ELSEVIER

Energy Policy 36 (2008) 1195–1211

ENERGY POLICY

www.elsevier.com/locate/enpol

Oil vulnerability index of oil-importing countries ☆

Eshita Gupta

The Energy and Resources Institute, Darbari Seth Block, Habitat Place, New Delhi 110 003, India

Received 28 June 2007; accepted 13 November 2007
Available online 15 January 2008

Abstract

This paper assesses the relative oil vulnerability of 26 net oil-importing countries for the year 2004 on the basis of various indicators—the ratio of value of oil imports to gross domestic product (GDP), oil consumption per unit of GDP, GDP per capita and oil share in total energy supply, ratio of domestic reserves to oil consumption, exposure to geopolitical oil market concentration risks as measured by net oil import dependence, diversification of supply sources, political risk in oil-supplying countries, and market liquidity.

The approach using the principal component technique has been adopted to combine these individual indicators into a composite index of oil vulnerability. Such an index captures the relative sensitivity of various economies towards developments of the international oil market, with a higher index indicating higher vulnerability. The results show that there are considerable differences in the values of individual indicators of oil vulnerability and overall oil vulnerability index among the countries (both inter and intraregional).

Keywords: Oil vulnerability; Market risk; Supply risk

1. Introduction

Oil is the fuel that drives the economy, and its regular supply is vital for sustainable economic and social development of countries. The world is heavily dependent on oil for meeting its energy requirements—it fulfils about 35% of the global energy demand.[1] The oil industry is almost wholly globalized. In 2005, approximately 60% of the global oil supply was internationally traded.[2]

The mismatch between supply and demand drives international trade in oil. On the one hand are North America, Asia-Pacific, and Europe, which hold just 10% of world's reserves but account for about 78.6% of the demand. On the other hand are the Middle East, former Soviet Union (FSU), and Africa, with 81.3% of the world's reserves, but accounting for 15.5% of the world's oil demand in 2005.[3]

On the supply side, oil reserves are unequally distributed, with over 60% of the world's oil reserves concentrated in the sedimentary basins of the Middle East.[4] The Organization of Petroleum Exporting Countries (OPEC) members—Saudi Arabia, Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, United Arab Emirates, Angola, and Venezuela—hold 75.2% of world's oil reserves and control about 41.7% of oil production.[5] Many of these oil-exporting countries are characterized by high degree of political instability (Table 1). Besides, about two-thirds of the global oil is transported by sea through various 'chokepoints' such as Strait of Hormuz, the Strait of Malacca, Suez Canal, Strait of Bab el-Mandeb, and Bosphorus. About 88% of the Persian Gulf oil bound to Asia, Western Europe and United States is transported through the Strait of Hormuz.[6] The chokepoints are

☆The paper refers to the conventional mineral oil and does not include oil sands and other heavy oil sources. The author is responsible for all of the comments and errors in this paper.

E-mail address: eshita.gupta@rediffmail.com

[1]IEA (2006a, b, c), world energy outlook 2006.

[2]BP (British Petroleum) (2006).

[3]BP (British Petroleum) (2006).

[4]EIA (2007), oil and gas journal estimates.

[5]BP (British Petroleum) (2006).

[6]For details see 'A maritime geostrategy of petroleum distribution', Jean-Paul Rodrigue (http://www.erudit.org/revue/cgq/2004/v48/n135/011797ar.html).

0301-4215/$ - see front matter
doi:10.1016/j.enpol.2007.11.011

Table 1
ICRG political risk ratings of the oil producing countries (2004/05)[a]

Country	Political risk rating
Iraq	33.792
Nigeria	43.083
Venezuela	51.333
Indonesia	51.583
Angola	57.458
Algeria	58.250
Iran	60.375
Libya	65.083
Argentina	65.458
Brazil	66.500
Saudi Arabia	66.583
Russian Federation	67.875
China	69.792
Kazakhstan	70.333
Mexico	72.833
Qatar	73.125
Oman	76.125
Malaysia	76.625
Kuwait	77.292
United Arab Emirates	77.958
United States	82.542
United Kingdom	85.500
Canada	86.542
Norway	88.125

[a]ICRG political risk ratings range between 0 for high risk and 100 for low risk.

extremely susceptible to shipping accidents and terrorist attacks in their narrow channels.

Another important factor impacting the world oil market and the price of oil is the peak oil factor. In nearly 50 countries of the world, the production of crude oil has already reached its peak. This includes eight of the top oil producers in the world—the US peaked in 1971, Canada in 1973, Iran in 1974, Indonesia in 1977, Russia in 1987, UK in 1999, Norway in 2001, and Mexico in 2002.[7] Once worldwide oil production peaks, geopolitics and market economics will result in even more significant price increases and security risks. As production in most non-OPEC countries has already peaked, the ability of OPEC to control world oil supplies is likely to increase in the near term. In addition, OPEC is not investing sufficiently to meet the rising oil demand from emerging countries in Asia and elsewhere. As a result, spare capacity is falling continuously and making markets increasingly volatile and vulnerable to disruptions.

On the demand side, large consuming countries such as the US, European Union (EU), Japan, India, and China are increasingly becoming dependent on oil imports to meet their requirements. Further, at present, the US and most European countries obtain the bulk of their oil from non-OPEC sources. However, as the production in non-OPEC regions (such as the North Sea) is declining, all the consuming countries are progressively becoming dependent on a few OPEC countries for oil imports. The growing dependence on the same sources is increasingly stimulating intense geopolitical competition among the major importing states to strive and secure potential imports.

The expanding international trade, peaking oil production, and growing dependence of major consuming countries on a few politically difficult producing countries are likely to increase the world's vulnerability to long-term oil supply disruptions. The high cost of oil imports, the risk of sudden supply interruptions, and the insecurity about oil market conditions make oil-importing countries extremely vulnerable to such oil disruptions.

The objective of this paper is to quantify and assess the relative oil vulnerability of 26 net oil-importing countries for the year 2004 on the basis of four market risk indicators—(1) the ratio of value of oil imports to gross domestic product (GDP), (2) oil consumption per unit of GDP, (3) GDP per capita, and (4) oil share in total energy supply; and three supply risk indicators—(1) ratio of domestic reserves to oil consumption, (2) exposure to geopolitical oil market concentration risks as measured by net oil import dependence, diversification of supply sources, political risk in oil-supplying countries, and (3) market liquidity. The composite oil vulnerability index (OVI) is computed as the weighted average of these individual indicators, where weights are derived using a multivariate technique of principal component analysis (PCA). We will show that the various indicators of oil vulnerability are interrelated and that the OVI derived using principal component technique provides a composite quantitative measure of the oil vulnerability, by systematically accounting for the interactions and interdependence between the identified set of indicators. Such an index captures the sensitivity of the economies to developments in the international oil market, with a higher index indicating higher vulnerability. We also obtain the relative contribution of each indicator in the OVI on the basis of the PCA.

For this purpose, we have selected 26 net oil-importing countries from three major oil-consuming regions—Europe, North America, and Asia-Pacific—which together account for about 80% of the total world oil consumption. The countries studied include USA, Japan, Korea, Germany, India, Italy, France, China, Spain, Netherlands, Belgium, Turkey, Sweden, Greece, Poland, Portugal, Philippines, Finland, Austria, the Czech Republic, Slovakia, Hungary, Switzerland, Australia, New Zealand, and Ireland.

Previously, Amarach Consulting had developed an OVI based on three measures—the sensitivity of an economy to a rise in oil prices (using World Bank estimates), oil import dependence, and oil energy dependence (Forfas, 2006). They aggregated the above three measures by assigning equal weights. The basic advantage of using the PCA is that, unlike the conventional methods of index construction, the PCA does not assign subjective ad hoc weights to different indicators. Here, the weights are the result of multivariate statistical analysis of the proposed indicators.

[7]I am extremely grateful to one of the anonymous referees for providing this information.

The overall oil vulnerability depends upon a number of factors that need to be studied together, rather than in isolation. Unlike previous studies, this paper addresses the problem of oil vulnerability in a holistic manner, and thus, contributes significantly to the existing literature. The ranking of all the selected countries on the basis of their overall vulnerability and the individual indicators help in evaluating the vulnerability position of a given oil-consuming country vis-à-vis other oil-consuming countries. The analysis helps policy-makers in understanding the intensity of different indicators for a given economy and thus, the sensitivity of its OVI to different indicators. Appropriate sensitivity analysis of these can bring out in sharp focus the country-specific policy options and strategies that can be adopted by policy-makers for mitigating the impact of oil disruption.

The rest of the paper is organized as follows. Section 2 provides the literature review on oil vulnerability and the selected indicators to measure it. Section 3 describes the indicators and their sources. Section 4 derives the OVI using the principal component technique. Section 5 discusses the results of the PCA. Section 6 highlights the policy directions. Section 7 gives the limitations, and the way forward for constructing such an index.

2. Literature review on oil vulnerability and its indicators

The notion of oil vulnerability is multidimensional and is defined as a state that makes oil-consuming countries extremely vulnerable to international developments such as higher oil prices and oil supply disruptions. The literature on oil vulnerability highlights the fact that there are three major risks that contribute to the overall oil vulnerability of an economy—market (or economic) risk, supply risk, and environmental risk. Market risk of an economy refers to the risks of macroeconomic effects due to erratic price fluctuations in oil markets. Supply risk of an economy refers to the risks of physical disruptions in oil supplies. The environmental risk of an economy refers to the risks related to climate change, global warming, accidents, and polluting emissions due to increased oil usage. In this paper, we have focused on the first two types of risks—market risk and supply risk (Planning Commission, 2006; CIEP, 2004; INDES, 2004; IAEA, 2005; APERC, 2003).

Exposure to market risk measures the market vulnerability of economies. In this context, the World Bank has conducted two studies—'The impact of higher oil prices on low-income countries and the poor' and 'The vulnerability of African countries to oil price shocks'—highlighting the major determinants of the vulnerability of these economies to higher oil prices. A large number of studies such as UNDP/ESMAP (2005), IAEA (2005), ESMAP (2005), IEA (2004), and ORNL (2006) show that the market risk or macroeconomic effects (such as increase in inflation and unemployment and negative repercussions on balance of payments) of higher oil prices depend on the cost of oil in national income, degree of dependence on imported oil, oil consumption per unit of GDP, share of oil in energy supply, strategic petroleum oil reserves, foreign exchange reserves, and level of economic development of an economy.

High import bills relative to GDP or high oil consumption per unit of GDP result in larger macroeconomic adjustment costs (in terms of impact on inflation, unemployment, balance of payments, and so on) in the face of a given increase in the international oil price. The oil price increase (associated with supply interruption) impacts a significant part of the economy, and consequently, has a larger economic effect. Similarly, the higher the share of oil in total primary energy supply, the greater is the direct exposure of an economy to such developments. Two other important factors are the foreign exchange reserves and GDP per capita. These factors are negatively related with oil vulnerability, as they are measures of international competitiveness and thus, determine the overall paying capacity for imported oil in foreign exchange. Further, the expansion in domestic storage capabilities increase the countries' ability to bear short-run oil supply disruptions. The higher the strategic petroleum reserves, the lesser are the likely macroeconomic impacts at least in the short run. However, strategic reserves do not play a significant role in achieving oil security when disruptions are for longer duration.

Exposure to supply risks measure the supply vulnerability of economies. A large body of literature exists on the indicators for measuring oil supply risk. Factors such as level of domestic reserves relative to oil consumption and exposure to geopolitical risks determine the oil supply vulnerability of oil-importing countries. Higher is the ratio of domestic reserves relative to consumption, lower is the oil vulnerability. The ratio indicates the consumption equivalent life of the proven oil reserves (which is the number of years the reserves are expected to last if they are consumed at the current rate of consumption). Also, dependence on domestic oil supply is preferred over imported oil, as it avoids risks from geopolitical insecurities and exchange rate uncertainties. The literature on geopolitical oil supply risks makes a distinction between short- and long-term risks. Short-term risks are usually linked with supply shortfalls due to acute weather conditions, localized terrorist attacks, accidents, and other events that affect 'operational security' or 'systems security'. Long-term risks to oil security are associated with the supply shortfalls due to the major changes in the political set-up, strategic actions and policies of producing countries, large-scale damages to oil-producing facilities or reservoirs, decline in investment in oil production and transportation facilities, market failures or government failures (CIEP, 2004; INDES, 2004).

The impact of geopolitical uncertainties (such as the oil embargo of 1970 by OPEC) on an economy can be measured by a large number of indicators, such as level of imports, diversification of supply sources, political risk in the supplying countries, and market liquidity. The higher the level of imports, the greater the possibility and cost of disruption, if it occurs. The higher the geographical diversification of the supply sources, the lower is the risk associated with the loss from any particular supply source. Currently, the overall supply capacity is not substantially higher than the world demand. Any small disruption, therefore, can affect different countries differently, depending on their sources of supply. Despite the oil market being global, diversification is important as a large quantity of oil exported by producing countries is sold on term contract basis and is not available for open oil market trade. Thus, in case of a sudden oil disruption, it may not always be possible to arrange new oil supplies immediately (even by offering higher prices).[8] In addition, diversification in favour of economies that are politically more stable can further shield importing countries from geostrategic risks. Another important factor that determines geopolitical risk is the size of domestic demand relative to world supply and is termed as market liquidity. This measures the ability of a given country to switch between various suppliers (see Blyth and Lefevre, 2004; Van Hove, 1993; Neff, 1997; von Hirschhausen and Neumann, 2003; ECN, 2004; Gupta, 2007).

3. Indicators and sources

For the PCA, we have selected three supply risk indicators and four market risk indicators for the 26 net oil-importing countries for 2004.

The following are the supply indicators.

- *DoR/DoC (domestic oil reserves relative to total oil consumption)*: The first indicator is negatively related to oil supply vulnerability and is expressed as the ratio of domestic oil reserves to domestic oil consumption.[9]
- *GOR (geopolitical oil risk)*: The second indicator, which explains the oil supply vulnerability, is the exposure of an economy to geopolitical oil risks. In this paper, we focus on the long-term geopolitical risks of oil supply disruptions. Geopolitical oil risk is defined as the exposure of an economy to physical supply distortions due to strategically motivated control of supply by oil-exporting countries or breakdowns in political and economic systems[10] (such as war or government failures in the centralist political structures of producing states) (Blyth and Lefevre, 2004; CIEP, 2004; INDES, 2004; IEM, 2005).

The exposure to geopolitical risks is measured on the basis of four factors—(1) net oil import dependence of an oil-importing country, (2) diversification of oil imports, (3) political risks in oil-supplying countries, and (4) market liquidity. Neff (1997), von Hirschhausen and Neumann (2003), ECN (2004), and Blyth and Lefevre (2004) have suggested a methodology for quantifying such risks using the 'Shannon diversity index' or the 'Herfindahl-Hirschman index'. The two components of GOR are explained below:

(a) *GOMCR (geopolitical oil market concentration risk)*: The first three geopolitical risk indicators, namely, net oil import dependence, diversification of oil imports and political risks in oil-supplying countries are combined for all the selected 26 countries using the modified version of the 'Herfindahl-Hirschman market concentration index'.

First, for every consuming country, market shares for each of the country from which it imports its oil are calculated as a proportion of its total oil demand. If a consuming country also produces oil domestically, then it is considered as one of the suppliers with its share of the market determined by its' production. One should note that the net oil import dependence (which is equivalent to 1—domestic supply share) is defined as the ratio of net oil imports (defined as the sum of the net crude oil imports and net refining product imports) to the oil supply (defined as the sum of crude oil domestic production and net oil import). This is done because instead of sourcing crude oil and refining it, the refined products might be simply imported from other countries, which can significantly reduce the reliance on the crude oil deliveries. However, for calculating the market shares of oil suppliers, we have only considered the import sources of crude oil (exporting countries of refined products have not been considered) for simplicity.[11]

[8]According to portfolio risk theory there are two types of risks—systematic risks and specific risks. Systematic risks refer to the risks, which affect global oil markets as a whole, and thus, affect all the importing countries alike. Systematic risk is non-diversifiable. On the contrary, specific risk is the risk associated only with a particular or unique condition. The reasons behind this specific risk are usually very much country or region specific. For example, a natural disaster in some oil-exporting country will disrupt supply of oil from that country. Or political upheaval in a country can cause supply volatility. Risks from these situations can be diversifiable. An importing nation can shift towards other sources and can cover risk.

[9]The commonly used indicator is reserves to production ratio. We have not taken reserves to production ratio because this measure does not give a clear picture in all the cases. For instance, most European countries have very less domestic reserves along with negligible domestic production resulting in very high reserves to production ratio. On the other hand, reserves to consumption ratio will indicate the amount of reserves a country possesses relative to its requirements.

[10]To some extent oil-importing countries can reduce their geopolitical risks by establishing a long-term supply contract with countries including the politically unstable ones. However, by establishing long-term contracts, oil-importing countries can reduce the risk of the deliberate strategic actions of producing countries. But, the risk of disruption due to political turmoil still remains. For instance, in situation of war Iran may not be able to honor the contracts. Further, it can be argued that if there is any disruption, these countries can return to the spot market to secure their supplies. But, the role of spot markets is limited whenever large supplies are required on an urgent basis. It is not always possible to get right quantity and right types of crude required instantly, and thus, make countries extremely vulnerable to higher prices during the period of adjustment. I am grateful to Mr. P.K. Aggarwal and Mr. Prabir Sengupta for their useful insights on this issue.

[11]Petroleum products market is much more volatile as compared to crude oil market. However, for simplicity it is assumed that the vulnerability is same irrespective of the fact whether you import crude

Table 2
Geopolitical oil market concentration risk (GOMCR) measures

Countries	Measure 1	Rank for measure 1	Measure 2	Rank for measure 2	Measure 3	Rank for measure 3
Asia-Pacific						
Australia	29.2	22	0.039	26	0.061	26
New Zealand	84.5	17	0.157	23	0.231	23
Japan	99.2	5	0.834	1	1.416	1
Korea	99.6	3	0.579	8	0.982	7
India	69.3	19	0.316	17	0.536	17
China	47.7	21	0.049	25	0.081	25
Philippines	99.1	7	0.777	4	1.319	2
Average A (All 7c)	75.5		0.393		0.661	
Average A (3 c) Japan; Korea; Philippines	99.3		0.730		1.239	
North-America						
United States	64.1	20	0.120	24	0.196	24
Europe						
Austria	93.0	13	0.331	14	0.536	16
Belgium	100.0	1	0.270	18	0.415	18
Czech Republic	93.8	11	0.706	6	1.041	6
Finland	99.1	6	0.669	7	0.981	8
France	97.9	8	0.253	19	0.396	19
Italy	92.7	15	0.360	13	0.594	13
Spain	99.7	2	0.327	16	0.542	15
Hungary	74.3	18	0.537	11	0.791	10
Ireland	100.0	1	0.543	10	0.620	12
Netherlands	93.8	10	0.241	21	0.375	20
Poland	93.3	12	0.824	2	1.214	4
Turkey	92.9	14	0.458	12	0.764	11
Slovak Republic	89.7	16	0.791	3	1.166	5
Sweden	100.0	1	0.235	22	0.301	22
Switzerland	100.0	1	0.774	5	1.314	3
Portugal	100.0	1	0.330	15	0.552	14
Greece	99.4	4	0.550	9	0.913	9
Germany	95.7	9	0.248	20	0.358	21
Average-E (18c)	95.3		0.469		0.715	
Average-E (5c)	99.7		0.573		0.876	
Average-total (26 c)	88.8		0.435		0.681	

Notes: c denotes countries, E denotes Europe, A denotes Asia-Pacific.
Measures are explained in detail in appendix.

Secondly, for each consuming country, the degree of supply concentration is measured using modified HHI, which is defined as the sum of squares of the adjusted market shares of different oil-exporting countries. We have assumed that OPEC[12] member countries act as a single supplier. The crucial design of supply diversification entails independence of the sources. The current structure of the oil market, where production quotas for all member countries are currently defined by OPEC, oil prices are very sensitive to changes in OPEC production policies.

The market shares are adjusted for political risk in the oil-exporting countries using the International Country Risk Guide (ICRG) risk ratings.[13] The higher the GOMCR, the higher is the vulnerability of a given economy towards geopolitical uncertainties (see Tables 2 and 3).

(b) *ML (market liquidity)*: The second component of geopolitical risk is the market liquidity. Unlike Blyth and Lefevre (2004), who have measured market liquidity as the ratio of world oil supply to the oil demand of a consuming country, we have measured

(*footnote continued*)
oil or refining products. I am extremely thankful to Mr. R.K. Batra who guided me in deriving this measure.

[12]For the current paper, we have assumed that OPEC includes 11 countries: Saudi Arabia, Iran, Iraq, Kuwait, Venezuela, UAE, Algeria, Nigeria, Qatar, Libya, and Indonesia. Angola, which has joined OPEC in 2007, has been excluded.

[13]ICRG political risk ratings present a comprehensive risk structure, covering 12 important factors (with different weights) contributing towards the overall political risk in a given country. These 12 factors include government stability, socioeconomic conditions, investment profile, internal conflict, external conflict, corruption, military in politics, religious tensions, law and order, ethnic tensions, democratic accountability, and the bureaucracy quality.

Table 3
Diversification and political risk in all 26 countries for 2004

Region	Countries	Major suppliers	Dependence on OPEC[a]	Average political risks[b]
Asia-Pacific	China	DS (52%), AP (13%), A (10%), FSU (5%), ME (18%)	16.3	0.76665
	Australia	DS (71%), AP (24%), ME (5%)	9.6	0.45978
	New Zealand	DS (15%), AP (43%), ME (40%)	25.3	1.23453
	India	DS (31%), A (16%), ME (47%)	55.9	1.14252
	Korea	AP (13%), A (5%), ME (77%)	75.7	1.63746
	Philippines	AP (6%), ME (92%)	87.8	1.66965
	Japan	AP (6%), A (4%), ME (89%)	91.2	1.67054
	Average AP	DS (24%), AP (15%), A (5%), ME (52%)	51.69	1.23
North America	United States	DS (36%), NA (19%), LA (14%), A (12%), ME (14%)	31.8	0.98126
Europe	Sweden	E (61%) FSU (26%), ME (8%)	12.4	1.30370
	Germany	E (33%), A (15%), FSU (40%), ME (7%)	19.2	1.35312
	France	E (30%), A (19%), FSU (22%), ME (27%)	40.1	1.44946
	Netherlands	DS (6%), E (25%), A (5%), FSU (27%), ME (33%)	37.1	1.36712
	Belgium	E (27%), FSU (38%), ME (28%)	32.0	1.45348
	Hungary	DS (26%), FSU (73%)	0.0	1.09197
	Slovak Republic	DS (10%), FSU (89%)	0.0	1.31903
	Czech Republic	DS (6%), A (6%), FSU (84%)	5.6	1.39721
	Austria	DS (7%), E (7%), A (24%), FSU (33%), ME (28%)	46.7	1.45758
	Poland	DS (7%), FSU (91%)	0.0	1.36371
	Spain	NA (13%), E (7%), A (35%), FSU (16%), ME (27%)	52.6	1.57884
	Turkey	DS (7%), A (21%), FSU (25%), ME (46%)	62.6	1.51573
	Italy	DS (7%), E (5%), A (33%), FSU (26%), ME (28%)	53.6	1.48488
	Finland	E (17%), FSU (81%),	0.0	1.39994
	Portugal	NA (5%), E (8%), LA (8%), A (46%), FSU (15%), ME (16%)	54.2	1.56490
	Ireland	E (97%)	2.8	1.16071
	Greece	A (7%), FSU (31%), ME (61%)	67.2	1.61572
	Switzerland	E (8%), A (80%), FSU (4%), ME (8%)	87.8	1.64581
	Average E	DS (5%), E (18%), A (16%), FSU (40%), ME (18%)	31.88	1.43

DS—domestic supply, NA—North America, E—Europe; LA—Latin America; AP—Asia-Pacific; A—Africa; FSU—Former Soviet Union, ME—Middle East.
[a]While deriving GOMCR measures OPEC is considered as a single supplier as it acts as a oil cartel.
[b]Average political risk is obtained by taking weighted average of the political risk factors based on the ICRG political risk rating. The weights are the respective market shares of the different supplying countries for a given country.

market liquidity as the ratio of world oil imports to the net oil imports of a given country (as the amount which an exporting country consumes domestically is not available for trade).

The 2004 data on oil import diversification has been obtained from various sources: (1) *Oil Information 2005* for the Organization for Economic Cooperation and Development (OECD) countries (IEA, 2005), (2) *BP Statistics 2006* for China, (3) *Integrated Energy Policy 2006* for India, and (4) *Energy Statistics Yearbook 2006* for the Philippines (DESA, 2006). The data on the oil reserves, production and consumption has been taken from *BP Statistical Review 2006* and the *Energy Information Administration* (*EIA*) *2006*.

The following are the selected market risk indicators.

- *GDP/POP (GDP per capita at market exchange rate)*[14]: It is expressed as a ratio of GDP measured in US $ at 2000 exchange rate to population.
- *OI (oil intensity at market exchange rate)*[15]: It is expressed as the ratio of oil consumed in an economy (measured in tonnes) to its GDP (US$2000). Oil intensity is expressed as tonnes of oil equivalent per unit of GDP or toe/GDP
- *VOM/GDP (cost of oil in national income)*[16]: This is measured as the ratio of value of net oil imports to GDP measured at the market exchange rate. Its unit is percentage.[17]
- *OS (oil share)*: It is expressed as the ratio of oil consumption in total primary energy consumption. Its unit is percentage.

The data on GDP per capita at exchange rate, oil intensity, net oil imports, oil share and GDP has been taken from the International Energy Agency (IEA), 'Energy balances of OECD countries' statistics for the

[14]Gross domestic product/population.

[15]Oil intensity.

[16]Value of oil imports/GDP.

[17]The ratio can be factored as a product of three terms: oil imports/GDP = (oil imports/total oil use)(total oil use/total energy use)(total energy use/GDP) (UNDP/ESMAP, 2005).

OECD countries, and 'Energy balances of non-OECD countries' for the non-OECD countries. The value of oil import for an economy is computed by multiplying its net oil imports with the 2004 international crude oil price as reported in the BP (British Petroleum), 2006.[18] It is important to note that oil is internationally traded and thus, indicators at market exchange rate better reflect the macroeconomic vulnerability (Callen, 2007).

4. Constructing OVI using the PCA

The PCA is a multivariate statistical approach that transforms a set of correlated variables into a set of uncorrelated variables called components. These uncorrelated components are the linear combinations of the original variables. The underlying logic behind the PCA is to reduce the dimensionality of the data set and to transform interdependent coordinates into significant and independent ones.[19] This method was first introduced by Nagar and Basu (2002).[20]

We now briefly describe the model to compute the 'OVI'.

We interpret oil vulnerability as an unobserved or a latent variable, which cannot be observed directly. The OVI is assumed to be linearly related with the above five indicators and a disturbance term capturing error:

$$\mathrm{OVI}_K = \beta_1 X_{1k} + \beta_2 X_{2k} + \beta_3 X_{3k} + \beta_4 X_{4k} + \beta_5 X_{5k} + \beta_6 X_{6k} + \beta_7 X_{7k} + \varepsilon, \tag{1}$$

where OVI_K is the OVI of country 'k'; $X_{1k} \ldots X_{7k}$ is the set of proposed indicators corresponding to the country 'k' and ε is the error term.

Thus, the total variation in the index for oil vulnerability is composed of two orthogonal parts—variation due to proposed components and variation due to error.[21] We compute the principal components (PCs) as follows.

First, we normalize all the selected indicators and make them positively related with oil vulnerability in the following manner[22]:

$$x_{ik} = \frac{X_{ik} - \mathrm{MIN}(X_i)}{\mathrm{Max}(X_i) - \mathrm{Min}(X_i)} \tag{2a}$$

for i = GOMCR, VOM/GDP, OI, and OS

$$x_{ik} = \frac{\mathrm{Max}(X_i - X_{ik})}{\mathrm{Max}(X_i) - \mathrm{Min}(X_i)} \tag{2b}$$

for i = DR/DC, ML, and GDP/POP

The above adjustment transforms all the selected variables on the 0–1 scale. The value of 0 is assigned to the country with the lowest value of the selected oil vulnerability indicator and value of 1 is assigned to the country with the highest value of the selected indicator.

We calculate the 7×7 correlation matrix R of the normalized indicators (given in Table 4)

We then solve for the following determinantal equation:

$$|R - \lambda I| = 0 \quad \text{for } \lambda. \tag{3}$$

This gives a seventh degree polynomial equation in λ and therefore, five roots can be derived. These five roots are the eigenvalues corresponding to R. We arrange λ in descending order of magnitude, $\lambda_1 > \lambda_2 > \lambda_3 > \lambda_4 > \lambda_5 > \lambda_6 > \lambda_7$ (Table 5)

And corresponding to each value of λ, we solve the matrix equation:

$$(R - \lambda_j I)F'_j = 0, \tag{4}$$

where $F_j = [f_{1j}, f_{2j}, f_{3j}, \ldots, f_{7j}]$ is a 1×7 eigenvector corresponding to λ_j, subject to the condition that $F'_j F_j = 1$. Thus, we have seven eigenvectors F_1, F_2, F_3, F_4, F_5, F_6, and F_7, which correspond to $\lambda_1 > \lambda_2 > \lambda_3 > \lambda_4 > \lambda_5 > \lambda_6 > \lambda_7$ (Table 6).

We then compute the seven PCs by weighting normalized indicators with eigenvectors corresponding to eigenvalues $\lambda_1 > \lambda_2 > \lambda_3 > \lambda_4 > \lambda_5 > \lambda_6 > \lambda_7$ in the following manner:

Table 4
Correlation matrix (R) of normalized indicators[a]

Indicators	DR/DC	GOMCR	ML	GDP/POP	OI	GOV/GDP	OS
DR/DC	1						
GOMCR	0.4794	1					
ML	−0.0604	−0.2277	1				
GDP/POP	−0.2217	0.1375	−0.2384	1			
OI	−0.3061	0.1096	−0.0407	0.8578	1		
VOM/GDP	0.2732	0.3579	−0.0161	0.693	0.7822	1	
OS	0.3954	0.0336	0.3421	−0.4327	−0.3018	0.0434	1

[a]*Note*: All the normalized indicators are made positively related to the oil vulnerability. One should note that the ratio of domestic reserves to consumption is negatively related with the geopolitical oil market concentration risk. However, the table shows a positive correlation coefficient of 0.479. This is so because the table gives the correlation between the normalized value of DR/DC (which is made positively related to OVI) and GOMCR. The same is true for other coefficients such as correlation coefficient of .86 between OI and GDP/POP.

[18]It is difficult to derive oil import prices for individual countries and thus, for simplicity, the international oil price for 2004 is obtained by taking the average of Brent, Dubai, Nigerian Forcados, and West Texas Intermediate oil prices.

[19]For details see Jolliffe (1986), Kim and Mueller (1979), UNCTAD (2005), and Stockburger (1996).

[20]An application of this methodology is provided in Klein and Süleyman (2003), Shukla and Kakar (2006), Basu (2002, 2007) and Rahman et al. (2005).

[21]The variation in the error term is caused by the factors that could impact oil vulnerability but have not been considered, such as specific domestic policies of the countries, risks associated with the domestic oil production, and so on.

[22]All the indicators are made unidirectionally (positively) related to the oil vulnerability. Two of the five indicators, oil reserves relative to consumption and GDP per capita, are negatively related with the oil vulnerability. Thus, for these two indicators, Eq. (2b) is used.

Table 5
Eigenvalues

	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7
Eigenvalue	2.7839	1.83014	1.27893	0.543481	0.396094	0.131905	0.035551
Variability	39.77	26.14	18.27	7.76	5.66	1.88	0.51
Cumulative	39.77	65.91	84.19	91.95	97.61	99.49	100

Table 6
Eigenvectors

Indicators	F_1	F_2	F_3	F_4	F_5	F_6	F_7
DR/DC	−0.105017	0.65395	−0.120346	−0.115415	−0.625876	0.08285	0.367331
GOMCR	0.1611519	0.527149	−0.317288	0.613723	0.463917	0.054366	−0.025337
ML	−0.162095	−0.008981	0.74893	0.588575	−0.216294	0.1398	−0.000119
GDP/POP	0.5674961	−0.068912	0.028456	−0.097992	−0.066528	0.810733	−0.032752
OI	0.5596422	−0.061514	0.246682	−0.018409	0.148908	−0.368108	0.681284
VOM/GDP	0.4769322	0.348354	0.2627	−0.165818	−0.153202	−0.3714	−0.627112
OS	−0.27205	0.405585	0.439631	−0.475569	0.544249	0.199765	0.077042

$$P_{1k} = x_k F'_1, \quad \vdots \quad P_{7k} = x_k F'_7, \tag{5}$$

where, $x_k = [x_{k1}, x_{k2}, x_3, \ldots, x_7]$ is a vector of standardized indicators for country k.

The first PC accounts for the maximum variance of the original indicators. The second PC accounts for the maximum variation of the remaining variance, and so on. Maximizing variances helps to maximize information involved among the set of indicators. We compute as many PCs as the number oil vulnerability indicators and the total variation in all the selected indicators is accounted for by all PCs together. All the PCs are mutually orthogonal.

It is important to note that $\lambda_j = \text{var}\ (P_j)$ and thus $\lambda_1+\lambda_2+\lambda_3+\lambda_4+\lambda_5+\lambda_6+\lambda_7 =$ total variation in OVI. Therefore, $\lambda_j/\Sigma\lambda_j$ is equal to the proportion of total variance accounted for by P_j. Finally, the OVI is computed as a weighted sum of seven PCs, where weights are the variances of successive PCs:

$$\text{OVI}_K = \frac{\lambda_1 P_{1k} + \lambda_2 P_{2k} + \lambda_3 P_{3k} + \lambda_4 P_{4k} + \lambda_5 P_{5k} + \lambda_6 P_{6k} + \lambda_7 P_{7k}}{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7}.$$

A simple rearrangement of the weighted components of the OVI helps to express it as a weighted sum of the normalized version of the indicators and thus, enables us to work out the relative importance of the respective indicators in determining the OVI score.

5. Empirical results

5.1. Discussing OVI values

The final values of OVI for all the countries are shown in Fig. 1.The rank of 1 represents the most vulnerable country, while the rank 26 represents the least vulnerable country. The average oil vulnerability for the selected 26 countries is 0.64.

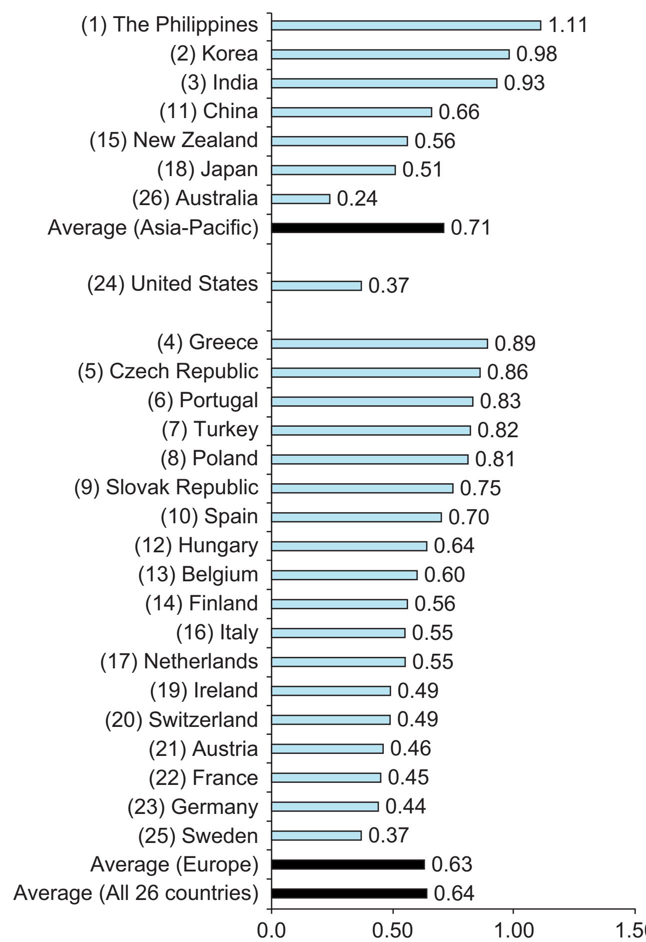

Fig. 1. Oil vulnerability index of all 26 countries (2004).

In Table 7, we have categorized the 26 countries into four homogeneous classes on the basis of their OVI values

Table 7
Grouping of the countries using univariate clustering

Most vulnerable average OVI = (1.003)	More vulnerable average OVI = (0.810)	Less vulnerable average OVI = (0.562)	Least vulnerable average OVI = (0.389)
Philippines	Greece	China	Austria
Korea	Czech Republic	Hungary	France
India	Portugal	Belgium	Germany
	Turkey	Finland	United States
	Poland	New Zealand	Sweden
	Slovak Republic	Italy	Australia
	Spain	Netherlands	
		Japan	
		Ireland	
		Switzerland	

using univariate clustering.[23] The class of 'most vulnerable' countries has an average OVI of 1 and includes three countries—Philippines, Korea, and India. The 'more vulnerable' countries, with an average OVI of 0.81, are slightly less vulnerable and include seven countries—Greece, the Czech Republic, Portugal, Poland, Turkey, the Slovak Republic, and Spain. The third tier of 'less vulnerable' countries consists of ten countries—China, Hungary, Belgium, Finland, New Zealand, Italy, the Netherlands, Japan, Ireland, and Switzerland—with an average OVI of 0.562. The fourth class of 'least vulnerable' countries has the OVI of 0.389 and consists of six countries—Austria, France, Germany, the US, Sweden, and Australia.

The above intercountry differences, with respect to the OVI, also indicate certain regional patterns. The average OVI of all the selected European countries, at 0.63, is almost equal to the all-country average OVI. The average OVI for the six European countries (in most and more vulnerable class), at 0.810, is much higher than the average OVI of the rest of the European countries (0.53 for other 12 countries).

The average OVI of all the seven Asian economies, at 0.71, is found to be somewhat higher than the European and the all-country average. However, for the three Asian economies—the Philippines, Korea, and India—the average OVI of 1 is significantly higher than the all-country and the Asian average.

5.2. *Ranking of the countries on the basis of individual indicators*

The analysis done so far is based on the aggregate OVI. However, it is important to analyse the selected indicators to understand relative positions of countries in the overall OVI. Figs. 2 and 3 give the values of individual indicators for all the selected countries in the descending order of OVI. Table 8 gives the average values of the individual indicators for the above-classified four groups. As the OVI implies, more vulnerable countries perform poorly for most of the individual indicators. The above-mentioned seven indicators are discussed below.

1. *Ratio of domestic reserves to domestic consumption*: With regard to the ratio of domestic reserves to consumption, the worst performers are European countries such as Belgium, Finland, Ireland, Sweden, Switzerland, Portugal, and Asian countries such as Korea and Japan, which have zero domestic reserves and are entirely dependent on imports for meeting their oil requirements. Australia, China, India, and the US, on the other hand, are the five best performers. On the whole, we see that the 'least vulnerable countries' with an average ratio of 2.5 perform better than all the other groups.
2. *Geopolitical oil market concentration risk*: It is seen from Table 5 that the second indicator, GOMCR, is significantly negatively related to the domestic reserves to consumption ratio with a coefficient of correlation of (−) 0.48. This is expected because the level of domestic oil reserves largely determines dependence on imported oil and thus, exposure to geopolitical oil risk. Similar to the above trend, the countries in the 'least vulnerable' with an average GOMCR of 0.308 are the best performers. The 'most vulnerable' countries lead with an average GOMCR of 0.946 and are followed by the 'more vulnerable' countries with an average GOMCR of 0.885 and the less vulnerable countries with GOMCR of 0.68. Japan has the highest GOMCR, followed by the Philippines and Switzerland. The major factors, which make these countries most geopolitically oil vulnerable, are their almost 100% import dependence, poorly diversified sources with major imports from politically difficult OPEC countries. Australia has the lowest GOMCR and is followed by China and the US (see Tables 2 and 3).
3. *Market liquidity*: The adjustment for market liquidity has a significant effect on the overall risk for the US and most Asian economies. In all the 26 countries considered, the US, followed by Japan and China, presents the worst situation with respect to market liquidity. In

[23] Homogeneity is measured using the sum of the within-class variances. To maximize the homogeneity of the classes, the sum of within-class variances is minimized. This methodology was first introduced by Fisher (1958).

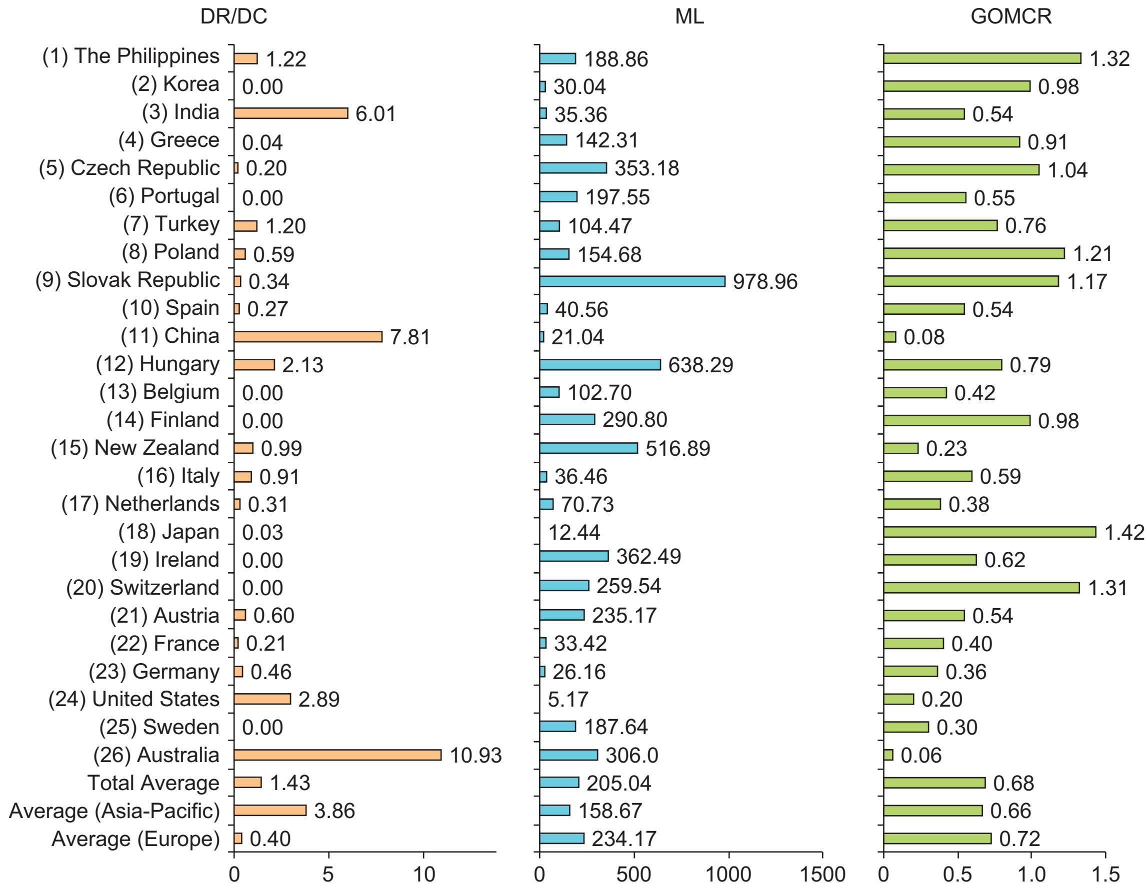

Fig. 2. Individual supply risk indicators for all 26 countries for 2004 (actual values in descending order of the OVI).

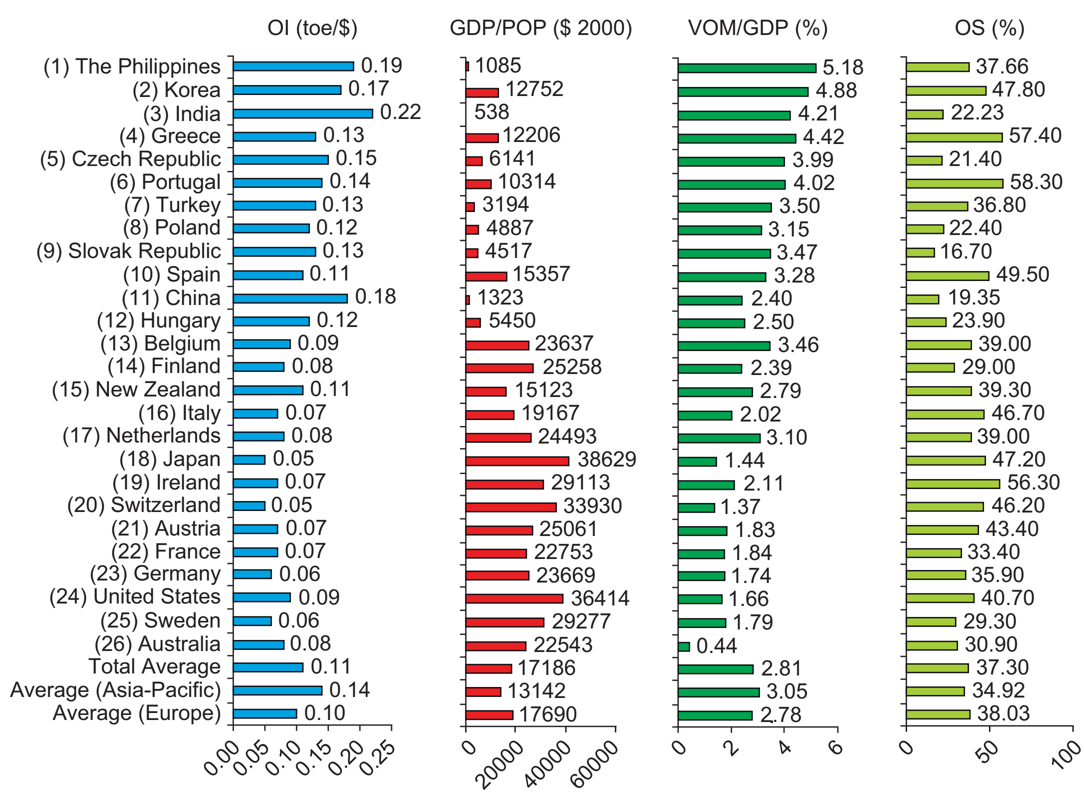

Fig. 3. Individual market risk indicators of all 26 countries for 2004 (actual values in descending order of the OVI).

Table 8

(a) Descriptive statistics of indicators (for all 26 countries)

Domain	Indicators	Mean	CV (%)	Max	Min
Supply risk	DR/DC	1.428276	1.8915343	10.93058	0
	GOMCR	0.680545	0.5889386	1.416199	0.0614643
	ML	205.0367	1.1057484	978.9614	5.170814
Market risk	GDP/POP ($ 2000)	17185.86	0.6766534	38628.71	538.2977
	OI (toe/$)	0.1089558	0.4166111	0.219098	0.0493696
	VOM/GDP (%)	2.807266	0.4249366	5.178133	0.4377757
	OS (%)	37.29732	0.3221341	58.3	16.7

(b) Descriptive statistics of indicators (group-wise)

Class	Average value indicator						
	DR/DC	GOMCR	ML	GDP/POP ($ 2000)	OI (toe/$)	VOM/GDP (%)	OS (%)
Most vulnerable	2.40801	0.945681	84.7536966	4791.506	0.190966	4.75617	35.89483
More vulnerable	0.378475	0.884509	281.67137	8088.036	0.130216	3.690466	37.5
Less vulnerable	1.21730806	0.68175	231.138051	21612.39	0.092094	2.358355	38.59457
Least vulnerable	2.51478827	0.308011	132.2688357	26619.63	0.07125	1.5505976	35.6

contrast, the market liquidity of most European countries (except Germany) is relatively higher. The adjustment has very little effect on the overall risk of most of the European economies (particularly the Slovak Republic and Czech Republic) reflecting their relatively greater ability to switch between different oil suppliers.

4. *GDP per capita (exchange rate)*: The countries display significant variability with respect to this indicator. While in the 'least vulnerable' and 'less vulnerable' countries, it is $26,619.63 and $21,612.39, respectively; in the 'more vulnerable' and 'most vulnerable' countries, it is $8088 and $4791, respectively. Japan has the highest GDP per capita, followed by the US and Switzerland. India has the lowest GDP per capita and is followed by the Philippines, China, Turkey, and Poland.
5. *Oil intensity:* The level of oil intensity is significantly negatively correlated with the level of GDP per capita (coefficient of correlation = −0.86, Table 5). This is expected because more advanced countries have more efficient and competent technologies, which enable them to sustain low levels of oil intensity.[24] Accordingly, the oil intensity for 'less' and 'least' vulnerable countries is much lower than those for 'more' and 'most' vulnerable countries. While the most vulnerable countries have an average oil intensity of 0.19, for the 'least vulnerable' countries it is almost half (0.07).
6. *Net oil imports as percentage of GDP*: The ratio of net oil imports to GDP is also significantly negatively related to the GDP per capita ($r = -0.69$) and the level of oil intensity ($r = -0.78$). The 'most vulnerable' countries have the highest net oil imports as percentage of GDP of 4.7% followed by 'more vulnerable' countries with an average of 3.69%. The other two groups perform much better with 2.36% (less vulnerable) and 1.55% (least vulnerable).
7. *Oil share in total primary energy supply*: It is observed that most of the selected countries are highly dependent on oil for meeting their energy requirements (with average oil share of about 37%). The share of oil significantly deteriorates the relative vulnerability position of most European economies (with average oil share of 38% for selected 18 countries), Japan, Korea, the Philippines, and the US. Notable exceptions to this trend include the Slovak Republic, Poland, Hungary, Czech Republic, India, and China, each deriving about 20% of their primary energy from oil in 2004.

5.3. Contribution of individual indicators in OVI

In order to obtain the relative contribution of the different indicators in the overall OVI, we obtain the coefficients of all the selected indicators on the basis of the PCs. We derive the following relationship between the

$$\mathrm{OVI}_K = \underbrace{0.26\mathrm{OI}_k + 0.297\frac{\mathrm{VOM}}{\mathrm{GDP}}k + 0.216\mathrm{GDP\ per\ capita}_k + 0.08\mathrm{OS}_k}_{\text{Market risk}} + \underbrace{0.07\frac{\mathrm{DR}}{\mathrm{DC}}k + 0.22\mathrm{GOMCR}_k + 0.11\mathrm{ML}}_{\text{Supply risk}}.$$

[24] France, Sweden, Switzerland, and Japan have about four times lower oil intensity than India.

OVI and indicators:

However, it is important to note that these coefficients should not be interpreted as the partial regression coefficients, as unlike the usual linear regression, here the dependent variable (the OVI) is not observed.

The results show that the ratio of oil imports to GDP is the largest contributor (with average share of 21.9%), followed by GDP per capita (18.63%), GOMCR (15.36%), market liquidity (14.94), oil intensity (12.8%), the ratio of domestic reserves to consumption (9.68%), and oil share in total primary energy supply (6.6%).[25] Furthermore, the four indicators—ratio of oil imports to GDP, oil intensity, GDP per capita and oil share—are highly correlated and are expected to measure market risk for a given economy. Thus, the sum of the shares (in the OVI) of these three indicators (62.49%) gives the contribution of the market risk in the OVI. The other three factors, namely, geopolitical oil market concentration risk, market liquidity and the ratio of domestic reserves to consumption are likely to determine the supply risk for a given economy. Thus, the joint share of these two indicators (37.51%) is the contribution of supply risk in the OVI.

We observe that there are significant differences among countries with regard to the respective contribution of these indicators. Fig. 4 shows the relative contribution of different indicators in OVI for all the selected 26 countries.

Fig. 5 plots all the selected countries in a market risk–supply risk score plane. Quadrant 1 represents the best scenario and is occupied by nine countries, namely, Australia, the US, Sweden, Germany, Austria, France, Ireland, the Netherlands, and Belgium. These countries have below-average vulnerability scores with respect to both types of risks. All these are economically developed, oil-efficient countries with very high paying capacity and very low cost of oil in income and therefore, have a below-average market risk. Further, they have relatively lower GOMCR due to well-diversified sources of oil supply. For instance, the US imports oil from almost all producing regions—the North Sea, Western Europe, the Middle East, Latin America, Africa, and FSU (Former Soviet Union). While Australia and the US have indigenous oil production and are relatively less dependent on imports, the European countries have very high dependence on imports. Fig. 4 shows that the ratio of domestic reserves to consumption is the major contributor to the oil vulnerability of these European countries. But their relatively lower market liquidity and GOMCR (due to well-diversified imports) enables them to attain below-average supply risks. Australia, with the lowest supply risk, is uniquely placed (at the bottom of the quadrant 1) away from the other countries.

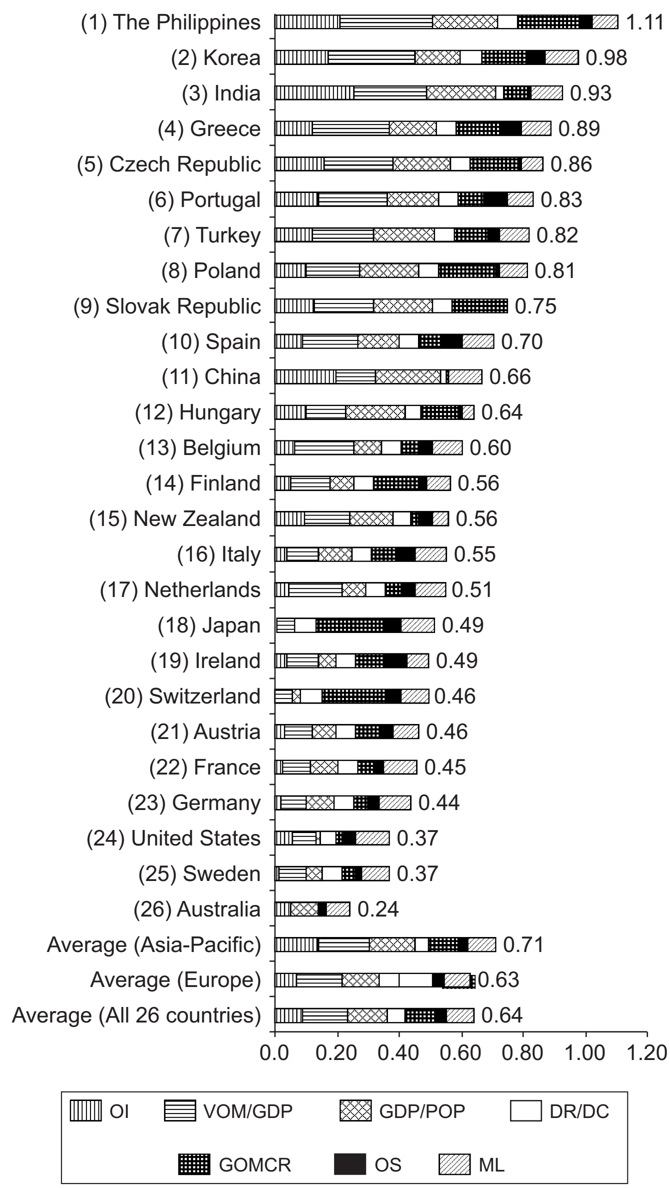

Fig. 4. Relative shares of individual indicators in the OVI of all 26 countries.

Quadrant 3, on the other hand, signifies the scenario where the occupant countries present above-average vulnerability positions with respect to supply risk as well as market risk. It consists of the two most vulnerable Asian countries, namely, the Philippines and Korea, and the six most vulnerable European countries—Greece, Turkey, Poland, the Slovak Republic, the Czech Republic, and Spain. All these countries have almost zero domestic reserves and are entirely dependent on oil imports for meeting their oil requirements. Their GOMCR is also relatively very high; except Spain and Turkey the oil imports of all others are very poorly diversified. Poland, the Slovak Republic, and the Czech Republic import over 90% of their oil from a single source—FSU. Similarly, the Philippines and Korea import about 90% and 80%,

[25]For example, in order to derive the average share of OI, the current value of OI (normalized value) for each country is multiplied by the value of the coefficient (0.26) and divided by the country's OVI value. The average of countries share of OI in OVI is then computed.

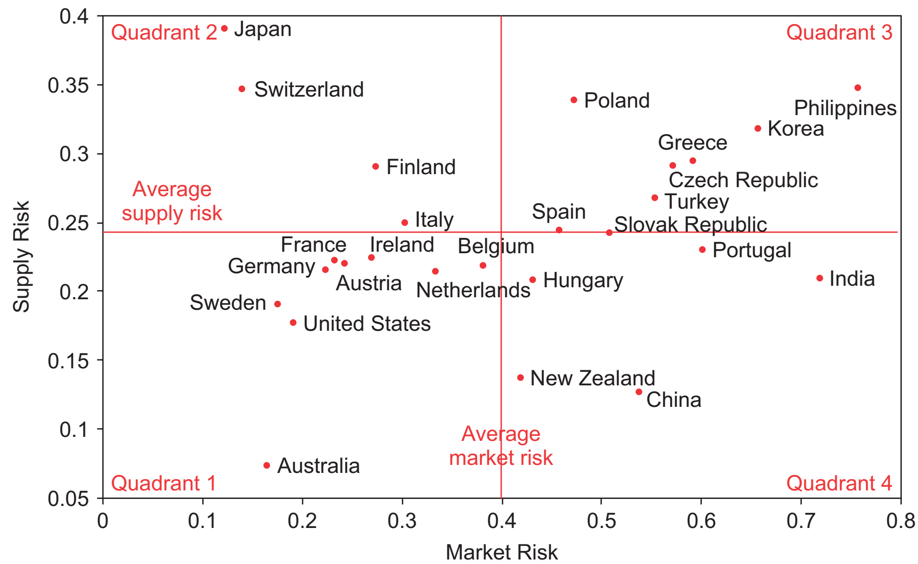

Fig. 5. Countries in the market risk and supply risk plane.

respectively from politically unstable OPEC Middle East countries. Except for Poland, the Slovak Republic, and the Czech Republic (which are about 20% oil dependent), the energy mix of all other countries is highly biased in favour of oil (Greece, Spain, and Korea derive almost 50% of their primary energy from oil). Further, these countries are also among the most vulnerable countries with respect to all the individual indicators of market risk (Fig. 3). Interestingly, the two European countries, Spain and Slovak Republic, have almost identical overall oil vulnerability scores despite differences in individual indicators. While Spain has well-diversified sources and thereby much lower GOMCR, relatively higher paying capacity as compared to the Slovak Republic, the latter's relatively higher market liquidity and lower oil share makes its OVI equivalent to that of Spain.

Quadrant 2 represents countries with an above-average supply risk but a below-average market risk. The group consists of the four 'less vulnerable' countries—Italy, Japan, Switzerland, and Finland. As discussed earlier, most of these countries are reasonably less vulnerable for all the market risk indicators but are extremely vulnerable with respect to the supply risk indicators. Japan and Switzerland are the two most oil-supply-vulnerable countries. They have almost complete dependence on imports with zero domestic reserves. Also, their imports are very poorly diversified with very high dependence on the OPEC countries (OPEC Middle East in the case of Japan and OPEC Africa in case of Switzerland). However, their exceedingly low market risk significantly lessens the overall oil vulnerability as compared to other countries in the overall index.

Similarly, in contrast to quadrant 2, quadrant 4 presents the reverse scenario. Here, the countries are characterized by below-average supply risk but above-average market risk. This includes three Asian countries—India, China, and New Zealand, and two European countries—Hungary and Portugal. Both China and New Zealand have almost equal OVI but New Zealand's import dependence and share of oil in TPES is almost double that of China. While New Zealand has much higher paying capacity and much lower oil intensity; India exhibits the second highest vulnerability with respect to the market risk (lowest GDP per capita and highest oil intensity) after the Philippines and is placed at the extreme right corner of the quadrant, with much higher supply and market risk than China. Its high macroeconomic vulnerability is only partially offset by relatively lower supply risks (as compared to the countries such as the Philippines, Korea, and Greece in quadrant 3) and makes its overall OVI lower than that of the Philippines and Korea.

6. Policy implications for sustainable development

The analysis in the previous sections shows that there are considerable differences in individual performances among the countries in terms of their final risk and individual indicators of oil vulnerability. Despite differences in individual indicators, some countries have almost identical OVI. By evaluating the basis of the variation in the overall OVI of various economies, policy-makers can identify and thus, address the problems that can cushion nations from the threat of sudden oil supply interruptions.

The OVI has a different sensitivity with respect to the individual indicators of oil vulnerability. On an average, market risk indicators turn out to be more significant than the supply risk indicators in determining the overall oil vulnerability of the selected countries. This implies that the policies aimed at improving market risk may be more effective in addressing the problem of oil vulnerability than the policies that focus on dealing with the supply risk. This is further explained by the fact that market risk is more governed by the internal factors such as oil intensity and paying capacity, which are relatively easier to address as compared to the domestic endowments of reserves or geopolitical risks (which is more determined externally such as political unrest in the supplying countries). Also, there should be greater focus on the oil conservation and substitution policies (such as reducing import demand, improving oil efficiency), which help in bringing energy demand and supply balance and thus, address both market risk and supply risk.

Further, each country requires a specific policy package because each country's OVI has a different sensitivity to the individual indicators. Thus, an oil security policy at the national level should prioritize the use of selected set of policy instruments for meeting their objective of oil security. Among the selected 26 countries, it is observed that for the most developed countries supply risk is relatively higher than the market risk, while for the less developed countries market risk is relatively higher than the supply risk. The two most developed countries, namely, Japan and Switzerland, have the highest supply risk but the lowest market risk. Thus, for these economies it may be pragmatic to adopt policies to reduce their supply risk, in particular, their GOMCR (by measures such as diversifying their sources). The results show that 10% reduction in the GOMCR of Japan reduces its OVI by about 4.3%. Similarly, we observe that India has the second highest market risk and its supply risk is the sixth lowest. One immediate option for India's energy security planners is to give priority to encourage more efficient use of oil. In case of India, 10% reduction in oil intensity reduces its OVI by about 8% (also see Figs. 4 and 5).

Besides, Fig. 5 displays that the coordinates of some countries, such as Austria, the Netherlands, Ireland, Germany, Belgium, and France in quadrant 1; Turkey, Slovak Republic, and Spain in quadrant 3; New Zealand and Hungary in quadrant 4; or Italy in quadrant 2, are very close to the coordinate representing the all-country average of market risk and supply risk. Thus, even a marginal change in their vulnerability scores can change their quadrant location. More specifically, with appropriate energy policies it is possible for the countries (Slovak Republic and Spain) in quadrant 3, the worst scenario, to move to quadrant 1, the best situation or quadrant 4. At the same time, inappropriate policies can push the countries representing the best scenario into the quadrant representing the worst scenario. On the other hand, countries that are quite far from the average risk point, such as India and China in quadrant 4; Greece, Korea and the Philippines in Quadrant 3, require a substantial improvement in their respective vulnerable indicators to move to a better quadrant.

Overall, the global oil security will require an integrated energy policy approach, addressing both oil supply and oil consumption sustainability, at national and international levels. At the national level, we see that the policies that can reduce oil vulnerability can be broadly classified into two groups—one that reduces market risk and the other that deals with the supply risk. At the same time, the selection of the policy tool is also dependent on the time frame of implementing a policy tool such as short term, medium term or long term.

First, policy tools which can reduce overall oil supply risk include reducing oil import demand by restraining such demand, increasing investments in exploration and domestic production, and diversifying supply sources and fuel choices. In the very short run, physical controls such as rationing oil supplies or banning the use of cars during some periods and cutting wastage through education and awareness are the most effective strategies for reducing the impact of oil supply disruptions.

In the short to medium-term, there is not much that can be done with respect to the ratio of domestic reserves to consumption (life of the reserves) or amounts of imports and thus, the diversification of oil supply sources is a more feasible option for dealing with such risks.[26] In this regard, it may be pragmatic for the consuming countries (particularly the Asian economies) to reduce their dependence on OPEC countries. These countries could diversify their import sources in favour of relatively more secure regions such as FSU and the Caspian Sea, or work at seeking improvements in geopolitical relationships through consumer–consumer or consumer–producer dialogues, social investments in oil-producing countries, and oil equity (Gupta, 2007).

In the medium to long term, the best policy measures should induce reduction in overall oil dependence through procedures that help in improving oil efficiency. For instance, technological changes that reduce specific energy consumption in oil-intensive activities should be encouraged (such as reducing usage of oil in transportation by replacing existing fleet of vehicles with fuel-efficient vehicles). Oil demand should be made more responsive to prices and subsidies on the petroleum products should be minimized (subsidies distort market signals and divert limited government resources to inefficient use). Further, oil efficiency requires transformation in the lifestyles of the people such as increasing use of public transport for mass transit.

Other measures in the long run include diversifying energy choices by increasing use of alternative fuels (higher oil prices make these fuels economically competitive) such as renewable energy (wind, wave, and tidal energy), biofuels (ethanol from sugar cane is a mandatory blend with petrol in Brazil and the US, biodiesel is mixed with diesel but needs plantations like jatropha) and enhancing investments in domestic exploration and production activities.

[26]First, most of the Asian and European economies such as Japan, Korea, Philippines, Belgium, and the Slovak Republic have no indigenous reserves and are entirely dependent on imports for meeting their requirements. Other countries such as the US, China, and India have only limited reserves and thus, domestic supply increase would be achieved at very high costs. Secondly, the economic cost of eliminating oil imports by reducing oil consumption would be enormous.

Secondly, policies that can be adopted to reduce market risk or overall macroeconomic vulnerability include measures such as increasing strategic petroleum reserves, building foreign exchange reserves, and promoting exports to oil-producing countries. Thus, for sustainable development, energy planning should be closely integrated with the overall economic planning.

At the international level, sustainable development of oil resources requires greater cooperation among the consuming countries (such as the EU, US, India, China, and Japan) as this will help in reducing the negotiating stance of oil-exporting countries. For instance, joint bids for oil exploration fields, which reduce the potential geopolitical competition among the consuming countries could be encouraged. Apart from this, there is a need for greater collaborations and commitments among the consuming countries to build joint strategic oil stocks. Coordinated use of strategic oil stocks is one of the most important means to mitigate oil supply disruptions in the short run. IEA member countries manage global emergency oil-sharing systems. The inclusion of more countries such as India and China (where the oil demand increase is likely to be highest) would benefit global oil security by minimizing overall costs of disruptions. Also, bilateral and regional cooperation with respect to the oil-sharing mechanisms would reduce potential conflicts among countries.

Further, developed nations should invest heavily in the research and development of advanced energy technologies such as hydrogen and carbon sequestration, which could reduce growth in oil consumption, as well as the environmental impacts of energy production and use. They should also share information on energy efficiency policies and transfer technology to developing countries (which in general are relatively more oil-intensive as they do not have access to efficient technologies).

There is a need for expansion in cross-border trade in all energy types such as natural gas and nuclear energy. This would help countries in diversifying their energy mix away from oil, with better access to other energy resources.

Also, global oil security requires sustainable international investments in oil development in oil-producing countries. For this, the consuming countries should assist the economically and politically unstable producing countries in overcoming their difficulties and in creating conditions that facilitate greater transparency and good governance. To achieve global oil market stability, there is a need to increase volumes of oil from all oil-rich areas outside OPEC such as the Caspian Sea and Russia.

7. Conclusion

While the above analysis has provided us with interesting insights, it has a number of limitations. First, this paper explores the inter-relationship between seven observed indicators of oil vulnerability. However, the analysis can benefit from the inclusion of more factors. Due to data limitations, we have not considered some factors such as strategic petroleum reserves, country-specific energy policies, ability of the countries to substitute oil by domestic fuels, availability of refining facilities, and foreign exchange reserves. Apart from these, environmental risks have also not been considered. Furthermore, there are quite a few areas in which improvements in data and methods are desirable. For instance, the analysis does not incorporate geopolitical risks due to factors such as infrastructural breakdowns (chokepoints vulnerability, terrorist attacks on the infrastructures or natural disasters). We have assumed that domestic production is free from supply risk. However, disruptions in domestic production (due to factors such as strikes or infrastructure-related breakdowns in domestic oil industry) should also be addressed. Secondly, policy reform is a dynamic process as it changes over a period of time. The scope of the current OVI is limited as it is static (constructed for the year 2004). For instance, cross-sectional study limits the possibility of looking at the issue by including changes in demand resulting from the high economic growth. Thus, the further work should look at the OVI in a dynamic framework. Nonetheless, it is hoped that this analysis contributes to a better understanding of intercountry variations in oil vulnerability and the factors responsible for such differences. In addition, any work in the future should seek to extend the current index of oil vulnerability to the total energy (gas, coal, etc.) vulnerability that also incorporates environmental risks, and emphasis may be given to increasing country coverage.

Acknowledgements

This paper is based on an ongoing study 'Assessing the relative oil vulnerability of oil-importing countries', developed as a part of the research under the project titled 'Building an energy-secure future for India through a multistakeholder dialogue process', supported by the Nand and Jeet Khemka Foundation. The author gratefully acknowledges other contributors to the study—Mr. Anandajit Goswami, Mr. Prabir Sengupta, Mr. R.K. Batra, Mr. P.K. Aggarwal, Dr. Puneet Chitkara, Dr. Ligia Noronha, Dr. Nilanjan Ghosh, Dr. Hari Nagarajan, Mr. Pavel Chakorvorty, Devika Sharma, Ms. Arshi Ahmad, Mr. Saptarishi Mukherjee, Mr. Nitya Nanda, and Dr. Ritu Mathur—for their inputs and guidance. The author is extremely grateful to both the anonymous referees for their valuable comments on this paper. The author would like to thank Mr. M.K. Bineesan for his assistance in data operations.

Appendix. Illustration for explaining GOMCR (case of India)

In 2004, India imported 69.3% of its total oil. India's geopolitical oil market risk (GOMCR) is obtained in the following manner:

Step 1: Computing market shares.

The following are the market shares of various suppliers for India:

Domestic supply—30.7%, OPEC—56%, Malaysia—2.5%, non-OPEC Middle East—3%, Mexico—1.6%, Angola—1.7%, Egypt—1.5%, Brazil—0.2%, Ecuador—0.1%, FSU—0.1%, Oman—0.1%, Cameroon—0.24%, Gabon—0.2%, and non-specified—2.2%.

Here, the share of domestic production reduces the market shares of other suppliers and thus the GOMCR tends to favour countries with higher domestic production. Thus, import dependence represents first measure of geopolitical oil supply risk.[27]

Step 2: Deriving second measure of geopolitical risk.

The import dependence is combined with the concentration of the imports sources (using the HHI of market concentration).[28]

In this example it implies

$$\begin{aligned}\mathrm{HHI} = {} & 0.56^2 + 0.025^2 + 0.03^2 + 0.016^2 \\ & + 0.017^2 + 0.015^2 + 0.002^2 + 0.001^2 \\ & + 0.001^2 + 0.001^2 + 0.0024^2 + 0.002^2 \\ & + 0.022^2 = 0.3.\end{aligned}$$

Step 3: Adjusting second measure with the political risk in supplying countries.

International Country Risk Guide (ICRG) political risk ratings ranges between 0 for high risk and 100 for low risk. The risk ratings (for various supplying countries) given by ICRG are first expressed as a proportion of 100 (maximum stability) and then the reciprocal of this figure is used as the political risk factor. This is done to derive a parameter, which moves in the direction of the overall index.[29] For instance, in the case of OPEC, which has the average political risk rating[30] of about 59, the political risk factor is obtained in the following manner:

Political risk factor corresponding to OPEC $= 1/(59/100) = 1.69$. Likewise, political risk is calculated for all other sources.

Thus, third measure of geopolitical risk

$$\begin{aligned} & = 0.56^2 \times 1.69 + 0.025^2 \times 1.3 + 0.03^2 \times 1.6 \\ & \quad + 0.016^2 \times 1.37 + 0.017^2 \times 1.74 + 0.015^2 \times 1.5 \\ & \quad + 0.002^2 \times 1.5 + 0.001^2 \times 1.72 + 0.001^2 \times 1.47 \\ & \quad + 0.001^2 \times 1.3 + 0.0024^2 \times 1.77 + 0.002^2 \times 1.65 \\ & \quad + 0.022^2 \times 1 = 0.536.\end{aligned}$$

[27] Net oil import dependence is defined as the ratio of net oil imports (defined as the sum of the net crude oil imports and net refining product imports) to the oil supply (defined as the sum of crude oil domestic production and net oil import).

[28] Here we have only considered import sources of the crude oil.

[29] For details refer to Blyth and Lefevre (2004).

[30] The political risk of OPEC is obtained by taking the weighted average of the political risk in the individual member countries. Here, the percentage of the total OPEC reserves held by each member is used as the weight for each country.

The above three measures of geopolitical oil risk for the selected 26 countries are given in Table 2.

References

APERC (Asia Pacific Energy Research Centre), 2003. Energy Security Initiative: Some Aspects of Oil Security. Institute of Energy Economics, Tokyo.

Basu, S.R., 2002. Does governance matter? Some evidence from Indian states. Paper presented at the VIIth Spring Meeting of Young Economists, Paris, 18–20 April 2002.

Basu, S.R., 2007. Comparing China and India: is dividend of economic reforms polarized? Graduate Institute of International Studies HEI Working Paper No. 01/200, Geneva.

Blyth, W., Lefevre, N., 2004. Energy Security and Climate Change Policy Interactions: An Assessment Framework. IEA (International Energy Agency), Paris [Information Paper].

BP (British Petroleum), 2006. BP Statistical Review of World Energy 2006. BP, London.

Callen, T., 2007. PPP versus the market: which weight matters? International Monetary Fund 44 (1), 1–4.

CIEP (Clingendael International Energy Programme), 2002. Study on Energy Supply Security and Geopolitics. Institute for International Relations 'Clingendael', The Hague.

DESA (Department of Economic and Social Affairs), 2006. Energy Statistics Yearbook 2003. DESA, United Nations.

ECN (Energy Research Centre of the Netherlands), 2004. Designing Indicators of Long-term Energy Supply Security. ECN, Petten.

EIA (Energy Information Administration), 2007. International Energy Outlook 2007. EIA, Washington, DC.

ESMAP (Energy Sector Management Assistance Program), 2005. The vulnerability of African countries to oil price shocks: major factors and policy options: the case of oil importing countries. Details available at 〈www.esmap.org〉.

Forfas, 2006. A Baseline Assessment of Ireland's Oil Dependence: Key Policy Considerations. Forfas, Dublin, Ireland.

Gupta, E., 2007. Geopolitical oil vulnerability of oil importing countries. Energy Security Insights 2(1), in press.

IEA (International Energy Agency), 2004. Analysis of the impact of high oil prices on the global economy. Details available at 〈http://www.iea.org/Textbase/Papers/2004/High_Oil_Prices.pdf〉, last accessed on 10 October 2007.

IEA (International Energy Agency), 2005. Oil Information 2005. IEA, Paris.

IEA (International Energy Agency), 2006a. Energy Balances of Non-OECD Countries 2006. IEA, Paris.

IEA (International Energy Agency), 2006b. Energy Balances of OECD Countries 2006. IEA, Paris.

IEA (International Energy Agency), 2006c. World Energy Outlook 2006. IEA, Paris.

IAEA (International Atomic Energy Agency), 2005. Energy Indicators for Sustainable Development: Guidelines and methodologies. United Nations Department of Economic and Social Affairs, Vienna. Details available at 〈http://www-ub.iaea.org/MTCD/publications/PDF/Pub1222_web.pdf〉, last accessed on 20 October 2007.

IEM (International Energy Markets), 2005. Security of energy supply: comparing scenarios from a European perspective. Social Science Research Network Electronic Paper Collection. Details available at 〈http://ssrn.com/abstract=758225〉, last accessed on 10 October 2007.

INDES, 2004. Market-based options for security of energy supply [INDES working paper No.1/March 2004].

International Country risk guide, 2004–05. http://www.prsgroup.com/FreeSamplePage.aspx.

Jolliffe, T., 1986. Principal Component Analysis, Springer Series in Statistics. Springer, New York.

Kim, J.-O., Mueller, C.W., 1979. Factor Analysis Statistical Methods and Practical Issues [Series/Number 07-014, 88]. Sage Publications, London.

Klein, L.R., Süleyman, O., 2003. The estimation of China's economic growth rate. Journal of Economic and Social Measurement 28 (4), 187–202.

Nagar, A.L., Basu, S.R., 2002. Infrastructure development index: an analysis for 17 major Indian states. Journal of Combinatorics, Information and System Science 27, 185–203.

Neff, T., 1997. Improving Energy Security in Pacific Asia: Diversification and Risk Reduction for Fossil and Nuclear Fuels. Centre for International Studies, Massachusetts Institute of Technology, Cambridge, USA.

ORNL (Oak Ridge National Laboratory), 2006. The Oil Security Metrics Model: a tool for evaluating the prospective oil security benefits of Doe's energy efficiency and renewable energy R&D programs. ORNL, Oak Ridge, TN, USA (Report No. ORNL/TM-2006/505).

Planning Commission, 2006. Energy Security In Integrated Energy Policy. Planning Commission, Government of India, New Delhi, pp. 54–67.

Rahman, T., Mittelhammer, C., Wandschneider, P., 2005. Measuring the Quality of Life Across Countries: a sensitivity analysis of well-being indices. United Nations University and WIDER (World Institute For development Economic Research), USA [Research Paper No. 2005/06].

Shukla, R., Kakar, P., 2006. Role of science and technology, higher education and research in regional socio-economic development. Working Paper, NCAER.

Stockburger, D., 1996. Multivariate Statistics: Concepts, Models, and Applications. Missouri State University, Springfield, MO.

UNCTAD (United Nations Conference on Trade and Development), 2005. Trade and Development Index; Developing Countries in International Trade 2005. UNCTAD, Geneva.

UNDP/ESMAP (United Nations development programme/world Bank Energy Sector Management Assistance Program), 2005. The Impact of Higher Oil Prices on Low Income Countries and on the Poor. ESMAP, Washington, DC.

Van Hove, L., 1993. Diversification of energy imports and security of supply: the case of six West European countries. CFEC Paper No. 93-05, May 1993.

von Hirschhausen, C., Neumann, A., 2003. DIW Berlin (German Institute for Economic Research) security of gas supply: conceptual issues, contractual arrangements, and the current EU situation. INDES Workshop, Amsterdam, 6–7 May 2003, 〈http://www.ecn.nl/fileadmin/ecn/units/bs/INDES/indes-ch.pdf〉.

Further Reading

Asfi, M., Muneer, T., 2005. Energy supply, its demand and security issues for developed and emerging economies. Renewable and Sustainable Energy Reviews 11 (7), 1388–1413.

Bentley, R.W., 2002. Global oil and gas depletion: an overview. Energy Policy 30, 189–205.

Cleveland, C.J., Kaufmann, R.K., 2003. Oil supply and oil politics: deja vu all over again. Energy Policy 31, 485–489.

Correlje, A., van der Linde, C., 2006. Energy supply security and geopolitics: a European perspective. Energy Policy 34, 532–543.

Deese, D.A., 1979. Energy: economics, politics, and security. International Security 4 (3), 140–153.

Energy Modeling Forum, 1982. World Oil Summary Report. Stanford University, California.

FICCI (Federation of Indian Chambers of Commerce and Industry), 2005. Impact of high oil prices on the Indian economy. Details available at 〈http://www.ficci.com/studies/study_on_oil_price_impact__may_17.pdf〉, last accessed on 15 October 2007.

Jaffe, A., Wilson, W., 2005. Energy Security: Oil-geopolitical and Strategic Implications for China and the United States. James A Baker III Institute for Public Policy, Rice University, Houston, TX.

Lindsay, S., 2002. A tutorial on principal component analysis. Details available at 〈csnet.otago.ac.nz/cosc453/student_tutorials/principal_components.pdf〉, last accessed on 18 October 2007.

Munasinghe, M., 1990. Energy Analysis and Policy. Butterworths, Kent, London.

Noronha, L., Sudarshan, A., Dasgupta, M., 2006. Contextualizing India's Energy Security. TERI (The Energy and Resources Institute), New Delhi.

Salameh, M.G., 2003. Quest for Middle East oil: the US versus the Asia-Pacific region. Energy Policy 31 (11), 1085–1091.

Sen, S., Babali, T., 2006. Security concern in the Middle East for oil supply: problems and solutions. Energy Policy 35 (3), 1517–1524.

Sihag, A.R., Chatterji, S., Khetan, A., 2002. Vulnerability of the Indian economy to tensions in the Middle East: impacts and responses. Pacific and Asian Journal of Energy 12 (1), 7–22.

Singh, M.P., Acharya, A., Somasundram, P., Chang, Y.H., Ruey, J.L.S., Shiping, T., Katsumata, H., Ivanov, V.I., 2006. Energy and Security: the Geopolitics of Energy in the Asia–Pacific. Institute of Defence and Strategic Studies, Nanyang, Singapore.

Sterling, 1999. On economic and analysis of diversity. SPRU Electronic Working Paper Series Paper No. 28.

USGAO (United States General Accounting Office), 1996. Energy security—evaluating US vulnerability to oil supply disruptions and options for mitigating their effects. Report to the Chairman, Committee on the Budget, House of Representatives, USA.