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REVIEW OF ACTIVITIES OF THE SUBSIDIARY BODIES OF THE COMMITTEE

Energy Security Dialogue: Indicators of Energy Vulnerability

Note by the secretariat

Summary

At its seventeenth session, held in November 2008, the Committee on Sustainable Energy asked the secretariat to develop indicators of energy vulnerability for member States of the Economic Commission for Europe (ECE) in cooperation with the World Energy Council (WEC) for presentation at the Committee's annual energy security dialogue. The Committee also requested the secretariat to prepare a note on the use of the indicators for the eighteenth session of the Committee. (ECE/ENERGY/78, Annex I para. 3(f)(iv)).

In response to that request, this document, based on the experience of WEC, illustrates how energy vulnerability can be complementarily assessed using quantitative indicators and qualitative analyses. It is intended to help guide discussions on the issue at the eighteenth session.

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INTRODUCTION

1. Concerns about energy vulnerability have increased in recent years as a consequence of the high volatility of energy prices, economic instability and uncertain geopolitics of energy resources. While diverse and complex relations characterize energy economics, the need to use a limited number of indicators for monitoring energy policy at national and international levels is more and more stringent. Vulnerability is one of the main aspects addressed by policy measures. It is expected that designing an adequate vulnerability indicator system would contribute to enhancing international dialogue in order to harmonize national energy policies and encourage improvement of energy security.

2. However, limiting the assessment of energy vulnerability to a few indicators would be misleading. In its two studies on *Europe's Vulnerability to Energy Crises* (WEC 2007) and *Assessment of Energy Policy and Practices* (WEC ongoing project), the World Energy Council bases its assessment on three principles: relevance, representativeness and completeness. While the assessment must comply with all the three principles, the indicator system is restricted to being relevant and representative of well selected dimensions. The relevance of an indicator means that the background issue is meaningful and significant with respect to the energy vulnerability theme and to international comparison. The representativeness principle ensures that the indicators altogether cover a significant share of selected multidimensional facets of energy vulnerability.

3. As completeness is not required for an indicator system, it is not necessarily comprehensive and therefore may only represent a part of the global assessment of the energy

vulnerability. The complementary part may be a structured discussion on all the topics which are addressed by the theme, even though few of them are qualitative.

4. Based on the experience of WEC and especially on Part Two of its report *Europe's Vulnerability to Energy Crises*, the present document illustrates how energy vulnerability can be complementarily assessed using quantitative indicators and qualitative analyses.

I. ASSESSMENT FRAMEWORK

5. Based on the above-mentioned principles, WEC's energy vulnerability assessment identified three relevant levels: economy (macroeconomic and microeconomic), environment, and social and society level.

A. Economic level

1. Macroeconomic sub-level

6. Different issues can be discussed under this sub-level such as: energy intensity, energy dependence in the case of net energy importers; reliance on energy export revenues in the case of net energy exporters; volatility of energy prices; exchange rate and technology ownership.

(a) <u>Energy intensity</u>

7. As far as energy vulnerability is concerned, the use of energy intensity aims at estimating how far the economy is sensitive to energy crises. The background idea is that the more an economy needs energy to produce one Euro of national income, the more it will be sensitive to energy crises. The energy intensity of GDP is commonly utilized and is expressed as the ratio of total primary energy supply (TPES) (in tonnes-of-oil-equivalent – toe) to GDP (in Euros in the cases of European countries). Since the first oil shock, industrialized countries have witnessed a significant drop in energy intensity resulting from energy conservation, technical progress and changes in economic activities (larger share of tertiary activities in GDP). The reinforcement of voluntary energy efficiency measures can contribute to reducing the European economy's sensitivity to fluctuating energy prices. Further decreases could result from structural changes in the transition economies like Poland, Slovakia, Hungary, Romania and Bulgaria where energy intensity is still high compared to most other European Union (EU) member states.

(b) <u>Energy dependence</u>

8. With respect to vulnerability, energy dependence is related to the magnitude to which the energy supply of a net energy importer country relies on uncertain external sources. A country which imports the majority of its energy at a sustainable cost and ensures the security of its supply by means of well-diversified sources will be dependent but not vulnerable. A country which produces the majority of its energy at a prohibitive cost or using obsolete technologies will be vulnerable, even if independent of external suppliers. A country may be considered vulnerable when energy policy decisions are dictated by economic factors beyond its control. For example, a country which mainly relies on the short-term market for its energy supply can be

vulnerable when energy spot prices increase as the import energy bill will become too costly in macroeconomic terms.

9. Energy dependence is broadly measured using the ratio of net energy import to the TPES. For instance, following this simple definition, the energy dependence rates in 2007 for certain countries are estimated as follows based on international statistics (IEA 2009a, IEA 2009b): 51 per cent for Bulgaria against 66 per cent in 1990; 56 per cent for Croatia against 43 per cent in 1990; 49 per cent for France, relatively stable since 1990 due to nuclear power, against 67 per cent in 1970 and 43 per cent in 1960; 59 per cent for Germany against 47 per cent in 1990, 42 per cent in 1970 and 12 per cent in 1960; 32 per cent for Sweden against 37 per cent in 1990, 83 per cent in 1970 and 73 per cent in 1960; 41 per cent in Ukraine against 46 per cent in 1990. Thus there is a variety of situations among industrialized countries depending on the evolution of both endogenous production and total primary energy supply.

10. It is important to calculate a separate rate of dependency for each type of energy (i.e. the ratio of net imports to gross consumption). As an example table 1 lists the rate of dependence per energy sources i.e. coal & peat, oil, and gas for few countries. Each energy source has to some extent a captive market (oil in the transport sector for instance) and uses different logistic systems for delivery. Oil fosters the highest energy vulnerability in Europe because the EU relies significantly on imports and a substantial volume of imports comes from those regions considered to have a high geopolitical risk.

11. Oil price volatility is greater than that of other energy sources, particularly coal. Other energy systems depend to a certain extent on transport and therefore on oil. However the share of oil in the TPES varies from one country to the other. As table 1 shows, the energy sources that have been taken into consideration represent altogether variable percentages of the TPES, spreading from 51 per cent (France) to 82 per cent (Ukraine). The share of oil in the TPES changes from 11 per cent (Ukraine where gas is the first contributor to the TPES) to 32 per cent in France.

Table 1. Rate of energy dependence in 2007 for selected fuels

Country	Coal & peat (%)	Oil (%)	Gas (%)	Percentage of TPES (%)
Bulgaria	39.0	99.5	92.2	77.8
	38.8	24.1	14.9	
France	98.2	98.7	97.6	51.2
	5.0	31.6	14.6	
Germany	37.0	95.7	83.2	80.8
	26.2	31.5	23.1	
Ukraine	17.2	71.2	68.5	81.8
	29.6	11.3	40.9	

Sources: Gnansounou (2009), IEA (2009a), IEA (2009b)

(c) Volatility of energy prices

12. Energy vulnerability may be linked to the volatility of energy prices. When an oil crisis occurs, investing heavily in alternate high-cost sources may be imprudent, especially if there is a subsequent oil price collapse. As there is high capital intensity in the energy sector, certain investments are only profitable in the long term. This volatility demonstrates the cost of irreversibility (sunk costs) and explains why many investors will choose technologies with low risk and a short payback period. Encouraging customers to choose natural gas when the price of hydrocarbons is low may be questionable if the oil price increases sharply. Hence there is a need to consider mechanisms for stabilizing prices in order to protect certain areas of the industrial sector from extreme price fluctuations.

13. As an example, during reconstruction after the Second World War, France developed coal (as well as hydroelectric power). The choice of coal was perfectly justified at that time but became questionable at the beginning of the 1960s, a period of low international oil price. French industry became vulnerable due to the high cost of national energy supplies, while having to face strong international competition (creation of the Common Market). The main policy response was to substitute cheap imported oil for expensive national coal, a measure which justified the "coalmine decline" process.

14. This choice proved to be a source of vulnerability at the time of the first oil crisis (1973-1974), as the rate of energy dependency rose from under 48 per cent in 1960 to nearly 75 per cent in 1973. Priority was given to nuclear power at national level as a means of reducing the energy vulnerability of the French economy. However, the large investment required for nuclear development may have negative effects, such as cancelling investments in other resources that then become vulnerable. In this case, we could speak of a "crowding out effect" of certain technologies, by nuclear technology or others.

15. The pursuit of energy independence may thus increase the vulnerability of the rest of industry, weakened through lack of investment. When energy prices rise sharply, the revenues of an oil exporting country are suddenly increased, which may impact negatively on the rest of the economy and the competitiveness of the industrial or small-scale sectors. This is the "Dutch Disease" syndrome which bedevils oil-producing economies. These "windfall profits" could cause vulnerability to a certain extent, in the long run.

16. Germany's choice to phase out nuclear power and to give priority to renewable energy sources (notably wind energy) may lead to vulnerability if the technology employed is not competitive in the long term or if the development of wind farms on a large scale is not accepted. In such circumstances, it is often preferable to opt for a diversity of alternative or complementary solutions with the aim of reducing the risk of vulnerability, "flexible systems" being theoretically less vulnerable than "rigid systems" in view of the uncertainty related to energy price in the medium and long term.

17. The issue of flexible versus rigid systems raises an interesting debate as to whether market mechanisms or central planning deliver the optimum portfolio of energy investments in terms of vulnerability. Experience gained in many countries shows that a well balanced regulation and market mechanisms are required to manage the risks of energy insecurity.

2. Macroeconomic sub-level

18. At the macroeconomic sub-level, vulnerability can be analysed from the energy consumer or supplier viewpoints. The fossil energy supply is addressed first and then vulnerability of electricity supply is discussed.

(a) Consumer perspective

19. **Vulnerability of fossil fuel supply: role of stockpiles.** For the consumer, vulnerability is characterised by the risk of supply disruption and associated price increases. An example of a physical supply disruption happened in the summer of 2005 in the United States caused by hurricanes Rita and Katrina, which not only destroyed the oil and gas production rigs in the Gulf of Mexico, but also damaged several refineries. The corrosion on pipelines transporting crude oil from Prudhoe Bay, Alaska, during the summer of 2006, caused a 400 000 b/d drop in production, provoking fears of a disruption of supply to refineries on the United States Pacific coast. However, a distinction should be drawn between a real supplies disruption and those that threaten.

20. Prevention naturally implies stockpiling. The consequences of hurricanes Rita and Katrina were contained by reliance on the strategic stocks of the International Energy Agency (IEA) which released 2 Mb/d for 30 days. In the summer of 2006, the American administration authorized access to the Strategic Petroleum Reserve to contend with the problem of lower output from Alaska. Thus, the level of stocks is a meaningful indicator especially for short term energy vulnerability. The best measurement should be expressed as the number of consumption days. In the case of oil, the EU rules impose strategic stock levels of 90 days of consumption of the main petroleum products, while the IEA rules stipulate 90 days of net imports of crude oil and petroleum products. Substitution of energy sources is important in order to alleviate consumer vulnerability. An attempt can be made to estimate the political acceptance of the number of days without supply. This level is suggested in table 2.

Table 2: Stocks requirements per fuel and type of consumer

Energy	**Type of Consumer**	**Day(s) to be considered a crisis**
Gas	Domestic	1-3 days
Gas	Industry	1 week
Gasoline, diesel oil	Domestic	1-3 days
Fuel oil/diesel oil	Industry	1 week
Coal	Industry	8 weeks

21. Some companies can also change energy sources mainly for producing heat depending on relative price variations.

22. **Interruptible provision of gas.** Especially for gas, interruptible provision may be agreed between contractors. Many medium and large gas customers choose to buy their gas on an interruptible basis. The gas supplier and the customer can jointly decide the commercial terms and the conditions under which supplies can be interrupted by either party. With an interruptible contract, the customer can switch to alternative supplies in order to optimize economics in certain market situations. This flexibility, in addition to the lower price paid for an interruptible supply of gas, should compensate for the extra cost incurred by the interruptible customer for securing alternative operational solutions in case of imposed interruption, such as investment in dual firing back-up facilities.

23. **Vulnerability of electricity delivery.** There are several examples of electricity disruption in the last decade. Severe damage was caused by the storm that occurred in France in December 1999. Major blackouts were experienced by the United States and Ontario in August 2003, and Italy in September 2003. Regarding oil products and natural gas, the risk of supply disruption for consumers is reduced due to storage possibilities. In contrast, it is not possible to store electricity, consequently it is necessary to have production or import capacities instantly available in order to meet any unexpected increase in demand or plant failure. Electricity vulnerability thus depends on three main factors.

24. **The first factor** is the “reserve margin” in relation to the peak load. In a public monopoly system, this margin is often comfortable, since one of the priorities of the monopoly is to prevent energy failure. It is certainly a costly strategy as reserve capacities are not used and it is the consumer who bears the cost. Since 1996, when the EU Directives on Gas and Electricity were implemented, the reserve margins have been significantly reduced as the companies have no interest in keeping reserves. However, the national regulators are responsible for monitoring countries’ demand/supply adequacy at state level.

25. **The second factor** is the “interconnection rate” between countries. Electricity interconnection with neighbouring countries makes mutual assistance possible in periods of pressure on supply and demand and this limits the risks of failure. It is well-known that the European Commission Directive recommends an interconnection rate of about 10 per cent in terms of the installed electricity capacity of a country. The situation varies from one European country to another. The vulnerability of the “electricity peninsulas” (the Iberian and Italian peninsula and the British Isles) is significantly higher than that of continental countries with many borders. Governance of an interconnected system is an important factor and if not managed properly can present a vulnerability threat in the form of a High Impact Low Probability event.

26. **The third factor** is the “net import rate”, i.e. the percentage of electricity consumption which is imported. About 60 per cent of gas consumed within the European Union crosses at least one border, while cross-border electricity only amounts to 7 per cent of the electricity consumed within the European Union. Electricity long distance transport costs are high due to line losses and there is a maximum level of electricity imported that should be considered as politically acceptable. As electricity cannot be stored, dependence on imports is sometimes considered as implying a great risk and some countries will not accept to be so dependent for such a strategic good. With a percentage of electricity imports amounting to 15 per cent, Italy is

now considered to be highly dependent on foreign countries. The blackout of September 2003 reopened the debate about the need to increase capacities of national supply (even if this blackout was due to problems with transmission, communication and information management and not to a shortage). Due to the high cost of the national supply, a large part of the demand was met by cheaper importations. This is a controversial topic. The challenge is to achieve a safe mutual dependency arrangement. The ratio of investments to turnover represents a good indicator of potential vulnerability in the energy sector when it is maintained under a certain level. In the electricity and gas sectors, according to Cap Gemini (2006), this rate has been decreasing steadily over the past years falling from 10.3 per cent in 1998 to 5.5 per cent in 2004 within the European Union.

(b) Energy supplier perspective

27. Vulnerability can be analysed from the viewpoint of energy utilities and characterized by the risks to which they are exposed. At present, there are several forms of vulnerability affecting energy suppliers which were until recently integrated public monopolies. As in the case of the consumer, certain factors can be measured quite easily by indicators, others not so easily. Even if difficult to quantify, it may be useful to keep these factors in mind.

28. **Vulnerability related to unbundling.** Unbundling of the electricity production, transmission and distribution activities, currently legal and probably in the form of ownership unbundling in the near future, is a potential factor of vulnerability for many operators. Transmission and distribution are profitable regulated activities which earn a large part of the profits of electricity (and gas) companies. Charges set by regulatory commissions for third party access to networks cover costs while ensuring a sufficient return on invested capital, with the aim of encouraging facility investments. There is uncertainty concerning the production and marketing activities in the open market due to the volatility of spot prices and the uncertainty as to the market shares of each operator. Once the incumbent unbundling has occurred, they become more vulnerable. The electricity spot price escalation in the United States over the period 2000-2001 led to a capacity investment boom until 2003: more than 200 GW were built to achieve a total installed power of around 800 GW. This "boom and bust" phenomenon generated an electricity overcapacity that brought down the prices on the electricity spot market, causing the bankruptcy of numerous "merchant plant companies", hence some companies made the choice to give up the pure producer model in favour of vertical integration.

29. **Vulnerability linked to cross-border exchanges.** The goal of an open market for network industries in Europe is not to size-up 27 competitive markets but to create a single gas and electricity market in the long term within the EU. This implies a convergence, i.e. a levelling of gas and electricity prices for all the European consumers. Removal of bottlenecks that still exist in the electricity interconnections between the EU countries is a prerequisite. These cross-border interconnections are generally defined as a potential factor in reducing the vulnerability of national electricity systems. They were moreover encouraged by the Union for the Coordination of Transmission of Electricity, well before the introduction of the European Directives on the open market. The advantages of interconnections are clear. However, the convergence of the electricity spot prices due to interconnection is sometimes perceived as a factor of vulnerability by some consumers who are afraid of losing a comparative advantage in the context of international competition. Thanks to nuclear power, the French industrial firms benefited from

low electricity prices, and took investment decisions according to the electricity price structure, but risk losing this advantage.

30. **Vulnerability related to regulatory uncertainties.** In some countries, the volatility of the regulations is a significant risk factor. In the Russian Federation, the lack of transparency, the complex interrelations between federal and regional laws, and evolving tax arrangements associated with the wish of the government to regain control of the petroleum sector, are often mentioned factors of vulnerability for the petroleum operators.

31. In Europe, as a result of the European Directives, some of which are still in the course of preparation, and the progressive transposition of the Directives into national legislation, the regulatory framework is far from being definitive for electricity and gas operators. The uncertainty created by this continual change of regulation affects the strategies of the operators who cautiously hesitate to commit themselves in the long term. It is sometimes more difficult to adapt to regulatory uncertainties than to market ones.

32. Some tariffs continue to be regulated. Gas prices for retail customers in France remain subject to government approval. This could be a factor in reducing the vulnerability of the historic operator Gaz de France (GDF). Although unlikely, a situation of production overcapacities, as in the refining sector, could drive market prices below average production costs in certain periods. Regulated tariffs should help to avoid corresponding losses. In contrast, for political reasons, regulated tariffs may be fixed at levels and supply cost increases cannot be fully passed on. The decision in 2006 of the French Government to postpone the increase in domestic tariffs of GDF is a good illustration of that situation. Applying a government measure caused GDF to lose 250 million Euros. Above all, it cast a doubt on the willingness of the Government to behave in the manner of a “shareholder at common law”. Consequently, the quoted price of GDF shares has suffered a downward trend.

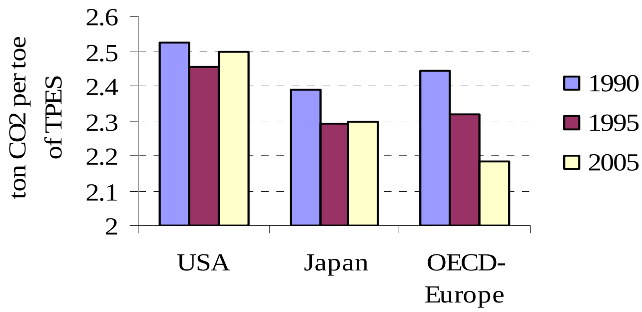
B. Environmental level: carbon content of the total primary energy supply

33. Rising concerns about global climate change will make greenhouse gases and particularly CO_2 emissions more and more costly in Europe and probably worldwide. Efforts are being made internationally in order to improve market access for Environmental Goods and Services (EGS). It is noteworthy that the CO_2 content of the EGS will be a key attribute of their environmental performance.

34. The CO_2 content of the TPES is used as an environmental indicator at macro-level and its evolution depends mostly on energy substitution. Countries such as Australia, Greece and Poland with a significant market share of coal have a high carbon content in their primary energy supply. From 1990 to 2005, the ratio of CO_2 emissions to TPES decreased by 5.1 per cent in the countries of the Organisation for Economic Co-operation and Development (OECD) as a whole while this pattern varies from one country to the other.

35. Figure 1 shows that the ratio was stable in the United States and decreased by 10.6 per cent in OECD-Europe. The performance of OECD-Europe was mainly due to the substitution of coal and oil by natural gas and nuclear. From 1973 to 2005, the share of coal and oil in OECD-

Europe decreased from 84.5 per cent to 54.5 per cent while natural gas and nuclear energy accounted for 11 per cent in 1973 and 37.8 per cent in 2005.



Source: *IEA (2007)*

Figure 1: Ratio of CO_2 emissions to total primary energy supply

C. Social and society level

1. Fuel poverty

35. Low income households may be affected depending on the effectiveness of social protection measures. The concept of energy poverty, also termed fuel poverty, has gained in importance during the recent past. It originated in early the 1980s from the grassroots environmental health movements of the United Kingdom and Ireland. With the energy crises of 1973/74 and 1979, low income households experienced difficulties with increased heating bills.

36. The Fuel Poverty Concept is an interaction between poorly insulated housing and inefficient in-housing energy systems, low income households and high energy services prices. At the beginning of the twenty-first century, the British Government set up a strategy on fuel poverty aiming at eradicating this phenomenon by 2010 (DTI/DEFRA 2001) for vulnerable households and by 2016 for all English households.

37. According to the British standard definition that was adopted, a household is poor in fuel if it needs to spend more than 10 per cent of its income on all fuel use to heat the home to an adequate standard and to meet its needs for other energy services (lighting, cooking, cleaning, etc.). This standard definition calls for comment.

38. Related to the fuel needs, the standard indicator of Fuel Poverty is based on the fuel households need to consume and not on how it is actually consumed. In the case of heating, the definition of internal temperature was compatible with the recommendations of the World Health Organization (WHO1989). This definition varies according to the type of household (DETR 2000). For example, 21^{o} in the living room and 18^{o}C in other occupied rooms for the whole house:

- 9 hours a day for households in work or fulltime education (standard heating regime)

- 16 hours a day, for households likely to be at home all day (full heating regime)
- Related to income, the indicator depends on the way the income is assessed (available or total income).

2. Social acceptance of energy technology

39. When the energy technology is not diversified, the social rejection of the dominated technology is a significant vulnerability factor. A certain technology can be banned in a given country due to an accident in another country. The case of nuclear power plants is a concern that particularly needs an international agreement on a high security and reliability standards. Another case is the development of electrical power transmission networks with its cohort of oppositions.

II. DESIGN OF A SYSTEM OF INDICATORS

A. Choice of selected dimensions

40. It is difficult to quantify the influence of a single vulnerability factor using indicators, and there are cases where the enhancement of a given indicator can have negative effects. It is even more difficult to attempt to synthesize different factors. For illustration purposes, an indicators' system is presented in the case of long term energy vulnerability, based on the following five vulnerability performances (Gnansounou 2008): energy intensity (X_1), energy import dependency (X_2), carbon content of energy supply (X_3), vulnerability of electricity supply (X_4), and non-diversity of transport fuels (X_5). Each dimension is evaluated in the due unit. The lower the rating, the higher the performance values.

41. **Energy intensity EI (X1).** This dimension hides a number of biases. As GDP often increases faster than energy consumption, high GDP leads to reduced EI. Furthermore the embodied energy in imported goods is not accounted in the energy consumption statistics. Hence substitution of endogenous production by importation may result in improvement of EI. Finally, how GDP is measured is of utmost importance. In economically advanced countries GDP at market exchange rate (MER) is generally higher than GDP at power purchase parity (PPP), leading to an underestimate of their EI when using MER. On the other hand, as PPP reflects more retail prices than prices of intermediate goods, countries with a higher productivity of their manufacturing sectors will have their GDP underestimated when using PPP, resulting in an overestimation of their EI. In this illustration GDP at MER was used.

42. **Energy import dependency (X2).** X2 was limited to oil and gas imports which were considered as more challenging for the countries under study. Furthermore, as far as energy supply vulnerability is concerned, the values of positive net export were set to zero. That means there is no vulnerability at that dimension for the energy net export countries. However, for these countries, vulnerability of energy exportation may also be further considered. The net import ratio to the TPES is estimated by accounting for non-diversity of the oil and gas import origins as well as geopolitical factors.

43. **Carbon content of energy supply (X3**). X3 is the carbon emissions ratio to TPES. This indicator is supposed to represent the environmental dimension of energy vulnerability.

However, in a more general view, local environmental impacts should be also taken into account as they are factors of unsustainability.

44. **Electricity supply vulnerability (X4).** For this illustration, X4 mainly denotes self-sufficiency in electricity supply coupled with a well balanced electricity mix. Hence, net electricity import countries were penalised, and to a lesser extent countries with a high share of risky electricity options.

45. **Non-diversity in transport fuels (X5).** This indicator is supposed to reward efforts for diversification of the energy supply mix of the transport sector. Actually, the variability within the countries is not high on this dimension. However, in the future, some countries may increase their use of alternative fuels in transport.

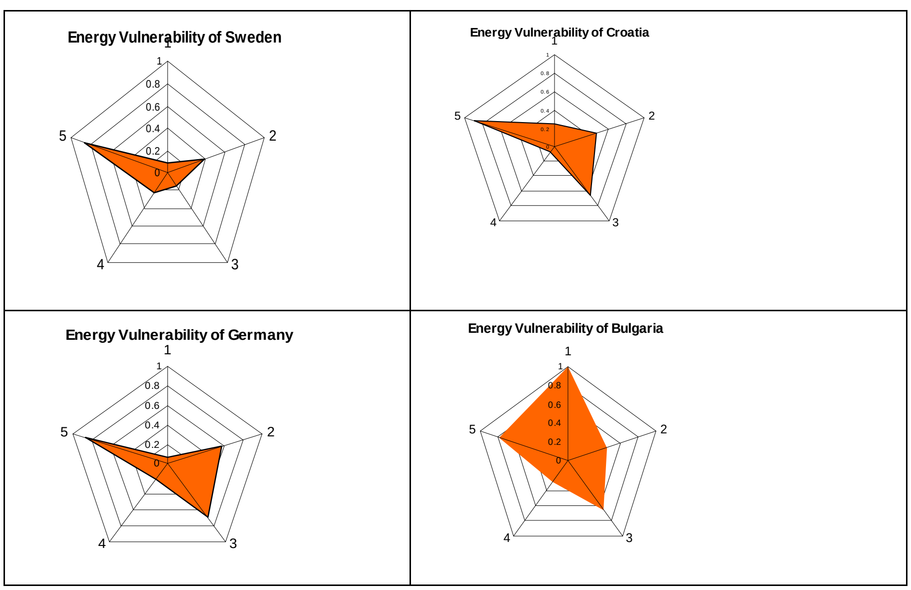
B. Normalization

46. In order to present the indicators simultaneously and facilitate comparisons and aggregations, the various indicators were normalized to values between 0 and 1.
Such a normalised index can be defined by means of the formula:

$$I_j = \frac{X_j - \min_{k=1}^{n}(X_{jk})}{\max_{k=1}^{n}(X_{jk}) - \min_{k=1}^{n}(X_{jk})} \quad j = 1, 2, ..., 5$$

where X_{jk} is the indicator X_j considered of a country k among n countries.

47. The normalization allows a graphic representation of the vulnerability of a country based on several indicators as shown in figure 2.

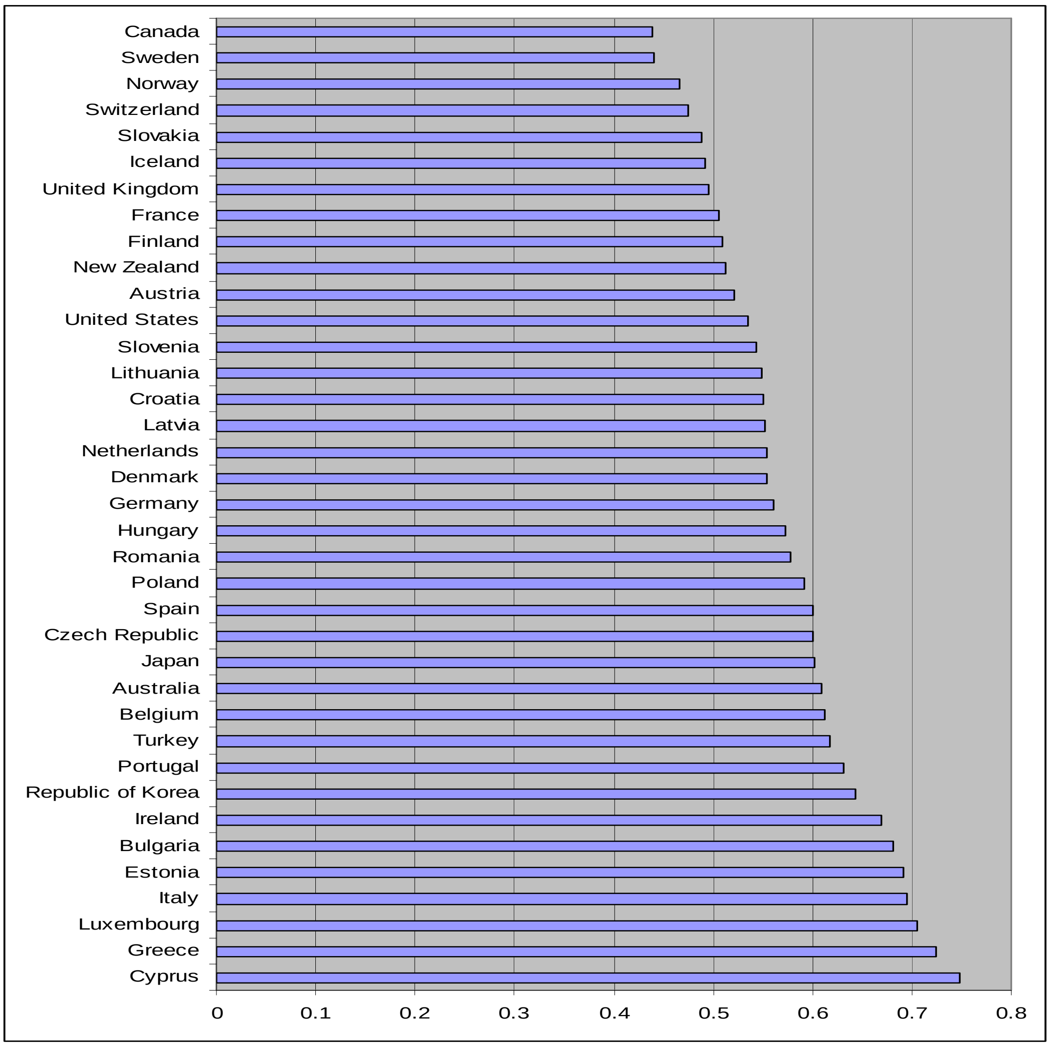


Source: Gnansounou (2009)
Figure 2: Energy vulnerability indexes in 2003 of selected countries.

C. Composite index of energy vulnerability

48. A composite index can be used in order to aggregate the multidimensional performance of each country. The aim of such an index is not to replace the partial performance indexes by a unique aggregate one. The role of the composite index is rather to facilitate the benchmark visualization. However in order to prevent loss of information, a composite index must be used in pair with multidimensional representation such as the polar diagram shown in figure 2. A composite index can be computed in many ways.

49. The most common model is the weighted mean. It has the advantage of simplification. However, it allows too much compensation between the various dimensions. Using non-linear aggregation reduces the compensation effect and penalizes very bad performers in one or few dimensions.



<u>Source:</u> Gnansounou (2009)

Figure 3: Ranking of selected industrialized countries based on their energy vulnerability

50. A composite index (I) was evaluated as the Euclidian distance (ED) to the best energy vulnerability performance which is represented by the zero point. When the normalized indicators are significantly correlated, the ED is evaluated in the orthogonal system defined by the principal components. The ED is normalized in order to restrict the value between 0 and 1. The energy vulnerability index (I) was evaluated for 37 countries using data related to the year 2003. As figure 3 shows, Canada was found to have the lowest vulnerability and Cyprus the highest.

D. Examples of four countries: Bulgaria, Croatia, Germany and Sweden

51. **Bulgaria**. With regard to the composite index, Bulgaria ranks 32 among the 37 industrialized countries. This country has the least energy intensity and ranks twenty-third and twenty-fifth for carbon content of energy supply and for electricity vulnerability respectively. Its strengths are on transport fuels diversity where it ranks fifth. However, the difference in performance among the countries is not significant on that dimension.

52. **Germany.** Germany is nineteenth according to the composite index. Its weaknesses are on energy dependence (twenty-second) and carbon content of energy supply (twenty-fourth). Its strengths are on energy intensity (ninth) and transport fuels diversity (ninth).

53. **Croatia.** With a rank of 15, Croatia exhibits a good performance on electricity vulnerability (fifth) but is weak for energy intensity (twenty-eighth) and carbon content (twenty-sixth).

54. **Sweden**. Sweden is second behind Canada due mainly to its good performance on carbon content. Its apparent weakness is low diversity of electricity generation based only on hydro and nuclear. However, that mix contributes to its good performance concerning carbon content.

IV. CONCLUSION

55. The concept of energy vulnerability takes various forms. It is undeniably linked to the degree of dependency on energy supplies, but cannot easily be depicted by a single indicator. At the macroeconomic level, the main indicators pertain to the concentration (or diversification) of supply, to the energy bill and to price volatility.

56. For the fossil energy consumer, short term vulnerability is naturally associated with stock levels, while that of the electricity consumer can be reduced mainly by means of increasing production capacity surplus and adequate network interconnection. The various indicators that have been examined should be useful in drawing up policies to reduce vulnerability. It is only natural that the results of a policy will always be hard to appreciate using aggregate indicators. We have in fact observed a number of backlash effects. However, aggregate indicators when used in couple with multidimensional discourse can help to communicate more clearly on the global performances, the strengths and the weaknesses of each country.

57. It is important to distinguish between dependency and vulnerability. Thus, a reliance on domestic energy production to limit dependency on imports can lead to costlier solutions, penalising certain industries. It is important to reinforce the interconnected grids which may

help to address various accidents. However, the growth of cross-border electricity exchanges does not have solely positive effects.

58. Finally, a number of analyses are suggested and further research work is needed to scrutinize certain issues. Policies or measures designed to limit the vulnerability of a country or a group of stakeholders cannot be restricted to the search for actions addressing any specific individual indicator. Global perspectives should be developed that distinguish short term energy vulnerability with its requirements on emergency actions and long term vulnerability that needs structural design of energy supply mix.
