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Measuring the security of external energy supply in the European Union ☆

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ABSTRACT

The security of energy supply is one of the main objectives of EU energy policy. In this paper, we introduce an index designed to evaluate the short-term risks associated with the external supply of energy to the EU Member States. It 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. We construct separate indexes for three primary energy types, oil, gas and coal, and demonstrate that Member States' levels of supply risk exposure differ across energies. Most other studies of this kind provide aggregate indexes combining different types of energy. Our results suggest that an aggregate approach could be misleading, at least for discussions of the short-term response to risks. We discuss the implications of our findings for the common energy policy.

1. Introduction

Since the creation of European Coal and Steel Community (ECSC) in July 1952, the security of the energy supply has been a core item on the European political agenda. In 2006 the European Union (EU) declared it as one of the cornerstones of the common energy policy, alongside environmental objectives and economic competitiveness.[1]

The recent developments in the energy markets have heightened concerns about the feasibility of supply security, usually defined as a continuous availability of energy at affordable prices.[2] European EU countries buy more than half of their energy from non-EU sources. Since demand for energy is growing in the EU, dependence on foreign suppliers will increase 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 have proven that the threat of supply disruption is real. In January 2009, Western Europe experienced a severe shortfall of gas due to Russia's decision to suspend gas deliveries to Ukraine. The same happened with oil deliveries via Belarus in January 2007, when a pipeline with a capacity of 50 million tons of oil was shut down.

Before deciding on the remedies, we need to understand more about the size and nature of the supply risk problem facing the EU. This paper aims to measure the exposure of EU Member States to energy supply risks. We address the issue of the energy security from an "external" perspective, focussing on the risks associated with energy supplied by producers from outside the EU. So far, the EU has taken mainly an internally oriented perspective on the security of supply. Its objective has been to create a single, integrated European energy market in order to realize more competitive prices, improve infrastructure, and facilitate cooperation in case of an energy supply crisis.[3] However, the security of the "external" energy supply may have at least as much importance for the EU, given its 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 a "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

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[1] See European Commission (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 European Parliament and the Council (1996, 1998).

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and a rationing (interruption of supply) occurs, the market, by increasing prices, may be not able to solve the problem. The external energy supply is also subject to "[…] macro-economic instability in producer countries, socio-political instability in producer countries and/or regions, […] and government failures" (Van der Linde et al., 2004).

To assess the vulnerability of EU Member States to such disruptions, we construct an index that evaluates the risks associated with the external energy supply. The index combines measures of net import dependency, political risks of the supplying country, energy transport risks, energy fungibility and the economic importance of each energy type for the country's energy bundle. We construct indexes for the EU members and for three primary energy types: oil, gas and coal. We rank the European countries according to each of our indexes and compare our results to existing measures of the external energy supply risks.

Our *Risky External Energy Supply* (REES) index is designed to measure short-term risk to the security of energy supply. We consider the case of a sudden disruption in supply that cannot be accommodated immediately by the market. For this type of disruption, the substitutability among different energy types (oil, gas and coal) is very limited. Therefore, we present a separate index for each type of energy. This approach distinguishes our work from most other studies, which propose an aggregate index that combines different types of energy. Our results justify the use of a disaggregated index. We find that the EU countries' exposure to risks varies across different energy types. The implication is that an aggregate energy security index may be misleading, at least for discussions of the short-term response to risks. For example, the risk index for the oil supply is higher for Poland than for Portugal, while the situation is the reverse for the gas risk index; an oil supply disruption will have a bigger impact on Poland than on Portugal, while the opposite would be true for a gas supply disruption. Put succinctly, our index enables us to evaluate the potential damage caused by a supply disruption in a specific energy market in a specific country, an assessment that cannot be made using an aggregate index.

We also address the security of energy supply from the EU perspective by measuring the relative contribution of each country to overall EU risk exposure. We argue that, other things equal, countries with more imports incur bigger shares of the risk to the EU. To map this idea, we weight the REES supply risk index by the Member countries' shares in total EU energy imports. The resulting *Contribution to EU Risk Exposure* (*CERE*) index suggests that EU countries contribute differently to EU-wide risk. This tool could be useful in a political debate shaping a common energy policy.

The structure of the paper is as follows. In Section 2 we present the methodology used to construct our indexes of the short-term risk of supply disruption, and relate it to the existing literature. In Section 3 we describe the data used in the analysis. In Section 4 we present the indexes calculated for different primary energy types (gas, oil and coal) and for all 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.

2. Methodology and related literature

The security of energy supply is commonly defined as availability of demanded energy volumes at a reasonable price. This definition suggests that there are a number of characteristics of supplying and consuming countries that could be used to measure the potential risks of the energy supply.

Given that we focus on the security of external supply, our energy security index naturally includes a measure of import dependency. We account for import dependency as the ratio of the sum of net positive imports over all foreign suppliers to the domestic consumption of the respective energy in the country considered.[4]

The composition of energy imports also matters for security. If energy imports are well diversified, the consuming country faces a smaller risk of supply disruption than if all its energy imports come from a single supplier, other things equal.[5] 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. To reflect this, we multiply the import dependency ratio by a measure of the diversification of the energy portfolio. Our diversification measure parallels the Herfindahl–Hirschman approach. The standard Herfindahl–Hirschman index is used in industrial organization literature to evaluate market concentration. It equals the sum of the squares of each participant's market share. Similarly, we measure the diversity of energy supplies by summing the squared shares of all foreign suppliers in the total net positive imports of the considered country. An alternative approach to measuring the diversity of energy suppliers would be to use the Shannon–Wiener concentration index. However, the Shannon–Wiener index puts relatively more weight on the impact of smaller market participants (see DTI, 2005), while the Herfindahl–Hirschman index places more emphasis on larger suppliers. We believe that, other things equal, suppliers that constitute a larger share of country's energy imports potentially may cause more problems for energy security. Therefore, we argue that the Herfindahl–Hirschman index is better suited to reflect the risks, associated with the non-diversified energy portfolios.[6]

Obviously, more factors can influence the security of external energy supply. Therefore, we supplement our measure of import dependency and diversification with 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, a supply disruption may take place during the energy's transport, for infrastructural or political reasons. For example, a supplier country may enter a political conflict with a third party. In this case, the consuming country is more likely to be affected if the conflict occurs "on the path" of the energy in transit from the supplier to the consumer country. An ideal way of capturing this kind of risk would be to account for the exact path of each energy import flow into each consuming country, e.g., whether the energy is exported through vulnerable areas, whether alternative transport routes are available, and so on. However, to our knowledge such data are not available. Instead, our index

[4] The logic behind using net positive imports is as follows: 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 case the amount of energy provided by this supplier falls below the contracted level (e.g., if the supplier defaults on the contract), a consuming country may compensate its losses by cutting the respective exports. If this ratio exceeds 1, it implies that the considered country (say, country *a*) is a net reseller of energy. In this case we replace the value of this ratio by 1, thereby ignoring the chain effect an energy security problem in country *a* will have on its trade partners.

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

[6] In addition, it is known that the possible range of the Shannon–Wiener index values increases unboundedly with the number of market participants (see Frondel et al., 2008) which undermines the usefulness of the index for comparison across markets/countries.

accounts for potential supply disruptions during energy transport by factoring in the distance between the consuming and the supplying countries. The thinking here is that the distance measure can proxy for the number of transit countries along the energy's path to its destination. It is also reasonable to expect that the probability of energy transport failure increases with the length of transport. Therefore the distance can be viewed as a measure of the ease of energy delivery from the supplier.

Another factor likely to have a significant impact on the security of energy supply is the ease of switching between suppliers, in case of a supply disruption. For example, a gas supplied via a pipeline is considerably less substitutable in the short run than is Liquified Natural gas (LNG). In other words, the level of energy security will depend also on how fungible energy supplies are (which, in turn, is related to how the energy is transported and to the size of that energy's market). To capture this point, we incorporate a fungibility measure into our risk index, with higher values corresponding to less substitutable, and thus riskier, energy. More precisely, a value of 1 means the respective flow of energy is fungible (oil transported by tankers, LNG, coal; all of these commodities' markets are considered global in the literature).[7] A value of 2 indicates a less fungible flow of energy (energy types transported via pipeline). We use the fungibility measure for each supplier and each energy type.

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

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 among different energy types. We construct separate indexes for oil, gas and coal, a disaggregation that allows us to assess more accurately the specific risks for each energy type.[8]

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

$$REES_a^f = \left[\sum_i \left(\frac{NPI_{ai}^f}{NPI_a^f} \right)^2 F_{ia}^f r_i d_{ia} \right] * NID_a^f * SF_a^f,$$

where NPI_{ai}^f is the net positive imports of fuel *f* from country *i* to country *a*, NPI_a^f is the sum of the net positive imports over all suppliers of country *a*, F_{ia}^f is the fungibility of imports of fuel *f* from country *i* to country *a*, r_i is the political risk index of the supplier country, d_{ia} is a measure of a distance between countries *i* and *a*, NPI_a^f is the net import dependency of country *a* for fuel *f* and SF_a^f is a share of fuel *f* in country *a*.[9] For each energy type, this index estimates how much the security of external supply matters for the country considered. Note that the index decreases with import diversification and the proximity of the consuming and supplying countries, and increases with political risks. Hence, higher values of the index correspond to riskier supply.

Then, we measure the contribution of each Member State to the risk that the EU faces due to external energy supply. We argue that the risk faced by large EU countries has a greater impact on EU-wide energy security than does the risk faced by smaller EU members. To account for this, we approximate the degree of influence of each country on the EU risk using the 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:

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

where $Share_j^f$ is the share of country *j* in net EU imports of fuel *f*, $Share_j^f = (\sum_i NPI_j^f)/NPI_{EU}^f$ and NPI_{EU}^f measures the EU's net positive import of fuel *f*. As we will see, adjusting for country size might change the ranking of the EU Member States in terms of the external energy security.

The CERE index could offer a useful perspective in the discussion about a common energy policy. While the public debate has acknowledged that the Member States differ in their contributions to the EU's energy risk exposure, without quantifying these differences it is difficult to evaluate the policy options. The CERE index might explain the position of each Member State, or of groups of Member States, so it could help develop acceptable and mutually beneficial policy proposals. Further, changes in the CERE index over time could be used to evaluate the impact of these policies.

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

In the first group of papers, a proxy for the security of external supply serves only as a component of more complex indexes that account for both internal and external energy security. For example, De Jong et al. (2007) use security of external supply in their index of short-term responsiveness to an energy crisis, together with measures of security of internal supply and stability of the energy transport system. They proxy the security of external supply by multiplying the shares of different energy types in the total energy imports by risk associated with each energy type. To obtain a long-term index, they modify their approach by 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 accounts also 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, in which 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 in this first group of papers is that typically, they focus on more general issues 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 approximate the external supply risks with a measure of import dependency, they do not account for the diversity of energy supply or specific risks associated with each supplier, etc. Here, we concentrate on quantifying the security of external supply in the EU *per se* and therefore use more detailed

[7] See Blyth and Lefevre (2004).

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

[9] More explicitly, we have: (i) $NPI_{ai}^f = \{0, M_{ai}^f - X_{ai}^f\}$, where M_{ai}^f and X_{ai}^f are respectively the import and the export of energy *f* from country *i* to country *a*; (ii) $NPI_a^f = \sum_i NPI_{ai}^f$ and (iii) $NID_a^f = NPI_a^f / C_a^f$, where C_a^f is the total consumption of fuel *f* in country *a*.

measures. Further, most of the indexes in this group combine data on different energy types to estimate an average risk of an energy supply disruption. We argue that the EU countries' exposure to risk is not the same for different energy types. This implies that aggregation across energy types may lead to a loss of information about the risks associated with a specific type of energy. Therefore we propose separate indexes for three primary energy types.

The second group of studies in the literature deals specifically with measuring the security of external energy supply. Therefore, it captures more of the underlying complexity involved in the external supply risks than does the first group. These papers are more precise when addressing the diversification of energy imports. They also take into account many more specific factors that are related directly to the security of external energy supply. Our study belongs to this second group; we concentrate on the external security of energy supply, and our methodology follows a similar general strategy. However, there are a number of important differences between our work and the papers mentioned below.

Blyth and Lefevre (2004) use the Herfindahl–Hirschman index, focusing on energy supplier characteristics and availability of the fuel supply in the supplier country. They argue that the market for each country is determined by the potential exports of all potential foreign suppliers. 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 our supply diversity measure relies on the net positive imports as compared to the Blyth and Lefevre's potential exports. We believe that our measure provides a better account of risks, because the potential exports market in 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 provided by one single supplier that is small on the market of potential exports. In this case a risk associated with this supplier may be significant for the country's energy security, since switching to an alternative supplier may take some time and effort. However, this risk is not captured by the Blyth and Lefevre index. Another difference is that Blyth and Lefevre aggregate the index across 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 a country's total oil demand. These shares are adjusted for the political risk of the supplier. The index also incorporates the measure of market liquidity and a measure of the consuming country's self-sufficiency, measured as a ratio of country's oil reserves to the total oil demand. The basic difference between Gupta's approach and ours is that we create an index for different energy types, not only for oil. This allows us to assess the overall picture of the security of the EU's energy supply. Further, we include a measure of the ease of energy transport, a factor that may have a significant impact on energy security.

Frondel et al. (2008) also employ the Herfindahl–Hirschman approach, basing their index on the share of all suppliers in the domestic energy supply, and including a measure of political stability. However, they do not account for transport risks or the fungibility factor.

Neumann (2004, 2007) approach is probably the closest to ours. She suggests separate indexes for oil, gas and coal. She measures suppliers' diversity using the Shannon–Wiener index and then adjusts this for the indigenous production of the export country and the political stability of the import supplier country. However, there are differences between Neumann's approach and ours. First, we measure the diversification of the energy portfolio of each country using the Herfindahl–Hirschman index (rather than the Shannon–Wiener index in Neumann, 2004, 2007). As argued above, the former places more emphasis on the larger suppliers which, in our view, enables it to depict better the energy security risks. Second, we extend the set of risk measures captured by the index by including the proxies for transport risk and energy fungibility, which are 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 country's overall energy consumption. Finally, we offer a European perspective by providing a measure of the relative contribution of each EU Member State to the overall EU-wide risk.

In a discussion of our results further below we return to the comparisons between our indexes and others.

3. Data

We compute our indexes for each of three primary energy types: oil, gas and coal. The data on exports, imports, consumption and share in total energy consumption for each energy type all come from Eurostat, except for the data on LNG which originates from the International Energy Agency. More specifically, the indexes are based on 2006 data for the import volume, export volume, consumption level of oil and oil products, natural and LNG, and hard and brown coal, respectively.[10] We also use the identity of the supplier countries that provided each of the energy commodities to the EU Member States in 2006. We consider all EU Member States except for Cyprus, Luxembourg and Malta, for which complete data were not available. Since we want to measure the risk associated with external energy supply, we exclude imports from the EU Member States and Norway.[11] Table 1 presents the overview of the energy profile of the countries considered.

We base our measure of political risk on the index produced by the PRS Group. This political risk rating assigns countries values between 1 and 100, with higher numbers indicating lower risk. We compute our risk measure as

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

so that higher values are associated with a higher political risk and the variable r_i is between 0 and 1.[12]

To assign the fungibility index, we look at the ease of switching suppliers in case of disruption, for each energy type and source. As we discussed in the methodology section, coal and LNG are associated with a fungibility index of 1, while pipeline gas imports have a fungibility index of 2.[13] Since we do not have data on oil supplies by type of transport, we cannot distinguish pipeline oil imports from non-pipeline ones. We assume therefore that all oil supplies are highly fungible, and assign a value of 1 to the oil fungibility index. This assumption produces a conservative index

[10] We aggregate different energy products within the same energy type (e.g., brown and hard coal) by taking into account their caloric values. In doing so we rely on the conversion coefficients published by International Energy Agency (2006) for gas and oil and by BP (2007) for coal.

[11] Inclusion of the EU suppliers does not result in a substantially different security index. The results are available from the authors on request.

[12] In cases where the PRS Group has no data on geopolitical risk, we approximate these by the risk associated with a neighbouring country (or countries) of a comparable development stage (for example, the risk for Turkmenistan is approximated by the risk of Kazakhstan).

[13] If a supplier exports both LNG and natural gas to the consuming country, the fungibility of its exports is a weighted average between 1 and 2, with the weights representing the share of LNG/pipeline gas in the total export.

Table 1
Energy profile of EU Member States, 2006.

ENERGY	Oil and oil products					Gas					Hard and Brown coal				
	Cons.	Prod.	Net M	Net M, non-EU/NW	Share	Cons.	Prod.	Net M	Net M, non-EU/NW	Share	Cons.	Prod.	Net M	Net M, non-EU/NW	Share
COUNTRY	Kt				%	10^3*Terajoules				%	Kt				%
Austria	14,184	983	13,506	8299	42	347	73	304	234	22	4982	0	4258	293	9
Belgium	23,619	0	32,488	24,334	39	698	0	699	179	25	7472	0	7267	7562	9
Bulgaria	5082	28	5128	5157	25	135	17	121	121	14	30,034	25,678	3901	3726	33
Czech Rep.	9887	285	9559	8763	22	352	7	368	276	16	57,419	62,444	−5883	−260	45
Denmark	8090	16,839	−7955	−187	39	211	434	−218	0	22	9172	0	8578	7834	26
Estonia	1084	140	1229	730	20	38	0	38	38	15	14,098	14,095	86	86	56
Finland	10,728	0	11,342	9877	29	180	0	180	180	10	7612	0	6684	6095	13
France	90,844	1100	92,560	72,704	34	1843	49	1836	848	15	19,069	0	20,251	16,934	5
Germany	121,539	4981	118,856	74,916	36	3698	654	3091	1478	23	241,916	200,083	41,985	29,937	23
Greece	18,076	94	21,507	21,534	58	128	1	127	127	9	64,795	64,521	373	300	27
Hungary	7696	1380	5990	7337	28	533	111	438	352	41	12,032	9952	1939	1201	12
Ireland	8446	0	8690	308	55	187	19	168	0	26	2597	0	2597	1465	11
Italy	82,646	5769	79,791	87,760	45	3219	418	2935	2234	37	24,806	21	24,640	24,261	9
Latvia	1452	0	1687	914	32	65	0	71	71	30	130	0	160	160	2
Lithuania	2659	181	2733	8509	32	114	0	115	115	29	399	0	394	392	3
The Netherlands	30,969	2022	46,943	49,534	41	1596	2577	−983	0	43	12,683	0	13,025	22,067	10
Poland	23,664	796	23,495	21,589	25	576	181	414	286	13	146,930	155,251	−11,459	3170	62
Portugal	13,594	0	13,937	10,582	54	169	0	170	170	14	5467	0	5777	5622	13
Romania	10,801	4996	4822	6310	27	680	445	223	209	36	40,423	34,923	4071	3581	22
Slovakia	3623	31	3435	5816	20	250	8	242	265	29	8316	2201	5597	1637	23
Slovenia	2629	0	2602	−217	36	42	0	42	35	12	5232	4522	571	571	21
Spain	70,040	139	79,185	64,393	49	1443	3	1462	1373	22	39,498	18,447	23,704	23,365	13
Sweden	14,174	0	15,731	7656	29	41	0	41	0	2	3235	0	3050	2476	4
United Kingdom	80,400	76,578	7062	6046	36	3771	3350	444	135	35	67,283	18,079	50,013	48,319	18

Source: International Energy Agency and Eurostat.
Abbreviations: Cons.: consumption; Prod.: production; Net M: net import; Net M, non-EU/NW: Net imports excluding imports from EU and Norway; Share*:* share of respective energy type in total energy consumption.

value, potentially causing some underestimation of the oil security risk.

Finally, we construct a measure of the distance between the supplier and the consuming country as a proxy for the risks involved in energy transport. While the safety of energy delivery to the consuming country is likely to decrease with distance, we argue that this relationship is not linear. Asserting a linear relationship would put a disproportionately high weight on the suppliers at the greatest distances. Rather, above a certain threshold the effect of any additional distance should level off, as long as any related political risks are accounted for. So, instead of using simply the geographical distance between the countries, we create a categorical distance variable. We classify all country pairs into three 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

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

The idea behind these thresholds is as follows. The European countries would not have much difficulty supplying energy to each other, and roughly these all form the first group. The index (weakly) increases with the distance between the supplying and consuming countries, but more and more distance is required for a country pair to fall into the next category, reflecting the non-linearity mentioned above.

4. Results

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

Table 2
REES index[a].

Country		Oil	Gas	Coal
Austria	AT	1.4	16.7	0.0
Belgium	BE	4.7	0.6	1.3
Bulgaria	BG	10.4	17.5	1.2
Czech Republic	CZ	4.9	12.4	0.0
Denmark	DK	0.1	0.0	5.0
Estonia	EE	1.9	10.3	0.3
Finland	FI	4.8	7.1	1.3
France	FR	1.7	0.9	0.5
Germany	DE	2.4	5.5	0.6
Greece	EL	8.4	8.0	0.1
Hungary	HU	18.3	33.6	0.3
Ireland	IE	0.0	0.0	4.7
Italy	IT	3.3	7.5	1.8
Latvia	LV	2.1	21.0	0.6
Lithuania	LT	10.2	20.1	1.0
The Netherlands	NL	4.3	0.0	2.0
Poland	PL	6.1	3.9	0.6
Portugal	PT	3.5	6.6	6.4
Romania	RO	5.8	15.2	0.6
Slovakia	SK	10.8	39.4	0.9
Slovenia	SI	0.0	5.4	4.1
Spain	ES	3.4	3.3	1.5
Sweden	SE	1.4	0.0	0.5
United Kingdom	UK	0.7	0.1	2.8
Average		4.4	9.8	1.6
Standard deviation		4.4	10.6	1.7

[a] Higher values correspond to higher risk.

4.1. Gas indexes

Different EU Member States face different situations in the gas market. Some have substantial indigenous production, some get most of their imports from EU suppliers or Norway, and some

Table 3
CERE index[a].

Country		Oil (%)	Gas (%)	Coal (%)
Austria	AT	1	5	0
Belgium	BE	6	0	2
Bulgaria	BG	4	3	1
Czech Republic	CZ	2	5	0
Denmark	DK	0	0	10
Estonia	EE	0	1	0
Finland	FI	2	2	2
France	FR	6	1	2
Germany	DE	9	11	4
Greece	EL	9	1	0
Hungary	HU	7	16	0
Ireland	IE	0	0	2
Italy	IT	14	23	11
Latvia	LV	0	2	0
Lithuania	LT	4	3	0
The Netherlands	NL	12	0	11
Poland	PL	6	1	1
Portugal	PT	2	2	9
Romania	RO	2	4	1
Slovakia	SK	3	14	0
Slovenia	SI	0	0	1
Spain	ES	10	6	9
Sweden	SE	1	0	0
United Kingdom	UK	1	0	34
Total, 24 EU Members		100	100	100

[a] Higher values correspond to higher risk.

purchase their gas only from outside the EU/Norway area. Moreover, the shares of natural gas in individual countries' energy portfolios vary, with some relying more on gas while others on oil, coal or other fuel types (see Table 1). This difference is reflected in the REES index for gas, according to which the EU countries can be subdivided into three groups.

The group with a relatively high index includes Austria, Bulgaria, Czech Republic, Hungary, Latvia, Lithuania, Romania and Slovak Republic. These countries do not produce any gas and usually import most of their gas from non-EU/Norway suppliers, so both the distance and political risk factors are contributing here to higher index values. Further, the share of gas in these countries' total energy consumption is relatively high and on top of that, some do not have a well-diversified external gas supply.

A second group, with medium-level gas supply risk, includes Estonia, Finland, Germany, Greece, Italy, Ireland, Poland, Portugal, Slovenia and Spain. These countries have better diversified gas imports and/or less reliance on gas in their aggregate energy portfolios. The remaining countries have lower indexes, due either to their indigenous production (the Netherlands or the UK) or to their mostly European import origins.

While LNG is commonly believed to be less risky than the pipeline gas due to both lower transport risks and possibility to substitute among suppliers, LNG imports are not necessarily associated with a very low risk index. In our sample there are seven EU Member States that have some LNG consumption: Belgium, France, the UK, Greece, Italy, Portugal and Spain. None of these belongs to the highest risk group. However, only the first three countries have low risk indexes, while the last four show medium-level gas supply risk. The elevation of the risk in the latter group may be due to insufficient diversification LNG portfolio. Further, an overall security of gas supply is determined by both LNG and pipeline gas imports. All seven countries consume some pipeline gas, so higher index values in the latter group may also result from risk associated with their pipeline gas imports.

The ranking based on CERE index moves Germany, Italy and Spain up the scale, placing them among the biggest contributors to EU-level risk exposure. The reason is that they have high levels of gas consumption relative to the rest of the EU.[14] But smaller countries like Hungary and the Slovak Republic also are big contributors to EU-level risk, because they rely almost entirely on non-EU suppliers for gas imports.

4.2. Oil indexes

The supply of oil to EU countries bears less risk than does the gas supply and the differences in index values among the countries are smaller. The average value of the REES index is 9.79 for gas but 4.4 for oil, and the standard deviation decreases from 10.63 (gas) to 4.4 (oil). One possible reason for this difference in REES values is that we cannot account for oil transported by pipeline; all oil imports are then considered highly fungible, which lowers the oil index. Moreover, since the oil market is more globalized than the gas market, the variation in risk levels among the EU Member States should be smaller for oil consumption.

As Table 2 suggests, all EU members can be subdivided roughly into three groups. Bulgaria, Greece, Hungary, Lithuania and the Slovak Republic have the highest risk exposure. None of these countries has a well-diversified oil supply. For example, Hungary and Slovak Republic purchase most of their crude oil from a single, relatively risky supplier, Russia. Greece buys its oil mostly from Russia, Iran and Saudi Arabia and its economy is heavily dependent on oil which increases the risk index.

The medium-level risk group includes Belgium, Czech Republic, Finland, Germany, Italy, Latvia, the Netherlands, Poland, Portugal, Romania, and Spain. Some countries here (e.g., Belgium or the Netherlands) have slightly better diversified oil imports, still coming from relatively risky producers. Others (e.g., Czech Republic and Poland) purchase most of their imports from one or two risky suppliers, but their economies do not rely heavily on oil as the primary energy type.

The remaining countries have a relatively low external oil supply risk as measured by the REES index, thanks to more diversification and, in cases like Denmark or the UK, to domestic oil production.

The top contributors to overall EU risk exposure according to the CERE oil index are the major oil importers (like Spain or Italy), some of which also show substantial shares of oil in their energy portfolios.

4.3. Coal indexes

The security of the coal supply is not commonly considered a serious problem, because the world coal market is well diversified. Further, many Member States have indigenous coal production, and coal is easy to handle and store (IEA, 2005).[15] The average coal REES index is much lower than both the gas and oil indexes, and the difference in risk levels among the EU Member States measured as a standard deviation of the index, is smaller. Denmark, Ireland, Portugal and Slovenia have the highest REES indexes due to a poor diversification of suppliers, and no indigenous production. However, when controlling for the relative

[14] 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 that are responsible for larger shares of EU net imports are also bigger contributors to the overall EU external energy supply risk.

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

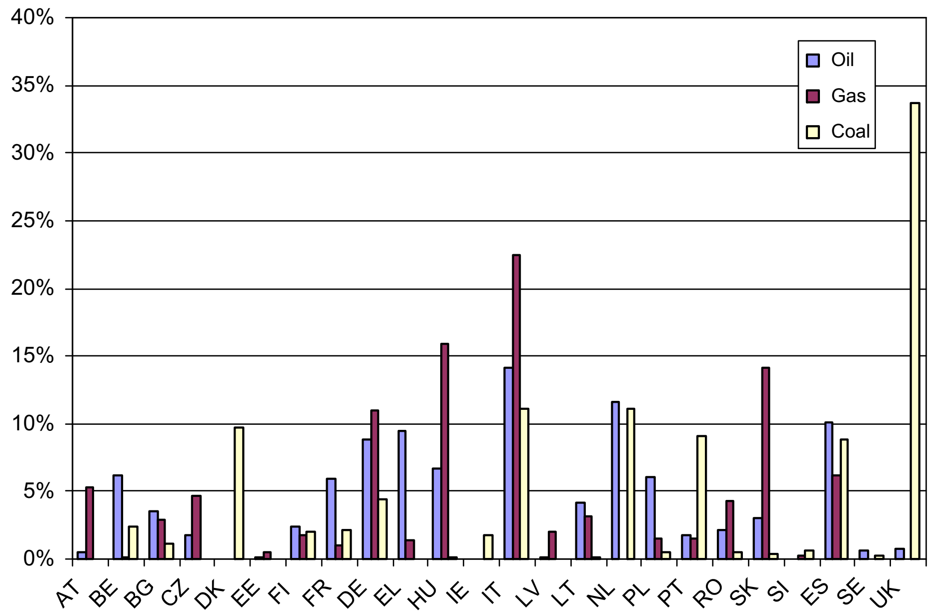

Fig. 1. Contribution to EU Risk Exposure (CERE) index.

share in total EU imports through the CERE index, the UK, the Netherlands and Italy move to the top of ranking for coal.

To sum up, according to both the REES and CERE indexes, individual EU Member States have different risk rankings depending on the energy type in question. The range of REES indexes also differs across energy types. The CERE index shows a wide variation in the relative contribution of EU Member States to the overall EU risk—for gas, oil and coal. This is easy to see in Fig. 1, which plots the CERE index for different energies. That confirms our hypothesis that EU Member States' exposure to energy supply risk varies across energy types. Considering the contrasts in the countries' energy supply situations, the Member States' preferences regarding an EU common energy policy are likely to be different too. Consequently, the understanding of EU energy security profile is important for accessing the feasibility and potency of particular policy tools. We return to this argument further below.

4.4. Comparison among indexes

Table 4 summarizes three other energy security indexes: Röller et al. (2007), De Jong et al. (2007) and Neumann (2007). Recall that the Neumann index is the only one that is directly comparable to ours. The other two do not concentrate only on the external security of supply; they consider also other security aspects and provide aggregate measures pooling energy types.

It is worth noting that these first two indexes are not consistent with each other. Poland, for example, is classified as a relatively secure energy consumer by De Jong et al. (2007), while it has a rather risky position according to the Röller et al. (2007) index. The reverse is true for Portugal. Our classification shows that Poland is exposed to more risks in the oil market (REES = 6.1 for Poland vs. 3.5 for Portugal), while Portugal is more vulnerable in the gas market (REES = 3.9 for Poland and 6.6 for Portugal). Thus aggregation across energy types can lead to inconsistent results because that it implicitly assumes substitutability across energies and does not account for energy-specific risks. However, in the short-term substituting among different energy types might be problematic and/or very costly, at least for end-users, such as the transportation industry.[16] Therefore, an aggregate energy security index may be misleading, at least for a discussion on the short-term response to risk.

Table 4
Other energy security indexes[a].

		De Jong et al.[b]	Röller et al.[c]	Neuman[d]		
Country				Gas	Coal	Oil
Austria	AT	57	5.1			
Belgium	BE	57	1.1			
Bulgaria	BG	59				
Czech Republic	CZ	64	4.0			
Denmark	DK	82	3.3			
Estonia	EE	55	3.2			
Finland	FI	53	2.0	1.3	1.2	1.6
France	FR	64	2.4			
Germany	DE	63	2.6	1.3	1.3	1.4
Greece	EL	44	3.3			
Hungary	HU	55	2.1			
Ireland	IE	75	0.7			
Italy	IT	50	2.6	1.3	1.0	1.3
Latvia	LV	40	1.7			
Lithuania	LT	45	2.1			
The Netherlands	NL	69	2.1			
Poland	PL	60	2.1	3.3	0.8	1.5
Portugal	PT	47	2.7			
Romania	RO	70				
Slovakia	SK	51	1.8			
Slovenia	SI	52	1.4			
Spain	ES	51	3.2	1.1	1.2	1.5
Sweden	SE	70	2.3			
United Kingdom	UK	80	2.4	1.7	1.1	3.3

[a] Higher values correspond to higher risk.
[b] Source : De Jong et al. (2007), Supply–Demand Energy Security index.
[c] Source : Röller et al. (2007), Security of Supply index.
[d] Source : Neumann (2007), Security Supply index.

[16] There could be some substitutability in the electricity sector, e.g. through switching among power plants based on alternative energy types. However, this substitutability is possible only if there is enough excess generation capacity. According to RWE (2007) capacity constraints are close to becoming binding in Europe. Hence a substitutability strategy might be possible in some EU Member States, but not for all.

The Neumann index shows results more consistent with ours, but our ranking of countries is different. For example, the Neumann index ranks Finland and Germany equally for gas supply risk, but our index suggests that Finland is more vulnerable than Germany to gas supply risk. The same occurs with the case of the Netherlands and Spain in the oil market: the two countries have the same Neumann index, while our index suggests that Spain's oil supply is more secure. These differences may be explained by our accounting for transport risk, fuel fungibility and the importance of each fuel in a country's total energy portfolio. Finally, we should point out that according to the Neumann index, coal is the most risky energy type across Europe.[17] Our index assigns lower risk to the coal supply (consistent with the common belief that coal is less risky than gas or oil). This observation suggests that our index might be better suited to reflect the energy supply risks.

5. Conclusions and policy implications

We propose a set of indexes to evaluate the energy security risks facing the EU, with a focus on energy supplied by external producers. These indexes take into account the energy consumption profile of individual consuming countries, the risks associated with supplying countries, the transport of energy, the energy fungibility, and the relative impact of different EU countries on the aggregate energy risk in the EU. We calculate the indexes for the EU Member States and for three primary energy types: oil, gas and coal. We find that individual countries' levels of risk exposure differ both across energy types and among EU Member States. These results may have implications for the design and implementation of an EU common energy policy.

The varying risk profiles across energies imply that a sectoral approach (i.e., by energy type) provides a more reliable basis for quantifying short-term external energy risks. Since short-term substitution among different types of energy is problematic and/or very costly, an aggregate risk index may be too imprecise to gauge the likelihood and the severity of damage caused by a supply disruption in a specific energy market. Moreover, security of supply may require specific policy tools for each energy type. Therefore, the design of a common energy policy, or at least its provisions for a short-term response to random supply disruptions, also would benefit from taking a sectoral approach. The EU is doing so in part already, for example by setting separate storage requirements for gas and oil.

The uneven distribution of supply risk among individual 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, should the EU decide to implement a common policy that allows Member States to share the energy supply risks,[18] the bigger contributors to EU-level risk would benefit more-perhaps at the cost of others, whose incentives to stick to the common agreement may be undermined. A well-devised common energy policy should then include a way to compensate the "losers", perhaps through policy measures unrelated to energy.

Our methodology could be extended to integrate the possibility of correlated energy shocks, such as a correlation between different suppliers (e.g., due to 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 reliance on the same pipeline). Taking these effects into account would, however, require an extensive data collection.

Another interesting exercise would be to track the evolution of our indexes under different energy market scenarios. A number of factors are likely to shape developments in energy security. For example, the domestic consumption of many EU countries and of supplying countries is expected to rise, which may intensify competition for energy and change the availability and prices of the supply (Stern, 2006). Competition for energy may become more global, as it already tends to be for LNG gas among the EU, North America and the Pacific region. Moreover, indigenous gas production of the EU Member States is anticipated to stagnate. Meanwhile, new energy sources that gain ground in the market also could have implications for the wider energy security picture.

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

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