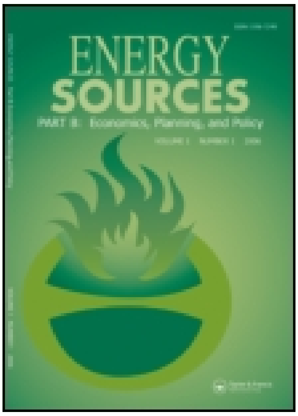

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Abstract *The aim of this article is the comparative analysis of oil and gas supply for the 27 European Union member countries throughout the measurement of the vulnerability that their economies exhibit to oil and natural gas. In this framework, 6 indicators that quantify the core concepts that affect the security of supply of a country have been integrated, with the usage of Principal Component Analysis, in two synthetic indices, which measure the vulnerability of the case study countries.*

Keywords energy security indices, energy supply security, energy vulnerability, oil and gas, principal components analysis

1. Introduction

Energy security can be defined as the continuous and uninterrupted availability of energy to a specific country or region. The security of energy supply conducts a crucial role in decisions that are related to the formulation of energy policy strategies. Most European Union (EU) countries' economies are dependant on the energy imports and exports in the notion that their balance of payments is affected by the magnitude of the vulnerability that the countries have in oil and natural gas.

The fact that oil-producing countries in the Middle East provide more than 50% of the world's consumption, as El-Genk (2008) points out, is indicative of the low diversification of energy sources and the accompanying risks on smooth energy supply. The diversification that is offered by the alternative supplies from Russia and Africa cannot provide a sound solution for a supply disruption that may occur in the Middle East region. In addition, the dependence that European member countries have in natural gas imports from the Russian Federation is also very high and expected to further increase within the coming decades. The overview of the oil and natural gas market, and the related risks and incidents, clearly indicate that even today the risks associated with energy supply are many. War and civil conflicts might have been replaced, to some extent, by weather conditions and monopolistic practices, but they are still playing a crucial factor in energy supply (Doukas et al., in press). Therefore, the high dependency that most countries have in energy imports made it essential for the policymakers to focus on the

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concept of security of energy supply. In the above framework, the EU has many times highlighted as a key priority the need to assess the current energy system and the risks of energy disruptions in order to better design and adopt the required policies. This article, following a brief review of existing studies in the topic of energy security in Sec. 2, presents the methodology (Sec. 3) and the methodology application results in Sec. 4. Finally, in the last section the main points drawn up from this article are summarized.

2. Literature Review on Existing Studies

An important number of academic studies have focused on the topic of energy security of supply. Significant research has been conducted by the Dutch Energy Research Centre (ECN; Jansen et al., 2004; Schapers et al., 2007). Jansen was the first that utilized the Shannon-Wiener diversity index as basic indicator (Gnansounou, 2008). The second study by the ECN and the Clingendael International Energy Programme proposed quantitative indicators for quantifying the concept of Security of Energy Supply. Additionally, they were the first who created a weighting and scoring system for the synthesis of the supply/demand index taking into account final energy demand, energy conversion and primary energy supply. Apart from the research work that has been conducted by the ECN, other research groups measured the concept of vulnerability that the European energy systems exhibit (Constantini et al., 2007; Gnansounou, 2008; Gupta, 2007, 2008; World Energy Council, 2008). All the aforementioned research efforts used subjective weights in order to derive a composite index (Jansen et al., 2004; Schapers et al., 2007). Grubb et al. (2006) explored the strategic security of electricity in the context of the United Kingdom electricity system. Using the concept of diversity of fuel source mix they measured the impact of source variability on a second dimension of security, the reliability of generation availability. Moreover, Chevalier (2005) used several indicators in order to measure the dependency that countries within the EU exhibit to oil and natural gas. They found that most European countries are exposed to a potential turbulence and they stated the need for the EU to formulate a common energy strategy.

3. Methodology and Data Sources

For the measurement of the security of supply that the 27 members of European Community are exhibiting, it is essential to apply a methodology that will take into account the main concepts that affect the supply of a particular primary energy fuel. In the above framework and in order to capture the concept of EU countries' security of energy supply, the vulnerability of the sample countries economy in oil and natural gas has been measured. The rational behind the selection of the usage of vulnerability as a metric for the security of energy supply can be identified in the definition of the term vulnerability. As Percebois, (2007, pp. 5) points out, "Vulnerability expresses the unbearable dimension of an energy supply." Furthermore as Gnansounou (2008, pp. 2) states, vulnerability is "the degree to which a system is unable to cope with selected adverse events." For the specification of the adverse events that might affect the system, which in our case is the economies of the countries under consideration, it is essential to specify via the usage of measurable indicators two main concepts of vulnerability: the market and supply risk.

In order to measure the security of supply that each of the 27 countries exhibits, a two-step approach was followed. First, using a set of indicators, the basic concepts of security of supply were measured and quantified. Second, using the statistical method of Principal Component Analysis (PCA), the individual indicators were synthesized and formed a synthetic index that measures the vulnerability of each sample country in oil and natural gas disruption of supply.

3.1. Indicators Selection

Using the appropriate indicators, the main aim is to quantify the main concepts that affect the security of supply that a country has. As Gupta, (2007) points out, three major risks that contribute to the overall oil and natural gas vulnerability of an economy exist: the market (or economic) risk, the supply risk, and the environmental risk. In this article we focus on the quantification of the market risk and supply risk of the countries under examination.

3.2. Market Risk

For the measurement of market risk for the two primary energy fuels, oil and natural gas, two indicators were used: primary energy security fuel (PES) consumed in an economy to its gross domestic product (GDP), and PES consumption to total primary energy consumption. The first indicator measures the PES fuel that is consumed in the countries' economies under consideration relative to their GDP and is expressed as tones of oil per unit of GDP and m^3 of natural gas per unit of GDP. The second indicator is calculated as the percentage of the PES fuels under examination relative to the total PES fuels that each country consumes.

3.3. Supply Risk

In order to measure the supply risk, which refers to the risks of physical disruptions in PES fuel supplies, four indicators were used (Gupta, 2007).

Each indicator was calculated for both oil and natural gas. The selection of the supply risk measurement indicators occurred on the basis of four factors: net PES import dependence of an importing country, diversification of PES imports, political risks in PES supplying countries, and market liquidity (Gupta, 2007).

More specifically, we have selected two indicators that capture the essence of the geopolitical risks: the political measurement indicator and the market liquidity indicator, and two indicators that quantify the diversification of the energy mix that the sample countries have: diversification of primary energy demand (DPED) and net energy import dependency. The first pair of indicators captures and quantifies the impact of the geopolitical risks that the countries under examination have, while the second pair of indicators measures the diversification that each country has relative to the primary energy demand and the net import dependency that the countries under examination have.

3.4. Principal Component Analysis

Having explained the intuition behind the selection of meaningful indicators that will measure and quantify the two main concepts of security of supply, in this section we will proceed to the description of the second step, that allows the integration of the 6 market and supply risk indicators into two indices, one for oil and one for natural gas (Figure 1) that measure the level of vulnerability that the EU countries exhibit to oil and natural gas.

For the development of the two sub-indices, the PCA has been used. PCA is a multivariate statistical approach that transforms a set of correlated variables into a set of uncorrelated variables called components.

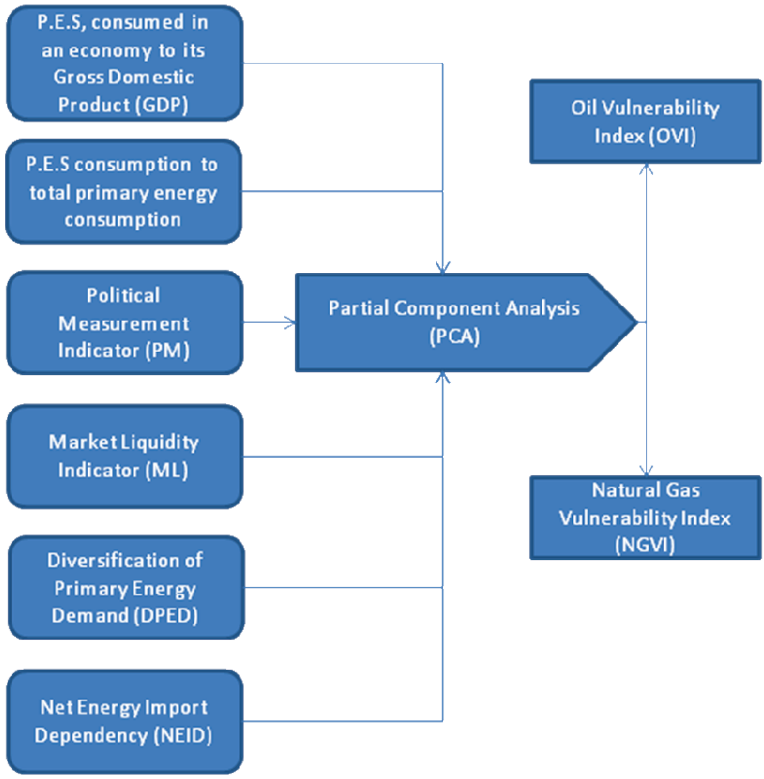

Figure 1. Formulation of the indices. (color figure available online)

3.5. *Development of Indices*

More specifically, the general form of our model, the gas and oil vulnerability index, that will be used for the development of the two indices, the oil vulnerability index (OVI), and the natural gas vulnerability index (NGVI), is presented below:

$$GOVI = a + \beta_1 X_1 + \cdots + \beta_K X_K + e \tag{1}$$

where X_1, X_K, are a set of the proposed indicators that were used for capturing and quantifying the two main elements of energy security of supply, market, and supply risk. Additionally, β_1, β_K are the corresponding vectors of parameters in each domain, and e is the error term.

3.5.1. Oil Vulnerability Index and Natural Gas Vulnerability Index. Having presented the general form of our model, we can proceed to the development of the two indices that will measure the vulnerability that our sample countries exhibit relative to oil and natural gas.

Equation (2) exhibits the OVI and Eq. (3) exhibits the NGVI:

$$GVI = \beta_1 \chi_1 + \beta_2 \chi_2 + \beta_3 \chi_3 + \beta_4 \chi_4 + \beta_5 \chi_5 + \beta_6 \chi_6 + \varepsilon \tag{2}$$

$$NGVI = \beta_1 \chi_1 + \beta_2 \chi_2 + \beta_3 \chi_3 + \beta_4 \chi_4 + \beta_5 \chi_5 + \beta_6 \chi_6 + \varepsilon \tag{3}$$

The total variation in the two indices is composed of the variation due to sets of indicators, and the variation due to error. If the model is well specified, including an adequate number of indicators in each domain, so that the mean of the probability distribution of e is 0, ($E(\varepsilon) = 0$), and error variance is small relative to the total variance, we can reasonably assume that the total variation in the two indices is largely explained by the variation in the indicator variables in each domain included for the computation of this composite index.

3.6. Data Sources

For calculating the oil and natural gas vulnerability index for 2006 the necessary data was obtained from the following documents: Oil Information 2005 for the Organization for Economic Cooperation and Development countries (IEA, 2006a), BP Statistics 2006 Integrated Energy Policy 2006 (BP, 2006), and Energy Statistics Yearbook 2006 (DESA, 2006). The data on the oil reserves, production and consumption has been taken from BP Statistical Review 2006 and the Energy Information Administration (EIA, 2010).

4. Results and Analysis

Table 1 displays the correlation matrix of the normalized indicators for the computation of the composite index that measures oil vulnerability for the selected 27 countries, while Table 2 exhibits the correlation matrix for the indicators that are used for the computation of the natural gas index. It must be stated that the indicators are positive related to oil and natural gas vulnerability. Of particular interest is that the correlation between the DPED indicator is positively related with the political measurement indicator in the correlation matrix of oil indicators, while the same indicators are negatively related in the natural gas correlation matrix. This can be explained by the fact that most EU-27 member countries import oil from several countries, most of them exhibiting a quite high political risk, and in this regard increasing the diversification leads to a lower political risk. On the other side, EU-27 member countries import natural gas from a few countries, some of them of negligible political risk (Norway, the United Kingdom, The Netherlands, and Belgium) and others of higher political instability. Therefore in the current static application for 2006, an increase in natural gas imports diversification by importing natural gas from non-EU countries leads to a decrease to the political

Table 1
Correlation matrix of oil indicators

Variables	DPED	NEID	Political measure, PM	Market liquidity, ML	NG/GDP	NG/TPES
DPED	1					
NEID	0.451	1				
Political measure (PM)	0.492	0.774	1			
Market liquidity (ML)	0.168	0.645	0.561	1		
OIL/GDP	0.014	0.420	0.259	0.287	1	
OIL/TPES	0.301	0.250	0.337	0.239	0.073	1

Table 2
Correlation matrix of natural gas indicators

Variables	DPED	NEID	Political measure	Market liquidity	OIL/GDP	OIL/TPES
DPED	1					
NEID	0.172	1				
Political measure (PM)	−0.445	0.332	1			
Market liquidity (ML)	0.127	0.448	0.199	1		
NG/GDP	−0.279	0.084	0.129	0.092	1	
NG/TPES	−0.083	0.072	0.219	0.141	−0.098	1

measurement indicator (higher political risk). Of course, the aforementioned correlations are expected to gradually change accordingly to future natural gas supply in the medium- to long-term.

The final results relative to the vulnerability that the EU-27 are exhibiting to oil and natural gas are presented in Figure 2 for oil and Figure 3 for natural gas. The country that has been assigned with the rank 1 represents the most vulnerable country, while the country that is ranked 27 represents the least vulnerable country in terms of oil and natural gas.

4.1. Oil Vulnerability Index

As it can be observed, the most vulnerable country in terms of oil is Cyprus while the least vulnerable country is Sweden. This result can be explained by the fact that Cyprus is highly dependent on and thus vulnerable to oil, as its energy mix for the year 2006 is constituted of 94% from oil and only 2% and 4% of solid fuels and renewable, respectively. On the other hand Sweden has a diversified portfolio of energy sources. Moreover, Sweden imports oil from countries that are considered to be politically stable and secure, therefore minimizing the security of supply threats. Most EU member

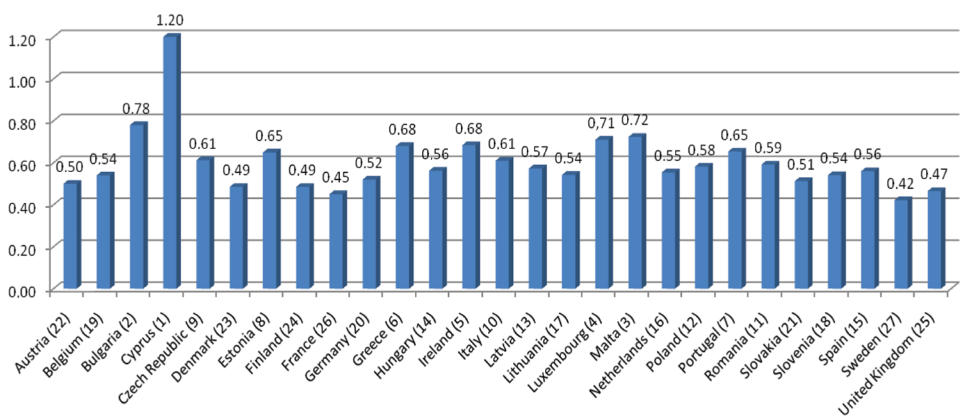

Figure 2. Oil vulnerability index. (color figure available online)

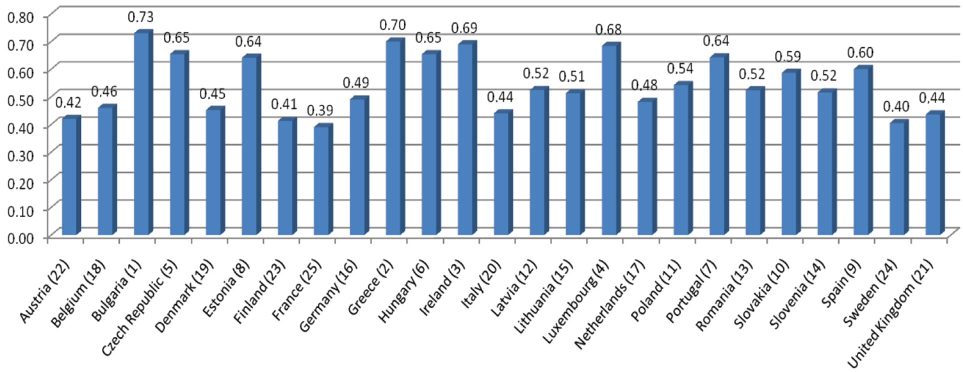

Figure 3. Natural gas vulnerability index. (color figure available online)

countries' economies are vulnerable to oil. This can be explained by the fact that the EU-27's main oil suppliers are Russia with a share of 26% of oil exports to the sample countries and the Middle East countries with a total share of 30%. The instability that characterizes the Middle East countries and the use of energy as a policy pressure tool by Russia plays an important role in the security of oil supply. On the contrary, countries that import oil from countries like Norway and Denmark are less vulnerable to oil and are considered to face limited risks in terms of security of oil supply.

4.2. Clustering

Using the k-means clustering function of XLSTAT the sample countries were organized in 3 groups relative to the OVI. Table 3 represents the results of the k-mean clustering analysis. Table 4 in the same line represents the results of the k-mean clustering Table 3 analysis for gas. Class 1 contains the countries that are most vulnerable to oil, Classes 2 and 3 contain countries that are exhibiting an average vulnerability to oil, and Class 4 contains the least vulnerable countries.

Table 3
Clustering analysis of oil indicators

Level of vulnerability	Most vulnerable	Average vulnerability		Least vulnerable
Class	1	2	3	4
	Cyprus (1) Bulgaria (2) Greece (6) Ireland (5) Luxembourg (4) Malta (3)	Czech Republic (9) Estonia (8) Italy (10) Poland (12) Portugal (7) Romania (11)	Belgium (19) Germany (20) Hungary (14) Latvia (13) Lithuania (17) Netherlands (16) Slovakia (21) Slovenia (18) Spain (15)	Austria (22) Denmark (23) Finland (24) France (26) Sweden (27) United Kingdom (25)

Table 4
Clustering analysis of natural gas indicators

Level of vulnerability	Most vulnerable	Average vulnerability		Least vulnerable
Class	1	2	3	4
	Bulgaria (1) Czech Republic (5) Greece (2) Hungary (6) Ireland (3) Luxembourg (4)	Estonia (8) Portugal (7) Slovakia (10) Spain (9)	Germany (16) Latvia (12) Lithuania (15) Netherlands (17) Poland (11) Romania (13) Slovenia (14)	Belgium (18) Denmark (19) Finland (23) France (25) Italy (20) Sweden (24) United Kingdom (21)

4.3. Natural Gas Vulnerability Index

Similar conclusions are obtained from the results of the NGVI. Bulgaria is the most vulnerable country in terms of natural gas and Sweden is again the less vulnerable country relative to natural gas. At this point it must be stated that Cyprus is not included in the OVI, as natural gas is not part of its energy mix.

The least vulnerable countries in natural gas are the Scandinavian countries: Denmark, Finland, and Sweden, a neighbor country to the United Kingdom and the central European country of France. All these countries apart from France are in the same geographical area. Finland and Sweden are importing natural gas on a 100% basis from the Russian Federation and Denmark, respectively. The United Kingdom imports natural gas mainly from Norway, while France imports from the Russian Federation and Norway. One reason that explains the low vulnerability that these countries have in natural gas is the well-diversified energy mix that these countries have and the usage of nuclear and renewable energy sources. On the other hand, Bulgaria, Greece, Ireland, and Luxemburg are the most vulnerable countries in natural gas. One explanation is the pure diversified energy mix that these countries have and the fact that their indigenous production in natural gas is very low or nonexistent.

The results that are obtained from the NGVI are in convergence with the results that the OVI provides us with. This can be explained by the fact that for the synthesis of the two indices we used the same indicators and therefore the same concepts of security of supply were examined.

4.4. Clustering

According to the oil vulnerability clustering, the sample countries were organized in 4 groups relative to their vulnerability to natural gas. Class 1 contains the countries that are most vulnerable to natural gas, Classes 2 and 3 contain countries that are exhibiting an average vulnerability to natural gas and Class 4 contains the least vulnerable countries.

5. Conclusion

Import increasingly contributes to energy the consumption of the EU. According to the commonly accepted energy outlooks (European Commission, International Energy

Agency, etc.), in 2030 about 70% of European energy needs will be met by primary (and nonrenewable) sources originating from foreign areas, some of which are very remote and geopolitically unstable. A relevant issue involves the reliability of the infrastructures (for extraction, primary processing and transport to the EU), as far as likely accidents and terrorist attacks are concerned. Therefore the future dependence on foreign suppliers impacts directly the European security of supply and indirectly the other two main targets of the EU energy policy, economic development and climate change mitigation. The multidimensional character of countries' vulnerability on primary energy sources supply has clearly emerged through the review of relative literature and gave the signal for the need to integrate several measurable indexes in appropriately developed synthetic indices. The principle component analysis multivariate statistical approach has been used for the transformation of the correlated indexes into the oil and natural gas vulnerability indices. The comparative analysis of the calculated indices has provided useful insights relative to the vulnerability that the 27 European Member countries exhibit to oil and natural gas. Although, despite the useful results that were obtained from the application of the two synthetic indices, the analysis that was performed was static as the indices were synthesized for the year 2006. It is in the authors' plans to develop indices that will operate in a more dynamic environment and to incorporate more indicators capturing all the essences of vulnerability and security of supply.

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