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Investigating the natural gas supply security: A new perspective

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ABSTRACT

This paper assesses the natural gas supply security of 23 importing countries from divergent regions of the world for the period between 2001 and 2013. The indicators used for the study are the volume of imported natural gas, the number of natural gas suppliers, the level of dependency on one country, import dependency, the fragility of supplier countries, and the share of natural gas in primary energy consumption. The method used to establish the supply security index is the PCA (principal component analysis) over the indicators in the model for each country on a yearly basis for the period 2001 to 2013. The dispersed country sample enables the established index to measure the sensitivity of specific natural gas importer countries using a uniform framework. According to the results, the most effective indicators for the measurement of supply security are the number of supplier countries, supplier fragility, and the overall volume of imported gas.

1. Introduction

Following oil and coal, natural gas is the third most consumed fuel, accounting for 23.7% global energy consumption [5]. The share of natural gas in global energy mix is increasing, since it is highly concentrated, flexible and versatile - as it can be used for not only for power generation, but also industrial, commercial and residential applications. This is because, compared to other fossil fuels, it is reliable, easy to store and transport, extremely efficient, and less harmful to the environment [14].

Hence, the consumption level has increased from 1960.14 bcm in 1990–2412.53 bcm in 2000, and to 3347.63 bcm by the end of 2013 [5]. Currently, OECD members account for 47.8% of the global consumption. The main contributors to this increase in consumption are OECD member countries, particularly The United States (US), Mexico, Canada, Japan, South Korea, Germany, Italy, Turkey, France, The United Kingdom (UK) and Spain. However, there are differences between the consumption trends for European and Asian OECD countries, which are generally importing countries, and OECD countries in North America, which account for 35.8% global production [5].

There has been a corresponding rapid increase in Non-OECD members' natural gas consumption. The level of consumption has increased from 1057.14 bcm in 2000, accounting for 43.8% of the global consumption, to 1751.12 bcm in 2013, accounting for 52.2% of the global consumption. China's natural gas consumption increased six-fold from 2000 to 2013 [5]. Economic growth and increasing needs in both power and industrial sectors are the key drivers for this rapid escalation [14].

Production has increased in line with consumption, growing from 2006.64 bcm in 1990–3369.88 bcm in 2013. The US has become the leading producer, with a 20.6% share of the global production in 2013, followed by Russia with 17.9%, Iran with 4.9%, Qatar with 4.7%, Canada with 4.6%, China with 3.5%, Norway with 3.2% and Saudi Arabia with 3.0%. These countries' combined production accounts for 62.4% of the global production [5]. These production trends are not, however, in proportion to the reserves of the countries concerned, the biggest of which are held by Iran, with 18.2% of the world's reserves, followed by Russia with 16.8%, Qatar with 13.3%, Turkmenistan with 9.4%, US with 5.0% and Saudi Arabia with 4.4%. These six countries combined account for 67.1% of the global reserves [5].

Since natural gas reserves are limited geographically, the largest natural gas consumers are dependent on imports, resulting in an increase in the global natural gas trade from 554.27 to 1035.95 bcm between 2001 and 2013 [5]. Currently, the major importers are Japan, the US, Germany, Italy, South Korea, UK, France, Turkey,

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China, and Spain. Of these, all except the US, the UK and China are dependent on imports for at least 80% of their consumption, due to the low level of indigenous production [5]. Nevertheless, China's escalating energy consumption, in addition to its policy of increasing the proportion of natural gas in its energy mix, sealed with a recent $400 billion deal with Russia [4], will reposition China in the group of natural gas importers, with an increase of 80% or more in the medium term.

Another important issue regarding trade is the method of natural gas transportation. Unlike the transportation of oil, at present, there are only two methods, pipeline and LNG (liquefied natural gas). The share of LNG in overall trade in 2001 was 25.7 percent at 142.95 bcm. By 2013, it increased to 31.4 percent at 325.32 bcm, representing a more than two fold increase in terms of volume [5].

Thus, natural gas prices have increased due to growing demand, similar to global oil prices. The UK Heren NBP (national balancing point) prices increased from 1.87 to 10.63 US dollars per Btu between 1996 and 2013, while the average German import LNG prices (Union CIF) increased from 2.46 US dollars to 10.72 US dollars per Btu [5] over the same period. The higher prices of LNG compared to piped gas reflects the additional costs incurred, due to transportation, liquefaction, and re-gasification.

Despite the increasing exploitation of natural gas, there are continuing problems related to supply. Natural gas importers around the globe are increasingly affected by factors such as the increasing level of traded volume, mounting fragility due to economic, political, and legal conflicts in the producing areas and transit countries, fluctuating prices, the growing dependency on foreign imports, the escalating share of natural gas in final energy consumption, and a lack of diversification [3]. In particular, level of supply security needs to be reconsidered by those countries highly dependent on a single supplier, such as Turkey, the UK, Poland, Hungary, Singapore, and Brazil. The dangers of dependency can be seen in the crises between Russia and Ukraine, in 2007, 2008 and 2009, which led to a supply disruption in the European Union (EU), due to its dependency on Russia for almost one third of its natural gas imports [20]. Similarly, dependency on a small number of suppliers could result as a threat to supply security. For instance, the negative impact of the Arab Spring on Libyan and Egyptian gas infrastructure and production threatened supplies to Italy and Israel respectively [2].

In addition, a larger portion of LNG in overall natural gas imports allows the importer countries to increase the level of supply security by adding more suppliers. However, it is important to note that there are currently only 17 LNG exporter countries available in the global natural gas market; Qatar leads with a 32.6% share in 2012, followed by Malaysia with 10%, Australia and Nigeria with almost 9% respectively, and Indonesia with almost 8%. These five countries account for almost 70% of the global LNG supply [15]. Countries such as Japan, South Korea, Chile, Spain and Portugal use LNG to meet more than 60% of their natural gas demand, leaving them vulnerable to various challenges to their supply security, for example the effects of Fukushima disaster, and price increases caused by increasing Asian demand [15].

There is a strong possibility that lack of supply security and diversification could jeopardize the economies of all natural gas importer countries. Taking steps to counteract all the above mentioned problems, while increasing diversification efforts is key to sustaining natural gas supply security worldwide. However, the number of importing countries is large, and each will require a specific strategy to secure their supply. Therefore, it is important to develop a supply security index which can adequately measure and evaluate the supply security of the major main natural gas importers.

Prior to the current study, a number of studies focused on developing a SSI (supply security index), mainly for the supply security of oil for the importing countries [9,11]; and [27], although a small number consider the supply security of natural gas importers [6,7,28]. The emphasized studies above present security indexes for the classification of related countries for their oil and/or gas vulnerability through a group of distinct variables, classified as market risk, supply risk and environmental risk factors [10]. While, in previous studies, a number of variables have been proposed for the relevant risk factors, no consensus currently exists as to the relative significance of indicators for the robustness of the indexes [7]. This is due to the country-specific variations for both importers and exporters of oil and natural gas.

The first common econometric model used is the PCA (Principal Component Analysis) [6,27,28]. The oil vulnerability index is calculated through the PCA method, which assigns weights for the principal components of the model-making indicators in the model. These components are each assigned specific weights, unlike the more subjective approach of the composite index method, which is the second most commonly used econometric model in studies related to SSI [7,9]. The interrelated indicators inserted into the index serve to rank the countries depending on their score, with a higher the score showing a greater risk.

Furthermore, the supply security literature indicates different approaches to measurement, therefore it is difficult to "*quantify and assess*" the level of energy vulnerability. The factors affecting vulnerability are dispersed across the market, supply and environmental levels, thus causing problems for the calculation of vulnerability indexes due to the extensive indicator portfolio that needs to be considered [30]. Additionally, the weights and scoring rules of the indicators by subjective expert opinions also vitiates the significance of the model, which negatively affects the actual outcome of the security indexing.

Considering the above analysis, the main aim of the current study is to measure and evaluate the natural gas supply security of the major main natural gas importers in regard to the supply risk and market risk factors. This evaluation is based on indicators such as the volume of the imported natural gas, diversification level, the level of dependency on the dominant supplier, import dependency, the economic, political and security risks related to supplier countries, supplier fragility, and the share of natural gas in primary energy consumption. The principal component analysis method is used to create the supply security index for the selected countries, taking into consideration country variables on an annual basis between 2001 and 2013, as indicated in the established model.

2. Research design and indicators

In the first stage, the selection of appropriate indicators is crucial to obtaining accurate results. Therefore, the primary phase of the indicator selection process was the review of the common indicators cited in the existing literature, specifically for supply side of the matrix. After this review, the two selected indicators were *import dependency* and *share of natural gas in primary energy consumption.* However, in order to show the importance of the *volume of the natural gas imported*, it was decided to include the actual volume, rather than simply demonstrating the impact of import dependency as a percentage. A comparison between the US and Turkey illustrates the reason for this. Although the US and Turkey had similar import volumes in 2013, 49.64 and 45.64 bcm respectively, their dependency level was vastly different, 7% and 99% respectively. Thus, from current study's perspective, import dependency as a percentage alone is not as significant as the actual volume. Moreover, as diversification is key to increasing a state's level of natural gas supply security [12,22,24], it is also important to include *the dependency on largest supplier* in the overall imports. Moreover, in this study, it is argued that it is crucial to include the supply levels of increasingly important LNG for importer countries in the calculation of supply security. However, rather than simply taking into account LNG as a percentage of overall imports, this study includes *the total number of natural gas suppliers*. It is clear that the countries with a larger number of suppliers tend to include higher amounts of LNG in their mix [6,7]. and [27,28] both included geopolitical risk and political measurement indicators to determine a range of risks presented by supplier countries, including security and political risks. Hence, in this study, it was decided to enhance the perspective related to supplier countries by employing an index which is well-recognized in the social sciences literature [8,17–19], namely, the *State Fragility Index,* developed by Ref. [23]. The State Fragility Index provides scores on both effectiveness and legitimacy in four different dimensions, namely; security, political, economic and social for 167 countries with populations greater than 500,000 (Center for Systemic Peace, 2013). Therefore, using fragility scores for selected countries allows us to calculate the *fragility of supplier countries*.

As discussed in the above analysis, environmental risk is also an important factor for inclusion in the SSI; therefore, in order to construct the index that takes into account every risk aspect, *carbon dioxide emission* data from BP (British Petroleum) Statistical Review of 2014 was initially considered as a potential variable for environmental risk factor. However, due to the inconsistency between the carbon dioxide emission data and the remaining dataset, it was decided to remove the variable from the model. Following this, *greenhouse gas emission* was considered as a replacement for carbon dioxide emission, due to its broad similarities. However, again the dataset, collected via the OECD library, OECD StatExtracts, was inconsistent with the dataset of this study. A third indicator, *natural gas reserves/total energy consumption*, was also considered, as proven reserves in proportion to consumption is a good indicator of a country's potential to improve its air quality [29]. However, this also was rejected, because it failed to fit with the remaining dataset. Detailed analysis and explanation regarding the considerations for possible environmental risk factors are represented in Appendix B.

In the majority of the existing literature, the indexing has been conducted using single year data. However, in the current study, each year has been considered independently, in order to show the changes in countries' overall position in the ranking, and to reveal trends in their natural gas supply security policies according to the related indicators for the period between 2001 and 2013. Consequently, PCA method has been chosen for three reasons. First, this method has been commonly used in the existing literature [6,11,27,28]. Second, it allows the current study to produce a dependent variable via indexing through the mentioned indicators, and finally, it enables the objective calculation of component weights [9].

2.1. Data

The data of the study covers the period of 2001–2013 for 23 countries from different parts of the world, and aims to establish SSI scores for each country. The dispersed sample of countries enables the establishment of a generalized index score. Thus, in order to reach consistent and unbiased data for our indicators on a yearly basis, information for a range of selected countries was taken from two BP (British Petroleum) Sources: Annual reports, and statistical reviews of world energy published between 2001 and 2013. The sample consists of 23 countries: Austria, Belgium, Brazil, Czech Republic, Finland, France, Germany, Greece, Hungary, Iran, Ireland, Italy, Mexico, Netherlands, Poland, Singapore, Slovakia, Spain, Thailand, Turkey, United Arab Emirates, United Kingdom and United States (US). BP data was considered the most appropriate data for country selection in this case, because it takes into account the gradual increase in the importance of the role of LNG in various countries, in terms of annual volume, thus, allowing an extended study period.

Volume of natural gas imported and *import dependency* data are calculated using the data obtained from US EIA (Energy Information Administration's) database. EIA data was chosen because it enables us to work with the small production and consumption volumes. These smaller volumes did not appear in the BP's annual reports, which rounded down to zero volumes less than 0.05 billion cubic meter (bcm). BP's annual reports also provided the data related to the indicators of *share of natural gas in primary energy consumption, dependency on largest supplier* and *the number of suppliers*. The indicator *Supplier fragilities,* calculated using SFI (State Fragility Index), showing the geopolitical risk of each country, is composed of effectiveness score, legitimacy score, security effectiveness, security legitimacy, armed conflict indicator, political effectiveness, political legitimacy, regime type, economic effectiveness, economic legitimacy, net oil production or consumption, social effectiveness, social legitimacy and regional effects. In our study, the fragility of each supplier is considered as the share of the natural gas imported from the supplier countries, multiplied by the state fragility index score of the relevant supplier countries.

2.2. Research model

The method used for the study is the PCA (principal component analysis) to calculate the natural gas supply security index. PCA is a very popular and well-established multivariate statistical technique used in specific disciplines [1], and is also utilized in the energy research literature in the calculation of the oil vulnerability index [11,27]. The aim of the method is to reduce the dimension of the variables in the dataset, in order to transform the correlated into uncorrelated variables called components, which are the linear combinations of the original variables [13,16,26]. The PCA method calculates the dependent variable as a synthetic index score [27] by assuming index variables as being linearly related with the dependent variable, while indicating the natural gas supply security of each country. In other words, the interactions of the variables, and selected security index variables are captured by PCA on the index score without an observed dependent variable. As a result, the covariance of the independent variables, rather than being subjective judgements, are the weights of those variables for the model [21], thus increasing the robustness of the results reached through PCA. The indexing takes into account the country variables on a yearly basis, as indicated in the model below.

$$SSI_j = \beta_1 x_{1j} + \beta_2 x_{2j} + \beta_3 x_{3j} + \beta_4 x_{4j} + \beta_5 x_{5j} + \beta_6 x_{6j} + \varepsilon \qquad (1)$$

The indicators represented as $x_{1j}......x_{6j}$ are calculated as shown in the below formula corresponding to the country "j" and error term "ε". After their calculation, indicators are scaled between 0 and 1in the form of $\gamma_{1j}......\gamma_{6j}$ according to whether they have a positive or negative effect on the index in the study. The value "0" as a scale outcome represents the lowest value of the supply security indicator, whereas value “1” represents the highest value of the selected indicator for that country.

$$x_{1j} = NGC_j - NGP_j \tag{2}$$

$$\gamma_{1j} = \frac{x_{1j} - Min(x_1)}{Max(x_1) - Min(x_1)} \tag{3}$$

x_{1j}: *Volume of natural gas imported* is calculated by natural gas consumption volume minus natural gas production volume for each country. The effect of x_{1j} on the index is positive, as a higher x_{1j} will increase the supplier security risk of importer country.

$$x_{1j} = NGC_j - NGP_j \tag{4}$$

$$\gamma_{2j} = \frac{Max(x_2) - x_{2j}}{Max(x_2) - Min(x_2)} \tag{5}$$

x_{2j}: *Number of natural gas suppliers* of each country. The effect of this indicator to the index is negative, as a higher number of suppliers decreases the supplier security risk of the importer country.

$$x_{3j} = \frac{Max(m_{ij})}{NGI_j} \tag{6}$$

$$\gamma_{3j} = \frac{x_{3j} - Min(x_3)}{Max(x_3) - Min(x_3)} \tag{7}$$

x_{3j}: *Dependency on largest supplier* is calculated by dividing the maximum volume of natural gas imported from the related supplier by the total natural gas imports. The effect of x_{3j} on our index is positive, as increasing the imported volume from any one country increases the supplier security risk of the importer country.

$$x_{4j} = 1 - \frac{NGP_j}{NGC_j} \tag{8}$$

$$\gamma_{4j} = \frac{x_{4j} - Min(x_4)}{Max(x_4) - Min(x_4)} \tag{9}$$

x_{4j}: *Import dependency* is calculated by dividing natural gas production by consumption, and then subtracting the outcome from 1 in order to calculate the natural gas import dependency of each country. The effect of x_{4j} on our index is positive, as an increase in import dependency also increases the supplier security risk of the importer country.

$$x_{5j} = \sum_i f_i \left(\frac{m_{ij}}{NGI_j} \right) \tag{10}$$

$$\gamma_{5j} = \frac{x_{5j} - Min(x_5)}{Max(x_5) - Min(x_5)} \tag{11}$$

x_{5j}: *Supplier fragility* is for the fragility calculation of natural gas supplier, calculated by multiplying the state fragility of the natural gas supplier by the amount of natural gas imported from the relevant country. This figure is then divided by the total volume of natural gas imports for the importer country. The effect of x_{5j} on the index is positive, as the high level of fragility of the supplier country would increase the supplier security risk of the importer country.

$$x_{6j} = \frac{NGC_j}{PEC_j} \tag{12}$$

$$\gamma_{6j} = \frac{x_{6j} - Min(x_6)}{Max(x_6) - Min(x_6)} \tag{13}$$

x_{6j}: *Share of natural gas in primary energy consumption* represents the natural gas consumption divided by primary energy consumption. The effect of this indicator on our index is positive, because the increase in consumption increases dependency on natural gas suppliers, and therefore the supplier security risk of the importer country.

The correlation among the scaled indicators supports the PCA model, due to the interdependency of the variables. The outcomes for the six eigenvalues gathered through the analysis of the variables allows to the calculation for variance maximization, which can be formulated as:

$$P_{1j} = \sum_{i=1}^{7} F_{1ij} * \gamma_{1j} \tag{14}$$

The first PC (partial component) here represents the maximum variance of the original indicators, and the second PC stands for the maximum variation of the remaining variance. As all the PCs are mutually orthogonal, the number of PCs for the supplier security is considered for the total variation of all the PCs together. As $\lambda_j = \text{var}\ (P_j)$, the total variation in the SSI is reached by the summation of $\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6$ [11]. As a result the SSI is computed as:

$$SSI_j = \frac{\lambda_1 P_{1j} + \lambda_2 P_{2j} + \lambda_3 P_{3j} + \lambda_4 P_{4j} + \lambda_5 P_{5j} + \lambda_6 P_{6j}}{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6} \tag{15}$$

3. Empirical results

In this study, the SSI is calculated for 23 countries over a period of 13 years. In order to accomplish the calculation, the data is processed as mentioned above. The characteristics of dataset are evaluated using the descriptive statistics for six scaled indicators utilized in the construction of the index for 2013 (Table 1). The position that the sample members are successfully diversified during the sample selection process are supported by the centralized mean and median, and the low (level of) standard deviation in the sample (Table 1).

In order to conduct accurate principal component analysis, there needs to be correlation between at least some of the variables within the dataset. If there is no correlation between any of the variables, it means that there is already a set of uncorrelated axes, which makes the use of PCA inappropriate. Therefore, after scaling related indicators, 6 x 6 correlation matrix was calculated in order to conduct PCA (Table 2).

Table 1
Descriptive statistics 2013.

	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6
Mean	0.7789	0.6522	0.5639	0.8187	0.3584	0.4242
Median	0.7487	0.8182	0.6101	0.9386	0.3552	0.4376
Std. Dev.	0.0948	0.3331	0.3588	0.2337	0.2154	0.2376
Skewness	0.3726	−0.5104	−0.2627	−1.5805	0.8779	0.8698
Kurtosis	1.1204	−1.2910	−1.2662	2.6271	2.4512	0.6328

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Table 2
Correlation matrix 2013.

Indicators	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6
γ_1	1					
γ_2	−0.4584	1				
γ_3	−0.4800	0.6752	1			
γ_4	0.4459	0.0297	−0.1817	1		
γ_5	−0.0709	−0.1644	−0.0007	0.1111	1	
γ_6	−0.1379	0.0827	0.2496	−0.5892	0.0159	1

As seen in Table 2, the correlation coefficients among indicators are strong enough for the implementation of principal component analysis. After the data was deemed to be suitable for PC analysis, eigenvalues and eigenvectors were calculated in order to obtain principal components (Table 3). Eigenvectors and eigenvalues are always estimated in pairs; in other words, each eigenvector has its own corresponding eigenvalue. While eigenvector indicates a direction, eigenvalue specifies the amount of variation regarding that direction. Therefore, the eigenvector with the highest eigenvalue points to the direction which has greatest variation. Due to the high significance of each vector's contribution to the total variance, during the calculation of SSI, all eigenvectors were included in the calculation process.

Hence, as displayed in Table 4, this study includes the calculations for the natural gas supply security index for the selected 23 countries; as well as the scores themselves. The lower scores represent higher levels of security.

As well as the results for the year 2013, all other remaining years are shown in Fig. 1, in order to demonstrate how a country's natural gas import policies have affected its standings in the ranking. In addition to the scores, a detailed analysis is provided for 2013, the most recent year, and therefore the most useful in terms of revealing the preferences of the most secure countries. The rankings of the remaining years between 2001 and 2012 are shown in Appendix A.

The results of our findings indicate that the greatest consumers of gas by volume, and those with the greatest dependence on imports are not necessarily those most exposed to supply security threats. In fact, it is possible that these are very secure countries, if they have a high level of supply diversification. Our study shows that the five most secure countries not only have more suppliers than the others, but also a low level of dependency on the largest supplier. However, in our calculation, we consider not only the number of suppliers and dependency on the largest supplier, but also the volume of natural gas imported (bcm), the import dependency of the importer country, the overall fragility of supplier countries, and the share of natural gas in primary energy consumption.

An important contribution of the study is the detailed comparison of countries in the supplier security index, based on the volume of imported natural gas for each country in the sample. Incorporating imported volume into our study shed light on the significant risk involved in obtaining high levels of natural gas from a single supplier. The results indicate that the most secure countries, i.e. Spain, France, Italy, the UK and Belgium, are also the most dependent ones in terms of volume (in bcm) of natural gas imported. None of these have a dependency on a single country exceeding 57% of their imports. On the other hand, Brazil, Mexico and the US, which have between 7 and 10 suppliers, have the highest levels of import dependency on a single supplier, ranging from 67% to 97%, making them less secure than those in which the total volume of natural gas imported is higher. It is interesting to compare examples of US and France. Both have similar volumes of imports, 49.64 and 42.83 bcm respectively, and both have diversified supplier countries, 7 and 9 respectively. However, France is much more secure, due to its lower single supplier dependency (39% compared to 97% for the US), in spite of the fact it has a 99% import dependency, compared to 7% for the US. Therefore, two indicators the volume of natural gas imported, and dependency on largest supplier, can be used to measure a country's risk level, and help it to establish import policies enabling it to secure its natural gas supplies.

The least secure countries in our index are Hungary, Slovakia, United Arab Emirates, Iran and Finland. In spite of their lower imported volumes, ranging between −4.38 and 12.36, these countries have an import dependency of −3 to 100 percent on a maximum of two suppliers, and a dependency on a single supplier of between 93 and 100%. These results indicate that the low level of diversification, combined with a high level of dependency on one country leads to a low level of supplier security, even when the imported volume is low. As a result of our comparison among countries, it can be concluded that when considering the volume of imports, the importance of dependency on the largest supplier is a crucial factor; in other words, the imported volume indicator can be considered as an effective robustness tool in determining the supplier security level of the importer countries.

To our knowledge, this study is the first to calculate the index score of each country's supplier security index on an annual basis from 2001 to 2013. Yearly calculation is important in revealing the changes and trends in the implementation of natural gas import policies across countries (Fig. 1). An interesting example is Thailand, the least secure country until 2010, after which time it was able to significantly improve its supply security score by increasing the number of supplier countries from 1 to 6. Thailand was one of the least import dependent countries, with an average of 24% up to 2010. Before this time it had been the most vulnerable due to its high dependency on the largest supplier, with an average of 100%. However, the diversification of suppliers after 2010 is continuing to reduce this vulnerability, as shown in Fig. 1.

The annual calculation of the indicators for each of the 23 countries also enables the observation of countries' policy implementations aimed at securing natural gas imports. It was found that over the period studied, the most secure countries in our index, Spain and France, not only increased the number of suppliers, but also selected the more secure supplier countries in terms of fragility

Table 3
Eigenvalues & Eigenvectors 2013.

Eigenvalues	Value	Proportion	Cumulative proportion	Eigenvalues	F_1	F_2	F_3	F_4	F_5	F_6
λ_1	2.3430	0.391	0.391	γ_1	−0.502	−0.063	−0.213	0.653	−0.240	0.464
λ_2	1.4180	0.236	0.627	γ_2	0.454	0.501	−0.113	0.197	0.502	0.490
λ_3	1.0457	0.174	0.801	γ_3	0.523	0.296	0.080	0.303	−0.719	−0.155
λ_4	0.7056	0.118	0.919	γ_4	−0.383	0.597	0.095	0.298	0.230	−0.589
λ_5	0.3065	0.051	0.970	γ_5	−0.057	−0.049	0.962	0.124	0.049	0.225
λ_6	0.1811	0.030	1000	γ_6	0.344	−0.547	−0.018	0.583	0.345	−0.352

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Table 4
Index scores of selected countries for 2013.

		Score	x_1	γ_1	x_2	γ_2	x_3	γ_3	x_4	γ_4	x_5	γ_5	x_6	γ_6
1	Spain	[0.048]	28.97	0.60	12	0.00	0.38	0.00	1.00	1.00	9.91	0.59	0.20	0.25
2	France	[0.074]	42.83	0.71	9	0.27	0.39	0.03	0.99	0.99	4.39	0.26	0.16	0.18
3	Italy	[0.118]	57.14	0.88	9	0.27	0.44	0.10	0.89	0.94	7.38	0.44	0.36	0.54
4	United Kingdom	[0.180]	36.63	0.68	8	0.36	0.57	0.31	0.50	0.73	2.08	0.12	0.33	0.48
5	Belgium	[0.193]	45.64	0.52	6	0.55	0.37	0.00	1.00	1.00	3.58	0.21	0.25	0.33
6	Turkey	[0.195]	16.82	0.73	10	0.18	0.59	0.35	0.99	0.99	8.89	0.53	0.33	0.49
7	Germany	[0.220]	75.43	1.00	3	0.82	0.42	0.07	0.87	0.93	3.61	0.22	0.23	0.31
8	Brazil	[0.234]	16.31	0.48	10	0.18	0.67	0.48	0.46	0.71	8.77	0.52	0.12	0.12
9	Mexico	[0.285]	26.10	0.38	9	0.27	0.71	0.53	0.07	0.50	4.54	0.27	0.40	0.59
10	United States	[0.346]	49.64	0.76	7	0.45	0.97	0.95	0.07	0.50	0.20	0.01	0.30	0.42
11	Netherlands	[0.418]	−31.61	0.00	4	0.73	0.61	0.37	−0.87	0.00	2.34	0.14	0.38	0.57
12	Czech Republic	[0.467]	8.42	0.42	2	0.91	0.65	0.44	0.98	0.99	5.26	0.31	0.18	0.22
13	Austria	[0.492]	8.49	0.40	3	0.82	0.76	0.61	0.79	0.89	5.78	0.34	0.22	0.30
14	Thailand	[0.535]	10.47	0.44	6	0.55	0.81	0.70	0.20	0.57	16.77	1.00	0.41	0.61
15	Greece	[0.535]	3.58	0.38	2	0.91	0.79	0.67	1.00	1.00	5.96	0.36	0.12	0.12
16	Poland	[0.546]	12.50	0.45	2	0.91	0.84	0.75	0.67	0.82	6.21	0.37	0.15	0.17
17	Singapore	[0.568]	10.53	0.43	2	0.91	0.83	0.73	1.00	1.00	8.48	0.51	0.13	0.13
18	Ireland	[0.626]	4.45	0.38	1	1.00	1.00	1.00	0.92	0.96	0.00	0.00	0.30	0.43
19	Finland	[0.668]	2.84	0.37	1	1.00	1.00	1.00	1.00	1.00	7.00	0.42	0.10	0.08
20	Iran	[0.681]	−4.38	0.31	2	0.91	0.93	0.88	−0.03	0.45	9.07	0.54	0.60	0.94
21	U. Arab Emirates	[0.682]	12.36	0.45	1	1.00	1.00	1.00	0.19	0.57	4.00	0.24	0.63	1.00
22	Slovakia	[0.688]	5.39	0.41	1	1.00	1.00	1.00	0.99	0.99	7.00	0.42	0.29	0.42
23	Hungary	[0.695]	8.56	0.40	1	1.00	1.00	1.00	0.70	0.84	7.00	0.42	0.38	0.56

x_1: volume of imported gas, x_2: the number of natural gas suppliers, x_3: dependency on largest supplier, x_4: import dependency, x_5: fragility of supplier, x_6: share of natural gas in primary energy consumption
γ_1, γ_2, γ_3, γ_4, γ_5, γ_6 indicate the scale value of relating indicators.

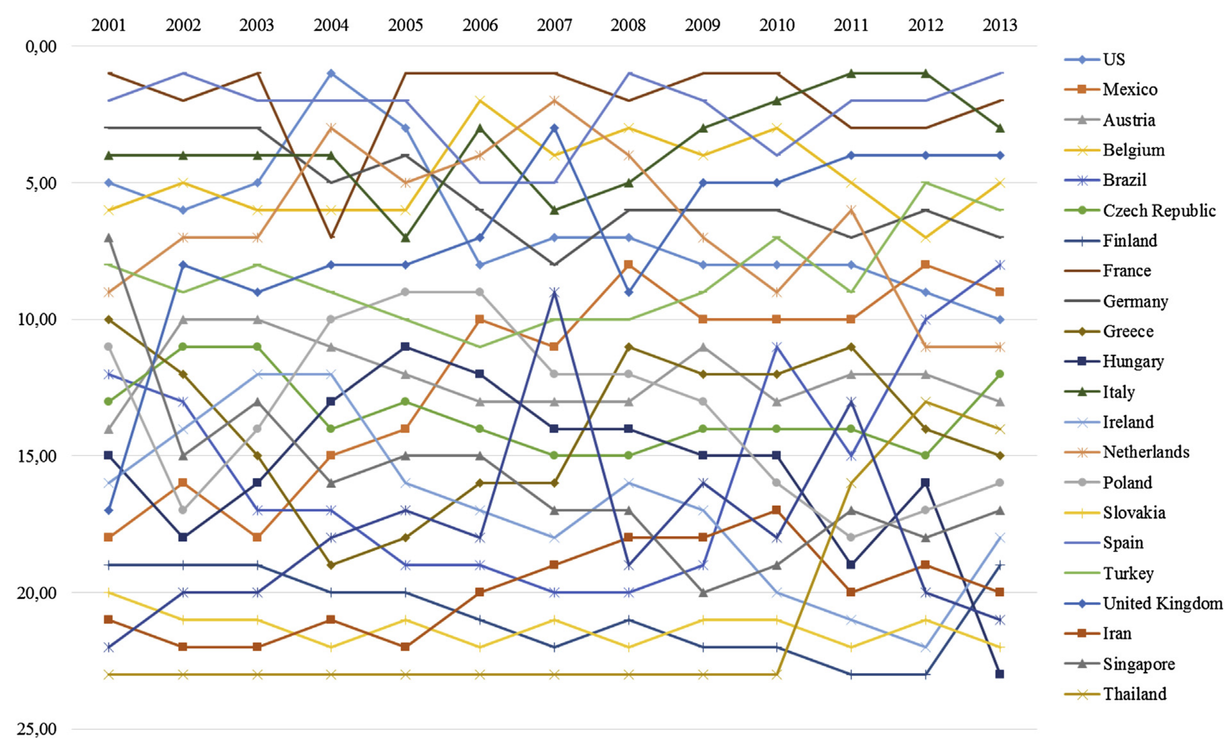

Fig. 1. Ranks of selected countries from 2001 to 2013.

scores. This can be seen in the reduction of fragility scores. France fell from 12.08 to 9.91, and Spain from 5.07 to 4.39 over the 13 year period. Additionally, despite the fact that Spain is the most secure country, its supplier fragility score for 2013 remains higher than the average for the 23 countries, which was only 6.01. These results indicate that Spain and France can be considered as having the most secure natural gas supplies, due to their low level of dependency on the largest supplier, and an increased number of suppliers. This shows the importance of reducing dependency on the largest supplier, and increasing the number of suppliers in maintaining a higher level of supply security.

Mexico is another country with significant changes in policy. Despite its failure to join the ranks of the most secure countries, there is a noteworthy improvement in Mexico's supplier security. The country increased its ranking by 9 levels during the sample period, from 18th to 9th. At the beginning of the sample period, the country was dependent on a single supplier, but was able to increase the number to 9, enabling a reduction of dependency on one country from 100 to 71%, resulting in a positive effect on the level of supply security in Mexico.

The examples mentioned reveal some outstanding results pursuant to effects of the policy implications on related SSI scores. However, not all countries within the sample have applied significant policy changes, and consequently their place in the rankings remains almost unchanged. The Czech Republic is an important example. In terms of SSI ranking, the country logged in as 13th, and completed its journey 12th in 2013. When the details of this case are analysed, it is seen that number of suppliers, import dependency and share of natural gas in primary energy consumption indicators maintained their initial value 98% and 19% for the period between 2001 and 2013. Despite the lack of change in these indicators, the remaining indicators improved. Imported volume, the dependency on largest supplier and fragility of supplier countries decreased from 8.94 to 8.42, 82 to 65% and 8.52 to 5.26 percent respectively. There are two possible reasons why these improvements have not greatly affected the overall ranking of the country. First, the majority of countries in the sample made similar efforts to improve supplier security in the sample period. Second, the changes made by the Czech Republic involve relatively insignificant amounts. Austria's import policy reflects a similar pattern, with rank changing from 14th to 13th over the study period. For Austria, during the sample period, number of suppliers, import dependency, share of natural gas in primary energy consumption and imported volume all remained at constant values: 3, 79%, 23% and 8.60 bcm respectively. Despite the upward trend on supplier security-oriented import policies across the rankings, Austria was able to maintain its position because of its reduction in dependency on a single supplier, and improved supplier fragility indicators. Between the period of 2001 and 2013, Austria's dependency on one country decreased from 86% to 76%, and fragility of suppliers decreased from 9.67 to 5.78. This highlights that, countries able to increase number of suppliers, decrease dependency on a single supplier and improve supplier fragility, are able to achieve greater supply security.

4. Conclusion

There are many potential constraints in establishing a natural gas supplier security index across countries. The six major factors in measuring vulnerability are: volume of imported gas, number of natural gas suppliers, dependency on largest supplier, import dependency, fragility of suppliers, and share of natural gas in primary energy consumption.

Our study indicates the annual changes in the relationship of the indicators for each country for the period of 2001–2013. One of the major findings is the potential importance of supplier diversification through the consideration of both LNG and pipeline transportation. The countries studied are large scale consumers which are generally highly dependent on fragile suppliers. Nevertheless, they have been successful in securing natural gas supplies through implementing policies of diversification of suppliers, and optimum weighting of import dependency among suppliers, which takes into account the fragility of the supplier countries.

Overall, results indicate a significant relationship between diversification and natural gas supply security. It is observed that diversification has a greater impact than any other issues in supply security policy making, in line with the common sense rule of “not putting all the eggs in the same basket”. Clearly, countries with higher level of dependency on a single or limited number of suppliers have a lower level of natural gas supply security than those with a higher level diversification. However, it is also important to note that, as well as increasing the number of suppliers, supplementing the share of piped gas with LNG also contributes to diversification efforts. In recent years the diversification of suppliers through supplementing piped gas with LNG has become an important tool for securing supply because it allows countries to increase their security of supply, as determined by our index results.

Even though our results indicate that diversification is the primary tool in this context, it is observed that choosing suppliers with lower state fragility scores also contributes to the natural gas supply security of consumer countries. Therefore, in line with the findings of this research, governments should establish policies aimed at supplier diversification, and risk diversification, taking into account supplier fragility and the effect of dependency on one country.

An additional important finding of this study is that the analysis of supply security which ignores imported volume can be deceptive, as two countries importing similar volume amounts may be completely different in their levels of diversification and import dependency, as in the cases of Turkey and US. The current study also differentiates itself from other supply security studies by the increased dynamism enabled by analyzing trends on an annual basis between 2001 and 2013.

While the study is unique in covering the interrelationship of six variables for the developed SSI, considering the supply and market risk factors, it was decided to remove the environmental risk factor from our model due to inconsistency between the data for carbon dioxide emissions and the remaining dataset, and also the weak correlation between changes in natural gas usage and changes in carbon dioxide emissions, as discussed above. Therefore, this study also highlights the importance of further research into the role of environmental risk factors in the supply security of countries.

This study makes a valuable contribution to the currently limited literature on the analysis of the natural gas supply security for consumer countries. It demonstrates an empirical test of the relations between factors, and develops a discussion based on the innovative natural gas supply security index, presenting valuable statistical evidence. We consider that this index has the potential to act as an effective decision-making which will enhance natural gas security, not only at the country-specific level, but also at the regional and even global levels.

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Appendix A

Table A.1
SSI scores from 2001 to 2006.

	2001	2002	2003	2004	2005	2006
1	France [0.010]	Spain [0.155]	France [0.123]	United States [0.167]	France [0.198]	France [0.133]
2	Spain [0.039]	France [0.158]	Spain [0.155]	Spain [0.238]	Spain [0.215]	Belgium [0.176]
3	Germany [0.087]	Germany [0.227]	Germany [0.179]	Netherlands [0.240]	United States [0.251]	Italy [0.220]
4	Italy [0.151]	Italy [0.286]	Italy [0.226]	Italy [0.242]	Germany [0.274]	Netherlands [0.258]
5	United States [0.158]	Belgium [0.295]	United States [0.228]	Germany [0.256]	Netherlands [0.280]	Spain [0.261]
6	Belgium [0.178]	United States [0.333]	Belgium [0.235]	Belgium [0.259]	Belgium [0.284]	Germany [0.275]
7	Singapore [0.385]	Netherlands [0.387]	Netherlands [0.320]	France [0.284]	Italy [0.291]	United Kingdom [0.340]
8	Turkey [0.389]	United Kingdom [0.512]	Turkey [0.493]	United Kingdom [0.422]	United Kingdom [0.410]	United States [0.360]
9	Netherlands [0.473]	Turkey [0.518]	United Kingdom [0.541]	Turkey [0.556]	Poland [0.474]	Poland [0.471]
10	Greece [0.478]	Austria [0.553]	Austria [0.545]	Poland [0.564]	Turkey [0.585]	Mexico [0.501]
11	Poland [0.486]	Czech Republic [0.558]	Czech Republic [0.556]	Austria [0.577]	Hungary [0.599]	Turkey [0.568]
12	Brazil [0.495]	Greece [0.594]	Ireland [0.571]	Ireland [0.597]	Austria [0.611]	Hungary [0.604]
13	Czech Republic [0.497]	Brazil [0.602]	Singapore [0.574]	Hungary [0.601]	Czech Republic [0.627]	Austria [0.605]
14	Austria [0.499]	Ireland [0.604]	Poland [0.588]	Czech Republic [0.603]	Mexico [0.642]	Czech Republic [0.638]
15	Hungary [0.514]	Singapore [0.632]	Greece [0.597]	Mexico [0.606]	Singapore [0.643]	Singapore [0.657]
16	Ireland [0.521]	Mexico [0.638]	Hungary [0.598]	Singapore [0.648]	Ireland [0.649]	Greece [0.669]
17	United Kingdom [0.587]	Poland [0.647]	Brazil [0.610]	Brazil [0.659]	U. Arab Emirates [0.691]	Ireland [0.689]
18	Mexico [0.609]	Hungary [0.649]	Mexico [0.616]	U. Arab Emirates [0.661]	Greece [0.696]	U. Arab Emirates [0.699]
19	Finland [0.618]	Finland [0.732]	Finland [0.723]	Greece [0.674]	Brazil [0.723]	Brazil [0.737]
20	Slovakia [0.625]	U. Arab Emirates [0.755]	U. Arab Emirates [0.748]	Finland [0.767]	Finland [0.775]	Iran [0.775]
21	Iran [0.733]	Slovakia [0.782]	Slovakia [0.753]	Iran [0.783]	Slovakia [0.792]	Finland [0.788]
22	U. Arab Emirates [0.770]	Iran [0.792]	Iran [0.794]	Slovakia [0.785]	Iran [0.803]	Slovakia [0.792]
23	Thailand [0.779]	Thailand [0.862]	Thailand [0.861]	Thailand [0.875]	Thailand [0.897]	Thailand [0.917]

Table A.2
SSI scores from 2007 to 2012.

	2007	2008	2009	2010	2011	2012
1	France [0.166]	Spain [0.181]	France [0.122]	France [0.057]	Italy [0.076]	Italy [0.024]
2	Netherlands [0.237]	France [0.201]	Spain [0.166]	Italy [0.158]	Spain [0.106]	Spain [0.049]
3	United Kingdom [0.268]	Belgium [0.278]	Italy [0.177]	Belgium [0.165]	France [0.166]	France [0.080]
4	Belgium [0.291]	Netherlands [0.300]	Belgium [0.228]	Spain [0.176]	United Kingdom [0.187]	United Kingdom [0.131]
5	Spain [0.294]	Italy [0.319]	United Kingdom [0.267]	United Kingdom [0.195]	Belgium [0.219]	Turkey [0.178]
6	Italy [0.308]	Germany [0.371]	Germany [0.277]	Germany [0.263]	Netherlands [0.228]	Germany [0.181]
7	United States [0.341]	United States [0.398]	Netherlands [0.326]	Turkey [0.284]	Germany [0.324]	Belgium [0.222]
8	Germany [0.376]	Mexico [0.462]	United States [0.343]	United States [0.288]	United States [0.350]	Mexico [0.301]
9	U. Arab Emirates [0.455]	United Kingdom [0.487]	Turkey [0.381]	Netherlands [0.324]	Turkey [0.395]	United States [0.312]
10	Turkey [0.488]	Turkey [0.520]	Mexico [0.391]	Mexico [0.369]	Mexico [0.456]	Brazil [0.363]
11	Mexico [0.502]	Greece [0.570]	Austria [0.550]	Brazil [0.451]	Greece [0.474]	Netherlands [0.364]
12	Poland [0.557]	Poland [0.590]	Greece [0.554]	Greece [0.457]	Austria [0.495]	Austria [0.434]
13	Austria [0.593]	Austria [0.596]	Poland [0.579]	Austria [0.578]	U. Arab Emirates [0.515]	Thailand [0.447]
14	Hungary [0.595]	Hungary [0.622]	Czech Republic [0.592]	Czech Republic [0.597]	Czech Republic [0.531]	Greece [0.492]
15	Czech Republic [0.642]	Czech Republic [0.656]	Hungary [0.626]	Hungary [0.610]	Brazil [0.597]	Czech Republic [0.492]
16	Greece [0.666]	Ireland [0.688]	U. Arab Emirates [0.638]	Poland [0.645]	Thailand [0.613]	Hungary [0.530]
17	Singapore [0.674]	Singapore [0.694]	Ireland [0.666]	Iran [0.661]	Singapore [0.647]	Poland [0.536]
18	Ireland [0.692]	Iran [0.704]	Iran [0.666]	U. Arab Emirates [0.665]	Poland [0.653]	Singapore [0.571]
19	Iran [0.728]	U. Arab Emirates [0.712]	Brazil [0.685]	Singapore [0.666]	Hungary [0.656]	Iran [0.572]
20	Brazil [0.747]	Brazil [0.739]	Singapore [0.691]	Ireland [0.681]	Iran [0.674]	U. Arab Emirates [0.573]
21	Slovakia [0.780]	Finland [0.782]	Slovakia [0.749]	Slovakia [0.745]	Ireland [0.727]	Slovakia [0.593]
22	Finland [0.788]	Slovakia [0.784]	Finland [0.758]	Finland [0.752]	Slovakia [0.770]	Ireland [0.646]
23	Thailand [0.869]	Thailand [0.877]	Thailand [0.837]	Thailand [0.832]	Finland [0.776]	Finland [0.672]

Appendix B

The study considered three types of environmental risk factor, which are *natural gas reserves/total energy consumption*, *carbon dioxide emission* and *greenhouse gas emission*. Correlation values for each possible environmental risk factors are estimated for each remaining risk factors and for each year (Table B.1). Since, statistically there is no any solid relationship between possible environmental risk factors and the remaining risk factors, the environmental risk factors failed to satisfy main requirement of principal component analysis, which is being correlated with at least some of the variables within the dataset to obtain accurate principal component analysis results. If there is no correlation between any of the variables within the dataset, it means that there is already a set of uncorrelated axes, which makes the use of PCA inappropriate.

Table B.1
Correlations between possible environmental risk factors and the remaining risk factors.

	Natural gas reserves/Total energy cons.						Carbon dioxide emission						Greenhouse Gas emission					
	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6	γ_1	γ_2	γ_3	γ_4	γ_5	γ_6
2013	0.1591	−0.1446	−0.1905	0.1399	−0.0065	−0.3791	0.3751	−0.0029	0.1528	−0.1209	−0.1326	0.0556	–	–	–	–	–	–
2012	0.1662	−0.1718	−0.2335	0.1455	0.0000	−0.3624	0.3197	−0.0066	0.1556	−0.1329	−0.0939	0.0426	0.3104	−0.0701	0.3275	−0.1880	−0.2249	0.1378
2011	0.1177	−0.0639	−0.2136	0.1444	−0.0570	−0.3817	0.3512	−0.0222	0.1369	−0.1327	−0.1014	0.0140	0.3367	−0.0698	0.3320	−0.1971	−0.2556	0.0764
2010	0.1252	−0.1708	−0.2061	0.1606	−0.0368	−0.3478	0.1661	−0.0423	0.0834	−0.1161	−0.0716	0.1976	0.1689	−0.0968	0.2534	−0.1906	−0.1447	0.0467
2009	0.1377	−0.1680	−0.1858	0.1671	−0.0271	−0.3637	0.1193	0.0356	0.0744	−0.1205	−0.1014	0.0121	0.1191	0.0106	0.2636	−0.1929	−0.1857	0.0683
2008	0.1071	−0.1510	−0.1588	0.1455	−0.0458	−0.3374	0.2364	−0.0119	0.0955	−0.0885	−0.1094	0.1910	0.2386	−0.0403	0.2649	−0.1492	−0.2113	0.0387
2007	0.1374	−0.1798	−0.0463	0.1921	−0.0117	−0.3616	0.3329	−0.1185	0.0457	−0.0686	−0.0570	0.1885	0.3443	−0.1771	0.2066	−0.1478	−0.0753	0.0428
2006	0.1620	−0.2255	−0.2208	0.1049	0.0041	−0.3604	0.2606	−0.0097	0.0414	−0.0678	−0.0884	0.1704	0.2657	−0.0275	0.2195	−0.1543	−0.1345	0.0091
2005	0.1370	−0.1851	−0.2007	0.1967	0.0231	−0.3455	0.3477	−0.1903	0.0343	−0.0535	−0.1217	0.1698	0.3582	−0.2710	0.2095	−0.1406	−0.1716	0.0040
2004	0.1210	−0.1964	−0.1845	0.1791	0.0396	−0.3083	0.3453	−0.2211	0.1982	−0.0458	−0.1340	0.1782	0.3506	−0.3132	0.1575	−0.1259	−0.1676	0.0219
2003	0.1283	−0.1892	−0.1917	0.1896	0.0353	−0.2970	0.2964	−0.1784	0.0483	−0.0673	−0.1439	0.1836	0.2985	−0.2478	0.2084	−0.1738	−0.1500	0.0315
2002	0.0946	−0.2311	−0.1887	0.1833	0.0603	−0.3341	0.4099	−0.2176	0.0753	−0.0437	−0.1835	0.0054	0.4168	−0.2064	0.2479	−0.1430	−0.2191	0.0787
2001	0.1084	−0.1872	−0.2119	0.1613	−0.0702	−0.3066	0.2390	−0.2779	0.1240	−0.0618	−0.1634	0.0024	0.2363	−0.2712	0.2649	−0.1642	−0.1755	0.0727

γ_1: scaled volume of imported gas, γ_2: scaled the number of natural gas suppliers, γ_3: scaled dependency on largest supplier, γ_4: scaled import dependency, γ_5: scaled fragility of supplier, γ_6: scaled share of natural gas in primary energy consumption.
Natural Gas Reserves/Total Energy Consumption, Carbon Dioxide Emission and Greenhouse Gas Emission are also included in calculation through their scaled values.
The data of Greenhouse Gas Emission is collected via OECD's data library OECD StatExtracts [25]. The most recent data point within the data library belongs to 2012; therefore, 2013 correlation values between Greenhouse Gas Emission and remaining factors are absent. However, the trend of former years' correlation values points to improperness of the use of Greenhouse Gas Emission as an environmental factor in our model.

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