Measuring the Security of External Supply in the EU*

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Abstract

The security of energy supply is one of the main objectives of the common energy policy on the EU. In this paper, we provide an index that evaluates the risks associated with the external energy supply of the EU Member States. The index is designed to access the short-term risk to the supply security. The index combines measures of energy import diversification, political risks of the supplying country, risk associated with energy transit, and the economic impact of a supply disruption for each energy type. We provide estimates for a sample of eighteen EU Member States and for three primary energy sources: oil, gas and coal.

We construct a separate index for each energy type and demonstrate that European countries' exposure to risks differs across energies. Most other studies provide an aggregate index that combines different types of energy. Our results suggest that an aggregate approach might be misleading at least as regards the short-term response to risks. We also find that the relative contribution to the overall European risk exposure differs across EU Member States. We discuss the implications of our findings for the common energy policy.

Key words: Energy policy, EU, index, security of supply, supply risk
JEL codes: Q4, Q48, C8

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1 Introduction

Since the creation of European Coal and Steel Community (ECSC) in July 1952, the security of energy supply has been on the European political agenda. In 2006 it was stated as one of the cornerstones of the common energy policy, together with environmental objectives and economic competitiveness.[1]

The recent developments of the energy markets have reinforced concerns about the feasibility of supply security, usually defined as a continuous availability of energy at affordable prices.[2] Indeed, energy prices have increased drastically, and this tendency is likely to continue. Moreover European countries purchase more than half of their energy from the outside sources. Since the demand for energy is growing in the EU, the dependence on foreign suppliers will increase rapidly over time. Many of the energy imports originate from unstable regions and suppliers associated with a substantial risk of supply disruption, which puts European countries under serious pressure. At least two recent episodes demonstrated that this is not an empty threat. First, in 2006 Russia decided to suspend gas deliveries to Ukraine and this resulted in a shortfall of 100 million tons of gas undersupplied to Western Europe. The same happened for oil deliveries via Belarus in January 2007, when the pipeline with a capacity of 50 million tons of oil was shut down.

Before deciding on the remedies, it is however necessary to understand the extent to which the security of supply poses a problem at the European level. In this paper we aim at contributing to this understanding by measuring the exposure of EU Member States to the energy supply risks.

We address the issue of the energy security from an "external" perspective, looking at the risks associated with the energy supplied by the producers from outside the European Union. So far the EU has been mainly taking an "internal" perspective on the security of supply. The EU aimed at creating a single, integrated European energy market to achieve more competitive prices, improve infrastructure, and facilitate cooperation in case of energy supply crisis.[3] However, the security of "external" energy supply may be of even more importance for the EU, given European dependence on imported energy.

The key feature of the security of "external" supply is that it can be affected not only by economic rationales but also by political objectives. Röller et al. (2007) point out that "government-controlled foreign monopolist may restrict output beyond what a monopolist may do, in order to extract political concessions". When political pressure influences the seller's economic decisions and a rationing (interruption of supply) occurs, the market, by increasing prices, may be not able to solve this problem. Hence it will cause concerns for the security of external supply. There could also be a number of other reasons for the disruption of the "external" energy supply, such as "[...] macro-economic instability in producer countries, socio-political instability in producer countries and/or regions, [...] and government failures" (Van der Linde et al. (2004)).[4]

[1]See Green Paper "A European Strategy for Sustainable, Competitive and Secure Energy" (2006).

[2]"Security of supply in the energy field must be geared to ensuring [. . .] the uninterrupted physical availability on the market of energy products at prices for all consumers." (European Commission (2000), p. 9).

[3] See, e.g. Directive for Internal Market for Electricity (1996) and the Directive for Internal Market for Natural Gas (1998).

[4]The gas supply in Europe is a good example to illustrate the problem of the security of external supply. The major gas suppliers of the EU have a monopoly position in their domestic markets and are controlled by their states. This implies that the gas supply's disruption may result from political con-

To assess the vulnerability of EU Member States from this "external" perspective, we construct an index that evaluates the risks associated with the external energy supply. It combines measures of net import dependency, political risks of the supplying country, energy transport risks, and economic importance of each energy type for the country's energy bundle. We provide an index for a sample of eighteen EU members and for three primary energy sources: oil, gas and coal. We rank the European countries according to each of our indexes and compare our results to the existing measures of the external energy supply risks.

Our index is designed to measure the short-term risk to the security of energy supply. We consider the case of a sudden disruption in supply that cannot immediately be accommodated by the market due to a lack of flexibility. For this type of disruption the substitutability among different energy types is very limited. Therefore, we present a separate index for each energy type. This feature constitutes the particularity of our approach. Indeed, most other studies propose an aggregate index of the security of supply that combines different types of energy. However, our results justify the use of a disaggregated index. We find that the EU countries' exposure to risks is not the same for different energy types. This implies that an aggregate energy security index may be somewhat misleading at least as regards to the discussion of the short-term response to risks. Relying on an aggregate risk index without controlling for its composition may be a costly simplification since it is not possible to substitute different energy types in the short run. Poland, for example, has relatively high risk index for the supply of oil and a relatively low index for the supply of gas while the situation is the reverse for Portugal. Poland is therefore more likely to face an oil supply disruption than Portugal, while the opposite holds true as regards a gas supply disruption. With our index we are able to evaluate the potential damage caused by a supply disruption in a specific energy market in a specific country. This would not be possible with an aggregate index that estimates an average risk of an energy supply disruption.

Finally, we address the security of energy supply from the EU perspective, providing a measure of a relative contribution of each Member State to overall European risk exposure. We argue that, other things equal, countries with larger imports are responsible for greater part of the risk for the EU. So, for each country we weight the supply risk index by country's share in total energy imports of the EU, and then normalize it by the sum of similarly weighted risk indexes for all EU Member States. The resulting index suggests that the European countries contribute differently to the EU risk. This may lead to some energy policy tensions between the countries with high and low risk exposure. In order to reduce it, common energy policy in the EU needs to allow for mechanisms to compensate the potential "losers".

The structure of the paper is as follows. In section 2 we presents our methodology to construct an index of the short-term risk of supply disruption and relate it to the existing literature. In section 3 we provide the description of the data used in the analysis. In section 4 we present the indexes calculated for different primary energy types (gas, oil or coal) and for most of the EU Member States. We also compare our results to the other existing quantitative measures of energy supply risks. Finally, in section 5 we conclude by summarizing our findings, discussing extensions and suggesting some policy implications.

siderations/events that are completely unrelated to the market conditions. See Hedenskog and Larsson (2007) for a discussion concerning the Russian gas provider GazProm.

2 Methodology and related literature

As was already mentioned, the security of energy supply means that all energy volumes demanded are available at a reasonable price. This definition suggests that there is a number of characteristics of supplying and consuming countries that could be used to measure the potential risks of the external energy supply.

In this paper we concentrate on security of external supply. Therefore, the energy security index should naturally include some measure of *import dependency,* i.e. the importance of energy imports for domestic consumption. However, the composition of energy imports would also matter for the security. If energy imports are well diversified, the consuming country faces a smaller risk of supply disruption than in the case when all the energy imports come from a single supplier, other things equal. Therefore, one needs to account not only for the overall contribution of imported energy into the consuming country's energy portfolio, but also for the diversity of the energy suppliers that contribute to these imports.

Our measure of the diversification of the energy portfolio is based on the *Herfindahl-Hirschman index.* The standard Herfindahl-Hirschman index is normally used in industrial organization literature to evaluate the market concentration. It equals the sum of the squares of each participant's market share. More concentrated markets are characterized by a higher value of the index and the maximum is achieved when there is only one supplier. This index places extra emphasis on the contributions of participants with the largest shares. We adopt similar logic to construct our supply diversification measure: The foreign suppliers that constitute the larger share of domestic energy consumption may potentially also cause more problems to energy security.

To calculate the market shares for each foreign supplier we take the ratio of net positive imports from this supplier to the total energy consumption of the considered country.[5] Therefore, such an approach indirectly accounts for the indigenous production. We rely on the net positive imports as a measure of risk for the following reason: If the net imports from a supplier are negative, the country in question exports more energy to the supplier country than it receives from this supplier. Therefore in the case of a default from this supplier a consuming country may compensate for its losses by cutting the respective exports.

Obviously, there are more factors that can influence the security of external energy supply. Therefore, we supplement our measure of import dependency by several additional components.

First, the continuity of external energy supply may be affected by the political situation in the supplying country. We take this risk into account by using a measure of the political stability of the supplier.

Second, the supply disruption may take place during the energy transportation, both for purely infrastructural and for political reasons. For example, a supplier country may enter a political conflict with a third party. In this case it is more likely that the consuming country will be affected if this conflict is taking place "on the path" of the energy transport from the supplier to the consumer country. Our index accounts for potential supply disruptions during energy transportation by including the distance between the consuming and the supplying countries. The idea here is that the distance measure allows us to proxy the number of transit countries that have to be passed through in order to provide the energy. It is also reasonable to expect that the probability of energy

[5] We only look at the supplying countries and not firms due to the non-availability of the data.

transport failure increases with the length of transportation. Therefore the distance can be viewed as a measure of the ease of energy delivery from the supplier.

Finally, for each energy type, the economic impact of a supply disruption is taken into account. To do so, we multiply our index by the share of the respective fuel in total energy consumption of the considered country.

Furthermore, we concentrate on the short-term response to the risks associated with the external security of energy supply. The short-term perspective implies that we do not address the issue of substitutability between different energy types. As a result we construct a separate index for oil, gas and coal. Such a disaggregation allows us to better assess the specific risks for each energy type.[6]

This methodology yields a **Risky External Energy Supply (REES) Index** for each EU Member State and each energy type considered (gas, oil and coal). For each fuel type f the REES index for country a is defined by the following equation:

$$REES_a^f = SF_a^f \sum_i \left(\frac{NPI_{ai}^f}{C_a^f} \right)^2 r_i d_{ia},$$

where SF_a^f is a share of fuel f in country a's total energy consumption, NPI_{ai}^f are the net positive imports of energy f from country i to country a,[7] C_a^f is the total consumption of fuel f of country a, r_i is the political risk index of the supplier country and d_{ia} is a measure of a distance between countries i and a. For each energy type, this index gives an estimate of how much the security of external supply matters for the considered country. Note that the index decreases with the number of suppliers and the proximity of the consuming and supplying countries, and increases with political risks. Hence, higher values of the index correspond to more risky supply.

Then we proceed by measuring the contribution of each Member State to the risk that the EU is facing due to external energy supply. We argue that the risk faced by large EU countries have a greater impact on the EU energy security than the risk of the smaller EU members. To account for it, we approximate the degree of influence of each country on the EU risk by this country's share in total EU imports.

The resulting **Contribution to EU Risk Exposure (CERE) index** measures the relative impact of each Member State on the aggregate EU risk. It is calculated as the REES index multiplied by the share in EU imports over the sum of these products for all Member States

$$CERE_a^f = \frac{REES_a^f * Share_a^f}{\sum_{j \in EU} \left(REES_j^f * Share_j^f \right)},$$

where $Share_j^f$ corresponds to the share of country j in net EU imports of fuel f.[8] As we

[6] Note that our index does not account for environmental constraints. We argue that such constraints, even though important for the energy sector, are not linked, at least in the short run, to the problem of supply disruption.

[7]
$$NPI_{ai}^f = \max \left\{ 0,\ M_{ai}^f - X_{ai}^f \right\}$$

where M_{ai}^f is the import of energy f from country i to the country a, and X_{ai}^f is the export of energy f from country a to country i.

[8]
$$Share_j^f = \sum_i NPI_{ji}^f \Big/ \left(M_{EU}^f - X_{EU}^f \right)$$

where $M_{EU}^f - X_{EU}^f$ measures the European Union's net import of fuel f.

will see, an adjustment for the country size might change the ranking of the EU Member States in terms of the external energy security.

Obviously, our index is not the first attempt to quantify the security of external energy supply. The existing literature can be roughly subdivided into two groups.

In the first group of papers a proxy for the security of external supply only serves as a component of more complex energy security indexes that account for both internal and external energy security. Typically these papers approximate the external supply risks by a relatively simple measure of import dependency.

For example, De Jong et al. (2007) in their Crisis Capability Index account for the security of external supply by using the share of imports of different types of energy in the total energy imports. They weight these imports by their own assessment of risk associated with each energy type. To complete the index, they combine this resulting measure of external energy security with similar measures of the stability of the internal energy supply and energy transportation system. In their long-term Supply/Demand index they modify the approach, looking at the ratio of the energy net imports to the total energy consumption. There they further subdivide the imports by the source (EU/non-EU) to account for different risks associated with different suppliers, and use a complicated methodology to assess the "security" of the contracts. Still, the import risks constitute only a part of the overall index, which also accounts for the demand side as well as energy conversion and transport.

Similarly, Röller et al. (2007) measure import dependency by dividing the net energy imports on the total energy consumption. They use the resulting index as a component for a general energy security index where both the external energy supply (measured by the import dependency index) and the internal energy supply (measured by the power system capacity) are taken into account.

The common feature of the first group of papers is that they typically address issues that are more general than the security of external energy supply. As a result, these studies use rather simplistic proxies for the external energy supply risks. For example, they do not properly account for the diversity of energy supply, specific risks associated with each supplier etc. We, in turn, concentrate on quantifying the security of external supply in EU and, thus, are employing more sophisticated and more precise measures.

Another important distinction is that most of the indexes in this group are combining data on different energy types to estimate an average risk of an energy supply disruption. We argue that the EU countries' exposure to risks is not the same for different energy types. That implies that in the short-term the aggregation across the energy types may lead to a loss of information about the risks associated with a specific energy. To address this issue we suggest a set of separate indexes for three primary energy types.

The second part of the relevant literature deals specifically with measuring the security of external energy supply. Therefore it typically captures more underlying complexity of the external supply risks than the first group. First of all, they are much more precise when addressing the diversification of the energy imports. Second, they take into account many more specific factors that are directly related to the security of external energy supply. Our index clearly belongs to this second group. We concentrate on the external security of energy supply and our methodology follows a similar general strategy. However, our approach has some important differences as compared to the indexes mentioned below.

For example, Blyth and Lefevre (2004) use the Herfindahl-Hirschman index, focusing on the energy supplier characteristics and the availability of the fuel supply in the supplier country. They argue that the market for each country is determined by all potential foreign suppliers and by their *potential* exports (production minus consumption). For each fuel they calculate the market shares of each supplier in that market. Then they combine the resulting Herfindahl-Hirschman index with a political risk rating associated with the supplier country and a measure of the market liquidity (given by the ratio of the total supply available on the market divided by the consumption).

The main distinction of our approach is that in our supply diversity measure we rely on the net positive imports as compared to the Blyth and Lefevre's *potential exports.* We argue that our measure provides a better account of risks. The reason is that the potential exports market of Blyth and Lefevre (2004) may not reflect the short-term threats in the *actual* energy market faced by the country in question. For example, consider a country with all its energy consumption coming from one single supplier, that is small on the market of potential exports. In this case a high risk associated with this supplier is quite harmful for the country's energy security but it is not captured by the Blyth and Lefevre index. One could argue that their index could be better suited for reflecting the possibility of switching to a different supplier in the case of disruption. However, we concentrate on a short-term adjustment to shocks in which case a change of supplier is hardly relevant. Another difference is that Blyth and Lefevre aggregate the index across the energy types, similarly to the indexes discussed above.

Gupta (2008) focuses on the risks associated with the external supply of oil. Her supply risk index uses a modified Herfindahl-Hirschman index, based on the shares of different suppliers in the total oil demand of a country in consideration. These shares are adjusted for political risk of the supplier. Finally, the index also incorporates the measure of market liquidity and a measure of consuming country's self-sufficiency, measured as a ratio of country's oil reserves to the total oil demand. The crucial difference with her approach is that we create an index for different energy types, not only oil. This allows to access the overall picture with the security of energy supply in EU. Also, we include a measure of the ease of energy transport, which may have a significant impact on the energy security.

Probably, the closest approach to ours is the one by Neumann (2004 and 2007). Neumann suggests separate indexes for oil, gas and coal for a set of world countries. She measures suppliers' diversity by the *Shannon-Wiener concentration index.* This index is calculated by multiplying the market share for each participant by the log of the market share and summing up the absolute values of resulting products over all the market participants. A higher value of the index means a lower concentration and the minimum value for the index is achieved when there is only one supplier. She adjusts the Shannon-Wiener index by taking into account the indigenous production of the export country and the political stability of the import supplier country.

However, there is a range of differences between Neumann's and our approaches. First of all, we measure the diversification of the energy portfolio of each country using the Herfindahl-Hirschman index rather than the Shannon-Wiener index used by Neumann (2004, 2007). The Shannon-Wiener index puts weight on the impact of smaller participants. The argument for using this index for the energy market is that the smaller suppliers provide the options for potential switching between energy sources. In turn, the Herfindahl-Hirschman index places emphasis on larger suppliers. We argue that this feature makes it better suited to capture the risks associated with the non-diversified energy portfolios. Also, the Herfindahl-Hirschman index allows us to account for the indigenous production without introducing an additional term into the formula as is done in Neumann (2004). Second, we extend the set of risk measures captured by the index, by including the proxies for transport risk, which is not taken into account by Neumann. Third, for each energy type we account for the impact of a potential supply disruption on the consuming country's economy by estimating the importance of this energy type for the overall energy's consumption. Finally, in our index we concentrate on European perspective, in particular, providing a measure of relative contribution of each EU Member State into the overall European risk.

In the results section we return to the comparison between our indexes and some of the indexes discussed above.

3 Data

We compute our indexes for three primary energy types: oil, gas and coal. The data on the exports, imports and consumption for each energy type comes from the International Energy Agency. More precisely, the indexes are based on the 2006 data for the import volume, export volume, consumption level of crude oil, natural gas and hard coal, respectively. We also use the identity of the main supplier country(ies) that provided each of the energy commodities to the EU Member States in 2006. We were only able to obtain the complete set of data for eighteen EU Member States: Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Poland, Portugal, the Slovak Republic, Spain, Sweden, the United Kingdom. However, we believe that these countries are sufficiently representative for the EU energy profile. The data on the share of each fuel in total energy consumption of each EU Member State comes from Eurostat agency.[9] Table 1 presents the overview of the energy profile for the countries in our sample.

Note that we include the imports from the other EU Member States in our measure of the energy import diversification. The reason is that current European common energy policy does not fully internalize the potential energy problems of all EU countries. That is, each of the Member States has much more control over the domestically produced energy (if any), than over energy imported from the rest of the EU. As we calculate the indexes for each of the EU Member States separately, we take this observation into account by the including within-EU imports into the index. An alternative approach would be to consider only the imports from the non-EU countries. However, we believe that, at least qualitatively, these two approaches would not result in substantially different security indexes.[10] Indeed, the energy imports from other EU Member States are clearly associated with the lowest risk of disruption and thus their contribution to the overall energy supply risk is rather limited.

[9] We use the data from 2005, as 2006 data was not available. However the composition of energy portfolio of EU Member States is relatively stable over time, so we believe it does not have much impact on our indexes.

[10] E.g., they will produce the same ranking of EU Member States with respect to the energy supply risk.

Table 1: Energy Profile of EU Member States

Country	**Gas**					**Oil**					**Coal**				
	Cons	Prod	Net M	Net M, non-EU (*)	Share (**)	Cons	Prod	Net M	Net M, non-EU (*)	Share (**)	Cons	Prod	Net M	Net M, non-EU (*)	Share (**)
	Million M^3				%	Kt				%	Kt				%
Austria	8909	1819	7843	6177	41.6	8640	859	7698	7674	24.3	3884	0	4105	549	11.9
Belgium	16467	0	16500	4300	37.4	31656	0	31553	25090	25.7	8989	0	6978	7437	9.9
Czech Rep.	9325	169	9680	7249	21.8	8114	265	7725	7767	17.2	22196	13747	-4734	-254	44.9
Denmark	5060	10414	-5237	0	41.6	7958	16753	-8786	-1096	22.5	9259	0	8447	7703	19.0
Finland	4750	0	4750	4750	30.4	10617	0	10441	7428	10.4	5694	0	6671	6105	14.3
France	44699	1208	44511	20568	33.4	82909	1066	81821	60144	14.9	18897	0	20251	17084	5.2
Germany	100445	19609	82088	39405	35.7	113428	3382	109099	74747	23.4	65379	23762	41062	29475	24.0
Greece	3314	22	3295	3295	57.5	18804	83	18782	18782	7.5	514	0	482	358	28.7
Hungary	14202	3095	11526	10562	26.6	7098	886	6104	6104	43.3	1676	0	1755	871	11.1
Ireland	4697	510	4187	0	55.5	3233	0	3183	0	22.9	3036	0	2939	2574	17.8
Italy	84484	10979	77030	58615	44.5	91989	5890	85964	82001	37.8	24793	70	24634	24290	8.8
Netherlands	47804	77295	-29485	0	39.6	48038	1350	47065	38025	43.6	23060	0	13234	17210	10.1
Poland	16336	5963	10876	10005	24.0	20452	792	19531	19494	13.0	113815	94405	-11455	2331	58.7
Portugal	4175	0	4200	4200	57.8	13478	0	13363	11296	14.1	6097	0	5777	5617	12.5
Slovak Rep.	6575	123	6441	6940	20.8	5635	27	5528	5557	30.5	4817	0	4865	3085	22.1
Spain	33963	60	34409	32309	48.4	60933	139	60468	54783	20.8	34690	8353	23704	23590	14.4
Sweden	976	0	976	0	28.4	18791	0	19343	8423	1.6	2873	0	3054	2477	5.1
UK	94404	83821	11165	3399	35.6	76804	69709	6742	4220	36.6	69352	17253	50926	49625	16.4

(*) Net imports of respective energy type, excluding imports from EU and Norway;

(**) Share of respective energy type in total energy consumption.

Source: International Energy Agency and Eurostat

Our measure of political risks is based on the index produced by the PSR Group. The PSR Group's political risk rating assigns to the countries the values between 1 and 100, with higher values being associated with lower risk. We compute our risk measure as

$$r_i = \frac{100 - PSR\_Risk}{100},$$

so that higher values are associated with a higher political risk and the variable r_i is between 0 and 1.[11]

Finally, we construct a measure of distance between the supplier and the consuming country as a proxy for the potential risks of energy transportation. Our measure is based on the following logic: The safety of delivery to the consuming country declines with the distance to the energy source. However we argue this dependence is not linear. A linear relationship between the ease of delivery and the actual geographical distance would put a disproportionately high weight on the suppliers furthest away. Instead, for sufficiently long distances the effect of an extra distance should level off, as long as we account for associated political risks. Therefore, instead of using the geographical distance between the countries, we create a categorical distance variable: We classify all country pairs into 3 groups according to the distance between their capitals: under 1500 km, between 1500 and 4000 km and above 4000 km, with these groups being assigned a distance index of 1, 2 and 3 respectively

$$d_{ia} = \begin{cases} 1, \text{ if dist\_btw\_capitals} < 1500 \text{ km} \\ 2, \text{ if } 1500 \leq \text{dist\_btw\_capitals} < 4000 \text{ km} \\ 3, \text{ if dist\_btw\_capitals } \geq 4000 \text{ km} \end{cases}.$$

The idea behind choosing these thresholds is as follows: The European countries would not have much difficulty supplying energy to each other and they roughly belong to the first group. Then the index (weakly) increases with the distance between the supplying and consuming countries, but it takes greater and greater distance to fall into the next category.

From our earlier discussion of the possible energy transportation risks it follows that these risks are more relevant for the energy types that are, at least partially, supplied through networks or pipelines, such as gas and oil, and less relevant for coal. Therefore we do not include the distance measure (i.e., the proxy for the transportation risks) in our coal index.

4 Results

The results of our estimations are presented in Tables 2 and 3.

Gas indexes. Different EU Member States face different situations in the gas market: Some of them have substantial indigenous production, others obtain most of their imports from EU suppliers or Norway, while the third ones only purchase their gas from outside the EU/Norway area. Moreover, for some of the Member States natural gas constitutes a substantial share of their energy portfolio, while other Member States rely more on oil, coal or other fuel types (see Table 1).

[11] PSR Group has no data on the geopolitical risk for Turkmenistan and Uzbekistan. We approximate it by the risk associated with Kazakhstan, assuming that the Kazakhstan's index might reflect a regional risk.

Table 2: REES Index (higher values correspond to higher risk)

Country		Natural Gas	Crude Oil	Hard Coal
Austria	AT	8.1	3.5	1.3
Belgium	BE	1.5	6.3	0.6
Czech Republic	CZ	7.3	7.1	0.0
Denmark	DK	0.0	0.6	1.3
Finland	FI	3.6	4.9	2.1
France	FR	0.9	1.7	0.2
Germany	DE	2.8	3.3	0.4
Greece	GR	3.6	10.6	3.1
Hungary	HU	12.9	16.9	0.8
Ireland	IE	3.4	4.7	1.4
Italy	IT	3.6	2.9	0.6
Netherlands	NL	0.0	5.6	1.0
Poland	PL	1.2	7.3	0.0
Portugal	PT	5.2	3.7	1.6
Slovak Republic	SK	23.5	14.0	2.5
Spain	ES	2.8	4.1	0.4
Sweden	SE	0.3	2.1	0.3
United Kingdom	UK	0.1	0.9	0.9
Average		4.5	5.6	1.0
Standard deviation		5.8	4.4	0.9

As a result, countries can be subdivided into three groups with respect to their REES index. The group with a relatively high index includes Austria, the Czech Republic, Hungary and the Slovak Republic. These countries do not produce any gas and usually import most of their gas from non-EU/Norway suppliers, which implies that both the distance and political risk factor contribute to a higher index value. The share of gas in their total energy consumption is relatively high. On top of that, some of these countries do not have well-diversified external gas supply. Finland, Germany, Greece, Italy, Ireland, Portugal and Spain constitute the group of medium risk, with better diversified gas imports and/or less reliance on gas in their aggregate energy portfolio. The remaining countries have a relatively low index either due to their indigenous production (like the Netherlands, or the United Kingdom), or to their mostly European import origin.

CERE gas ranking moves Germany and Italy up the scale, making them the most important contributors to EU risk exposure. This is a result of their gas consumption being relatively important at the EU level.[12] However, smaller countries like Hungary

[12] This is a general result for all three energy types: the CERE indexes change the country risk ranking, moving larger countries up and smaller countries down the risk scale. This is due to the definition of the CERE index, since it is based on the countries' REES indexes weighted by the share of each respective country in the total EU imports. This reflects our belief that, other things being equal, countries, which

Table 3: CERE Index (higher values correspond to higher risk)

Country		Natural Gas	Crude Oil	Hard Coal
Austria	AT	5%	1%	3%
Belgium	BE	2%	5%	3%
Czech Republic	CZ	6%	1%	0%
Denmark	DK	0%	1%	6%
Finland	FI	1%	1%	8%
France	FR	3%	12%	2%
Germany	DE	21%	17%	10%
Greece	GR	1%	5%	1%
Hungary	HU	12%	1%	1%
Ireland	IE	1%	1%	2%
Italy	IT	22%	17%	9%
Netherlands	NL	0%	8%	10%
Poland	PL	1%	2%	0%
Portugal	PT	2%	3%	5%
Slovak Republic	SK	14%	1%	9%
Spain	ES	8%	13%	6%
Sweden	SE	0%	2%	1%
United Kingdom	UK	0%	8%	25%
Total, 18 EU members		100%	100%	100%

and the Slovak Republic are still in the top risk group because they rely almost entirely on non-EU suppliers for their gas imports.

Oil indexes. The supply of oil to EU countries bears slightly more risk than gas, but the difference between the countries is lower. Indeed, the average value of the REES index increases from 4.5 to 5.6 between the gas and oil indexes and the standard deviation decreases from 5.8 to 4.4. This is mostly due to the two main reasons: first, the share of oil in the Member States' energy consumption is higher on average than the share of gas. A disruption of oil supply would then be associated with higher costs. Second, oil market is more global than the gas market, implying that the difference in risks between the EU Member States should be lower for the oil consumption. As Table 2 suggests, all EU members can be roughly subdivided into three groups. Greece, Hungary and the Slovak Republic represent the group of countries with the highest risk exposure. Neither of these three countries has a well-diversified oil supply. Hungary and Slovak Republic purchase most of their oil from a single relatively risky supplier, namely Russia. Greece oil imports come mostly from Russia, Iran and Saudi Arabia and its economy is heavily dependent on oil which increases the risk index. Then Belgium, the Netherlands, the Czech Republic and Poland constitute a middle risk group. The first two countries in this list have a slightly more diversified oil import structure, while still consuming a most

are responsible for larger part of EU net imports, are also greater contributors to the overall EU external energy supply risk.

of their oil imports from a few relatively risky producers. The second two countries still purchase a sizable part of their imports from one or two risky supplier, but their economy does not heavily rely on oil as the primary energy source. Finally, the remaining countries have a relatively low external oil supply risk as measured by the REES index. This is due to more diversification and, in some cases (e.g. Denmark or the UK), noticeable domestic oil production.

As regards contribution to the EU's risk exposure represented by the CERE oil index, the countries at the top are mostly major oil importers (e.g. Germany or Italy), some of which also have a substantial share of oil in their energy portfolio.

Coal indexes. The security of coal supply is usually not considered to be a serious problem, because the world coal market is well diversified, many Member States have indigenous coal production, and coal is easy to handle and store.[13] Indeed, the average coal REES index is much smaller than for gas or oil, and so is the difference in risk between the EU Member States, measured as a standard deviation of the index. Greece, Finland and the Slovak Republic have the highest REES index due to a poor diversification of suppliers, non-EU/Norway imports and no indigenous production. However when controlling for the relative share in the total EU imports through the CERE index, the United Kingdom, the Netherlands and Germany go to the top of the ranking list.

Comparison among indexes. The EU Member States' ranking based on both the REES and CERE indexes differs for different energy types. Also, the range of REES indexes differs between energies. This confirms our hypothesis that EU countries' exposure to risks is not the same for different energy types. Hence, an aggregate energy security index may be somewhat misleading at least for the discussion of the short-term response to risks. In other words, in the short-term the substitutability among different energy types is problematic. Thus, relying on an aggregate risk index without controlling for its composition may prove to be a costly simplification.

Indeed, Table 4 summarizes three other energy security indexes: Röller et al. (2007), De Jong et al. (2007) and Neumann (2007).[14] As was mentioned above, only the Neumann index is directly comparable to ours. The other two indexes do not concentrate on the external security of supply, as they also deal with other security aspects and aggregate measure over different energy types.

One can see that the first two indexes are not even mutually compatible: for example Poland is classified as a relatively secure energy consumer by De Jong et al., while it has a rather risky position according to the Röller et al. index. The reverse is true for Portugal. Our classification shows that Poland is exposed to more risks in the oil market (REES=7.3 for Poland vs. 3.7 for Portugal), while Portugal is more vulnerable in the gas market (REES =1.2 for Poland and 5.2 for Portugal). Therefore, aggregation of different energy types may even lead to inconsistent results due to differences in methodologies.

The Neumann index is more consistent with our results. However, our index seems to produce more precise classification of countries. For example, the Neumann index ranks Finland and Germany equally in the gas market. Our index suggests that Finland is more vulnerable to the risks of gas supply disruption than Germany. The same holds true for the comparison of the Netherlands and Spain in the oil market - they have the same

[13] See, e.g. "Investment in Coal Supply and, Use", International Energy Agency and Coal Industry Advisory Board (2005).

[14] Please note that for our index higher value corresponds to higher *risk*, while for three other 3 indexes higher values correspond to higher *security*.

Table 4: Other Energy Security Indexes (higher values correspond to higher security)

Country	**De Jong et al.** (1)	**Röller et al.** (2)	**Neumann** (3) **Gas**	**Coal**	**Oil**
Austria	57	1.8			
Belgium	57	5.7			
Czech Republic	64	3.4			
Denmark	82	4.4			
Finland	53	5.1	1.3	1.2	1.6
France	64	4.4			
Germany	63	4.6	1.3	1.3	1.4
Greece	44	3.8			
Hungary	55	5.1			
Ireland	75	5.8			
Italy	50	4.5	1.3	1.0	1.3
Netherlands	69	4.8	3.3	0.8	1.5
Poland	60	1.6			
Portugal	47	4.5			
Slovak Republic	51	4.7			
Spain	51	4.2	1.1	1.2	1.5
Sweden	70	4.9			
United Kingdom	80	4.8	1.7	1.1	3.3

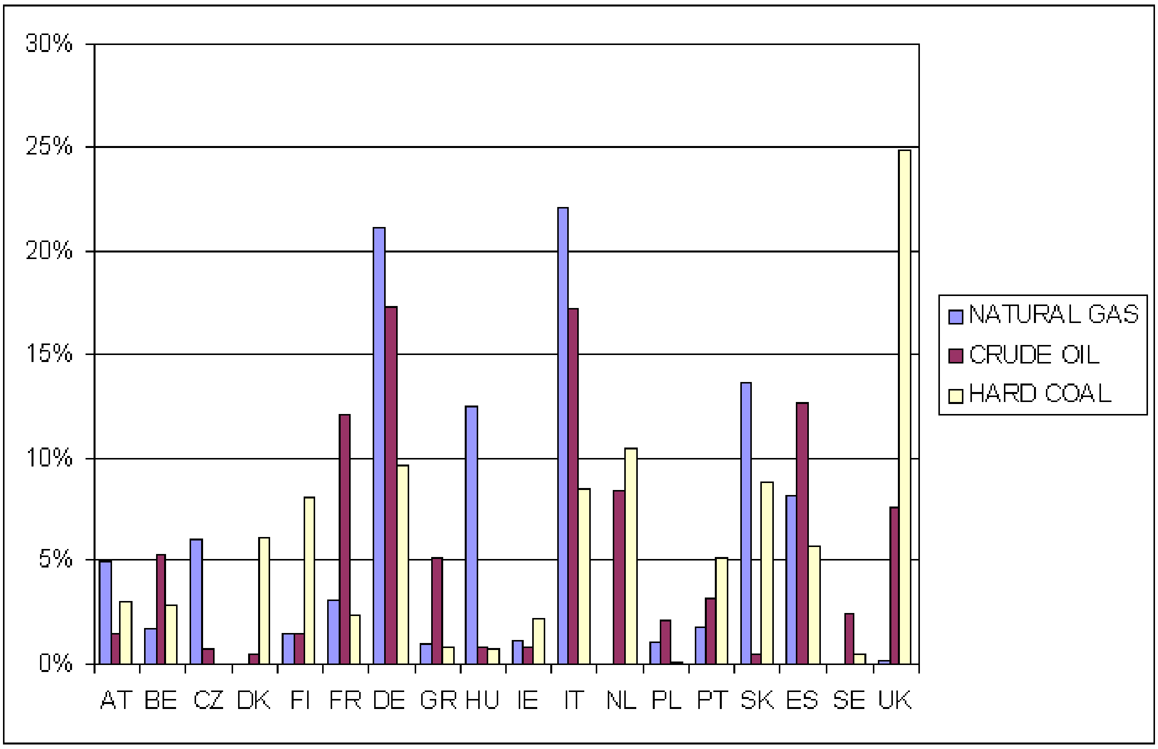
Source: (1) De Jong et al.(2007), Supply-Demand Energy Security Index,
(2) Röller et al. (2007), Security of Supply Index,
(3) Neumann (2007), Security of Supply Index.

Neumann index, while our index suggests that Spain oil supply is less secure. These differences may result from the use of different measures of import diversification, as well as from the fact that our index takes into account the transportation risks and the importance of each fuel in the total energy portfolio. Also, according to the Neumann index, coal seems to be the most risky energy type across the Europe[15]. However, as was discussed above, coal is generally believed to be less risky energy than gas or oil. This is in line with our index assigning lower risk to the coal supply. These observations suggest that our index is better suited to reflect the energy supply risks.

Another important remark concerns the CERE index. The relative contribution to the overall European risk differs substantially among EU Member States. This holds within each of the three considered energy types. It is especially easy to see in Figure 1, that plots the CERE index for different energies. This implies that the EU Member States' preferences over the European common energy policy are likely to be different too. Consequently, the understanding of EU energy security profile is important for accessing

[15] Low values of Neumann index correspond to high risk.

Figure 1: Contribution to EU Risk Exposure



the feasibility and potency of particular policy tools. We return to this argument below when discussing the policy implications of our analysis.

5 Conclusions and policy implications

This paper addresses the security of energy supply in the European Union. We propose a set of indexes evaluating the risks associated with the energy supplied by producers outside the EU. The indexes take into account the energy consumption structure of the consuming country, the risks associated with the supplying country and the transport of energy, as well as the relative impact of different EU members on the aggregate energy risk in the EU. We construct the indexes for the sample of eighteen European countries and three primary energy sources: oil, gas and coal. We compare our methodology and results to the previous literature, and argue that our indexes are better suited for capturing the short-term external energy supply risks.

We find that the EU Member States' exposure to risks differs both across the energy types and among the Member States. These results may have implications for the design and the implementation of a common energy policy in EU.

Different risk profiles across energies imply that a sectoral, i.e., according to energy type, approach provides a more reliable base for quantifying the short-term external energy risks. Since the short-term substitution among different types of energy is problematic or very costly, an aggregate risk index may be too imprecise to evaluate the potential damage caused by a supply disruption in a specific energy market. Moreover, the security of supply may require different policy tools for each energy type, which again can only be determined via sectoral approach. Therefore, a design of a common energy policy, or at least its aspects concerning the short-term response to the random supply disruptions would benefit from an energy-specific viewpoint. To some extent this approach is currently followed by the European Union, for example, in setting separate storage requirements for gas and oil.

Uneven distribution of risk among the EU Member States' suggests that their preferences over common energy policy are likely to differ. This may impact the feasibility of particular policy tools and lead to policy tensions. For example, suppose the EU designs and implements a common policy, allowing the EU Member States to share the energy supply risks.[16] Then the larger contributors to the European risk would benefit more from such a policy, sometimes at the cost for the others. This might undermine the other Member States' incentives to stick to the common energy policy agreement. This argument suggests that an adequate design of common energy policy should include a way to compensate the "losers", perhaps through energy-unrelated policy issues.

Our methodology could be extended to integrate more features of the energy security. For example, it does not address the technological aspect of energy supply. Gas can be transported through pipelines or as LNG, which also has implications for the way it can be stored. Clearly, the extent of diversification of energy supply with respect to technology may have an impact on the security of the supply and we do not account for it in our index. Second, our index does not account for the possibility of correlated energy shocks, such as a correlation between different suppliers (e.g. due to certain natural disasters or political events), or a correlation of shocks to the supply of the same energy to different EU members (e.g. due to a reliance on the same pipeline). Taking these effects into account would, however, be difficult at the moment due to the lack of respective systematic data.

Another interesting exercise would be to look at the evolution of our index under different development scenarios. For example, the domestic consumption of many EU countries as well as supplying countries is predicted to rise, which may boost competition for the energy and change the availability and prices of the supply (Stern, 2006). Also, the competition may become more global, as it already tends to be for LNG gas between the EU, North America and the Pacific region, which might also affect energy security. Moreover, it is anticipated that the indigenous gas production of the EU Member States will stagnate, which again may have some impact on the security of supply. Finally, new sources of energy may also affect energy security.

[16] This policy is referred to as "solidarity" among Member States (European Commission, 2006, p.8).

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