Value (NPV) criteria. This criterion, however, do not show to the buyer the economic merit of the project. From the gas buyer point of view, the project is feasible and desirable if the price of gas by the planning project is equal or lower than the projected gas market price. In this connection, in this study author employed the assessment of the economic feasibility of the project by slight different methodology which allows calculating the minimum acceptable price of gas at which the project could already proceed. Taking into account all differences with the previous studies mentioned above, our study on the gas supply from Chayanda and Sakhalin III gas fields with its consequent transportation to Pacific coast and then directly to Korea is unique in the literature on Russian gas supply to Korea and important for assessing the feasibility of the Russian-Korean gas supply project under the current economic conditions.

To define the possible minimum price of Russian gas supplied to Korea: DES.²⁾ (Samchuck³⁾) we calculate the total price of gas supply which includes the gas production cost in the prospective gas fields (Chayanda and Sakhalin III), gas pipeline transportation cost across Russia to the Pacific coast, the gas

2) Delivered Ex Ship (named port) -where goods are delivered ex ship, the passing of risk does not occur until the ship has arrived at the named port of destination and the goods made available for unloading to the buyer. The seller pays the freight and insurance costs. Costs for unloading the goods and any duties, taxes, etc... are for the Buyer [15].

3) The marine port, planning LNG terminal at the North-East coast of the Republic of Korea.

transportation cost from the Pacific coast by LNG tankers and alternatively by gas pipeline through the Korean Peninsula (PNG transportation), as well as the minimum rates of return by capital in each element of gas supply chain (gas production, transportation, liquefaction).

To determine the optimal parameters (diameter and working pressure) of trunk gas pipelines the author employed computational methods of fluid dynamics, constituting thereby a bottom-up cost estimation to make pre-engineering estimates of gas production, pipeline and LNG transportation costs. This analysis is integrated with a cost-benefit and breakeven analysis of all gas supply related projects, such as production, transportation, gas liquefaction projects.

2. Planning Russian-Korean natural gas supply project: general information

This section provides some general information about the possible Russian-Korean natural gas supply project and its background.

2.1. Russian-Korean natural gas supply project: background

Korea's interest in the Russian gas supply dates back to the late 1980's. Since that time, the Russian Eastern Siberia and Far East regions had been considered as a potential base for gas supply to Korea. During the Soviet era and the first decade after the breakup of the Soviet union in 1991, all gas export projects to Asian markets have however failed to progress because of a mixture of political, commercial and institutional obstacles [3]. Since 2002 the situation changed fundamentally after the Russian Government started preparing the program

for a unified system of gas production, transmission and distribution in Eastern Siberia and the Far East, taking into account the possibility of exports to China and other Pacific-Asia countries (Eastern gas program [7]). The Russian gas monopoly company JSC Gazprom was appointed by the Russian government as the program execution coordinator. Russian-Korean negotiations about the gas industry progressed since that time. On May 12, 2003 Gazprom and Korea's Kogas entered into a five-year Agreement of Cooperation which was extended for another five-year term in 2008. The agreement embraces a wide spectrum of issues including the study of possible ways to deliver Russian natural gas to Korea. In November 2010 the parties entered into the next stage of negotiations and signed a "road map" to export Russian gas to South Korea. According to the document deliveries of natural gas will start in 2017, and the volumes of import are planned to be as much as 10 billion cubic meters per year [4]. The duration of the planned long-term contract is expected to be 25 years.

2.2. Details of the gas supply

The natural gas to Korea from Russia may be delivered in liquefied (as LNG) or compressed (as CNG) form, by tankers or by a land pipeline (as PNG) [4]. A possible route of the pipeline is through the Korean Peninsula.

According to the Eastern Gas Program, the sources of gas supply to Korea would be the Sakhalin III gas field offshore of Sakhalin Island (RFE) and the Chayanda oil and gas condensate field (OGCF) in the Republic of Sakha (RES). According to this program, the transportation of gas will start from the Russian fields to its Pacific coast as follows:

1. From the Sakhalin III gas fields by the recently constructed Sakhalin-Khabarovsk-Vladivostok gas transportation system (GTS).

2. From the Chayanda gas field, by a planned pipeline Yakutia-Khabarovsk with subsequent integration into the Sakhalin-Khabarovsk-Vladivostok GTS.

In the Russian Pacific port Vladivostok, the gas would be pumped into the planned Trans-Korean gas pipeline, or optionally, liquefied in the planned LNG plant [8] and transported to Korea by tankers (Figure 1). The CNG transportation which is also one of the options of international gas transportation to Korea is not included in the scope of our study due to the lack of sufficient technical and economical data on marine CNG transportation methodology and gas compression plants.

Figure 1. The map of the possible project of gas supply from Russia to Korea.



As seen from the map, the physical infrastructure of the planned gas supply system to Korea includes the following seven elements:

1. The Sakhalin III gas field;
2. The Chayanda OGCF;
3. The Sakhalin - Khabarovsk - Vladivostok GTS ;
4. The Yakutia - Khabarovsk gas pipeline ;
5. The liquefaction plant (optional);
6. Marine LNG transportation (optional);
7. Trans-Korean gas pipeline (optional).

A short description of each of these elements follows.

2.3. Description of the projects

The Sakhalin III project involves the development of the Kirinskoye gas field (located 50 km offshore, at water depth around 150 m), which are the Ayashsky and East Odoptinsky blocks of Sakhalin III field. Gas reserves and resources of the Sakhalin III project are estimated at some 1.4 trillion cubic meters. The field is scheduled to become operational in 2014 [9] and the annual gas production from the field will be at the level of 28.6 billion cubic meters (bcm) [10].

The Chayanda OGCF in East Siberia in Sakha Republic (also known as Republic of Yakutia) is the biggest gas field in the planned Yakutsk center of gas production in Eastern Siberia.⁴⁾ The Chayandinskoye field's proved reserves consist of 1.24 trillion cubic meters of gas and 68.4 million (M) tons of oil and gas condensate [11]. Annual gas production from the field will be at the level of 31 bcm [12]. It is projected to start oil and gas production from the Chayandinskoye field in 2014 and 2016, respectively.

The Sakhalin - Khabarovsk - Vladivostok pipeline is for the transport of

4) According to the [7] it is planned to establish four new gas production provinces in east Siberia, namely Krasnoyarsk, Irkutsk, Sakhalin, Yakutsk gas production centers.

Sakhalin's gas to the Vladivostok port and then to the customers in the Far East countries. The total length of the Sakhalin - Khabarovsk - Vladivostok pipeline is 1,837 km. The maximal annual capacity is 31.7 bcm. The diameter of the pipeline is 1,220 mm, and the maximum rated pressure is 9.8 megapascals (MPa).

The Yakutia - Khabarovsk pipeline will start from the Chayanda OGCF in Yakutia. In Khabarovsk city, it will be connected with the Sakhalin-Khabarovsk-Vladivostok GTS. Together, the pipelines will feed a planned LNG plant that will produce LNG for export to NEA, or that will feed a Trans-Korean gas pipeline (if built). The total length of the Yakutia - Khabarovsk pipeline will be about 2,800 kilometres and total length of pipeline from Yakutia to Pacific Ocean (port Vladivostok) is 4,383 km. The maximum annual capacity is 31.7 bcm. The diameter of the pipeline is 1,220 mm, and the maximum rated pressure is 9.8 MPa.

The LNG plant near Vladivostok will be built in the period 2015~2018, and its capacity could be 10 M tons of LNG per year. Two 5 M ton LNG trains are expected to be built. Such plans had been considered by the Board of Gazprom's Directors (as related to the development of gas processing and gas chemicals industry in eastern Russia) in February 2011.

Until our study completion time there was no technical and economic information on a planned Trans-Korean gas pipeline (Figure 2). Consequently, the technical and economic parameters of planning this gas pipeline were determined and calculated by the author for this study. In this analysis she determined that for supplying 10 bcm of gas to Korea per year it is optimal to build the pipeline with a 1,020 mm internal diameter and operation at 5.45 MPa maximum rated pressure. The length of the pipeline from the Vladivostok port to the destination point - Korean port Samchuck, is 980 km. In the optimization analysis it was chosen to space the compressor stations 130 km apart, thus requiring 8 such stations.

Figure 2. Map of the Trans-Korean planned gas pipeline



Correspondingly, to calculate the final gas price of Russian gas in Korea it is necessary first, to find the price of gas in each of seven elements of the gas supply chain, described above, namely the price of gas production from two fields in Russia, the price of domestic gas transmission by two pipelines, the price of consequent gas liquefaction and LNG transportation as one alternative, and of compressed gas transportation by a Trans-Korean gas pipeline as the other.

To assess the economic merit of the project, the calculated minimum acceptable price (prices - according to the different means of international transportation: LNG or PNG⁵⁾) of Russian gas in Korea must finally be compared with the projected market price of crude oil (since currently the crude oil price serves as a reference for the LNG price in Korea) or the price of gas for the same region (NEA).

The comparison must be made on the same energy basis and in the same units. In this paper, it is million British thermal units (MBtu). In this study the comparison is made under the assumption that the average barrel of crude oil has

5) Pipeline Natural Gas

an energy content of 5.8 MBtu and the energy content of 1,000 m³ of gas is 36.235 MBtu as recommended by International Energy Agency (IEA) for natural gas from Russia [13].

The future crude oil prices in 2010 United States dollars (\$) for the period of the contract from 2017 to 2041 obtained from the projections of the IEA[1]while ignoring the effect of inflation⁶⁾ and extrapolating the price trend up to the end of the contract, are in the range from 18.37 and 25.79 \$/MBtu or 107 \$ to 150 \$ per barrel of crude oil. This information will be used as the base for comparison of the obtained gas prices with the projected oil price. We also compared the obtained gas prices by the contract with the average gas price projection. According to the IEA forecast on the gas prices in the different regions, the market price of gas for Asia during the same period of time is expected to be about 0.7 of the price of oil [1] in other words in the range of 12.86 and 18.05 \$/MBtu.

3. Methodology

In this study the cost-plus pricing methodology for calculation of the possible minimum price of Russian gas in Korea is described.

3.1. Cost-plus pricing methodology

Cost-plus pricing is a bottom-up approach in the sense that it starts by

6) The inflation rate is taken equal to 2.5% annually.

specifying production costs of gas, gas transmission costs, optionally cost of gas liquefaction and marine gas transportation, adds a profit elements in each segment⁷⁾ of the gas chain, and arrives at a cost and profit based price at the delivery point [13]. This method of pricing could help to determine the minimum price that the seller can accept, which includes the sellers' expenses for gas supply as well as the value that the sellers place for their own efforts to participate in this gas supply contract, i.e. the desired minimum rate of return on investment (hurdle rate). In other words the price which allows the project to **break even financially**. We will call this price a breakeven price (BEP) of gas and it is a key element for the calculation of the minimum price of Russian gas in Korea.

3.2. Calculation of the BEP through the cost-benefit analysis

To calculate the BEP of gas in each element of gas supply chain first it is necessary to conduct the cost-benefit analysis (CBA) of each element, precisely: CBA of gas production projects, CBAs of liquefaction and transportation projects. By CBA all benefits and costs related to the project (in money terms) then will be adjusted for the time value of money, using the discount technique, so that all flows of benefits and costs of project over time (which tend to occur at different points in time) are expressed on a common basis in terms of their "present value".

The central tool of CBA and the convenient method for identification of the break-even point (and consequently, the BEP) is the Net present value (NPV) of the project cash flows.

7) The adding of the profit elements separately by the each element of the seller's gas chain or aggregately to the total cost of gas supply depends on the physical structure of the seller's company, e.g. whether its gas production and transportation segments working as a separated businesses each with each own financial accounting system or not.

The formula for NPV is as follow:

$$NPV = \sum_{n=1}^N \frac{B_n - C_n}{(1+r)^n} \quad (1)$$

Where:

N - Analysis period, years.

B_n - Benefit of the project in year n , M USD

C_n - Cost of the project in year n , M USD

R - Discount rate (the time value of cash flows)

Since the price of gas (P) directly influences the benefits (B_n) of the project ((Eq. (2) below) and the investment and operational cost are essential components of the total costs (C_n)(Eq.(3)), they are integral parts of the NPV (Eq. (4)).

$$B_n = Q_n \times P \quad (2)$$

$$C_n = I_n + O_n \quad (3)$$

$$NPV = \sum_{n=1}^N \frac{(Q_n \times P) - (I_n + O_n)}{(1+r)^n} \quad (4)$$

Where:

B_n , C_n , r , n and N are as in Eq. (1).

Q_n - Gas production/transmission/liquefaction rate in year n , bcm

P - Unit price of gas in project in question, USD/1000 m³ of gas

I_n - Investment expenditures in year n , M USD

O_n - Operation and maintenance expenditures in year n , M USD

The calculation of NPV is to assess the total gain/loss from the project and therefore to identify the break-even point of the project. If NPV of the planning project under the chosen discount rate is less than zero ($NPV < 0$) the project will create financial losses to the investor and he would probably refuse to participate in the project; if $NPV = 0$, the investor would be indifferent whether to participate or not, because he will not see any profit or loss from the project. If, however, $NPV > 0$, the seller may be interested in participation because the investment creates added value for him.

The situation when $NPV=0$ is very similar to the break-even point situation by definition. When $NPV=0$ the total cost and benefit of the project are equal, i.e. there is no net loss or gain, which is a necessary but still insufficient condition for achieving the break-even point. The sufficient condition for achieving the break-even point is $NPV = 0$ at a discount rate (r) equal to the minimum expected rate of return by investor or hurdle rate (HR)⁸⁾ (5).

$$\sum_{n=1}^N \frac{(Q_n \times P) - (I_n + O_n)}{(1 + HR)^n} = 0 \quad (5)$$

Therefore from Eq. (5) the equation for the price (P) at a break-even point is:

$$BEP = \frac{\frac{\sum_{n=1}^N I_n + O_n}{(1 + HR)^n}}{\sum_{n=1}^N \frac{Q_n}{(1 + HR)^n}} \quad (6)$$

8) In business and engineering, the minimum acceptable rate of return, or hurdle rate is the minimum rate of return on a project a manager or company is willing to accept before starting a project, given its risk and the opportunity cost of forgoing other projects.

Where:

BEP is break-even price which is equal to the *P* at a break-even point.

For calculation of the minimum price of Russian gas to Korea, the BEPs of gas must be calculated for each of the seven component-projects described above, then correspondent BEPs must be added together to come up with two final prices of Russian gas, corresponding to the alternatives for international gas transportation to Korea, namely as PNG and LNG.

3.3. Calculation of the cost-based price of Russian gas in Korea

The prices of Russian gas delivered ex-ship to Korean port Samchuck (DES_Samchuck (Korea)) consist of two essential parts. The first part is the price of Russian gas delivered to Russian Pacific coast to port Vladivostok (FCA_Vladivostok).⁹⁾ This part is the same for both final PNG and LNG prices. However, the second part of the prices varies and depends on the chosen mean of international transportation, PNG or LNG, respectively.

To find the cost-based price of Russian gas at the Russian Pacific coast in port Vladivostok (P_{FCA}), after which the two different means of international gas transportation could be applied, the BEPs of gas production and pipeline natural gas (PNG) transportation across Russia must be summed together in the proportion shown in Eq. (7):

$$P_{FCA} = 0.4 \times (BEP_{prod}^{ch} + BEP_{tr}^{ch}) + 0.6 \times (BEP_{prod}^{skh} + BEP_{tr}^{skh}) \quad (7)^{10)}$$

9) FCA - Free Carrier (named places). The seller hands over the goods, cleared for export, into the custody of the first carrier (named by the buyer) at the named place. [15]

10) Since there is no any public information on the rate of gas which will come from Chayanda and Sakhalin III fields for supplying the natural gas to Rep. of Korea, the author decided to

Where:

P_{FCA} - Price of gas in Russian Pacific port Vladivostok, USD/1000 m³ of gas;

BEP_{prod}^{ch} - BEP of gas production in Chayanda OGCF, USD/1000 m³ of gas;

BEP_{tr}^{ch} - BEP of gas transportation from Chayanda field to Vladivostok by Yakutia – Khabarovsk and then by Khabarovsk-Vladivostok gas pipelines, USD/1000 m³ of gas;

BEP_{prod}^{skh} - BEP of gas production in Sakhalin III fields, USD/1000 m³ of gas;

BEF - BEP of gas transportation from Sakhalin III fields to Vladivostok by Sakhalin-Khabarovsk-Vladivostok GTS, USD/1000 m³ of gas.

The price of gas in port Vladivostok is serving as a basis for the calculation of the final price of Russian gas in Korea (DES_Samchuck).

As mentioned, in this study two options for international transportation of Russian gas to Korea (PNG and LNG) is considered, which will obviously have an influence on the level of the final prices of gas in Korea.

The formulae for final price of Russian gas in Korea are,

$$PNG_{Kor} = \frac{(P_{FCA} + BEF_{tr}^{PNG})}{(1 - 0.3)} \quad (8)^{11)}$$

$$LNG_{Kor} = P_{FCA} + BEP_{liq} + BEP_{tr}^{LNG} \quad (9)$$

choose the rates of gas as follows: 0.6 parts of gas from the closer field Sakhalin III and 0.4 from the Chayanda field.

11) The export of natural gas from Russia is subject to export duty equal to 30% (or 0.3) of the money-value of the exported gas, but the duty does not apply to gas exported as LNG [16].

Where:

P_{FCA} - is as in Eq. (7);

BEP_{tr}^{PNG} - BEP of PNG transportation by Trans-Korean gas pipeline;

BEP_{liq} - BEP of planning gas liquefaction project at Vladivostok;

BEP_{tr}^{LNG} - BEP of marine LNG transportation to Korea.

4. Data

The BEP calculation in each component project includes the following elements: investment, operational cost, related taxes and minimum return rate expected by seller (HR). It does not include here the R&D cost, environmental impact studies cost, costs of impacts on public health and environmental damage, costs of government subsidies, cost of rights of way for pipelines, transit fee, and others possible costs.

For the calculation of the BEP by each of seven planning investment component projects included in the gas supply plan, firstly we estimated the investment and operation costs for each project.

The estimation of the investment cost was primarily based on open media sources because most of the component projects for gas production and its transportation to the Russian Pacific coast are already in the planning stage and information on them is available to the public. However, the information on the investment cost for a Trans Korean gas pipeline is not yet available because its planning is still at an early stage. Author therefore used for this component the capital cost estimation methodology at the pre-design stage for gas pipelines that was developed in [17].

4.1. Cost estimation for CBA of the projects

In all component projects related to the gas supply to Korea the calculation of the operational expenses (O^{total}) include depreciation charges (D), other operational & maintenance costs (O), and in some cases the cost of fuel gas (F).

Based on the different publications and opinions of the experts working in the gas industry, the operational & maintenance cost (O) and volume of the fuel gas (F) in our study are taken as the annual percentage rate of the total investment¹²⁾ or annual throughput, respectively.

The annual cost of fuel gas (F_N) is calculated as (10)

$$F_N = BEP^{pr} \times r_f \quad (10)$$

Where

BEP^{pr} - The BEP of gas in the project, prior to the project in question¹³⁾,

r_f - Fuel gas rate taken annually as a percentage of the total annual volume of gas production/transportation/liquefaction;

All investments in this study are subject to value-added tax (VAT) and income tax, whose rates in Russia at the time of this study were 18% and 20%, respectively. Gas fields, LNG plants and LNG tankers in Russia are subject to property tax whose rate is 2.2% of the value of assets minus the value-added tax. Gas production is taxed by severance tax.¹⁴⁾ From the January 1st, 2013, the

12) Precisely the O is taken annually as the percentage rate of the total sum of the investment minus the Value-added tax charge from this sum of the investment.

13) For example, if the cost of fuel gas is calculated for the Sakhalin-Khabarovsk-Vladivostok gas pipeline project, then it is equal to the BEP of gas production in the Sakhalin III gas field.

severance tax rate will be 265 roubles¹⁵⁾ per 1000 m³ of gas produced [18] (or \$8.73/1000 m³ in year 2014). The basic calculation of the BEP of gas production will therefore be based on the rate of severance tax equal to \$8.73/1000 m³ (for the period from 2014). As it was already mentioned the export of natural gas from Russia is subject to export duty. For PNG it is equal to 30% of the value of the exported gas, and for LNG is 0%.

For calculation of BEP in the possible Russian-Korean gas supply contract we took the standard HRs of seller separately by up- and middle- stream segments of the gas chain. Since the gas seller in the planning contracts is the Russian monopoly gas company Gazprom, in our CBA we will use the HR of Gazprom in up- and middle-stream segments of gas chain, which is respectively 12% and 15%.¹⁶⁾

Most of the input data for CBA differs from project to project of our study, but there are several common elements. The base year to which all cash flows in the projects are converted is 2010. The Final year for all projects is 2041 because the gas supply contract will probably end in that year: the duration of the gas supply contract are expected to be 25 years.

Since almost all elements of the planned project will be constructed in Russia (except the LNG tankers), the calculation of costs was firstly made in current roubles (RUB). The costs in current RUB were then converted into constant RUB, using the inflation rate indexes. The base inflation rate index used in the study is the Producer Price Index (PPI) and the Core inflation index published by The Central Bank of the Russian Federation (CBRF) [19]. The CBA had been performed in current 2010 M United States Dollars. For this purpose,

14) Severance taxes are incurred when non-renewable natural resources are separated (or severed) from a taxing jurisdiction.

15) Russian Federation Currency (RUB).

16) The exception is the project of LNG marine transportation, where the ROR is taken equal to 10% as in the world in average.

the values of costs in constant RUB had been transformed into the value in constant USD, by using the official exchange rate of the RUB, published by CBRF [20].

4.2. Input data for CBA

The input data for the 7 projects included in the cost-based prices calculation vary from project to project and will be specified for each project in the following tables.

Table 1. Input data for the CBA of the gas production from the Sakhalin III and Chayanda OGCF projects

Attributes	Chayanda field	Sakhalin III field
Year of the investment beginning ¹⁷⁾	2012	
Start of gas production	2016	2014
Analysis period (years)	30	
Depreciation rate, D _r (%)	6.7 (100% / 15)	
HR (%)	15	
Maximum gas production rate (bcm/a)	31 ¹⁸⁾	28.6 ¹⁹⁾
Total investment (M US\$)	6,521	15,065
Annual operation cost ²⁰⁾ (%)	4	
Annual Loss of gas (% of the annual production)	2	
Taxes: VAT. Income, property and severance taxes as mentioned above.		

17) In which the actual investment occurs.

18) Production volume in the first years of Chayanda field development from 2016 to 2018 would be: 3.3; 13.9; 21.8 bcm/a respectively.

19) Production volume in the first years (from 2014 to 2016) of Sakhalin fields development will

The investment costs in the development of Chayanda and Sakhalin III projects are expected to be about 6,521 B USD and 15,065 B USD, including VAT respectively [21 - 22].

The higher investment cost in the Sakhalin III field in comparison with gas production at the Chayanda field can be attributed to more severe conditions of offshore gas production, which requires much larger investments than production onshore. Investment in the development of the Chayanda and Sakhalin fields will be committed consistently over 4 years (from 2012 till 2015) at the rate as scheduled below:

Table 2. Investment schedule into gas fields development and production

Year of inv.	2012	2013	2014	2015
Share of total investment (%)	40	30	20	10

Table 3. The Input data for CBAs of the gas transportation from the Chayanda and Sakhalin III fields to Vladivostok

Attributes	From Yakutia (Chayanda)	From Sakhalin
Year of the investment beginning	2013	2009
Start of operation	2016	2012
Analysis period (years)	30	
Depreciation periods (years):		
Pipeline	25	
Compressor stations	10	

<continued>

be 3.3; 13.9; 21.8 bcm/a respectively.

20) Taken annually as a percentage of total investment.

Attributes	From Yakutia (Chayanda)	From Sakhalin
HR (%)	12	
Throughput (bcm/a)	31.0	28.6
Total investment (B US\$)	26,185	11,684
Annual rate of fuel gas (% of the annual production throughput, for 1 station)	0.5	
Annual operation cost (%)		
Pipeline	1	
Compressor stations	3,5	
Taxes: VAT and income tax as mentioned above.		

The investment cost into pipeline from Yakutia (Chayanda field) is given as in [22].

The total investment cost of Sakhalin-Khabarovsk-Vladivostok GTS had been estimated by the author based on [23 - 24] and with help of methodology for the estimation of construction cost of trunk gas pipelines that was developed in [17].

It should be noticed that the throughput of pipelines that enable to supply gas from Chayanda and Sakhalin III fields to the Russian Pacific coast and the level of maximum gas production at the fields may vary significantly, since the gas from the fields will also be used for supplying the gas consumers in the Sakhalin Island and in the Republic of Sakha.

For both pipelines the following assumptions are made: the pipelines operate at load level of 95% of transportation capacity during the entire project. This assumption makes it possible to calculate the minimum price of gas transportation that will recoup the investment and operation cost in the pipeline and provide seller with the HR on his investment.

The planned LNG plant near Vladivostok city will be built in the period of 2015~2018. Such plan had been considered by the Board of Gazprom's Directors (within issue of development of gas processing and gas chemicals industry in the eastern Russia) on 1 October 2009 [25]. The parameters for the economic modelling of the liquefied gas production on the planning plant are as follow.

Table 4. Economic parameters of the Vladivostok LNG plant

Parameters of LNG plant	Value	Unit
Investment cost	10,000	M USD
HR	12	%
Operation and maintenance	4	% of the total investment, annually
Depreciation period	20	Years
Rate of Fuel gas	7	% of the total throughput
Cost of raw gas	270	USD/1000 m ³
Start of operation	2017	Year
Year of the investment beginning	2015	Year
Analysis period	30	Years
Taxes: VAT, property, Income as mentioned above		

The experts from Gazprom [26] argued that investment costs in the construction of the new onshore LNG plant are approximately the same as in the Yamal LNG project, namely \$1,000 per ton of LNG per year. In our economic modelling we will consequently take a unit investment cost equal to \$1,000/ton LNG/a, then the total investment cost into a 10 M LNG plant will be $10 \times 1,000 = 10,000$ M USD.

In our study we assume that the LNG plant work at a load factor²¹⁾ of 98%. The cost of fuel gas is equal to the cost of gas at the inlet of the plant.

The gas for liquefaction into the plant will come from the Sakhalin III and Chaynda gas fields in the following proportions:

- 60% of gas for liquefaction from Sakhalin III
- 40% of gas for liquefaction from Chayanda OGCF.

The economic parameters for the economic modelling of the marine LNG transportation to Korea are given in table 5.

Table 5. Input data for the CBA of the LNG transportation project

Data	Value	Unit
Investment year	2016	
Start of operation	2017	
Analysis period	26	Years
Depreciation period	20	Years
HR	10 ²²⁾	(%)
Volume of gas transported	10	Bcm/a
Total investment	441	M US\$
Rate of fuel gas	6.687	% of volume transported annually
Cost of gas	433	\$/1,000 m ³
Cost of fuel oil	390	\$/ton
Annual operation cost	4	% of total investment annually
Taxes: VAT, Income, Property taxes as explained above		

21) Load factor is the degree of utilization of the maximum pipeline capacity in percent.

22) Discount rate is taken by the world standards for the LNG transportation projects

Feasibility of Natural Gas Supply from Russia to Korea

As the basis for calculating the volume of investments in the LNG tankers which is necessary to carry the LNG from the plant to Korean consumers, we took information on the average cost of LNG carriers of a similar size purchased in Japan and Korea for LNG project Sakhalin-II in 2007. The total cost of three tankers was 424 million dollars. Taking into account the inflation rate in Russia, the total cost of the tankers in constant 2010 USD should be 441 M USD.

The calculated investment and other costs for the Trans-Korean gas pipeline are as follow:

Table 6. The input data for CBA of the Trans-Korean gas pipeline

Attributes	value	Unit
Investment years	2015, 2016	-
Start of operation	2017	
Analysis period	27	Years
Depreciation periods		
Pipeline	25	Years
Compressor stations	10	Years
HR	12	%
Total investment	3,273	B US\$
Annual cost of fuel gas	4	% of the annual production throughput
Annual operation cost		
Pipeline	1	%
Compressor stations	3,5	%
Taxes: VAT, Income tax, export fee as given above.		

There was no technical and economic information on the planned Trans-Korea pipeline at the time of writing. Consequently, the technical and economic parameters (including the investment costs) of the pipeline had been selected and calculated using the methodology for determining the optimal technical parameters of the pipeline based on the criterion of minimum BEP of gas transportation proposed by author in [27].

The detailed information on the calculation of the investment costs and economic modelling of the planning gas supply project could be also found in [27].

The BEPs of gas obtained as the result of the consequent seven CBAs of each projects will be described in the next section as well as the comparison of the obtained prices with the projected prices of crude oil and gas.

5. Results of analyses and validation

As the result of the seven subsequent CBAs of related gas production and transportation projects the following elements of the final prices of Russian gas in Korea had been obtained.

5.1. Results

The obtained BEPs of gas production in the distinguished fields and BEPs of transportation by pipelines, which are necessary for calculation of the price of gas at the Russian Pacific coast (P_{FCA} by (7) are given as in Table 7.

Table 7. BEP of Russian gas at the Russian pacific coast (P_{FCA}), USD/1,000m³

BEP	Chayanda field	Sakhalin III field
BEP of gas production, BEP_{prod}	79.31	144.62
BEP of gas transportation to Vladivostok, BEP_{tr}	254.08	90.73
Total: ($BEP_{prod} + BEP_{tr}$)	333	235
P_{FCA}	275	

As seen from the Table 7 the cost of gas production in Chayanda and Sakhalin III varies significantly. The price of gas is higher in Sakhalin III offshore gas fields due to the much higher investment costs, which is necessary to develop gas fields in the more severe conditions of offshore gas production than onshore. The costs of gas transportation also vary more than two-fold mostly due to the different distances between the specific fields and the Pacific coast; the total route from Chayanda field to Vladivostok is about 4,383 km, while the distance between Sakhalin III and Vladivostok is only about 1,890 km.

In Table 8 the BEPs of international gas transportation by pipeline (BEP_{tr}^{PNG}) and as LNG (BEP_{tr}^{LNG}), which are necessary for calculating the final prices of PNG and LNG by (8) and (9) are given.

Table 8 BEP of international gas transportation

BEP	USD/1,000 m ³
Trans-Korean pipeline (BEP_{tr}^{PNG})	52.8
Total by LNG, which is including:	204
- Liquefaction (BEP_{liq})	164
- LNG transportation (BEP_{tr}^{LNG})	40

Table 9 shows the results of calculation of the final minimum prices gas in Korea by the project in USD per 1,000 m³ of gas and in USD per MBtu for the further comparison purpose with the projected price of oil at the same energy basis.

Table 9 Obtained cost-based prices of gas and its oil price equivalent.

Cost-base price	USD/1,000 m ³	\$/MBtu	Crude oil price parity, \$/Bbl
PNG_{Kor}	468	12.91	75.03
LNG_{Kor}	479	13.22	76.88

As seen from the Table 9 the price of LNG and PNG or Russian gas in Korea is practically the same: LNG is more expensive than PNG by less than 3%.

Finally the author compared the obtained prices with the oil and gas prices projection given by IEA for the same period of time. The comparison is showed in table 10.

Table 10. Comparison of the project gas prices with the price projections

Price		USD/MBtu	Percentage of the oil price
Oil price projection	130 \$/bbl	22.31	100
Gas price projection	568 \$/1,000 m ³	15.62	70
Project PNG	468 \$/1,000 m ³	12.91	58
Project LNG	479 \$/1,000 m ³	13.22	59

The projections of the IEA crude oil import prices in 2010 dollars by the Current Policies Scenario assume the average price of oil for the period of the contract at the level of \$130/bbl and the ratio of gas prices (in the Asia Pacific Region (APR)) is forecasted to be equal to around 0.7 of crude oil price [28].

5.2. Validation and error analysis

As written in section 4, the estimation of the investment cost, which is the central and most important part of the calculations, was based on public data.

All the equations used in the calculations are commonly used for the assessment of the economic feasibility of the investment projects.

All calculations were performed in the Microsoft Excel program and then validated by manual calculation.

The comparison of the calculated investment costs with the actual costs for the same projects available in the public sources showed a high degree of accuracy of the obtained results. For example, for the gas pipeline Yakutia-Khabarovsk the difference between the investment cost calculated in our study and the officially-reported cost by the government of Republic of Sakha [12] is only 3%.

The comparison of the final gas prices of Russian gas for Korea as well as its individual elements - BEPs of gas by each segment (production, transportation, liquefaction) with the other cost/price indicators is almost impossible and even useless for the following reasons: Cost indicators of the gas value-chain worldwide may be included in information database of major consulting companies (for example, WoodMackenzie, IHS CERA and others) but these indicators are the intellectual property of these organizations and could be available only on a paid basis. Moreover, databases and computational models that are generated by large consultancies are the “black box” whose input is fed by a limited set of input data. Some information is available, perhaps, only in the annual reports of individual

companies doing business in certain countries. Cost indicators for the gas value-chain in Russia are a commercial secret of Gazprom Company and other independent gas companies in Russia.

Finally, the use of the information on the cost of gas production, transportation (by pipeline and tankers) and liquefaction in Russia and in the world as a whole could not be useful for the error analysis because each project is unique with its own internal characteristics (geological, climatic conditions, equipment and technology, etc.) and conditions of sale (legal, economic, political and other environments), which significantly affect the results of the CBA of the gas supply projects including the gas price calculation. Also, each state has its own regulatory and tax base, which also significantly affect performance.

5.3. Conclusions

As it is follow from the comparison of the PNG and LNG price by the project, the total economic effect on the supply of PNG compared with the supply of LNG could be: $(479-468) \times 10^6 = 110$ M \$/annum. However, under the existing conditions of political instability on the Korean peninsula, which makes the gas pipeline project through North Korea extremely risky, the potential economic losses in the event of unforeseen hostile acts or overlap of gas supply could, reach billions of dollars. Therefore, this economic benefit could be obtained only under conditions of signing the additional agreements which will warranty the security of the pipeline and the absence of the military actions in the Korean peninsula.

On the positive side, however, a joint project for pipeline construction between Russia, North and South Korea can pull the conflicting parties together, to develop economic and social ties between parts of the country that have the same language and ethnicity but separated by political tensions, and thus help to finally bring peace to the Korean peninsula, for which the residents of both

Koreas have been waiting more than fifty years. Cooperation in the pipeline construction through the Korean Peninsula can thus be an important opportunity to bring together the peoples of North and South Korea, with benefits far greater than just gas transportation.

Turning back to the assessment of the economic feasibility of the project, it is necessary to say that the following conversion of the obtained prices of gas by the energy parity on the basis of the oil price (Table 9) shows that the price of PNG of 468 \$/1,000 m³ and LNG of 479 \$/1,000 m³ are already competitive with oil price at the level of 75-77 \$/bbl. Taking into account the level of world oil prices at the time of writing this paper (April 2011) at around 110 \$/bbl and the projected increase of oil prices in the period of the contract being up to 130 \$/bbl (Table 10), it is obvious that the possible prices of gas by this project is much lower than the current and projected world oil prices. The project PNG and LNG prices are lower than the oil price projection by 42% and 41% correspondingly. Moreover, the comparison with the projected average gas prices for APR given by IEA, showed that the project also has the economic advantage. The project PNG and LNG prices are also lower than the IEA “Asian” gas price projection by 17.6% & 15.7% correspondingly.

This facts lead to the conclusion that the proposed contract for gas supplies from Russia to Korea has an economically good chance of success and could provide Korea with additional gas supply at reasonable price, as well as provide Russia with new gas consumers in the Asia-Pacific gas market. In this connection we could rather say that the gas supply project from Russia to Korea is economically feasible and could bring the additional benefits to all parties of the contract such as financial benefits, social benefits and improvement of energy security of the North-East Asian countries.

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