

Energy Vulnerability and EU-Russia Energy Relations

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Abstract

The concept of energy vulnerability is reviewed and discussed with a focus on Russia's foreign energy relations, in particular those with European countries. A definition and a conceptual framework for quantifying energy vulnerability are proposed in the context of a review of recent research on energy vulnerability indices. In particular it is suggested that source country diversification should be reflected using the expected shortfall measure used in financial economics, rather than the Herfindahl-Hirschman or Shannon-Wiener indices, and that the former should then enter a calibrated function in order to yield expected economic loss. The issues of asymmetric failure probabilities and accidental versus intentional supply disruptions are then discussed with examples of recent Russian actions. Energy vulnerability measurement and modelling should ultimately inform policy. In particular, member states should legislate that no energy infrastructure project by one or more member states may increase the energy vulnerability of another member state. Additionally, European environmental policies, notably the EU ETS, should be amended so as to account for induced changes in energy vulnerability. Finally, member states should increase the level of transparency and disclosure with respect to gas import statistics and gas supply contracts.

Keywords

Energy policy; energy security; energy vulnerability; EU; EU-Russia relations; nationalism; natural gas; Russia.

EUROPE DEPENDS TO AN IMPORTANT DEGREE ON RUSSIAN ENERGY SUPPLIES. HOWEVER, broader EU-Russia relations are difficult, essentially because of Russia's current political orientation. Three negative forces interact with each other within what has been dubbed the vertical of power: the apparent willingness of Russia's current elite to stay in power for the foreseeable future, various blends of nationalistic worldviews and corresponding geopolitical ambitions, and substantial high-level corruption which risks skewing decision-making both inside and outside Russia.

Russia ranks 147th out of 180 surveyed countries in Transparency International's 2008 corruption perception index. This puts Russia on a par with Bangladesh, Kenya and Syria, and is a worse result than what could be expected given Russia's current GDP per capita. But another phenomenon is even more important, that of cross-border bribery, in particular bribery of foreign government officials and of foreign politicians. In a groundbreaking study, (Transparency International 2008), researchers surveyed 2742 companies in 26 countries and asked them how often they believed firms *from other countries* (chosen from a list of 22 countries that partly overlapped with the list of surveyed countries) resorted to bribery of government officials and politicians. Russia ranked highest in both

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categories by a substantial margin, with around 50% of respondents estimating that Russian companies *frequently* bribe *both* foreign officials and foreign high-ranking politicians. Bribery is a potential problem, because it means that Russia may be able to buy the acquiescence of European politicians for energy projects or transactions that are not in the public interest.

Shevtsova (2008) argues that Russia's elites have used nationalism as part of a calculated subversion of the domestic political discourse. This subversion, she argues, was designed to deflect criticism of the incumbent rulers by shifting attention towards "external enemies" (or domestic forces said to be associated with them) that in reality pose no threat to Russian national security. Other measures designed to skew the political process in favour of the incumbents have included preventing the registration of opposition candidates (see Kramer 2007; Harding 2008), using state control of leading television channels to grant disproportionately high and disproportionately positive coverage to the incumbents, and the use of implausible ballot counts (see OSCE 2004).

However nationalism cannot be dismissed as merely one of many domestic political tactics. Umland (2009b) argues that extreme nationalist thinking is increasingly penetrating the highest levels of Russian political and cultural life, with potentially worrying consequences for the future. One manifestation of this trend is the rise in prominence of the extremist ideologue Alexander Dugin (see Laruelle 2006).

Another manifestation of Russian nationalism, economic nationalism, is also in evidence and has implications for the energy security of Europe. Russian economic nationalism, notably the use of varying degrees of coercion on foreign countries, on foreign investors in the country, or on domestic private investors in order to gain (perceived) national strategic economic advantages, has been documented by several authors (Christie 2007; Kalyuzhnova and Nygaard 2008; Larsson and Hedenskog 2007; Liuhto 2008).

In terms of foreign policy, Russia's recent actions resemble a return to the grand chessboard of global competitive geopolitics of bygone eras, with energy resources in a key (but not exclusive) role. For example, Russia's ambiguous relations with Iran and its recent interventions in Central Asia (notably in Kyrgyzstan), seem at least in part designed to create leverage against the United States. The Medvedev Doctrine (see Friedman 2008) also clearly states that Russia has "privileged interests" in the affairs of its close neighbours, and that Russia reserves the right to protect the "dignity" of its citizens abroad, and to defend its business interests abroad. Finally, Russia's carefully prepared invasion (see House of Lords 2009: 6; Felgenhauer 2008) of Georgia in August 2008 and its de-facto annexation of territories south of the Caucasus mountain range point to an expansionist agenda (i.e. control of the South Caucasus region), as well as to a readiness to use military force. Further military action can therefore not be excluded, in the South Caucasus or elsewhere (see Umland 2009a; *Georgian Times* 2009).

In terms of external energy policy, it is remarkable that Gazprom, which has the monopoly right to export gas out of the Russian Federation, the country that has the world's largest gas reserves, is so keen to develop ties with virtually every other supplier of gas to Europe. Indeed, Gazprom has expressed interest in strategic partnering with Algeria, Libya, Nigeria, Iran, Qatar, Azerbaijan and of course the Central Asian states. Simultaneously, Russia's stagnant domestic energy production levels is well-documented and a vital element in the analysis of the overall picture. Unfortunately, the very real issue of potential supply shortages has clouded the energy security analysis. The insistence of certain analysts to zoom in on the seemingly most important energy security issue and to label it as "the core issue" has prevented a synthesis. In fact, the combination of scarcity of resources and high

and rigid market penetration (i.e. through control of the cross-border transportation channels) is the optimal way of obtaining pricing power over consumer countries.

In this article it is taken as given that it is rational for Europeans to understand Russia as an ambitious geopolitical player whose ruling elites are motivated by a combination of nationalism, domestic political survival and national economic gain. Much of the literature on energy vulnerability implicitly neglects the distinction between accidental and deliberate energy supply disruptions, while much of the literature that does deal with deliberate disruptions focuses on physical attacks on energy infrastructure on the part of non-state (e.g. terrorist) actors. In this paper I propose a number of possible extensions to the analysis of energy vulnerability of energy importing nations (e.g. EU countries) with a focus on the threats posed by a large supplier who resorts to deliberate and well-calculated acts of coercion.

Definitions and theoretical framework

The vulnerability of a system in a general sense can be defined as the degree to which that system is unable to cope with selected adverse events (Gnansounou 2008). However, energy vulnerability lacks a unified definition. Gupta (2007) for instance, while offering a valuable review of the literature on oil vulnerability indicators, does not offer an explicit definition of oil vulnerability, but nevertheless argues for a specific methodology to calculate oil vulnerability indicators. Percebois (2007) also refrains from offering a definition, and yet suggests a list of variables that should be considered as candidates for calculating an index. Gnansounou (2008) on the other hand offers a useful discussion on the difficulties of arriving at a satisfactory definition, given the large number of adverse events one should in principle consider, as well as difficulties in estimating the probability of their occurrence.

The difficulty many authors have with respect to definitions lies, as Gnansounou (2008) explains, in the multiplicity and heterogeneity of adverse events that may be of interest to policy-makers. Additionally, different types of adverse events are emphasised by policy-makers and academics depending on current risk perceptions, often based on recent events. Also, there is often a lack of clarity about the type of time horizon one is considering. It is therefore necessary to explicitly state the type of event one is concerned about in order to guide the analysis. I start from the assumption that we are analysing the energy component of national security and national economic security from the point of view of a State that is dependent on imports for at least a part of its energy supplies.

A country's national security strategy typically reflects the current government's values and capabilities, as well as the international and domestic security situations. France and the United Kingdom provide good examples of this. Both countries revised their national security strategies recently. In the UK case, the National Security Strategy (United Kingdom Cabinet Office 2008: paragraph 1.9) states that the overarching national security objective is "protecting the United Kingdom and its interests, enabling its people to go about their daily lives freely and with confidence, in a more secure, stable, just and prosperous world." The French strategy (French Ministry of Defence 2008) states that the aim is "to ward off the risks and threats detrimental to the life of the nation", and goes on to define threats as coming from "States or transnational non-State groups" and risks as arising from "natural or health disasters". The document clarifies that adverse events may come "as a result of hostile intentions or of accidental breakdowns".

This leads us to propose a general normative definition of national security for the purposes of the current research effort. National security policy should aim at reducing the probability, severity and potential impact of exogenous events that are detrimental to the

welfare of the nation's population and/or to the integrity of the State, its territory and its institutions. A definition of national vulnerability naturally flows from that definition: the extent to which the welfare of the nation's population and/or the integrity of the State, its territory and its institutions may be detrimentally affected by exogenous events. Narrowing down to the case of energy, a general normative definition of energy vulnerability is proposed, namely: the extent to which adverse exogenous events with respect to a country's energy supply system may detrimentally affect the welfare of the country's population and/or the integrity of the State, its territory or its institutions.

Naturally, this definition is still quite general; therefore it is necessary to specify some of the components further. Energy supply system refers to the supply chains made up of domestic *and foreign* production, transportation and distribution assets that enable energy products to be delivered to their final users in the country. This includes foreign oil and gas fields and the corresponding extraction facilities, as well as other assets used for production or transformation (e.g. nuclear, hydroelectric or thermal power plants, refineries), the transportation infrastructure (e.g. terminals, pipelines, pumping stations, tankers, power lines, interconnectors) and the domestic distribution assets (e.g. local gas and electricity grids). Exogenous events refers to events that are essentially exogenous to the country's executive (or other) powers, usually because they are the result of deliberate actions on the part of foreign State and/or non-State actors (including private corporations) that the country cannot control, or because they are the result of uncontrollable natural events. Welfare of the population refers to outcomes in terms of health, the ability to exercise basic rights, and socio-economic welfare. Finally, integrity of the State, its territory and its institutions, refers to the extent to which the State is able to continue to fulfil its primary functions, notably territorial defence, as well as the extent to which the elected government of the day may continue to rule according to its mandate and to the constitutional order.

Now that the general definitions have been established, it is necessary to formalise the concepts of vulnerability, events, and effects, in such a way as to make them usable for analysis. Haimes (2006) uses concepts from control theory and defines the vulnerability of a system as being the states of the system that are such that they can be exploited in order to damage it. In control theory, a system is modelled as sets of state variables, control (or input) variables and output variables which are related through a set of dynamic equations. Generally speaking, states fluctuate within certain value ranges and the satisfactory operation of a system requires that the control values are set appropriately depending on the desired outputs and the current states of the system. A simple example may be given in the case of gas supplies. Suppose country A imports all of its natural gas needs through a single pipeline from country B. For security reasons it installs a storage facility on its territory. As the imported gas comes in – the volume is a control variable of the overall system, but it is controlled by country B – country A chooses how much gas to store or withdraw from its storage site, and it distributes the net amount to the final users domestically. Country A's control variable is the volume of gas it chooses to store or withdraw from storage. The state variables are the amount of gas held in storage and the amount of gas demanded by domestic end-users. The output variable is economic welfare. To simplify, let's assume that economic welfare is constant provided gas demand is met, and let's assume that demand for gas is constant. However economic welfare falls (more) in case of a (larger) gas delivery shortfall.

Now country A's energy vulnerability should be assessed by the values of its state variables. If the amount of stored gas is very low, even a brief supply cut would translate into a shortfall in deliveries to consumers and to a loss in economic welfare. The less gas is stored, the more vulnerable country A is to a supply shortfall of a fixed volume and duration. Also, higher gas demand to sustain a given level of economic welfare implies

higher vulnerability in the face of an identical supply shortfall. To take a recent example, Bulgaria was hit particularly hard by the cut in Russian gas supplies of January 2009 because of a low stockholding of gas and higher demand due to cold weather. On the other hand, Austria was essentially unaffected given a more substantial stockholding and being able to rely on other countries for supplies as well.

This discussion illustrates what control and state variables would be in a simplified example. Let us now formalise this framework. An event is formalised as an information set including exogenously imposed shifts in one or more control variables, the type of cause (human, natural or technical failure), the identity of the actor (if applicable), and the duration of the shifts. Examples of what such a formalisation may resemble are given in Table 1. The first example assumes a terrorist attack which completely disables the connector between a natural gas storage facility and the rest of the gas transportation network. The change in the value of the control variable (how much the operator may choose to put into or withdraw from the site) is -100% , i.e. the site may not be used at all in either direction. It is assumed that it takes 10 days to repair the infrastructure. The second example assumes that a natural cause (e.g. an earthquake) destroys several consecutive pylons of a cross-border power line, forcing a complete interruption of electricity trade through that line until it is repaired, which is assumed to take 30 days. The third example assumes that a foreign supplier of natural gas reduces the supply flow by 50% for a period of 14 days. The fourth example assumes that OPEC decides to reduce total oil supplies to the world market by 2 million barrels per day for the next 45 days. The last example assumes that a cross-border natural gas pipeline suffers a technical failure which requires a complete shut-down until it is repaired and usable again 10 days later.

Table 1: Example of a formalisation of hypothetical events

Control	Value change	Type of cause	Identity	Duration (days)
Gas storage site connector	-100%	human	terrorist	10
Cross-border power line	-100%	natural	-	30
Cross-border gas pipeline	-50%	human	supplier	14
OPEC oil supply	-2 mb/d	human	supplier	45
Cross-border gas pipeline	-100%	technical failure	-	10

The output of the system is formalised as one or more variables that have higher values for more desirable outcomes from the point of view of national security. Vulnerability should be measured based on the values of state variables, such that its value is larger for larger losses to the output function when a comparison is made either between the losses of two different systems exposed to the same event, or between the losses a given system would incur if exposed to one event or to another event.

The analysis of the probability of events occurring should be made separately however. Then, an overall assessment of the risks to the output variable(s) can be made based on scenarios that simulate the occurrence of events based on assumed probabilities. Different scenarios should then be defined, as one may not be able to confidently assign specific probabilities (or probability distributions) to single or combinations of events. The analysis is then completed by defining *risk* as the expected loss to the output variable(s) given a scenario of events and their probabilities of occurrence. This definition is broader than the one proposed in Haines (2006) which focuses only on events caused by deliberate human action. Also, the flexibility offered by the proposed framework enables the assessment of

the loss due to a specific event (by setting its probability of occurrence as 1), or of any combination of events.

Review of selected energy vulnerability indices

In Table 2 we review the main ingredients used by Gupta (2008) and Gnansounou (2008) for the computation of their energy vulnerability indices. As can be seen, there are certain differences notably due to different choices in terms of coverage. Gnansounou (2008) covers more energy products as well as more areas, while Gupta (2008) focuses strictly on oil and refined products at a national level. Both use what we choose to refer to here as the goalposts method in order to scale some of the chosen partial indicators so as to yield unit-less sub-indices that are strictly between 0 and 1.

Table 2: Methodological choices in Gnansounou (2008) and Gupta (2008)

Methodological choices	Gnansounou	Gupta
Coverage		
Fossil fuels covered	Oil and natural gas	Oil
Sub-sectors	Transport; electricity supply	-
Other dimensions	Greenhouse gas emissions	-
Variables		
<i>Fossil fuel supply</i>		
Own reserves	-	Reserves / consumption
Import dependence	Net (oil and gas)	Net (oil and refined products)
Diversification of suppliers	Weighted HHI	Weighted HHI
Political risk of suppliers	Author ratings by world region	Country risk ratings (ICRG)
Market liquidity	-	World imports / own imports
<i>Fossil fuel demand</i>		
Income per capita	-	GDP per capita
Energy intensity	TPES / GDP	Oil TPES / GDP (toe / USD)
Energy bill	-	Value of oil imports / GDP (%)
Energy product mix	Implicit to computation	Oil supply / TPES (%)
<i>Electricity supply</i>		
Import dependence	Net imports	-
Public disapproval measure	Threshold indicator	-
Primary energy diversity	Modified Shannon-Wiener Index	-
CO2 emissions	CO2 emissions / TPES	-
Diversity in transport fuels	Modified Shannon-Wiener Index	-
Computational choices		
Scaling of partial indicators	Goalposts method, other	Goalposts method
Computation of final index	Root mean square	Principal Component Analysis

The goalposts method is the method used by the United Nations Development Programme (UNDP) to compute the component sub-indices of its Human Development Index. For a given quantitative indicator X and a group of countries $j = (1, \dots, N)$, the corresponding scaled indicator is computed as shown in equation (1).

$$(1) \quad I_p = \frac{X_p - \min_j(X_j)}{\max_j(X_j) - \min_j(X_j)}$$

In order to account for diversity (of suppliers, of fuels), Gupta (2008) uses a weighted variant of the Herfindahl-Hirschman Index (HHI), while Gnansounou (2008) uses both a weighted HHI and a variant of the Shannon-Wiener Index. I label the former (in its classical form without weights) as HHI and the latter in the form used in Gnansounou (2008) as GSW. In each case the indices are computed based on the shares of each individual (supplier, fuel) with respect to the total as defined in (2). The formulae for the indices are given in equations (3) and (4).

$$(2) \quad S_j = \frac{X_j}{\sum_j X_j}$$

$$(3) \quad HHI = \sum_j S_j^2$$

$$(4) \quad GSW = 1 + \frac{\sum_j S_j \ln(S_j)}{\ln\left(\sum_j X_j\right)}$$

The values of these indices are shown in Table 3 for the case of two suppliers A and B with respective shares ranging from 10% to 90%.

Table 3: Example of HHI and modified Shannon-Wiener Indices

S(A)	S(B)	HHI	GSW
0.1	0.9	0.82	0.53
0.2	0.8	0.68	0.28
0.3	0.7	0.58	0.12
0.4	0.6	0.52	0.03
0.5	0.5	0.50	0.00
0.6	0.4	0.52	0.03
0.7	0.3	0.58	0.12
0.8	0.2	0.68	0.28
0.9	0.1	0.82	0.53

Both HHI and GSW are minimised if suppliers have equal shares, in other words if diversification is maximised given a fixed number of suppliers. It is easy to show that this

result holds for 3 or more suppliers. From the point of view of diversification both indicators therefore seem adequate and there is no prima facie case for favouring one over the other, unless one specifies an additional or different target function beyond the degree of diversification alone. This is what we will do now.

Connecting vulnerability measurement with potential economic loss

What matters for security of supply is to find the parameter values that are such as to minimise losses due to adverse events. But how that problem is precisely defined has consequences on the best choice for an indicator. In addition, adverse events will generally be associated with different probabilities of occurrence, and possibly with probabilities that vary through time. We start with the simplest case: two suppliers with equal but independent failure probabilities.

We note the shares of suppliers A and B as S_A and S_B , and assume that each supplier supplies its full share with probability $1-p$ and supplies nothing with probability p , and furthermore that the probabilities of non-delivery are independent. In that case, the expected level for the share of missing supplies, ms , is as given in (5).

$$(5) \quad E(ms) = p(1-p)S_A + p(1-p)S_B + p^2(S_A + S_B) = p(1-p) + p^2 = p$$

It is furthermore easy to show that this result holds for any number of suppliers. However the problem with this measure is that the values of the supplier shares have no impact. While the failure of neither supplier or of both suppliers have unambiguous outcomes (all or nothing is supplied), one would want to account for the fact that the failure of the larger of the two suppliers is more damaging than the failure of the smaller supplier.

One possibility is to use a non-linear loss function, such that larger losses are modelled as over-proportionately damaging. This may be done for instance with a quadratic loss function, leading to an expression for expected quadratic loss (EQL) as shown in (6).

$$(6) \quad EQL = p(1-p)S_A^2 + p(1-p)S_B^2 + p^2(S_A + S_B)^2 = p^2 + p(1-p)(S_A^2 + S_B^2)$$

Linking expected quadratic loss with the Herfindahl-Hirschman index yields (7).

$$(7) \quad EQL = p^2 + p(1-p)(S_A^2 + S_B^2) = p^2 + p(1-p)HHI$$

In other terms, HHI is the indicator of diversification which is consistent with a quadratic loss function. However there is a conceptual problem. There is no theoretical justification for any specific type of loss function, let alone a quadratic one. When comparing two events, the second representing a shortfall twice as large as the first, why should the incurred loss be exactly four times larger?

The approach preferred in this paper is to avoid arbitrary non-linearities in the loss function. Instead, it should be assumed that the sub-indicator we wish to define represents an expected lost value. In a potential second stage, that value may be chained with the

extent to which the national economy is dependent on the energy product being considered, possibly introducing (but only then) some form of systemic non-linear effect, e.g. to account for the impossibility to substitute towards other energy products if the missing level of supplies is too large and/or occurs too quickly.

Sticking to a linear transformation, we still wish to account for diversification. Our choice here is to use a comparatively recent measure of risk from the financial economics literature, namely the measure of expected shortfall, (see Acerbi and Tasche 2002).

With expected shortfall the idea is to focus not on the overall expected loss or gain, but on the expected loss of the worst cases. Such a measure is consistent with experimental data which shows that human agents do not seek to minimise overall expected loss, but instead also factor in a kind of "unacceptable loss". In what follows I choose to focus on the set of cases from the worst possible case (all suppliers fail) up to but excluding the cases of the least important supplier failing and of no supplier failing.

For two suppliers A and B with shares as shown in (8), one finds the expression for the expected shortfall, $es(2)$, as shown in (9).

$$(8) \quad 1 > S_A \geq S_B > 0$$

$$(9) \quad es(2) = p^2 + p(1-p)S_A = p^2 + p(1-p)(1-S_B) = p - p(1-p)S_B$$

The confidence level associated with (9) is equal to the probability that one of the cases considered occurs. That probability is given in (10).

$$(10) \quad P(es(2)) = p^2 + p(1-p) = p$$

For three suppliers as defined in (11) the expected shortfall, $es(3)$, is shown in (12) and (13). The corresponding confidence level is given in (14).

$$(11) \quad 1 > S_A \geq S_B \geq S_C > 0$$

$$(12) \quad es(3) = p^3 + p^2(1-p)[(S_A + S_B) + (S_A + S_C) + (S_B + S_C)] + p(1-p)^2(S_A + S_B)$$

$$(13) \quad (12) \Leftrightarrow es(3) = p^3 + 2p^2(1-p) + p(1-p)^2(1-S_C) = p - p(1-p)^2 S_C$$

$$(14) \quad P(es(3)) = p^3 + 3p^2(1-p) + 2p(1-p)^2 = p + p(1-p)$$

Expected shortfall is minimised by maximising the share of the smallest supplier. With two suppliers the lowest expected shortfall is achieved when the smallest supplier has a 50% share (equal to that of the other supplier), while with three suppliers the optimal share for the smallest supplier is one third (equal to the shares of the other two suppliers). While those results are the same as those that hold for HHI and GSW, there is in the case of

expected shortfall no arbitrary non-linear transformation, save through the threshold effect of focusing on the cumulation of the worst cases.

For the construction of a usable vulnerability indicator, it is therefore proposed that the expected shortfall approach be preferred over HHI, GSW, or other modifications of the Shannon-Wiener index.

A country has a natural gas intensity of GDP equal to θ . The latter represents the physical volume of natural gas which is consistent with one currency unit of value added generation at the current level. A physical shortage will impede value added generation. While the latter relationship is complex and typically non-linear, the impediment to normal economic activity will depend positively on θ , on GDP, and on the size of the supply shortfall. Expected shortfall is a share of missing foreign supplies so it should be multiplied by net import dependence (NID) to yield the share of the shortfall for domestic end-users. A general form for expected economic loss, EEL, is shown in (15).

$$(15) \quad EEL = f(\theta, GDP, NID \cdot es(n))$$

The scaling of the indicator between 0 and 1 has naturally been dropped. An additional modification would be to account for the role of fuel storage. In the simplest form (15) may be modified and calibrated so as to represent a preset period, e.g. one year. One would then specify EEL as a function of the size of the expected shortfall rather than its share, from which one would subtract the storage volume.

Concerning the functional form and parameters of EEL, the most comprehensive approach would be to use a purpose-built calibrated general equilibrium model which would account for economic losses through various channels and industries. As for calibration, empirical findings from past supply cuts should be used. The January 2009 supply cut by Russia can teach us useful lessons if one focuses on the effects on Bulgaria which, as explained earlier, had very limited stockholdings. Preliminary estimates, see (RIA Novosti 2009), suggest that Bulgaria suffered an economic loss of around 250 million Euros as a direct result of the cut. It is not clear how this estimate was arrived at and whether it represents a fall in output or a fall in gross value added. However a rough estimate, taking Bulgaria's GDP for the whole of 2008, suggests a GDP loss of 0.9% for the year due to that incident. Bearing in mind that the supply cut lasted only around two weeks, this also implies that GDP formation in that two-week period fell by 23%, in other words a very substantial temporary shock.¹ Detailed research on this topic would be highly welcome, as it would enable a comprehensive specification of the expected economic loss function which could then be used to simulate the effects of future supply cuts, for Bulgaria as well as for other countries.

The discussion so far has followed what is usually done in the energy vulnerability literature by explicitly or implicitly assigning equal probabilities to supply failures, as well as by not addressing the issue of intentionality. The next section provides a few pointers for future research in that direction in general terms, drawing from various developments in energy relations between European countries and Russia.

¹ These estimates are based on GDP data from the Bulgarian National Bank accessed on 1 March 2009. GDP for 2008 is reported to have been 54.3 billion Leva, equivalent to 27.8 billion Euros. This suggests (very roughly) a normal level of GDP formation over a two-week period of 1.07 billion Euros.

Asymmetric probabilities and intentionality

Game theoretic approaches in reliability analysis allow for the modelling of the actions of intelligent actors. This is particularly useful for the modelling and simulation of intentional attacks on a system. Modelling intelligent actors in a one-step game is conceptually simple: the opponent chooses his target(s) as the result of a maximisation problem subject to feasibility constraints. In a multi-stage game, a government chooses the level and distribution of funds to allocate for protection of potential targets (i.e. pre-emption measures), as well as the nature and degree of retaliation that it signals it is committed to (i.e. deterrence measures). The opponent reacts by updating his evaluation of the costs and probability of success of various types of attacks. Such analyses have been made for the case of terrorist groups targeting Western countries (see Sandler and Arce M. 2003; Rosendorff and Sandler 2004). An excellent recent collection of similar contributions is Bier and Azaiez (2009).

A framework for integrating the insights from game theoretic analysis in reliability theory into the analysis of cross-country energy supplies could be the following. The target function of the supplier country is, in its strictly economic component, to ensure the maximisation of the present value of future profits from the sale of its energy products. Christie (2007) shows that this assumption alone can explain many of Russia's actions, including Gazprom's downstream investments in EU distribution and sales assets and its opposition to diversification of supplies on the part of the EU. However, as shown in Larsson and Hedenskog (2007), there is sufficient evidence of political or geopolitical considerations trumping profit maximisation (in certain cases) to specify a broader target function. One key empirical observation is that Russia seeks ownership stakes, if possible controlling stakes, in the energy infrastructure of its neighbours, of its main European partners, and of potentially competing suppliers. In other terms, the goal is to corner the European market, with particular focus on the countries located in the Central and Eastern parts of the European Union, as well as the countries that are located in the common neighbourhood of the EU and Russia. The empirical evidence also shows that Russia has used various types of pressures in order to obtain assets in a number of countries, most notably Georgia, Lithuania, Latvia, Belarus and Armenia, (see Christie 2007). Moreover, Russia has also cut supplies in cases where the only explanations that stand up to scrutiny are of a purely political or geopolitical nature. Two recent cases include the oil supply cuts to the Czech Republic in July 2008 (Dempsey 2008) and the destruction of gas and electricity connections to Georgia in January 2006 (BBC 2006).

A properly specified target function for the Russian Federation would therefore have to include those elements, and should in a general sense be modelled as a utility function which depends positively on state-owned corporate profits and on geopolitical interests, i.e. on the desire to exert influence and control over foreign countries. The range of means which should be modelled include supply cuts in various guises, but also softer methods, such as the use of complex corporate ownership structures in order to circumvent existing foreign regulations, (see Skorlygina 2006), and/or the use of direct payments to selected individuals in order to facilitate certain transactions.

Starting with the simplest representation, the problem of the supplier may be formalised as the maximisation of the utility function shown in (16).

$$(16) \quad U = \alpha \cdot \pi + \beta \cdot PC$$

Where Π stands for the profits of the state-owned corporations (e.g. Gazprom or Rosneft) and PC stands for political control of the foreign country. While Π may be positive or negative, PC may be defined as non-strictly positive. As for the coefficients, the most general case would be to assume that one of them must be strictly positive while the other may be non-strictly positive. In a typical case Π and PC may be correlated with one another, as well as causally related. The maximisation problem should therefore be seen in a dynamic setting, so that the control variables of the supplier are set in such a way as to yield the optimal solution, subject to feasibility constraints. For instance, it may be preferable to favour legal corporate expansion, and hope for some political dividend at a later stage for some countries, while direct intervention in the other country's political equilibrium (e.g. bribery of politicians, supply cuts) in order to obtain higher profits at a later date may be preferred in other cases. Also, each of the two key variables may have positive or (at times) negative feedback effects onto one another, and indeed onto themselves. For the purposes of the current discussion, and in order to link the supplier's actions with the vulnerability indicators discussed previously, the following simplified framework may be proposed.

The supplier defines a specific goal, for example the ownership of a strategic energy asset in the consuming country. This is an interesting goal, because ownership of that asset would yield a higher profit flow, as the supplier country acquires a further component (downstream) along the supply chain. Political control would also be enhanced, as the strategic importance of the supplier country for the consuming country would also be raised. Thus utility as defined in (16) would rise. However, let us assume that the consuming country refuses to sell off the asset (for whatever reason). If the consuming country is vulnerable, for example because the supplier country is in a monopoly position, the supplier may opt for a deliberate supply cut, thus yielding an economic loss for the consuming country, or for the threat of a deliberate supply cut. Resuming supplies, or not carrying out the supply cut, may then be offered as a bargaining chip in exchange for the desired goal. The consumer country would be tempted to accept, if the economic loss from refusing the deal is strictly lower than the economic loss incurred as a result of the supply cut as defined in (15). On the other hand, the consumer country may also place value on political independence, so that the utility (or loss of utility) of the consumer country would depend on economic loss as derived from (15) as well as on additional factors, in effect a utility function similar to (16), but with domestic political control as the second variable. This simplified case may be seen as a formalisation of the Russian oil supply cut to Lithuania and the related issue of the ownership of the Mazeikiiai refinery (see Torbakov 2006).

Concerning the impact of the vulnerability of the consumer country, it is clear that the outcome desired by the supplier country will be more difficult to achieve with a supply cut if the consumer country can easily and cheaply diversify supply sources, and/or switch to other energy products. If vulnerability is lower, the supply cut would lead to a lower economic loss, potentially yielding an economic loss that would not lead to the consumer country accepting the bargain. In the latter case, the probability of the supply cut occurring would then fall to zero, if one assumes that the supplier country has full information and perfect foresight.

The approach described above offers a number of insights. First, the probability of a deliberate attack on a particular component should be modelled as a function of the expected gains that it will bring to the attacker, given feasibility constraints. Second, the expected gains depend positively on the level of expected loss of the target. Therefore the probability of an attack on a specific component depends positively on the vulnerability of

the component. In terms of countries, this means that an attack on a more vulnerable country is more likely, *ceteris paribus*.

Supply source diversification versus supply route diversification

Another insight from the game theoretic approach relates to the debate on supply *source* diversification versus supply *route* diversification. If one assumes constant levels of bilateral demand and supply, then intentionality of supply disruption is a key issue. Supply route diversification without supply source diversification, e.g. more pipelines from Russia to Europe but no other changes, is a good idea if the failure probabilities are independent from one another as well as independent from the actions of either the supplier or the final consumer. For instance, redundancy in supply routes is a worthwhile investment if there is a relatively high probability of failure due to technical or natural causes, or if there is a generally high probability of attack from an external actor, e.g. a terrorist group, whose goal would be to hurt both European and Russian interests. In that case, additional transport infrastructure may be worth the investment (depending on the level of threat and the size of the necessary investment). However this is not part of the debate as the probabilities mentioned above are considered (rightly) to be very low. Instead, supplies continue to come through a small number of lines, and natural, technical or terrorist attacks are cheaper to deal with by repairing the infrastructure after the event and relying in the short intervening period on other supplies and on storage.

In fact, the supply route diversification argument rests on the assumption that an entire corridor (i.e. consisting of one or more transit countries) presents a systemic risk to supplies. If, for instance, it could be shown that Poland repeatedly cuts the flow of gas between Russia and Germany, then the case for the Nord Stream pipeline (designed to link Northwest Russia directly to Germany) would be undisputable. However no such behaviour on the part of Poland has been observed. There is therefore no clear energy security argument in favour of Nord Stream. Instead, that project seems to be a complicated and costly way of supplying Germany with gas when an additional overland pipeline would be a cheaper solution, at least in terms of initial capital costs. Nord Stream AG has argued that lifetime operating costs for the projected line would be cheaper than with overland alternatives. This issue would naturally require independent evaluation. This is not currently possible due to commercial confidentiality restrictions. However, given the strategic importance of such projects, it would be in the public interest to lift those restrictions so as to enable a transparent verification exercise.

Turning briefly to the Ukrainian corridor, it is evident that the Russian Federation wishes to convince its European partners that Ukraine as a whole is not a reliable transit country. The latest gas crisis of January 2009 may well have damaged the reputation of Ukraine in this respect, and not entirely undeservedly – for a detailed early assessment of the crisis see Pirani *et al.* (2009). However, one should recall that it was Russia's decision to shut down *all* supplies, including those destined for European customers with whom Gazprom had no commercial dispute. In other terms, Russia voluntarily lost revenue (estimated at around 1.5 billion Euros) in order to try to inflict damage on Ukraine's reputation as a transit country and, quite possibly, on its economic and political stability. Shortly after the crisis, Russia resumed the promotion of its pipeline projects, Nord Stream discussed above, and South Stream, which would run from Russia's Black Sea coast, under the Black Sea, into Bulgaria and further into Central Europe and Italy. The key issue, as noted in Pirani *et al.* (2009), is which of the two countries (Russia or Ukraine) is considered to be the main security liability for European gas supplies. In the latter case, supply route diversification would be helpful. In the former case, supply route diversification would not help, and diversification away from Russia as a supplier would be the right course of action, i.e. supply source diversification.

Given available evidence, notably the fact that Russia has cut supplies multiple times to many different countries for a whole set of reasons, a rational policy on the EU side is to expect Russia to cut supplies in future, not only to Ukraine, but possibly to other countries. In this perspective, therefore, supply route diversification serves no useful purpose for the energy security of Europe. On the contrary, it would increase the likelihood of supply cuts, given that it would cost Russia less (in lost revenues) to cut supplies to specific countries if supplies to countries it is not targeting were less affected. For instance, the availability of Nord Stream would enable Russia to reduce supplies through the Belarus-Poland corridor (the Yamal-Europe pipeline) without substantially affecting supplies to Germany, and hence payments from Germany. It is easy to imagine that a dispute could arise between Russia and Poland, e.g. over the stationing of US or NATO assets, and that gas would be suddenly cut for 'technical reasons', in a manner reminiscent of the oil supply cut to the Czech Republic in 2008.

Vulnerable countries, geopolitics and the Russian national interest

Bulgaria appeared as a very vulnerable country in the wake of the January 2009 gas crisis. A much longer supply cut than was experienced would have caused much higher losses, but presumably below the estimated 23% of period GDP discussed earlier, as the affected country would then substitute towards other fuels and other sources. This would be very costly, but less costly than doing nothing. However, the preliminary estimates suggest that a relatively long supply cut (say, of a few months) would plunge a country like Bulgaria into a deep (if temporary) economic depression which could be sufficient to destabilise the country socially and politically. Clearly, countries like Bulgaria cannot afford to remain so vulnerable and should invest in storage and interconnection facilities with neighbouring countries, as well as shift their fuel mix away from natural gas. The same conclusion applies to other highly vulnerable states, notably the Baltic States, given high import dependence, reliance on a single source country, and lack of interconnections with other consuming countries. Indeed, certain analysts recommend that the Baltic States should stop using natural gas altogether (see Korski 2008).

While Bulgaria has apparently reached an agreement with the Russian Federation for compensation, the case of Ukraine is both fragile and strategically important from a European perspective. During the January 2009 crisis, Ukraine was able to operate its gas transit infrastructure in reverse flow, withdrawing stored gas from the facilities in the West of the country to send it to its Eastern regions (see Pirani *et al.* 2009). Ukraine's general economic and financial position is currently very difficult, but for its own purposes it needs to replenish those stocks in time for next winter. Also, Ukraine's storage capacity is potentially very interesting for the European Union, notably in light of the 23 March 2009 Joint Declaration between the European Commission and the Government of Ukraine which foresees EU assistance and investment in upgrading Ukraine's transit infrastructure. As a result, the satisfactory operation of Ukraine's storage capacity is in the joint interest of the EU and Ukraine, as this would make both Ukraine and the EU less vulnerable to future Russian supply cuts. Indeed Pop (2009) reports that Vladimir Putin has identified Ukraine's current vulnerability by stating that "gas must be pumped into underground gas reservoirs because with gas storage facilities empty, Ukraine's economy and community services will not be able to operate in the autumn-winter period". The correct course of action for the EU is therefore to ensure, with financial assistance if necessary, that Ukraine's storage capacity operates for the common energy security interest of the EU and Ukraine. Member states would be making a grave miscalculation if they refused to assist Ukraine, as a higher energy vulnerability of Ukraine would make supply cuts more likely rather than less likely. Renewed incidents, given Ukraine's current economic vulnerability, could have self-reinforcing effects, pushing Ukraine into an ever weaker bargaining position with Russia in other policy areas as well. Given Russia's geopolitical ambitions, this could cover

areas of strategic importance such as ownership of energy and other strategic assets, as well as foreign and defence policy concessions.

The EU's regulatory framework and some policy recommendations

The European Commission, several EU member states, and a large number of analysts have called for a fully integrated and liberalised internal gas market for the EU. A liberalised market would offer several energy security benefits. As argued particularly in Noel (2008), gas supply shocks currently do not translate into price shocks, so that there is no strong economic incentive to source more gas from other suppliers and to redistribute gas between member states. The absence of price signals also reduces incentives to invest in additional interconnection capacity. Gas supplies to the EU as a whole are quite diversified. However limited interconnection capacity implies fragmentation: the availability of North African gas for Spain and Italy did little to help Bulgaria in the recent crisis. Buras and Graetz (2009) come out in support of an integrated and liberalised internal energy market for the same reasons, and furthermore argue that such a course of action would strongly improve the scope for a unified EU external energy policy.

The European Commission has been keen to promote a number of reforms in that direction, notably ownership unbundling, the 'third country clause' (also dubbed the 'Gazprom clause'), as well as stronger energy solidarity mechanisms and more investment in storage and interconnection between member states. However a number of member states, in particular Germany, France and Austria, have opposed both ownership unbundling and the third country clause. This seems a paradox given that Russia had, in May 2008, introduced very stringent legislation regulating foreign investment in strategic industries. For a discussion on the new Russian legislation (see Liuhto 2008). As a result, what is happening is that strictly bilateral relations continue to be cultivated at the expense of a wider EU-Russia relationship, with the acquiescence of 'privileged' EU member states, e.g. Germany and Italy.

While this author shares and supports the ideas expressed in Noel (2008) and Buras and Graetz (2009), the positions of a number of key member states seem difficult to overcome. Other ways must therefore be explored in order to reduce the vulnerability of Central and Eastern European member states. I focus on that particular group of countries given that most of them have net import dependence rates of close to 100% for natural gas, in addition to sourcing virtually all gas imports from Russia, i.e. they are highly vulnerable. One preliminary idea for those countries would be the creation of an investment pool for shared gas and electricity interconnection, gas storage and LNG terminals, new nuclear power plants, and coordinated legislative reform. But an additional problem needs to be addressed. Natural gas is less carbon intensive than other fossil fuels. As a result, the EU's emission trading scheme, the EU ETS, will lead to a strong incentive for all member states to use a higher share of natural gas than they do at present. This runs counter to energy vulnerability reduction goals for the Central and Eastern European member states that should be reducing their dependence on natural gas. What would make sense in this particular instance would be to amend the EU ETS in order to take into consideration energy vulnerability issues. Ultimately a member state should have the right to define reasonable energy security red lines so that environmental policies do not have unintended consequences on national security.

One additional issue should be briefly addressed in this section. Gazprom negotiates bilaterally between itself and its corporate partners in the EU. That set-up is not particularly favourable for the EU as a whole. Bargaining power is naturally asymmetric in favour of Gazprom, notably due to information asymmetry, as Gazprom can centralise all the information about its separate negotiations, in addition to its private knowledge about its

future supply capacities. Individual European energy companies, on the other hand, effectively compete against one another with incomplete information about one another and about supply prospects. A relevant aspect in this regard is that member states have the right to partly conceal the value of gas imports in official trade statistics (as available from Eurostat's COMEXT database) by refusing to disclose the countries of origin of part (or all) of their imports. This means that implied bilateral import volumes and prices are not publicly available. A case could be made that it would be in the common European interest to disclose that information more widely, as this would improve the common information set available to European energy companies and governments. Other important information, such as the detailed clauses of existing and potential supply contracts could also be shared more broadly, again following the reasoning that this could benefit the EU in a collective sense and improve the average bargaining position of EU companies. Member states are currently considering the remit of a new EU body, the Agency for the Cooperation of Energy Regulators (ACER). The Commission could therefore assess whether ACER could serve a useful role as an energy information agency as well. The idea would be that ACER would centralise and re-distribute gas supply information between member states and the private sector. The optimal information sharing policy would of course have to be carefully studied, for example, based on models of strategic bargaining.

Conclusions

The preceding sections point to the need for a partly new approach to measuring energy vulnerability. The main suggestions for future efforts in this direction may be summarised as follows. First, rather than normalise indicators between 0 and 1 in order to rank countries (though that is also an informative exercise), it is preferable to construct a chained indicator that links failure events to economic losses. Second, while diversification of suppliers must be accounted for, this should not rely on arbitrary non-linear transformations such as required by the Herfindahl-Hirschman index or various forms of the Shannon-Wiener index as found in the existing literature. Instead it is preferable to use measures of expected shortfall from the financial economics literature. The latter then represents an actual volume of (expected) shortfall given a certain confidence level which can be directly chained with a country's fuel intensity of GDP. The latter can then be used as the core variable in a calibrated model of expected economic loss. Countries (or a given country over different time periods) may then be compared in terms of what would actually happen to their economies with a set confidence level. A shift term should also be added to represent the temporary reprieve offered by domestic fuel storage.

Also, it is implicit to the approach advocated in this article that each main type of fuel should be assessed separately, for example, crude oil, natural gas, coal. In addition, a set of modelling efforts are necessary in order to specify the economic loss functions in each case, as these should account for second-round effects, for example, economic effects of impeded transportation or of reduced electricity generation.

In a further stage, one idea would be to develop a sort of 'control panel' view of a country's energy vulnerability, enabling simulations of various scenarios under various assumptions on the probabilities and nature of specific exogenous events (including different time horizons), as well as on the values taken by additional state variables that cannot be easily included in the main measure of energy vulnerability, for example, increased supplies from suppliers that have not failed, subject to the situation in other consumer countries. Moreover, and this would require a somewhat novel research effort, the relationship between the probability of a supply cut and some of the state variables may be modelled, for example using a game theoretic approach. This requires taking into consideration the target function of the supplier. In the case of Russia, while profit maximisation is clearly in

evidence, geopolitical considerations need to be included as well. Also, other types of vulnerability, such as general economic, social or domestic political vulnerabilities may make supply cuts more likely, as in the case of Georgia in 2006.

Energy vulnerability measurement and modelling should ultimately inform policy. In particular, member states should legislate that no energy infrastructure project by one or more member states may increase the energy vulnerability of another member state. Additionally, European environmental policies, notably the EU ETS, should be amended so as to account for induced changes in energy vulnerability. Compensation mechanisms between member states should be set up in both instances. Additionally, member states should have the right to define and implement energy vulnerability red lines, within reasonable limits, for national security reasons. Finally, member states should consider expanding the remit of the planned Agency for the Cooperation of Energy Regulators (ACER) in the direction of an energy information agency that would collect and disseminate information on gas supply volumes, prices and contracts.

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