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Optimal Portfolio for LNG Importation in Korea Using a Two-Step Portfolio Model and a Fuzzy Analytic Hierarchy Process

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Abstract: A new energy transition policy in Korea has increased the importance of liquefied natural gas (LNG) in the energy mix. The Asia-Pacific LNG market is inflexible because long-term contracts are dominant. This market characteristic means that the development of policies that ensure a stable supply of LNG is essential. We developed a new model for the optimal LNG import portfolio. The model consists of a two-step portfolio model combining the mean-variance (MV) portfolio and the linear programming (LP) model. In the first step, the MV model was applied to derive the optimal ratio between the long-term and spot contracts. Next, the LP model was used to determine the optimal LNG portfolio. We also applied a fuzzy analytic hierarchy process (AHP) to determine the weights of the cost factors. The application of the fuzzy AHP enabled this research to reflect the tangible and intangible costs more effectively. The optimal LNG portfolio showed that the optimal ratios for the long-term and spot contracts are 89.72% and 10.28% respectively, and the supply ratios in the Middle East and Southeast Asia decreased, while those in the Far East and Oceania significantly increased. The proposed model is able to build an effective LNG import strategy because it reflects the characteristics of LNG markets better than previous models.

Keywords: liquefied natural gas (LNG) import; portfolio; fuzzy analytic hierarchy process (AHP); mean-variance portfolio; linear programming

1. Introduction

The Asia-Pacific gas market is growing due to the massive investment in liquefied natural gas (LNG) supplies and increasing demand. According to the International Energy Agency (IEA) [1], the Asia-Pacific demand for natural gas will increase from 732 billion cubic meters (bcm) in 2016 to over 1472 bcm in 2040. The predicted average annual demand growth rate of 3.0% between 2016 and 2040 is much faster than those projected for North America or Europe—0.7% per year and 0.3% per year, respectively, over this period [1]. Despite this increase in demand, structural oversupply of the gas market has occurred due to the construction of large-scale liquefaction facilities in the US, Australia, and Russia, and policies to expand Qatar's exports. Hence, the growth of the market has continued based on the abundant gas supply capability and because the current gas market is a buyers' market [2,3].

However, the presence of a buyers' market does not mean that risks to the security of supply have disappeared. This risk is demonstrated, for example, by the past disruption in supply caused by the Middle East war and Russia, and by the recent diplomatic confrontation between Qatar and its neighbors [1,4,5]. These events pose a serious threat to the energy security of certain LNG importing countries. The characteristics of the LNG market also increase the risks. Unlike the oil

market, long-term contracts have long dominated the Asia-Pacific market for LNG [6]. In the case of LNG, a long-term project period is required because the exporting country must build a large-scale infrastructure for transportation [7]. Therefore, the LNG market is inflexible in the sense that supply is unable to respond elastically to short-term increases in demand [8]. These market characteristics indicate that policy-making and research concerning stable importation is necessary.

Korea was the world's third-largest LNG-consuming country in 2017 [9], but its dependence on LNG imports was as high as 99.6% [10]. Due to the lack of domestic natural gas resources, the stability and security of LNG is an important policy issue. Korea is unable to trade with neighboring countries through pipelines due to geopolitical conditions caused by the ceasefire with North Korea. This means that Korea is an isolated market that depends entirely on LNG transport [11]. In addition, the storage cost of natural gas is high, and Korea's geographical features make the underground storage of natural gas difficult [12]. The Renewable Energy 3020 Implementation Plan [13], an energy transition policy established in 2017, further boosted the importance of stable LNG imports. The policy states that the electricity supply through renewable generation will be increased to 20% by 2030 [13]. An increase in renewable energy will increase the demand for LNG because the intermittency of renewable energy requires LNG-fired plants to serve as backup generators to stabilize the electricity supply [14,15]. With these conditions, any problems in a natural gas exporting country such as a natural disaster, or marine transportation accident can severely threaten energy security. Since the 2000s, the threat of terrorism on energy infrastructure and transportation has increased, and natural disasters such as hurricanes have an adverse ripple effect. Consequently, the understanding of energy security has extended beyond security and diversification of energy sources to include all energy supply infrastructures related to transportation and utilization [16].

Considering the Korean situation and value chain of the natural gas market, we developed an optimal LNG portfolio model that considers tangible and intangible costs to improve the importation stability of LNG from the perspective of Yergin's [16] energy security model. The model quantifies not only tangible factors that depend on the supply capability of each exporting country, such as the natural gas price, reserve capacity, and liquefaction facilities, but also intangible factors, such as the risk of natural disasters, transportation, and political influences.

Previous studies [17–21] based on the linear programming (LP) portfolio model did not consider spot contracts when determining optimal portfolio strategies and only considered long-term contracts. Since the demand for natural gas markedly differs between winter and summer, spot trading is used in winter to cope with natural gas shortages. Therefore, it is necessary to consider spot contracts within the model. We solved this problem by combining the Markowitz's mean-variance (MV) portfolio model [22] with the LP portfolio model. Also, we solved the problem of weight determination using the fuzzy analytic hierarchy process (AHP) methodology. The weights have a significant impact on the optimal portfolio strategy and therefore, it is essential to derive the weights quantitatively using a scientific methodology. The study of applying fuzzy AHP to determine weights has been applied in various fields, and its validity has been verified [23–25]. AHP plays a critical role in many decision-making problems [26]. Thus, this study more accurately reflects the tangible and intangible factors by using weights based on the results calculated from the fuzzy AHP.

Finally, we evaluated the optimal LNG portfolio derived from the models using Lefèvre's [27] energy security index. The energy security index showed that the optimal portfolio improves the energy security quantitatively compared to the actual LNG portfolio.

The remaining sections of the paper are organized as follows. The second section proposes a two-step portfolio framework. The third section presents the data to be calculated. The fourth section presents the results and discussion based on the optimal portfolio strategy. Finally, the fifth section concludes the paper and presents the policy implications.

2. Materials and Methods

2.1. Research Scheme

Figure 1 shows the analytical framework of this study. This study had three phases.

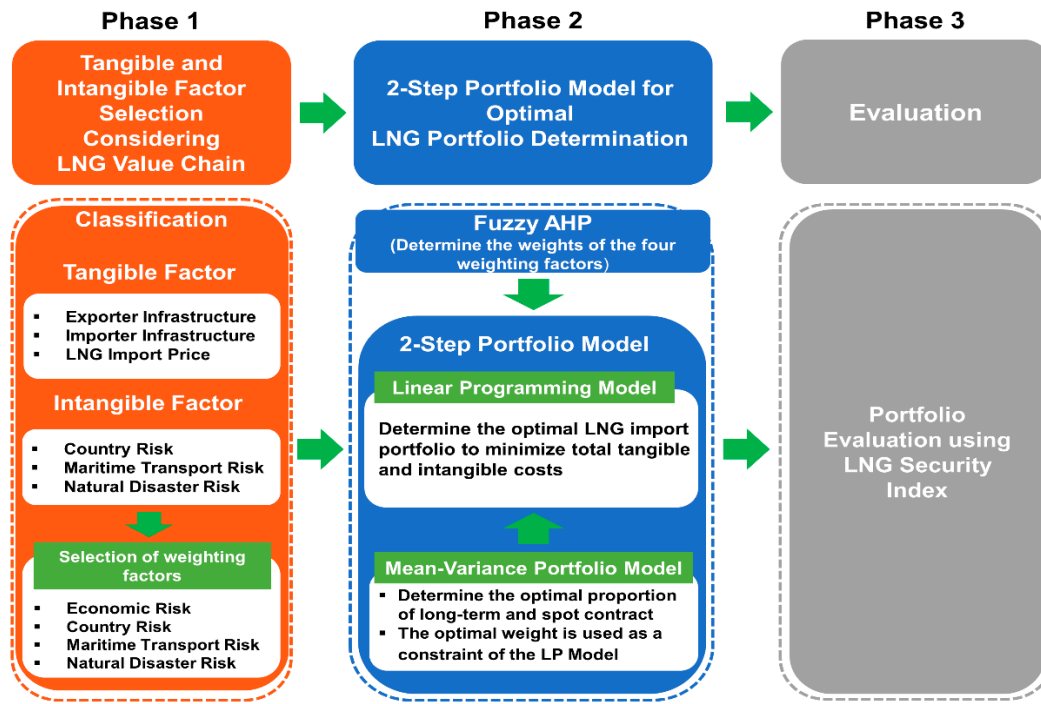


Figure 1. The analytical framework of this study.

1. **The selection of tangible and intangible factors considering the LNG value chain:** The LNG market has a value chain represented by liquefaction–transportation–storage and re-gasification [28]. To take into account the value chain and specificity of the LNG market, intangible factors, such as the national risk and transport risk, as well as tangible factors, such as the supply capacity and introductory price, were set as components and variables in the model. The risk factors to LNG importation may be approached from the following four perspectives: the risk of transportation, the risk of natural disasters, the economic risk, and the national risk. These factors have also been considered in previous studies [17–21]. These four weight factors were used as in the two-step portfolio model to determine the volume of supply from each country.
2. **Two-step portfolio model and fuzzy AHP for optimal LNG portfolio determination:** The model in this study consisted of a two-step portfolio model combining the MV portfolio model and the LP model. In the first step, we applied the MV portfolio to determine the optimal purchase ratio between the long-term and spot contracts. The optimal purchase ratio was calculated considering the prices of long-term and spot contracts as well as the correlation between them. The optimal ratio was calculated using the cost–risk efficient frontier on the basis of the price levels of the term contract and spot trading as well as the correlation between them. The optimal purchase ratio was used as the constraint equation in the LP model. In the second step, we applied the LP portfolio model based on Biresselioglu’s [17] model to determine the optimal LNG portfolio. The optimal LNG portfolio that minimized the total tangible and intangible costs was determined. Fuzzy AHP was applied to calculate the weights.
3. **Assessment of optimal introduction portfolio using the energy security index:** Finally, we evaluated the optimal portfolio derived from the model. The evaluation was based on the Energy Security Market Concentration (ESMC) model proposed by Lefèvre [27]. This assessment showed that the

optimal portfolio derived from the model compared to the actual portfolio used in Korea was quantitatively improved from a energy security perspective.

2.2. Fuzzy AHP

The AHP can derive weights for each criterion based on the decision maker's pairwise comparison. Qualitative factors can also be quantified through AHP. However, the original AHP analysis proposed by Saaty [29] is not performed considering the fuzziness of the decision makers. Fuzzy AHP is a synthetic extension of original AHP methods when the fuzziness of the decision makers are considered [30,31]. Much research on the fuzzy AHP, which is an extension of Saaty's theory, has provided evidence that the fuzzy AHP provides more adequate descriptions of decision-making processes than traditional AHP methods [32–35].

Among the various AHP methods involving fuzziness [36–39], Chang's calculation method [34] is the most preferred one [40]. Using triangular fuzzy numbers for a pairwise comparison scale, Chang introduced the extent analysis method for synthetic extent values of pairwise comparisons. In this study, we followed the method proposed by Chang's approach. Detailed calculations are presented in Chang [34].

2.3. Mean-Variance Portfolio Model

Under uncertain future conditions, the MV portfolio analysis is used to reduce risk without reducing the expected return by diversifying the investment assets and using the correlation between them [41]. Also, it enables the creation of an optimal ratio for any given level of expected cost. This MV approach is the most recognized approach to optimal portfolio selection [42]. Various studies have applied the portfolio theory in the energy field [42–46]. We analyzed the portfolio selection based on Markowitz [22] theory and Korea Energy Economics Institute (KEEI) [44] research.

Let us consider n assets. The cost of a portfolio constructed with these assets is given by

$$R_p = \sum_{i=1}^n w_i r_i \quad (1)$$

where w_i is the weight of asset i in the portfolio, and r_i is the cost of asset i .

The MV portfolio model for the optimal long-term/spot contract ratio can be defined as

$$\min \sigma(R_p) \quad (2)$$

$$\left\{ \begin{array}{l} \text{s.t. } E(R_p) = \sum_{i=1}^n E(r_i)w_i \\ \sum_{i=1}^n w_i = 1 \\ x_i \geq 0 \quad i = 1, \dots, n \end{array} \right. \quad (3)$$

where $E(R_p)$ and $E(r_i)$ denote, respectively, the expected cost of the portfolio and the expected cost of asset i , and $\sigma(R_p)$ denotes the portfolio's cost standard deviation (i.e., the portfolio's risk). The risk of the portfolio can be written as

$$\sigma(R_p) = \sqrt{\sum_{i=1}^n w_i^2 \sigma_i^2 + 2 \sum_{i=1}^{n-1} \sum_{j=i+1}^n w_i w_j \sigma_i \sigma_j \rho_{ij}} \quad (4)$$

where σ_i is the standard deviation of asset i 's cost, and ρ_{ij} is the correlation coefficient between the costs of assets i and j .

Given the abovementioned equations, the optimization process minimizes the variance of a portfolio that includes a fixed expected minimum cost. Therefore, an investor or decision maker can

calculate an efficient frontier with the minimum variance for each expected cost using the objective Equation (2) and the constraints (3). The efficient frontier is a set of optimized portfolios. A decision maker can choose an optimal portfolio for the efficient frontier, taking into account their preferences.

This study derived the optimal purchase ratio by solving the portfolio optimization problem with two purchase alternatives (long-term and spot contracts). Using Equations (2) and (3), we selected the optimal purchase ratio between the long-term and spot contracts with minimum risk on the efficient frontier. The optimal purchase ratio ($P_{long-term}$) was set as the constraint in the LP portfolio model.

2.4. Linear Programming Portfolio Model

The purpose of the LP portfolio model is to select the optimal LNG portfolio for Korea, which determines the LNG imports from each country that minimizes the sum of the types and intangible factors.

The parameters used were as follows:

(1) Set

i	Number of LNG-exporting countries
j	Korea
t	Time

(2) Parameters

CL_i	Importing price from the exporting country i ,
SC_j	Inventory holding costs for LNG at ports within the importing country,
IC_j	LNG storage capacity of importing country j ,
HC_i	Country risk for exporting country i ,
HT_{ij}	Maritime transport risks from country i to country j ,
HN_i	Nature disaster risks for exporting country i ,
D_{jt}	Amount of LNG demand in importing country j at time t
L_i	Annual liquefaction capacity of country i
R_j	Annual re-gasification capacity of country j
A_{it}	LNG supply volume of exporting country i ,
$Maxp_{it}$	Maximum percentage of LNG that one supplier country can export to one importing country at time t ,
$P_{long-term}$	The optimal <i>long-term</i> contract ratio derived from the MV portfolio model

(3) Variables

X_{ijt}	Amount of LNG imported from country i to country j at time t
S_{jt}	LNG storage capacity of the importing country j at time t

(4) Weights

wl	Weight for economic risk
wc	Weight for country risk
wt	Weight for maritime transportation risk
wn	Weight for natural disaster risk

The objective functions used in the study were established based on Biresselioglu's [17] and Lee's [21] models and by considering the equations and parameters used in previous studies [17–21]. The objective function was as follows:

$$\min f_{optimal} = wl \left(\sum_{i,j} CL_i X_{ij} + SC_j S_{jt} \right) + wc \left(\sum_{i,j} HC_i X_{ij} \right) + wt \left(\sum_{i,j} HT_{ij} X_{ij} \right) + wn \left(\sum_{i,j} HN_i X_{ij} \right) \quad (5)$$

When determining the optimal LNG portfolio, it is important to consider the infrastructure of importing and exporting countries and the diversification of importation sources [18]. To consider these conditions, we set constraints. The relevant formulas used for the constraints were as follows.

The market concentration of the LNG market is high. This situation increases the vulnerability of importing countries [34]. Importing countries should diversify their sources of LNG supply to enhance the security of energy. Considering previous studies [17,21] and to enhance the security of LNG importation, we assumed that the maximum ratio of supply by an exporting country did not exceed 25% of the total demand amount for the importing country. This constraint is shown by Equation (6):

$$X_{ijt} \leq 0.25D_{jt} \quad \forall i, t \quad (6)$$

An exporting country can export depending on the maximum percentage of LNG that it can export to importing country i at time t . This constraint is shown by Equation (7):

$$\sum X_{ijt} \leq \text{Maxp}_{it} \times A_{it} \quad \forall i, t \quad (7)$$

The importing country j , Korea, should secure the amount of LNG that meets the demand at time t . This constraint is shown by Equation (8):

$$\sum X_{ijt} + S_{jt} - S_{jt-1} \geq D_{jt} \quad \forall j, t \quad (8)$$

A liquefaction facility is needed to export natural gas in the form of LNG. The amount of LNG supplied from the exporting country i should be less than or equal to the liquefaction capacity in the exporting country i . This constraint is shown by Equation (9):

$$\sum X_{ijt} \leq L_i \quad \forall i, t \quad (9)$$

A re-gasification facility is required to gasify the imported LNG for utilization. Therefore, the total amount of LNG importation should be less than or equal to the annual re-gasification capacity in the importing country. This constraint is shown by Equation (10):

$$\sum X_{ijt} \leq R_j \quad \forall j, t \quad (10)$$

The volume of LNG held in the inventory of country j at time t cannot exceed the LNG storage capacity of importing country j . This constraint is shown by Equation (11):

$$S_{jt} \leq IC_j \quad \forall j, t \quad (11)$$

All variables in the model should be greater than or equal to zero. This constraint is shown by Equation (12):

$$X_{ijt}, S_{jt} \geq 0 \quad \forall i, j, t \quad (12)$$

Finally, by applying the optimal long-term contract purchase ratio derived from the MV portfolio model as the constraint equation, we considered the volume of the long-term contracts in the optimal portfolio strategy. This constraint is shown by Equation (13):

$$\sum X_{i,j,t} \geq P_{\text{long-term}} \times D_{j,t} \quad \forall i, j, t \quad (13)$$

3. Data

3.1. Selection of Exporting Countries

In this study, of the 17 countries that traded LNG with Korea from 2013 to 2015, all except Belgium were chosen as analytical subjects. Belgium was excluded because it is not an LNG producer country

but rather, an LNG importer and re-exporter. In addition, the amount of LNG imported from Belgium was just 0.3% of Korea's total import volume; consequently, the effect of this amount on the entire supply portfolio was negligible. The sixteen selected countries were as follows: Qatar, Indonesia, Oman, Malaysia, Russia, Yemen, Trinidad and Tobago, Nigeria, Equatorial Guinea, Australia, Peru, Egypt, Norway, United States, Brunei, and Algeria.

3.2. Tangible Factors

We used various references to obtain the LNG importation prices in Korea. The long-term contract price was calculated based on the internal data of the Korea Gas Corporation (KOGAS), IEA statistics [47], and the importation volume and bill from K-stat [48]. The spot contract price was obtained from the Platts's [49] JKM (Japan Korea Marker) LNG price. The LNG infrastructure data from Korea and the exporting countries, and the LNG trade volume in the exporting countries were determined from the IEA [47] and BP [50]. As in the previous study [18], the inventory holding cost for LNG was set at \$0.079 per cubic meter [18]. The demand for total natural gas in Korea was determined from KEEI [51]. In 2016, the demand for natural gas in Korea was 47,472 million cubic meters (mcm).

3.2.1. Infrastructure Data related to LNG

Table 1 shows the amount of global LNG exported by the exporting countries. We used the share (%) of the largest export target country as the maximum supply ratio of each exporting country in this study's constraint Equation (7).

Table 1. Liquefied natural gas (LNG) export amounts of exporting countries (mcm).

Exporting Country	Largest Export Target Country (A)	Total	Export Volume	Share (%) (Max_{it})
Qatar	Japan	98,374	22,676	23.05
Indonesia	Japan	20,243	7124	35.19
Oman	Korea	9757	4955	50.78
Malaysia	Japan	33,575	21,051	62.70
Russia	Japan	14,584	11,700	80.22
Yemen	Korea	8293	4000	48.23
Trinidad and Tobago	Chile	16,424	3196	19.46
Nigeria	Japan	25,727	7019	27.28
Equatorial Guinea	Japan	4148	1659	40.00
Australia	Japan	31,892	25,199	79.06
Peru	Mexico	5240	3997	76.28
Egypt	China	419	160	38.19
Norway	Spain	4750	1251	26.34
United States	Japan	429	348	81.12
Brunei	Japan	8270	6090	73.64
Algeria	Spain	17,922	5098	28.45

Since LNG should be liquefied in an exporting country before export, a country producing natural gas must construct the necessary infrastructure to export natural gas in LNG form. Table 2 presents data on the liquefaction infrastructures of the exporting countries.

An importing country also needs a facility to gasify imported LNG for use. Therefore, considering the re-gasification capacity reflects the uniqueness of the LNG market. Table 3 lists the capacity of the re-gasification facilities in Korea.

Table 2. Liquefaction and LNG storage capacity of exporting countries.

Exporting Country	Liquefaction		Storage
	Nominal Capacity		Capacity
	LNG (mcm)	Gas (bcm)	Thousand cm of LNG
Qatar	170.3	104.7	2340
Indonesia	55.9	34.4	1776
Oman	23.9	14.7	240
Malaysia	64.8	39.8	390
Russia	23.9	14.7	200
Yemen	15.9	9.8	280
Trinidad and Tobago	33.8	20.8	524
Nigeria	48.2	29.8	337
Equatorial Guinea	8.2	5.0	272
Australia	135.1	83.1	1808
Peru	9.8	6.1	260
Egypt	27.0	16.6	580
Norway	9.3	5.7	250
United States	23.2	14.3	908
Brunei	15.9	9.8	195
Algeria	63.0	38.8	1350

Table 3. Re-gasification and LNG storage capacity of Korea.

Location	Liquefaction		Storage
	Nominal Capacity		Capacity
	LNG (mcm)	Gas (bcm)	Thousand cm of LNG
Boryeong	7.0	4.3	400
Gwang-yang	3.9	2.4	530
Incheon	96.8	59.5	2880
Pyeong-Tack	88.3	54.3	3360
Samcheok	25.4	15.6	1800
Tong-Yeong	57.8	35.6	2620
Total	279.3	171.8	11,590

3.2.2. Price Data

The average LNG monthly import unit price from each exporting country was used as the price data in this study. Table 4 shows the average LNG import unit price in each exporting country for 2013 and 2015.

Table 4. LNG long-term contract prices for each exporting country (\$/MMBtu).

Exporting Country	2013	2014	2015
Qatar	16.16	18.34	17.51
Indonesia	13.06	13.96	13.85
Oman	16.06	18.70	18.06
Malaysia	9.78	11.01	13.31
Russia	7.19	7.62	6.01
Yemen	6.95	7.64	8.41
Trinidad and Tobago	11.50	12.14	12.89
Nigeria	12.26	14.61	15.36
Equatorial Guinea	12.22	14.15	17.05
Australia	11.32	14.30	14.13
Peru	10.40	0	16.99
Egypt	12.39	14.24	16.18
Norway	12.85	13.01	18.11
United States	10.99	0	0
Brunei	15.26	18.85	17.34
Algeria	0	17.65	16.03

Figure 2 shows the spot and the average long-term contract price and the rate of price change between 2013 and 2015. Table 5 shows the descriptive statistics for price data.

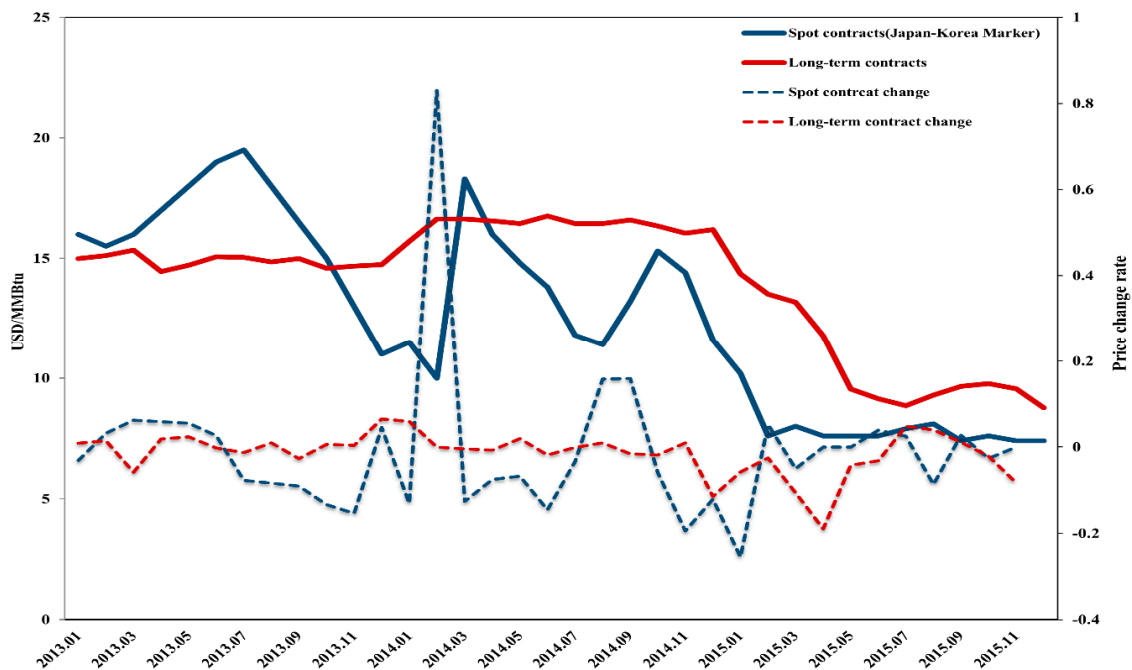


Figure 2. The price of spot and long-term contracts and the rate of price change.

Table 5. Descriptive statistics on price data.

Statistics	Long-Term Contract	Spot Contract	Change Rate of Long-Term Contract	Change Rate of Spot Contract
Mean	13.97	12.53	−0.0139	−0.0105
Standard error	0.46	0.67	0.0085	0.0292
Median	14.92	12.4	−0.0020	−0.0313
Mode	14.99	7.6	0.0000	0.0000
Standard deviation	2.73	4.03	0.0504	0.1728
Variance	7.48	16.26	0.0025	0.0299
Kurtosis	−0.65	−1.39	3.5037	16.6677
Skewness	−0.94	0.08	−1.5104	3.4461
Range	7.99	12.1	0.2544	1.0849
Minimum value	8.77	7.4	−0.1893	−0.2549
Maximum value	16.76	19.5	0.0651	0.8300
Number of observations	36	36	35	35
Confidence level (95%)	0.93	1.36	0.0173	0.0594

3.3. Intangible Factor Data

The intangible factors considered in this study consisted of the country risk, the maritime transportation risk, and the natural disaster risk. These factors were quantified and used as data for the optimal portfolio considering the value chain of the natural gas market. The country risk was calculated based on the Failed States Index [52]. The Failed States Index is calculated by measuring 12 indices for public services, human rights, and poverty, among others, for 178 countries. The maritime transport risk was obtained from the International Chamber Of Commerce (ICC) [53] report. Finally, the natural disaster risk for the exporting country was calculated using the Global Climate Risk index [54].

3.3.1. Country Risk

The country risk, also known as the political risk, indicates the risk of political instability, such as coup d'état, riots, and a low degree of political freedom [55,56]. From an energy security point of view, analyzing the country risk of a trading partner state is critical when constructing an LNG portfolio. The country risk was calculated using the Failed Country Index [52], which is based on the general political, economic and social issues of each country. The index is calculated by measuring 12 indices for public services, human rights, and poverty, among others, for 178 countries.

3.3.2. Maritime Transport Risk

Korea is unable to use a pipeline natural gas-related network connected to the Asian continent because of the division of South and North Korea. Thus, Korea's natural gas demand can only be satisfied by the marine transportation of LNG. Since the major marine transportation pathways used by Korea pass through areas such as the Malacca Strait and the Gulf of Aden where marine terrorism is frequent, it is important to include the risk of marine transportation in the model. We calculated the maritime transport risk by using the number of piracy incidents and armed robberies in the marine transportation pathways from the exporting country to Korea. The ICC [53] provides this data.

3.3.3. Natural Disaster Risk

To reflect the impact of natural disasters on infrastructure, this study used the Global Climate Risk Index [54], which assesses the risk of climate change and natural disasters. The index is calculated considering the impact and the amount of damage caused by natural disasters. Table 6 shows data on the intangible risks of the exporting country.

Table 6. The data on the intangible risks of the exporting countries.

Exporting Country	Country Risk	Maritime Transport Risk	Natural Disaster Risk *
Qatar	47.1	102.5	9.17
Indonesia	78.2	95	120.5
Oman	52	102.5	129.17
Malaysia	66.1	34	96.17
Russia	77.1	0	135.67
Yemen	107	116.5	115.67
Trinidad and Tobago	62.6	38	38
Nigeria	100.7	38	63.83
Equatorial Guinea	86.1	19	9.17
Australia	25.4	4	126.17
Peru	72.3	2.5	116.5
Egypt	90.6	147.5	60.83
Norway	21.5	148	48.17
Algeria	78.7	148	88.33
Brunei	63.2	34	21
United States	33.5	0	134.67

* The risk was calculated according to the method suggested by Lee [21] based on the Global Climate Risk Index [54].

3.4. Normalization

Before analyzing the optimal portfolio, we performed normalization. Normalization was performed to avoid distortion using the different scales of the individual risk factors. Table 7 shows the normalized values.

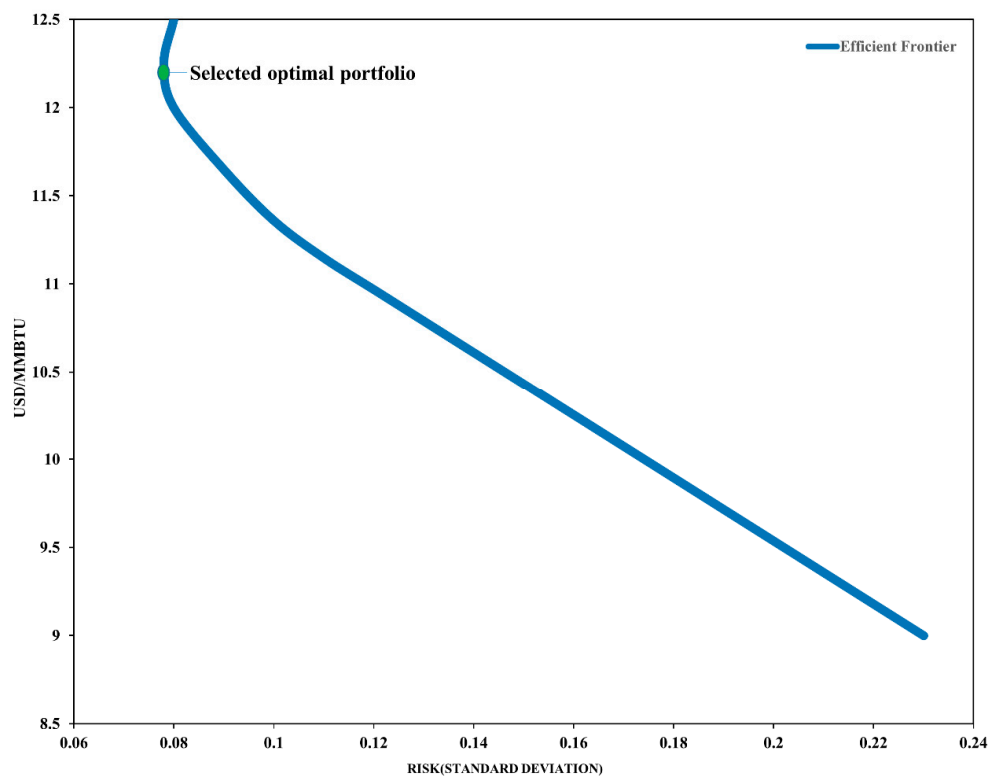
Table 7. Normalized values of the exporting country risks and prices.

Normalization				
Exporting Country	Country Risk	Maritime Transport Risk	Natural Disaster Risk	LNG Price
Qatar	0.440	0.693	0.068	0.985
Indonesia	0.731	0.642	0.888	0.774
Oman	0.486	0.693	0.952	1.000
Malaysia	0.618	0.230	0.709	0.646
Russia	0.721	0.000	1.000	0.394
Yemen	1.000	0.787	0.853	0.435
Trinidad and Tobago	0.585	0.257	0.280	0.692
Nigeria	0.941	0.257	0.470	0.8
Equatorial Guinea	0.805	0.128	0.068	0.822
Australia	0.237	0.027	0.930	0.753
Peru	0.676	0.017	0.859	0.519
Egypt	0.847	0.997	0.448	0.81
Norway	0.201	1.000	0.355	0.832
Algeria	0.736	1.000	0.651	0.638
Brunei	0.591	0.230	0.155	0.974
United States	0.313	0.000	0.993	0.208

4. Results and Discussion

4.1. MV Portfolio Result

The optimal purchase ratio was calculated using the MV portfolio model considering the price level and correlation between long-term and spot contracts. The optimal purchase ratio was selected using the efficient frontier. Figure 3 shows the efficient frontier and selected optimal portfolio. According to the analysis results, the optimal ratios for long-term and spot contracts were 89.72% and 10.28%, respectively.

**Figure 3.** The optimal purchase ratio on the efficient frontier.

4.2. Fuzzy AHP Results

As mentioned in the introduction, the weights derived by fuzzy AHP were applied as the weights for the economic, national, marine transportation, and natural disaster risks. Since we calculated the weight elements based on the KOGAS expert results, we were able to develop a model that more accurately reflects Korea’s situation. The fuzzy AHP results are shown in Table 8.

Table 8. Fuzzy analytic hierarchy process (AHP) results.

	Economic Risk	Country Risk	Maritime Transportation Risk	Natural Disaster Risk
Value	0.4512	0.2487	0.1410	0.1591

4.3. Optimal LNG Portfolio

Using the results of the fuzzy AHP and the optimal purchase ratio, we constructed the optimum LNG portfolio for each country. The results were compared with Korea’s actual LNG portfolio for 2012. Figure 4 and Table 9 show the optimal LNG portfolio.

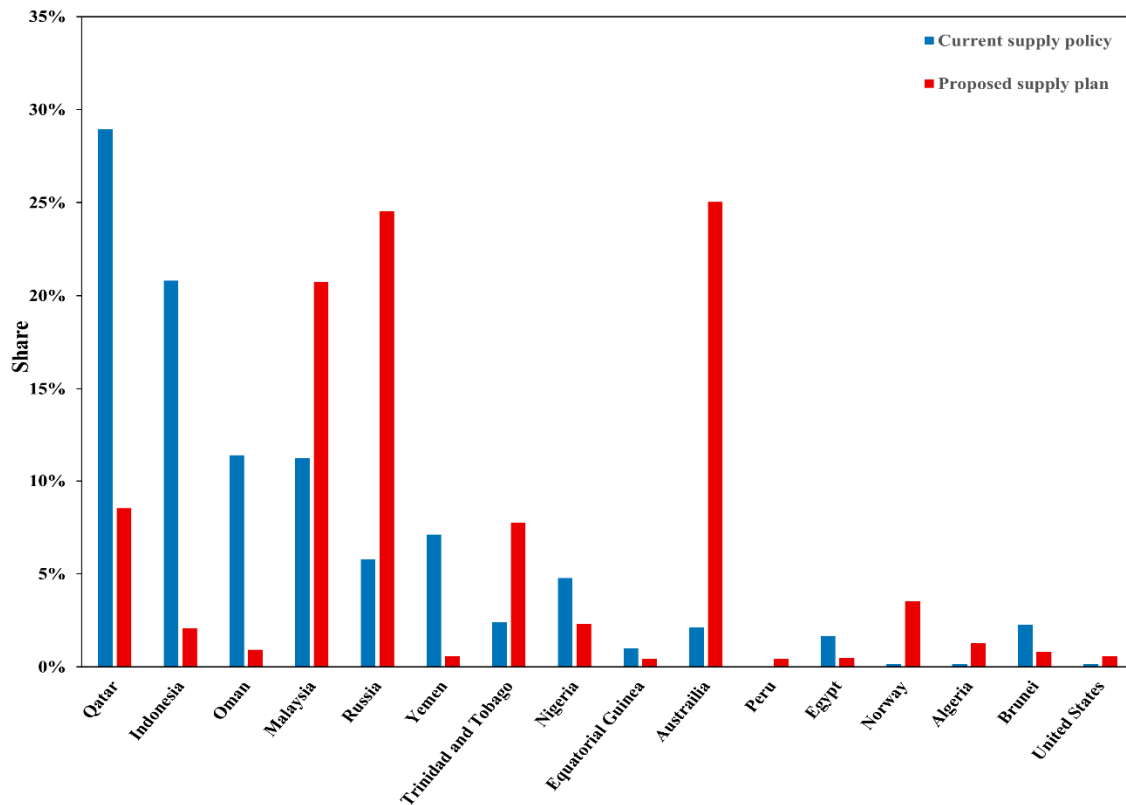


Figure 4. Comparison of portfolio analysis results.

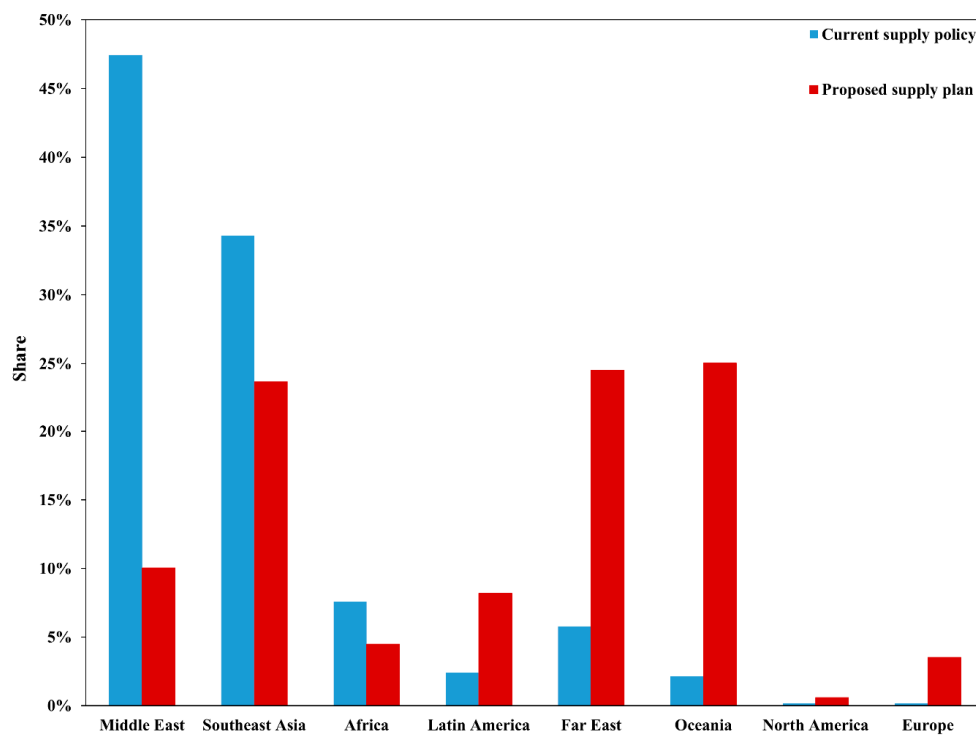
Also, we analyzed our portfolio using the analytical results on a regional basis because marine transportation, political, and natural disaster risks are not limited to the supplier country; the results have an interconnected effect on countries in the same region, as shown in Table 10 and Figure 5.

Table 9. Comparison of portfolio analysis results (%).

Exporting Country	Current Supply Policy	Proposed Supply Policy (the Optimal Result)
Qatar	28.95	8.53
Indonesia	20.81	2.07
Oman	11.38	0.92
Malaysia	11.21	20.73
Russia	5.78	24.54
Yemen	7.12	0.57
Trinidad and Tobago	2.42	7.75
Nigeria	4.77	2.31
Equatorial Guinea	1.00	0.44
Australia	2.12	25.04
Peru	0.00	0.43
Egypt	1.66	0.47
Norway	0.16	3.53
Algeria	0.16	1.27
Brunei	2.29	0.81
United States	0.17	0.59

Table 10. Comparison of portfolio analysis results for each continental region (%).

Supplier Country	Current Supply Policy	Proposed Supply Policy (the Optimal Result)
Middle East	49.12	10.03
Southeast Asia	34.31	23.61
Africa	5.92	4.48
Latin America	2.42	8.18
Far East	5.78	24.54
Oceania	2.12	25.04
North America	0.17	0.59
Europe	0.16	3.53

**Figure 5.** Comparison of portfolio analysis results for each continental region.

As shown in Table 10 and Figure 5, 49.12% of Korea's total LNG imports come from the Middle East and 34.31% are imported from Southeast Asia. This means that natural gas imports depend heavily on specific regions. More particularly, Qatar and Indonesia account for 49% of the total amount of imported natural gas. This high dependence on specific countries means that Korea should make policy efforts to diversify its import sources. A two-step portfolio model was developed in this study that considers a comprehensive energy security perspective and a value chain. The optimal portfolio derived from the model has results that differ to the current supply policy of Korea.

The proposed supply plan derived from the two-step portfolio shows that the supply volume from the Middle East and Southeast Asian regions decreases while that of the Far East and Oceania significantly increases. This is because the LNG unit price, national risk, and marine transportation risk in the Middle East are high. The supply volume from Southeast Asia is lower in the proposed plan than in the current supply policy because the risks of marine transportation and natural disasters are relatively high. In contrast, the supply volume from the Far East and Oceania, including Russia and Australia, considerably increases in the proposed supply plan because the risk of marine transportation and the unit price in these regions are lower than those in the Middle East and Southeast Asian regions. More specifically, the supply volume from all countries in the Middle East decreases. In Southeast Asia, the supply volume from Indonesia decreases significantly. This is because Malaysia's supply price and maritime transport risks are lower than those in Indonesia. Brunei's supply volume is slightly reduced. The supply volume from Latin America also increases. This is because the risk of marine transportation for countries in this region through the Pacific Ocean is much lower than that from countries in the Middle East, Southeast Asia, and Africa, which use high-risk sea routes. The opening of the Panama Canal has improved the region's competitiveness. Considering this situation, the prediction of an increasing supply volume from Latin America is reasonable. In Africa, there are also high levels of political and marine transportation risk; however, the import unit price is lower than that in the Middle East, resulting in a slight decrease in the supply volume in the optimal portfolio. Currently, KOGAS participates in gas field development and the acquisition of equity in Mozambique.

The supply volume of Australia is predicted to increase significantly in the optimal portfolio. Australia is expected to provide sufficient capacity because it has the world's largest liquefaction plant. Consequently, imports from Australia could be an excellent solution to the continually increasing demand for natural gas. In addition, since its marine transportation and political risks are low, it may be necessary to increase the supply volume from Australia, as indicated by the optimal portfolio. Russia is expanding its infrastructure capacity to increase LNG exports to Korea and Japan. Therefore, increasing the Russian supply ratio, as in the optimal portfolio, is a reasonable alternative.

According to the optimal portfolio, which considers tangible and intangible costs, the maldistribution of LNG supply in specific regions decreases compared to the current supply policy. To check the quantitative improvement from a security perspective, we used the natural gas security index model to evaluate the optimal portfolio. The model was proposed by Lefèvre [27]. The results of the comparisons are shown in Figure 6.

The results shown in Figure 6 represent the level of energy security evaluated in terms of diversification. A lower value means a higher level of energy security. By applying the current supply policy in Korea, the natural gas security index is shown to be 2.16. The result derived from the optimal portfolio is 1.67. These results indicate that the optimal portfolio has improved the energy security.

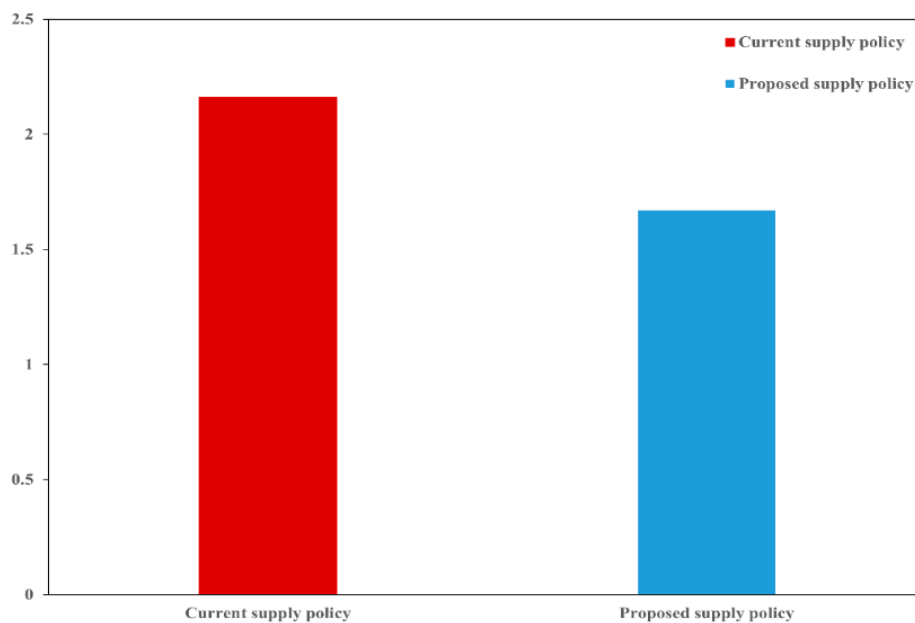


Figure 6. Portfolio assessment using the natural gas security index.

5. Conclusions

Korea has started to develop a new energy transition policy [13], and the policy has increased the importance of natural gas in the energy mix. Therefore, having stable LNG security is important. Considering the policy perspective, we developed a two-step portfolio model that reflects the price level, the correlation between long-term and spot contracts, and tangible and intangible costs based on the LNG value chain.

The optimal LNG portfolio calculated in this study has significant policy implications. The actual supply ratio of the Middle East and Southeast Asia (83%) significantly decreased to 30% in the optimal portfolio. This is because the tangible and intangible costs in these regions, such as maritime transportation and political risks, are higher than those in other regions. In contrast, the supply ratios of the Far East and Oceania increased sharply in the optimal portfolio. Accordingly, Korea's natural gas security index decreased significantly, indicating that the analytical results offer a crucial policy viewpoint. Indeed, the policy proposal derived from the optimal portfolio is consistent with the supply diversification policy that the Korean government has promoted. We propose that the Korean government consider the following policy directions.

- Diversification: Improving the LNG importation portfolio considering the economic and intangible risk.
- Increasing the flexibility of conditions for long-term contracts through cooperation with major LNG exporting countries.
- Utilization of spot and direct import to manage efficient supply and demand.

The analytical framework and results proposed by this study provide a solution to these policy goals. We suggest a diversification strategy and the optimal spot importation volume. In order to achieve comprehensive natural gas supply stabilization, the Korean government should increase its political action, such as through energy diplomacy that includes quota participation and the strengthening of their negotiating capability.

However, because long-term contracts dominate the natural gas market in Korea, it is not possible to change the LNG portfolio in the short run. Nevertheless, the findings of this study can be applied to formulate an LNG policy in the long run to significantly improve security policies and reduce the

tangible and intangible costs incurred [57]. Therefore, the novel analytical framework proposed in this study offers an effective tool for making decisions about the optimal LNG portfolio.

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