2011

The IEA Model of Short-term Energy Security (MOSES)

Primary Energy Sources and Secondary Fuels

International Energy Agency

Jessica Jewell

WORKING PAPER

2011

The IEA Model of Short-term Energy Security (MOSES)

Primary Energy Sources and Secondary Fuels

International Energy Agency

Jessica Jewell

WORKING PAPER

INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.

IEA member countries:

Australia
Austria
Belgium
Canada
Czech Republic
Denmark
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Japan
Korea (Republic of)
Luxembourg
Netherlands
New Zealand
Norway
Poland
Portugal
Slovak Republic
Spain
Sweden
Switzerland
Turkey
United Kingdom
United States

The European Commission also participates in the work of the IEA.

International Energy Agency
9 rue de la Fédération
75739 Paris Cedex 15, France

www.iea.org

Table of Contents

Acknowledgements ... 5

Overview ... 6

General model description ... 7

Background ... 7
Scope and purpose ... 7
Energy systems approach ... 7
Framework of analysis: dimensions of energy security ... 8
Identifying indicators ... 10
Combining and interpreting indicators ... 11
Limitations and future work ... 13

Evaluation of individual sources and fuels ... 15

Crude oil ... 15
Oil products ... 18
Natural gas ... 25
Coal ... 29
Biomass and waste ... 31
Geothermal, hydropower, solar, wind and ocean energy ... 36
Nuclear power ... 37

Conclusions ... 41

Country abbreviations ... 42

References ... 43

List of Figures

Figure 1 Energy systems approach ... 8
Figure 2 Energy security profiles ... 13
Figure 3 Crude oil: steps for assessing security of supply ... 17
Figure 4 Oil Products: steps for assessing security of supply ... 21
Figure 5 Natural gas: steps for assessing security of supply ... 27
Figure 6 Coal: steps for assessing security of supply ... 30
Figure 7 Biomass and waste: steps for assessing security of supply ... 33
Figure 8 Biofuels: steps for assessing security of supply ... 33
Figure 9 Nuclear power: steps for assessing security of supply ... 40

List of Tables

Table 1 Dimensions of energy security addressed in MOSES ... 10
Table 2 Table of risk and resilience indicators used in MOSES ... 11
Table 3 Crude oil: indicators ... 15
Table 4 Crude oil: ranges for indicators ... 16
Table 5 Crude oil: aggregating indicators for external resilience ... 17
Table 6 Crude oil: security profiles ... 18

Table 7	Oil products: indicators	19
Table 8	Oil products: ranges for indicators	20
Table 9	Oil products: vulnerability from crude oil supply and refinery flexibility	21
Table 10	Oil products: vulnerability for domestically refined products	21
Table 11	Oil products: external resilience	22
Table 12a	Oil products: gasoline import deficit	22
Table 12b	Oil products: middle distillates import deficit	22
Table 12c	Oil products: other import deficit	23
Table 13a	Oil products: gasoline total flow vulnerability	23
Table 13b	Oil products: middle distillates total flow vulnerability	23
Table 13c	Oil products: other oil products total flow vulnerability	23
Table 14a	Oil products: gasoline security profiles	24
Table 14b	Oil products: middle distillates security profiles	24
Table 14c	Oil products: other oil products security profiles	25
Table 15	Natural gas: dimensions of energy security and indicators	25
Table 16	Natural gas: ranges for indicators	26
Table 17	Natural gas: import infrastructure rating	27
Table 18	Natural gas: external resilience for highly import-dependent countries	27
Table 19	Natural gas: send-out capacity and external resilience	28
Table 20	Natural gas: security profiles	28
Table 21	Coal: dimensions of energy security and indicators	29
Table 22	Coal: ranges for indicators	29
Table 23	Coal: external resilience of supply	31
Table 24	Coal: summary of findings on security of supply	31
Table 25	Biomass and waste: dimensions of energy security and indicators	31
Table 26	Biomass and waste: ranges for indicators	32
Table 27	Biofuels: dimensions of energy security and indicators	32
Table 28	Biofuels: ranges for indicators	32
Table 29	Biofuels: external resilience for imports	34
Table 30a	Bioethanol: exposure to disruptions of external supply	34
Table 30b	Biodiesel: exposure to disruptions of external supply	34
Table 31	Biofuels: security of domestic production	35
Table 32	Biomass and waste: summary of findings on security of supply	35
Table 33a	Bioethanol: summary of findings on security of supply	35
Table 33b	Biodiesel: summary of findings on security of supply	35
Table 34	Hydropower: indicators for evaluating vulnerability	36
Table 35	Hydropower: security profiles	37
Table 36	Nuclear power: dimensions of energy security and indicators	38
Table 37	Nuclear power: ranges for indicators	39
Table 38	Nuclear power: evaluating risk exposure for security of supply	39
Table 39	Nuclear power: evaluating resilience capacity for security of supply	39
Table 40	Nuclear power: summary of findings on security of supply	40

List of boxes

Box 1	MOSES in the context of existing energy security studies	9

Acknowledgements

The Model of Short-term Energy Security was researched by a project team of the Directorate of Energy Markets and Security of the IEA. This Working Paper was written by Jessica Jewell. James Simpson started the work on MOSES and was responsible for setting up the data collection system. The author would like to thank Aad van Bohemen, Head of the Emergency Policy Division for his unflagging support and critical eye. Didier Houssin, Director of Energy Markets and Security provided strategic guidance and commitment. Doug Cooke, Laszlo Varro, Paolo Frankl, Anne-Sophie Corbeau, Julius Walker, Carlos Fernandez-Alvarez, Robert Arnot, Alexander Antonyuk, Toril Bosoni, Zuzana Dobrotková, Simon Müller, Adam Brown, Hugo Chandler all provided invaluable feedback on earlier versions of the MOSES concept as well as input to the indicator selection. Graphic design and layout was provided by Muriel Custodio, Bertrand Sadin, Angela Gosmann and Davina Till.

Overview

Ensuring energy security has been at the centre of the IEA mission since its inception. Founded in response to the oil crisis of 1973, the IEA initially focused on oil supply security. While the security of oil supplies remains important, contemporary energy security policies must address all energy sources and cover a comprehensive range of natural, economic and political risks that affect different energy sources, infrastructures and services. Due to this greater complexity, rigorous and comprehensive analysis of national energy security is increasingly important for informing energy policies.

In response to this challenge, the IEA is currently developing a Model of Short-Term Energy Security (MOSES), which evaluates and compares the energy security of IEA countries. MOSES does not rank countries from most to least secure; it defines countries' energy security profiles and groups countries with similar combinations of risks and resilience factors. This evaluation is based on a set of quantitative indicators that reflect both the risks of energy supply disruptions and an energy system's resilience, or ability to cope with such disruptions.

MOSES has been used to analyse security of supply of seven primary energy sources (crude oil, natural gas, coal, bioenergy and waste, hydropower, geothermal energy, & nuclear power) and two groups of secondary fuels (oil products and biofuels). The IEA is in the process of extending the analysis to electricity and end uses, which will be reflected in subsequent versions of MOSES.

MOSES involves a novel approach which combines indicators of energy security in a systematic, transparent and policy-relevant way. It highlights vulnerabilities of energy systems in IEA countries and can be used to track the evolution of a country's energy security profile. Policy makers and analysts can use MOSES to identify energy policy priorities by assessing the effects of different policies on a country's energy security. MOSES can serve as a starting point for studies of national energy security by providing a systematic, generic assessment framework that can be complemented by nationally relevant indicators and considerations. MOSES also allows for comparison of national energy security challenges in order to identify common strategies and responses and facilitate exchanges of information and policy experience among countries.

This paper provides a detailed description of MOSES. It first explains the general principles, the framework of analysis and lists the indicators used. The following sections describe the process and results of evaluating security of supply for seven primary energy sources and two secondary fuels. Each section devoted to an energy source or fuel starts by presenting indicators and the bands used for classifying risks and resilience capacities as high, medium and low. It then describes how the indicators are combined, and presents the resulting classification of IEA countries according to their energy security profiles related to these fuels. Readers interested in a short overview of MOSES are invited to read the brochure *Measuring short-term energy security*.

General model description

Background

Historically, energy security was primarily associated with oil supply. While oil supply remains a key issue, the increasing complexity of energy systems requires systematic and rigorous understanding of a wider range of vulnerabilities. Disruptions can affect other fuel sources (*e.g.* droughts causing a drop in hydroelectricity availability), infrastructure (*e.g.* technical failures affecting pipelines or power plants), or end-use sectors (*e.g.* sudden surges in demand for heat or electricity during extreme weather events). Thus, analysis of a country's oil import dependency, suppliers and emergency stocks is no longer sufficient for understanding its energy security situation.

The IEA has responded to this challenge by developing a comprehensive perspective on energy security that extends beyond oil to monitor and analyse all aspects of the energy system. This paper presents a tool designed by the IEA to analyse short-term energy security of its member countries. The IEA Model of Short-term Energy Security (MOSES) aims to help IEA countries understand their energy security profiles in order to identify energy policy priorities.

Scope and purpose

MOSES focuses on short-term energy security: vulnerability to physical disruptions that can last for days or weeks. Taking an energy systems approach, described in the next section, MOSES identifies a set of indicators for external risks (from energy imports) and for domestic risks (from transformation and distribution) as well as for resilience – a country's capacity to deal with different types of disruptions.

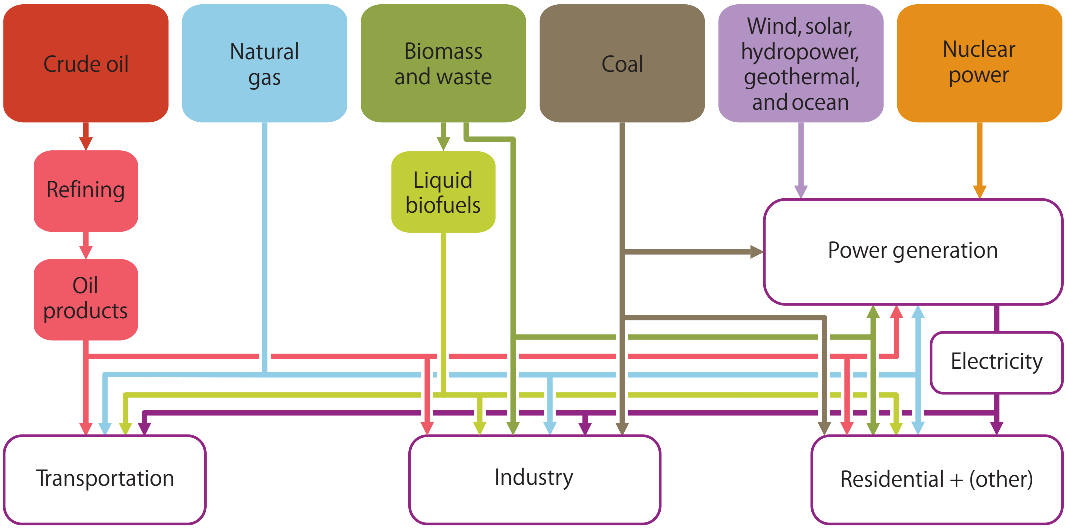
The first version of MOSES (Primary Energy Sources and Secondary Fuels) presented in this paper covers seven primary sources (crude oil, natural gas, coal, biomass and waste, hydropower, geothermal energy and nuclear power) and two sets of secondary fuels (oil products and liquid biofuels). The IEA is working to extend the analysis to power generation and end-uses of energy, which will be reflected in subsequent versions of MOSES.

MOSES highlights vulnerabilities of energy systems and can be used to track the evolution of a country's energy security profile. Policy makers and analysts can use MOSES to identify energy policy priorities by assessing the effects of different policies on a country's energy security. MOSES can serve as a starting point for studies of national energy security by providing a systematic, generic assessment framework that can be complemented by nationally relevant indicators and considerations. MOSES also allows for international comparison and interpretation of national energy security challenges in order to identify common strategies and responses and facilitate exchanges of information and policy experience among countries. The overall purpose of MOSES is to provide a basis for understanding the broader energy security landscape for IEA countries.

Energy systems approach

MOSES takes an energy systems approach, dealing with all parts of the energy system from supply to transformation, distribution and end-use energy services. For energy security, this means understanding how vulnerabilities of different parts of the system may affect energy services. In its current version, MOSES starts by analysing vulnerabilities of primary energy sources and assessing how these affect the security of secondary fuels. This version also lays the groundwork for extending the analysis to security of electricity and end-use sectors.

Figure 1 Energy systems approach



Note: This paper only discusses primary sources and two groups of secondary fuels (solid in figure). Analysis of power generation, electricity and end-uses is still under development.

By helping policy makers identify and understand strengths and weaknesses of a particular energy system, this systematic approach can be used to formulate strategies and policies for decreasing vulnerabilities and increasing resilience, targeting different elements of energy systems or their interconnections.

Framework of analysis: dimensions of energy security

The first step in designing MOSES was to identify the key dimensions of short-term energy security. There are dozens of scientific and professional publications proposing approaches to measuring energy security with different goals, assumptions, definitions of energy security and conceptual frameworks[1]. These approaches also vary in the way they identify temporal, sectoral and spatial boundaries of energy systems. While MOSES builds on the available scholarly and policy literature (Box 1), it does not strictly follow any existing approach. MOSES' novel framework responds to specific energy security concerns of IEA countries and is designed to offer policy-relevant insights into both the risks of short-tem disruptions of energy systems and their resilience to such disruptions.

[1] These approaches are reviewed in Cherp & Jewell 2010; Kruyt, van Vuuren, de Vries and Groenenberg 2009; Sovacool and Brown, 2010.

Box 1 MOSES in the context of existing energy security studies

Recent literature on energy security focuses on defining energy security and delineating its dimensions (Sovacool and Brown, 2010; Cherp and Jewell, 2011; Jansen and Seebregts 2009; Stirling 2010), and on metrics, indicators and quantification methodologies (APERC, 2007; Gupta, 2008; Jansen, Arkel and Boots, 2004; Kendell, 1998; Scheepers, Seebregts, de Jong, and Maters, 2007; Stirling, 1994). The literature is summarised in several recent meta-surveys (Cherp and Jewell, 2010, 2011; Kruyt, Vuuren, Vries, and Groenenberg, 2009; Sovacool and Brown, 2010).

One way of defining energy security is by delineating different types of risks, often including longer-term aspects. A commonly cited approach is the four As of energy security (APERC, 2007; Kruyt *et al.*, 2009) — availability (geological), accessibility (geopolitical), affordability (economic) and acceptability (environmental and social) — which includes concerns related to long-term depletion of fossil-fuel reserves and environmental aspects of energy security. A recent study by the U.S. Chamber of Commerce (2010) resembles this approach, presenting four dimensions of energy security: geopolitical (energy imports, particularly from politically unstable regions), economic (high energy intensity and trade imbalances), reliability (adequacy and reliability of infrastructure) and environmental (related to the carbon intensity of the energy system). While this approach is comprehensive, it does not lend itself well to a disaggregated energy system analysis because indicators often overlap in multiple dimensions and it lacks transparency in how it aggregates indicators to arrive at its index. Nor do these risk-focused approaches cover such key factors as the resilience of energy systems.

Definitions of energy security often emphasise the economic cost and physical availability of energy (*e.g.* Bohi and Toman, 1996, Kendell 1998; Gupta 2008). This echoes the IEA's own definition of energy security as "the uninterrupted physical availability at a price which is affordable, while respecting environmental concerns". However, the distinction between physical and economic concerns has been criticised on conceptual grounds (Keppler 2007). Environmental concerns are usually treated by policy makers as constraints rather than primary goals of energy security. While these concerns are important, they lie outside of the scope of MOSES, which focuses on short-term physical disruptions of energy supply.

The approaches closest to MOSES include one of the most prominent and widely cited studies on measuring energy security, which resulted in the Supply and Demand Index and the Crisis Capability Index (Scheepers, Seebregts, de Jong & Maters, 2007) as well as Cherp and Jewell's recently published framework on the benefits of disaggregated energy system analysis for energy security concerns (2010). Another recent approach that inspired MOSES is the energy security assessment framework in the Global Energy Assessment (Cherp *et al.*, *In press*), further elaborated in Cherp and Jewell (2011), which considers three aspects of energy security: robustness (adequacy and reliability of resources and infrastructure), sovereignty (exposure to threats from foreign actors) and resilience (ability to respond to diverse disruptions).

MOSES resembles recent approaches in considering risks and resilience related to imported and domestic sources. While many other studies focus on long-term energy security (Jansen 2004, Scheepers *et al.,* 2007; Cherp *et al.*, 2011), MOSES deals with short-term energy security (days to weeks), excluding indicators that are only relevant to the long-term perspective, such as environmental impact, rapid growth in demand and depletion of natural resources. By focusing on physical disruptions, MOSES also excludes economic issues related to affordability and volatility of energy prices.

MOSES addresses four dimensions of energy security (Table 1). These include **external** factors related to imported energy and **domestic** factors related to production, transformation and distribution of energy within national borders. External and domestic factors analysed in MOSES reflect both **risk exposure** and **resilience,** the ability of energy systems to adapt to or withstand disruptions.

Table 1 Dimensions of energy security addressed in MOSES

	Risk	Resilience
External	**External risks:** risks associated with potential disruptions of energy imports.	**External Resilience:** ability to respond to disruptions of energy imports by substituting with other suppliers and supply routes.
Domestic	**Domestic risks:** risks arising in connection with domestic production and transformation of energy.	**Domestic Resilience:** domestic ability to respond to disruptions in energy supply such as fuel stocks.

Identifying indicators

MOSES analyses the four dimensions of energy security using 35 indicators (Table 2), chosen to signal the level of risk or adequacy of resilience for different energy sources and fuels in national energy systems. Each indicator relates to at least one of the four dimensions of energy security.

Indicators used in MOSES (Table 2) – from one to seven for each fuel or source – were identified based on existing academic and professional literature and through expert consultations within the IEA. Most indicators are available in time-series with regular updates. The sources of data used in MOSES include the IEA and the OECD, the Nuclear Energy Agency (NEA), the World Bank, the International Atomic Energy Agency (IAEA), and Gas Infrastructure Europe (GIE).

Unfortunately, many indicators suggested during IEA expert consultations could not be used because the data are not available in a comparable form for all IEA countries. For crude oil and oil products, for example, it was suggested that the “network quality” of oil transport be measured. However, no objectively measurable indicator or index was identified across all IEA countries.

Table 2 Table of risk and resilience (res.) indicators used in MOSES

Energy Source	Dimension		Indicator	Source(s)
Crude oil	External	Risk	Net import dependence	IEA
			Political stability of suppliers	IEA, OECD
		Res.	Entry points (ports and pipelines)	IEA
			Diversity of suppliers	IEA
	Domestic	Risk	Proportion of offshore production	IEA
			Volatility of domestic production	IEA
		Res.	Average storage level	IEA
Oil products	External	Risk	Oil product net import dependence	IEA
		Res.	Diversity of suppliers	IEA
			Entry points (ports, rivers and pipelines)	IEA
	Domestic	Risk	Number of refineries	IEA
		Res.	Flexibility of refining infrastructure	IEA
			Average stock levels	IEA
Natural gas	External	Risk	Net import dependence	IEA
			Political stability of suppliers	IEA, OECD
		Res.	Entry points (LNG ports and pipelines)	IEA
			Diversity of suppliers	IEA
	Domestic	Risk	Proportion of offshore production	IEA
		Res.	Daily send-out capacity from underground and LNG storage	IEA
			Natural gas intensity	IEA, World Bank
Coal	External	Risk	Net import dependence	IEA
			Political stability of suppliers	IEA, OECD
		Res.	Entry points (ports and railways)	IEA
			Diversity of suppliers	IEA
	Domestic	Risk	Proportion of mining that is underground	Various national sources
Biomass and waste	External	Risk	Net import dependence	IEA
	Domestic	Res.	Diversity of sources	IEA
Biofuels	External	Risk	Net import dependence	IEA
		Res.	Entry points (ports)	IEA
	Domestic	Risk	Volatility of agricultural output	IEA
Hydropower	Domestic	Risk/ Res.	Annual volatility of production	IEA
Nuclear power	Domestic	Risk	Unplanned outage rate	IAEA
			Average age of nuclear power plants	IAEA
		Res.	Diversity of reactor models	IAEA
			Number of nuclear power plants	IAEA

Note: For details on indicator calculation please see the sections on each primary energy source and secondary fuel.

Combining and interpreting indicators

While indicators can provide insights into the state of an energy system, looking at dozens of them can quickly lead to information overload and confuse rather than facilitate decision-making. Thus a key step in working with indicators is combining and interpreting them in a way that is transparent, logical and relevant to policy.

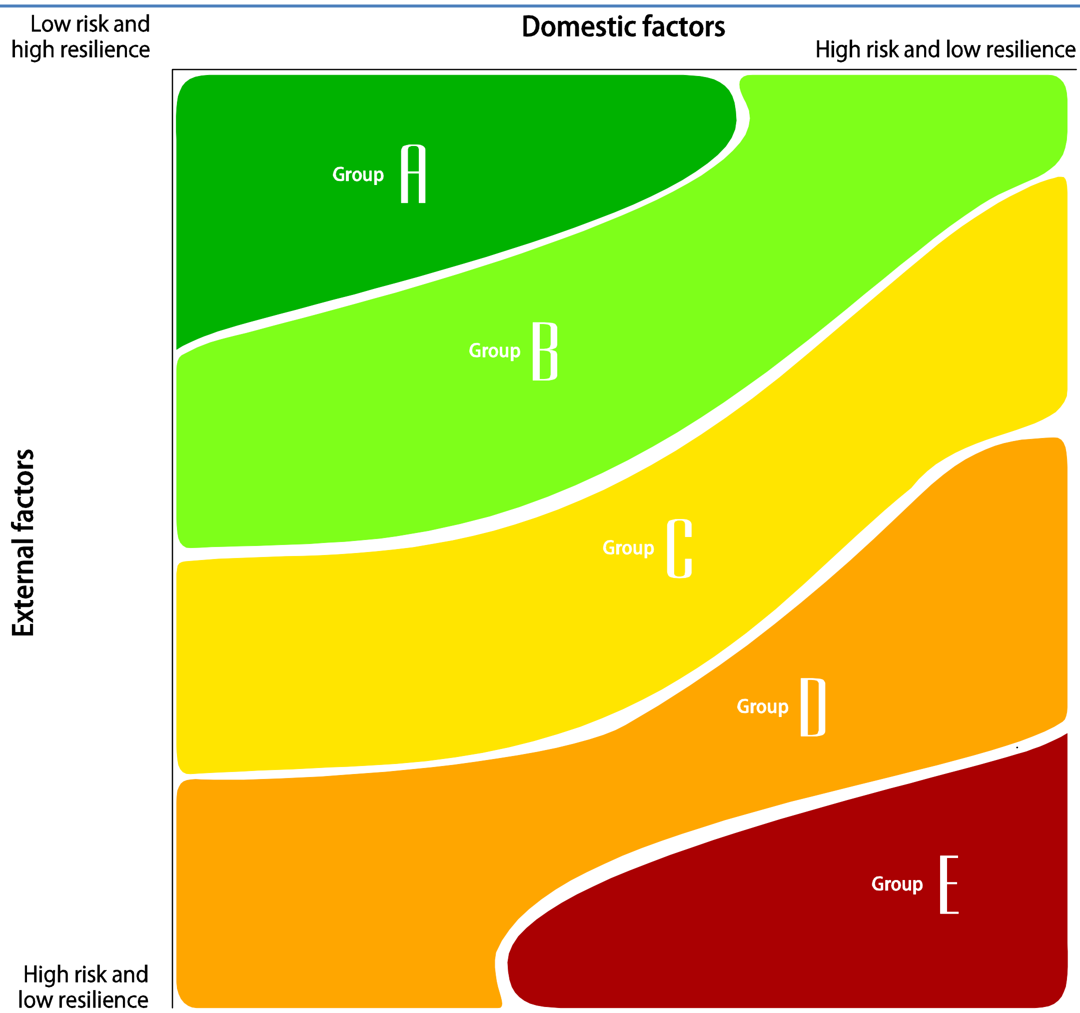
In MOSES, indicators are aggregated in two steps. First, three bands of values – corresponding to low, medium and high vulnerability – are established for each indicator. These bands are primarily based on the observed ranges of the indicator values in IEA countries. For example, crude oil import dependencies in IEA countries naturally fall into three categories: low (≤15%) import dependency and net-exporters, moderate import dependency (40%-65%), and high import dependency (≥80%). In some cases, expert judgements are used to determine the 'safe' levels of risks or 'adequate' resilience capacities. For example for crude oil, having 5 or more ports capable of receiving oil imports or 9 or more pipelines was considered as 'high' level of resilience.[2]

In the second step, this categorisation is used to establish an energy security profile for each country, by combining indicators in a way that takes into account how particular risks may exacerbate one another and how particular resilience capacities may mitigate specific risks. For example, the number of ports or pipelines mitigates risks of imports, but is not relevant for countries whose production is primarily domestic. In contrast, fuel storage is considered a resilience factor for risks related to both domestically sourced and imported fuels, since it mitigates risks from both sources.

Countries are then grouped in three to five energy security profiles for each energy source or fuel, based on their overall risk exposure and resilience capacities (Figure 2). This process clusters countries with similar risk/resilience profiles. The energy security profiles are marked by letters A to E, moving from lower risk/higher resilience profiles (higher energy security) to higher risk/lower resilience profiles (lower energy security). Details of this clustering are presented for each energy source or fuel in the following section.

[2] While ports can receive crude oil from any crude oil tanker, pipelines have a limited number of suppliers. Thus, in evaluating the import infrastructure, ports have a higher resilience capacity than pipelines.

Figure 2 Energy security profiles



Limitations and future work

Any study of energy security faces a series of choices and MOSES is no exception. The focus on short-term physical security of primary sources and secondary fuels excludes notions that are more relevant in medium- or long-term perspectives on energy security, such as the environmental impact of energy systems, rapidly growing demand for energy services and the depletion of natural resources. Aspects related to the "economic" or "affordability" dimension of energy security, such as the level and volatility of energy prices, are also excluded.

The security of an energy system is not limited to the state of its infrastructure (the primary focus of MOSES), but also to the effectiveness of its policies and regulations as well as the market structure and the investment climate. While governance, institutional and investment factors can be important for energy security, they are not easily quantified and thus only indirectly reflected in MOSES.

Additionally, MOSES deals exclusively with national indicators. While certain energy markets operate regionally (*e.g.* the European Union) or sub-nationally (*e.g.* Australia's regional gas markets), MOSES does not take these situations into account because it primarily focuses on infrastructure.

MOSES aims to evaluate security of supply of individual sources and fuels. It is not designed to compare security of supply across different energy sources, nor to produce an overall "energy security index" spanning several fuels and carriers. Consequently, it cannot be used to compare the "overall" energy security of countries, although the situation with respect to specific sources and fuels can easily be compared. Since this version of MOSES focuses on security of supply of primary energy and secondary fuels, it does not deal with security of solar, wind, and ocean energy which cannot be analysed separately from security of electricity systems.

While security of supply is important, ultimately consumers and policy makers are most concerned about the security of energy services, so incorporating electricity and end uses into MOSES will be key steps in providing policy-relevant analysis of energy security.

Evaluation of individual sources and fuels

This section presents an evaluation of the short-term energy security of seven primary energy sources and two sets of secondary fuels. For each source and fuel, the section presents:

(1) indicators;

(2) the assessment process; and

(3) consolidated results for IEA countries.

Crude oil

Indicators: crude oil

The analysis of crude oil vulnerability is based on eight indicators (Table 3) with ranges of values corresponding to high, medium and low levels of risk and resilience (Table 4).

Table 3 Crude oil: indicators

	Risks	Resilience
External	**External risks:** • import dependence • political stability of suppliers	**External resilience:** • number of ports • number of pipelines • diversity of suppliers
Domestic	**Domestic risks:** • share of offshore production • volatility of domestic production	**Domestic resilience:** • average storage level

The most important indicator in terms of crude oil supply security is **net import dependence**. IEA countries[3] naturally fall into three categories: low import dependency (≤15%) and net exporters; medium import dependency (40%-65%) and high import dependency (≥80%). A related external risk indicator is the **political stability of supplying countries**. This is calculated by taking a weighted average of the political stability of suppliers based on the proportion of crude oil imported from each supplier and the OECD political stability rating of that supplier. The OECD political stability rating ranges from 0 to 7, with OECD countries rated 0 and the most politically unstable countries rated 7. This indicator ranges from 0.4 to 5.1 in IEA countries.

External resilience indicators for crude oil include the number and type of **entry points** for imports and the **diversity of suppliers**. Crude oil can enter a country by maritime ports or pipelines.[4] The more entry points a country has, the less vulnerable it is to supply disruptions. Ports are valued higher than pipelines, as they can be used to receive crude from a larger number of suppliers. Five ranges for this indicator were established:

- lowest: only one import pipeline (no ports);
- low: only 1 port and/or 2 pipelines;
- medium: 2 ports or 3-4 pipelines;
- medium-high: 3-4 ports or 5-8 pipelines; and
- high: at least 5 ports or 9 pipelines.

[3] Luxembourg is not included in this analysis because it does not process any crude oil in its economy.

[4] Rivers and trains are rarely used for importing crude oil to IEA member countries.

The **diversity of suppliers** is calculated using the Herfindahl-Hirschman index, which is a measure of the concentration of supply. This index ranges from 0.1 (for high diversity) to 1.0 (for no diversity of supply). Three ranges of values for this indicator were established: high diversity of suppliers (<0.3), moderate diversity of suppliers (0.3-0.8) and low diversity of suppliers (>0.8).

The indicator for domestic resilience of crude oil supply is the **average level of crude oil storage** in 2010, divided by the maximum refinery intake in 2010. Three ranges of this indicator were established: low (≤15 days), moderate (between 20 and 50 days) and high (≥55 days).

Finally, for countries with significant domestic production of crude oil, internal risks are evaluated using two indicators: the **share of offshore production** and the **volatility of domestic production**. The ranges for the share of offshore production are low (<15%) and high (>90%). The ranges for the volatility of production, calculated by dividing the standard deviation of the monthly crude oil production in a given year by the average monthly crude oil production, are low (<20%) and high (>20%).

Table 4 Crude oil: ranges for indicators

Dimension	Indicator		Low		Medium		High
External risk	Import dependency		≤15%		40%-65%		≥80%
	Political stability of suppliers		<2.5		≥2.9		
Domestic risk	Volatility of production		<20%		>20%		
	Share of offshore production		<15%		>90%		
External resilience	Diversity of suppliers		>0.8		0.30-0.8		<0.30
	Import infrastructure (entry points)	Ports	0	1	2	3-4	≥5
		Pipelines	1	2	3-4	5-8	≥9
Domestic resilience	Storage levels		≤15		20-50		≥55

Assessment process: crude oil

Countries are assigned to five groups with different crude oil security profiles (Figure 3). At each step of the process, countries are sorted into categories according to one of the indicators described in the previous section. The resulting crude oil security profiles reflect unique combinations of risk and resilience (Table 6).

In the first step, countries are grouped according to their crude oil import dependency**.** Countries with low import dependency are assigned to Group A. Countries with medium import dependency are assigned to Group B. Risk factors associated with domestic production are further analysed for countries in these categories (for intra-group sorting without affecting their grouping).

In the second step, external and domestic resilience factors are analysed for countries with high crude oil import dependence. First, import infrastructure (the number and type of entry points) and the diversity of suppliers are analysed to determine the overall external resilience of a country (Table 5). Countries with high external resilience fall into Groups B and C, countries with moderate external resilience fall into Groups C and D, and countries with low external resilience fall into Groups D and E.

Figure 3 Crude oil: steps for assessing security of supply

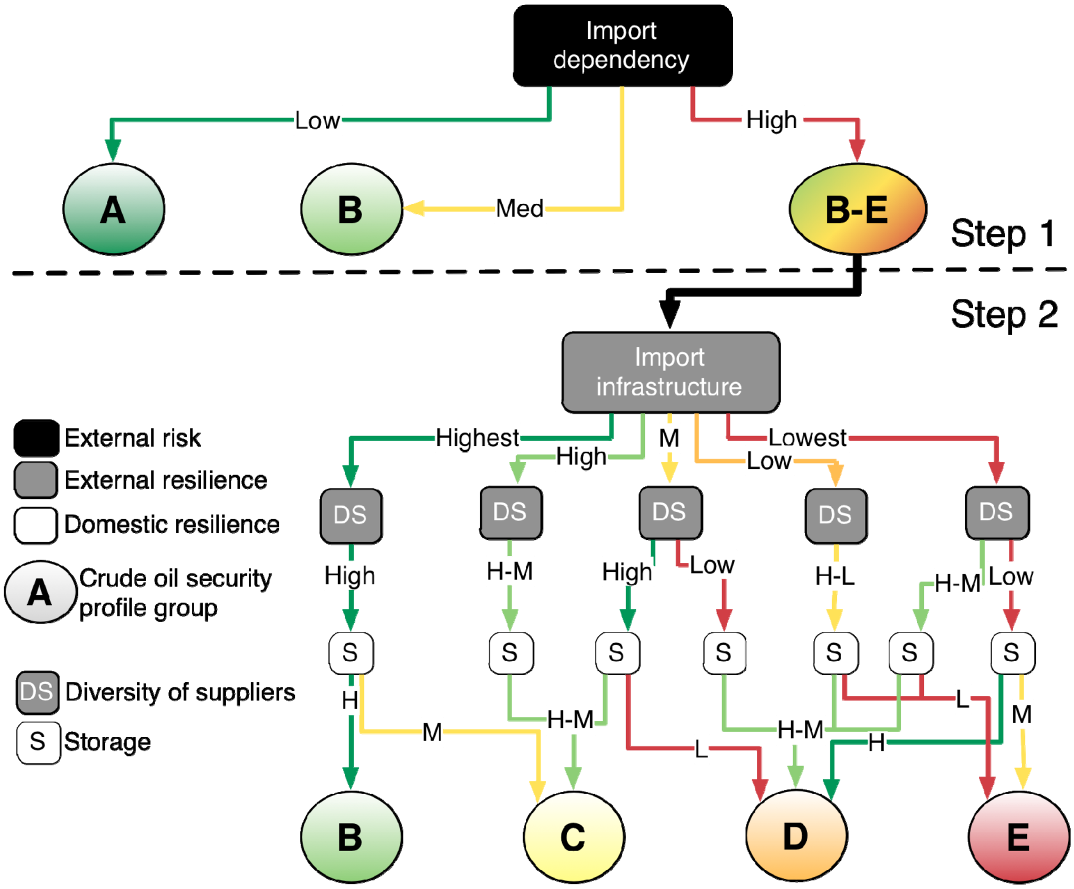


Table 5 Crude oil: aggregating indicators for external resilience

		Import infrastructure				
		Lowest	Low	Medium	Medium-High	High
Diversity of suppliers	Low	SK	PL	FI, HU		
	Medium	CZ	IE		SE,	
	High	AT	CH	BE, NL, PT, TK	GR,	DE, ES, FR, IT, KR, JP

Note: Country abbreviations are available on page 42.

The **crude oil storage level** is used as a differentiating factor for the final allocation of the highly import-dependent countries (Figure 5) between groups B and C (high vs. medium storage); C and D (high-medium vs. low storage); as well as D and E (high-medium vs. low and high vs. medium).

As the result of this second step, countries with the highest external and domestic resilience are assigned to Group B (the same as moderately import-dependent countries). The remaining countries are divided among groups C, D and E depending on their resilience capacities (Figure 5).

MOSES further refines this evaluation by considering group-specific factors such as:

- crude oil storage levels, volatility of domestic production and the share of offshore production for net exporters and nearly self-sufficient countries in Group A;

- the volatility of domestic production, the share of offshore oil production, importing infrastructure and the diversity of suppliers for moderately import-dependent countries in Group B; and
- the political stability of suppliers for highly import-dependent countries in Groups B, C, D and E.

Results: crude oil

Table 6 Crude oil: security profiles

Group	Countries that:	No. of countries
A	**Export crude oil** or **import ≤15%** of their crude oil consumption.	5
B	**Import 40%-65%** of their crude oil consumption or **Import ≥80%** of their crude oil consumption and have • ≥5 crude oil ports, high supplier diversity and ≥55 days of crude oil storage.	4
C	**Import ≥80%** of their crude oil consumption and have: • ≥5 crude oil ports, high supplier diversity, and <50 days of crude oil storage or • 2-4 crude oil ports, high supplier diversity and >20 days of crude oil storage.	9
D	**Import ≥80%** of their crude oil consumption and have: • 2-4 crude oil ports, high supplier diversity, and ≤15 days of crude oil storage or • 2 crude oil ports or 3 crude oil pipelines, low supplier diversity, and ≥15 days crude oil storage or • 1-2 crude oil pipelines or 1 crude oil port and have either: • medium to high supplier diversity and ≥15 days of crude oil storage or • low supplier diversity and ≥55 days of crude oil storage.	6
E	**Import ≥80%** of their crude oil consumption and have: • 1-3 crude oil pipelines or 1 crude oil port and ≤15 days of crude oil storage or • 1-2 crude oil pipelines, low supplier diversity and <50 days of crude oil storage.	3

Note: this table includes 27 countries because Luxembourg does not use crude oil.

Oil products

Oil products consumed can either be refined domestically (12 IEA countries refine virtually all their consumption needs) or imported. Each of these two supply streams is associated with specific risks and resilience factors. While imported products can be subject to disruption of trade, supply routes or compromised importing infrastructure, domestically refined products are exposed to the risks of refinery outages and disruptions of adequate crude supply.

The analysis in this section is conducted separately for middle distillates, motor gasoline and other oil products.

The **middle distillates** group includes: gas/diesel oil, kerosene-type jet fuel, and other kerosene. It accounted for between 24% and 84% of demand in IEA countries in 2010, while **motor gasoline** accounted for 5% to 45% of demand.

Other oil products is a diverse category that includes: fuel oil, refinery gas, ethane, naphtha, aviation gasoline, gasoline type jet fuel, petroleum coke, white spirit, lubricants, bitumen, paraffin waxes, and all other products. The vast majority of these products are used in small quantities (<5% of oil product demand) for most IEA countries. The most notable exception is naphtha, which accounts for 40% of oil product demand in Korea (primarily in the petrochemical industry) and 10% to 20% in seven other IEA countries. Another notable exception is fuel oil, which accounts for 10% to 30% of oil product demand in 10 IEA countries. Fuel oil can be easily substituted with crude oil, distillates or, in the case of power generation, natural gas. Naphtha was not analysed because it is used primarily in the petrochemical industry, not as an energy source but rather as an input resource. Detailed analysis of naphtha was deemed to be beyond the scope of this paper, which is designed to be a high-level tool for identifying key vulnerabilities in IEA countries. One key assumption in this aggregated analysis is that if an IEA country has one dominant "other oil product", the days of stock cover and product balance will primarily reflect the dominant product.

Indicators: oil products

The analysis for oil product vulnerability is based on nine indicators for each oil product category. Seven of these indicators are the same for all three categories and two are specific to each sub-category (Table 7).

Table 7 Oil products: indicators

	Risks	Resilience
External	**External risks:** • deficits: ○ gasoline ○ middle distillates ○ other oil products	**External resilience:** • entry points: ports • entry points: pipelines • entry points: rivers • diversity of suppliers
Domestic	**Domestic risks:** • crude oil supply vulnerability • number of refineries	**Domestic resilience:** • flexibility of refining infrastructure • average stock levels (2010): ○ gasoline ○ middle distillates ○ other oil products

Exposure to external risks is evaluated using deficits, *i.e.* the proportion of domestically consumed oil product that is imported. Separate indicators for each oil product category are used instead of the aggregate oil product import dependency, because while some countries are not net importers for total oil products, they are net importers for motor gasoline, middle distillates or other oil products. Since different categories of oil products are not interchangeable in most situations the analysis is done separately for each product category. Four ranges of values for oil product import dependency are used: lowest (<5%), low (5%-25%), medium (25%-45%) and high (>45%) fuel deficit.

External risks are mitigated by external resilience factors reflected in the number and type of entry points and the diversity of suppliers. The ranges for the diversity of suppliers indicators for oil products differ from those for crude oil and natural gas because of the differences between international markets for these fuels. While the crude oil and natural gas markets can only be supplied by countries with oil/gas deposits, the oil products market can be supplied by a much larger number of countries with refineries. Thus, more stringent ranges of supplier diversity were used: high (≤0.18), medium (between 0.18 and 0.54) and low (≥0.54).[5] The ranges for entry points (Table 8) are similar to those used for evaluating crude oil security of supply.

In line with MOSES' energy systems approach to energy security, the evaluation of oil product security takes into account the **vulnerability of crude oil supply**. The five groups of crude oil supply vulnerability described in the previous section form the five natural ranges for this indicator.

[5] Diversity of oil product suppliers is measured by the same Herfindahl-Hirschman index as used for crude oil supplier diversity.

The internal resilience indicators for oil products are **the number of refineries**, the **flexibility of the refining infrastructure** (*i.e.* the ability of refineries to deal with different kinds of crude oil calculated using the Nelson complexity index[6]) and the **storage levels** for respective oil products measured as the average number of weeks of forward demand (consumption) stored. The ranges for these indicators are presented in Table 8.

Political stability of suppliers was discarded as a discriminating indicator after detailed analysis. In general, the political stability of suppliers of oil products to IEA countries is high (weighted average generally less than 2 on a scale of 0 to 7, with 0 representing OECD countries and 7 the most politically unstable countries).

Table 8 Oil products: ranges for indicators

Dimensions	Indicator		Low		Medium	High
External risk	Deficit (gasoline/middle distillates/ other oil products)		<5%	5%-25%	25%-45%	≥45%
Domestic risk	Crude oil security profile		The five profiles evaluated in MOSES			
	Number of refineries		1		Indicator is only considered for countries with 1 refinery	
External resilience	Diversity of suppliers		≥0.54		0.18-0.54	≤0.18
	Import infrastructure (entry points)	Ports	0		2-4	≥5
		Rivers	1-2		No countries have more than 2 pipelines or river points without at least 5 maritime ports	
		Pipelines	1-2			
Domestic resilience	Flexibility of refining infrastructure (Nelson complexity index)		<6.0		6.0-9.0	≥9.0
	Average (2010) storage levels measured in weeks of forward demand		≤3	3-6	6-9	≥9

Assessment process: oil products

The analysis of oil product supply security is conducted in a four step process (Figure 4).

Step 1 evaluates the vulnerability of **domestically refined products** (based on refinery complexity and security of crude supply).

Step 2 evaluates the vulnerability of **imported oil products** based on external resilience and dependence on imported middle distillates, motor gasoline and other oil products.

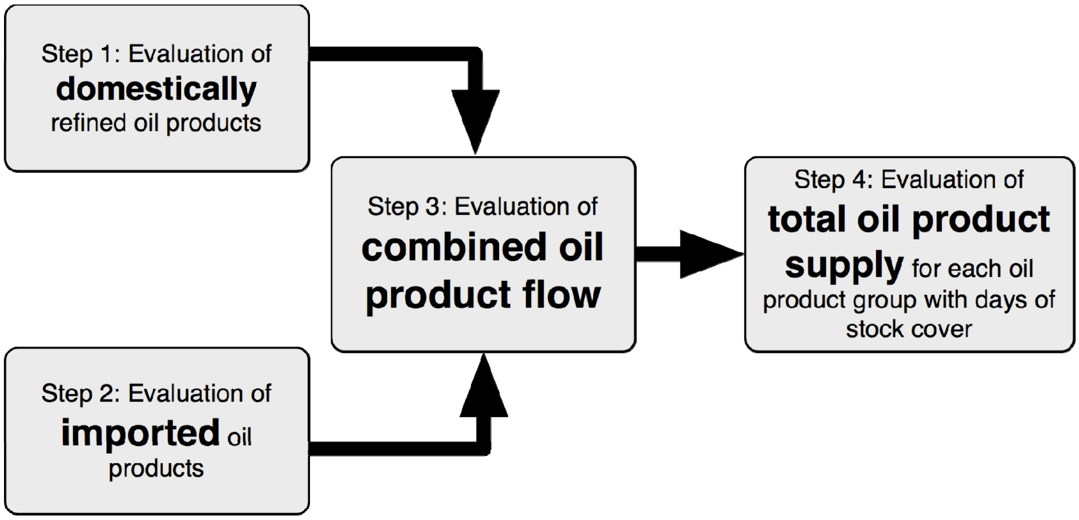
Step 3 analyses the vulnerability of **the combined oil product flow** by combining the results from the first two steps.

Step 4 evaluates the vulnerability of the **total oil product supply** by combining the combined oil product flow analysis with the product stock levels, which is a resilience measure that can mitigate all types of risk arising from the oil product supply chain.

[6] The Nelson complexity index is an industry standard used to measure the flexibility of refineries. If a higher grade crude would be disrupted, a refinery with a high-complex index can substitute with lower-grade crude. Methodology published by Reliance Industry Limited is available for download here:

http://www.ril.com/downloads/pdf/business_petroleum_refiningmktg_lc_ncf.pdf.

Figure 4 Oil Products: steps for assessing security of supply



Step 1: evaluation of vulnerability of domestically refined oil products.

The vulnerability of domestically refined oil products is evaluated in two stages. The first stage identifies five groups of countries based on their crude oil supply security and the flexibility of the refining infrastructure (Table 9).[7]

Table 9 Oil products: vulnerability from crude oil supply and refinery flexibility

		Crude oil supply				
		A	B	C	D	E
Refinery flexibility	High (≥9)	CA, UK	DE, US	GR	FI, HU, PL	SK
	Med (6-9)	AU	JP, NZ	BE, ES, FR, IT, KR, NL, PT, SE	AT, CZ	CH, IE
	Low (≤6)	DK, NO		TK		

Note: Refinery flexibility is measured using the Nelson complexity index.

In the second stage, the number of refineries is taken into account. While the number of refineries depends on a country's size, having a single refinery makes a country particularly vulnerable to natural or technical failures. The results of this analysis are five groups of countries according to the vulnerability of domestically refined products (Table 10).

Table 10 Oil products: vulnerability for domestically refined products

Oil product vulnerability from crude oil supply and refinery flexibility (Table 9)	Number of refineries	
	2+ refineries	Only 1 refinery
Highest	AU, CA, DE, UK, US	
High	DK, GR, JP, NO	
Medium	BE, ES, FI, FR, IT, KR, NL, PL, PT, SE	NZ
Low	CZ, TK	HU
Lowest	CH	AT, IE, SK

[7] Luxembourg has no refinery, so is not included here.

Step 2: evaluation of vulnerability of imported oil products.

This step is only relevant for the 24 IEA countries with a trade deficit in at least one of the categories of oil products. First, the nature and number of entry points is combined with the supplier diversity to divide the countries into three groups (Table 11).

Table 11 Oil products: external resilience

		Infrastructure rating		
		High (≥5 ports)	Medium (2 river entry ports, 2 ports)	Low (1-2 river entry ports, 0-2 pipelines)
Diversity rating	High	DK, ES, FR, IT, JP, KR, UK, US	PL	
	Med	AU, CA, DE, FI, NO, NZ, PT, SE, TK		AT, CH, CZ, HU
	Low	IE		LU

Note: External resilience is only evaluated for countries with net import dependency in at least one of the oil product groups.

Subsequently, the results of this evaluation are combined with the external risk exposure as represented by the deficit level. This is done independently for gasoline, middle distillates and other oil products (Tables 12a, 12b and 12c).

Table 12a Oil products: gasoline import deficit

Deficit levels			
Very low (<5%)	BE, CA, DE, DK, ES, FI, FR, GR, IT, JP, KR, NL, NO, PL, PT, SK, TK, UK, US		
	External resilience		
	High	Medium	Low
Low (5%-25%)	AU, SE	AT, CZ, HU	
Med (25%-45%)	NZ		
High (≥45%)		CH, IE	LU

Table 12b Oil products: middle distillates import deficit

Deficit levels			
No deficit	BE, CA, FI, GR, HU, IT, JP, KR, NL, NO, SK, SE, US		
	External resilience		
	High	Medium	Low
Low (5%-25%)	DE, ES PL, PT, UK	CZ	
Med (25%-40%)	AU, DK, FR, NZ		
High (≥45%)	TK	AT, CH, IE	LU

Table 12c Oil products: other import deficit

Deficit levels			
No deficit	BE, CZ, GR, HU, NL, SK, SE		
	External resilience		
	High	Medium	Low
Low (5%-25%)	DE, DK, ES, FR, IT, NO, UK	AT	
Med (25%-45%)	CA, JP, PL, PT, TK, US	CH	
High (≥45%)	AU, FI, KR, NZ	IE	LU

Step 3: evaluation of vulnerability of the combined oil product flows.

Step 3 combines the analysis from the previous two steps to evaluate the overall vulnerability of the oil product flows from both imported and domestically refined sources. As with step 2, gasoline, middle distillates and other oil products are evaluated separately. As a result, countries are divided into five groups of vulnerabilities with respect to supply of gasoline, middle-distillates or other oil products (Tables 13a, 13b and 13c).

Table 13a Oil products: gasoline total flow vulnerability

		Domestically refined gasoline					
		Highest	High	Medium	Low	Lowest	N/A
Imported gasoline	High	AU, CA, DE, UK, US	DK, GR, JP, NO	BE, ES, FI, FR, IT, KR, NL, NZ, PL, PT, SE	CZ, HU, TK	AT, SK	
	Med					CH, IE	
	Low						LU

Table 13b Oil products: middle distillates total flow vulnerability

		Domestically refined middle distillates					
		Highest	High	Medium	Low	Lowest	N/A
Imported middle distillates	High	AU, CA, DE, UK, US	DK, GR, JP, NO	BE, ES, FI, FR, IT, KR, NL, NZ, PL, PT, SE	CZ, HU	SK,	
	Med				TK	AT, CH, IE	
	Low						LU

Table 13c Oil products: other oil products total flow vulnerability

		Domestically refined other oil products					
		Highest	High	Medium	Low	Lowest	N/A
Imported other oil products	High	CA, DE, UK US	DK, GR, JP, NO	BE, ES, FR, IT, KR, NL, PL, PT, SE	CZ, HU TK	AT, SK	
	Med	AU		FI, NZ		CH, IE	
	Low						LU

Step 4: evaluation of the vulnerability of the total oil product supply.

Step 4 combines the above analysis for gasoline, middle distillates and other oil products with the average stock levels for these respective oil products. High stock levels can mitigate against both external and internal vulnerabilities arising at different stages of the supply chain. Countries with more than six weeks of stock levels are assigned to Groups A and B. Countries with the "highest" security of oil product flow (Tables 13a, 13b and 13c) are also assigned to Groups A or B.

Results: oil products

Table 14a Oil products: gasoline security profiles

Group	Countries that:	No. of countries
A	**Import ≤45%** of their gasoline consumption and are • in Crude oil groups A or B with ≥6 weeks of gasoline stocks or • in Crude oil groups C or D with a moderate to highly flexible refining portfolio and ≥9 weeks of gasoline stocks.	11
B_1	**Import ≤45%** of their gasoline consumption and are • in Crude oil groups A or B with <6 weeks of gasoline stocks or • in Crude oil group C with a moderate to highly flexible refining portfolio and 3-6 weeks of gasoline stocks.	9
B_2	**Import ≤45%** of their gasoline consumption and are • in Crude oil groups D or E with one highly flexible refinery and ≥9 weeks of gasoline stocks or **Import >45%** of their gasoline consumption and have • a moderate supplier diversity and ≥9 weeks of gasoline stocks.	5
C	**Import >45%** of their gasoline consumption and have • 6-9 weeks of gasoline stocks and either ≥6 sea ports for gasoline imports with low supplier diversity or 1-2 oil product pipelines with moderate supplier diversity.	2
D	**Import >45%** of their gasoline consumption and have • 3-6 weeks of gasoline stocks, one oil product pipeline, and low supplier diversity.	1

Table 14b Oil products: middle distillates security profiles

Group	Countries that:	No. of countries

A	**Import ≤45%** of their middle distillates consumption and
	• have ≥9 weeks of middle distillates stocks and are either
	  • in Crude oil groups A through C or
	  • in Crude oil group D with a highly flexible refining portfolio and at least 2 refineries.
		9

B_1	**Import ≤45%** of their middle distillates consumption and • are in Crude oil groups A through C with ≥3 weeks of middle distillates stocks or	10
B_2	**Import ≤45%** of their middle distillates consumption and • are in Crude oil groups D or E with a moderate to highly flexible refining portfolio and ≥6 weeks of middle distillates stocks or **Import >45%** of their middle distillates consumption with ≥9 weeks of middle distillates stocks and either moderate supplier diversity or ≥5 oil products ports.	5
C	**Import ≤45%** of their middle distillates consumption and in Crude oil group E with 1 highly flexible refinery and ≥6 weeks of middle distillates stocks.	1
D	**Import >45%** of their middle distillates consumption with moderate supplier diversity and 3-6 weeks of middle distillates stocks.	2
E	**Import 100%** of their middle distillates consumption through 1 pipeline with low supplier diversity and ≤3 weeks of middle distillates stocks.	1

Table 14c Oil products: other oil products security profiles

Group	Countries that:	No. of countries

A	**Import ≤45%** of their other oil products consumption and are
	• in Crude oil groups A or B with ≥6 weeks of other oil products stocks or
	• in Crude oil group C with either
	  • a highly flexible refining portfolio and ≥6 weeks other oil products stocks or
	  • a limited to moderately flexible refining portfolio with ≥ 9 weeks of other oil products stocks.
		4

B	**Import ≤45%** of their other oil products consumption and are • in Crude oil groups A or B with <6 weeks of other oil products stocks or • in Crude oil group C with moderate flexibility of refining and 3-9 weeks of other oil products stocks.	10

C_1	**Import ≤45%** of their other oil products consumption and are
	• in Crude oil group C with either:
	  • a moderately to highly flexible refining portfolio and <3 weeks of other oil products stocks or
	  • a relatively inflexible refining portfolio with ≥3 weeks of other oil products stocks or
	• in Crude oil group D with a highly flexible refining portfolio and at least 2 refineries.
		4

C_2	**Import >45%** of their other oil products consumption with ≥5 oil product ports and ≥6 weeks of other oil products stocks.	2

D	**Import ≤45%** of their other oil products consumption and are
	• in Crude oil groups D or E with either
	  • a moderately flexible refining portfolio and 3-6 weeks of other oil products stocks or
	  • a highly flexible refining portfolio and <3 weeks of other oil products stocks or
	Import >45% of their other oil products consumption with moderate supplier diversity and <3 weeks of other oil products stocks.
		6

E	**Import 100%** of their other oil products consumption with low supplier diversity and <3 weeks of other oil products stocks.	2

Natural gas

The indicators and the assessment process for natural gas are very similar to those for crude oil.

Indicators: natural gas

The analysis of natural gas security includes seven indicators related to external and domestic aspects that reflect both risks and resilience capacity (Table 15, with ranges in Table 16).

Table 15 Natural gas: dimensions of energy security and indicators

	Risks	Resilience
External	**External risks:** • import dependency • political stability of suppliers	**External resilience:** • entry points: Liquified natural gas (LNG) ports • entry points: pipelines • diversity of suppliers
Domestic	**Domestic risks:** • offshore production	**Domestic resilience:** • send-out capacity from natural gas storage • gas intensity

As with crude oil, the most important indicator in terms of natural gas supply security is **net import dependence**. Countries fall into three categories: low import dependency (≤10%) and net exporters; moderate import dependency (30%-40%); and high import dependency (≥70%).

The **political stability of supplying countries** is also considered. This is calculated by taking the weighted average of supplying countries using the OECD political stability rating. This indicator ranges from 0.4 to 4.4 for IEA countries.

External resilience indicators include the number and type **entry points** and **diversity of suppliers**. Natural gas can be imported through liquefied natural gas (LNG) ports and pipelines. The more entry points a country has, the less vulnerable it is to supply disruptions. LNG ports offer greater resilience than pipelines because they can receive imports from the spot LNG market while pipelines generally can only receive imports from predetermined suppliers.

The **diversity of suppliers** is calculated using the Herfindahl-Hirschman index. This indicator is broken into three ranges: high diversity (<0.3), moderate diversity (0.3-0.6) and low diversity (>0.6).

Domestic resilience is evaluated using **daily send-out capacity from natural gas storage**, measured by dividing the maximum drawdown rate from both underground and LNG storage by the peak daily demand. Countries can be separated into three groups: those that have a low send-out capacity compared with their peak daily demand (<50%), those that have moderate send-out capacity (between 50% and 100%) and those that have a high send-out capacity (>100%).

Natural gas intensity is also used as an indicator of domestic resilience. This is calculated by dividing a country's gas consumption by the GDP and is a sign of a country's economic exposure to gas disruptions.

Finally, for countries with significant domestic production capacities, domestic risks are evaluated using the **share of offshore gas production.** Countries are divided into two groups: high (≥80%) and low (≤30%). Offshore production is more vulnerable than onshore production.

Table 16 Natural gas: ranges for indicators

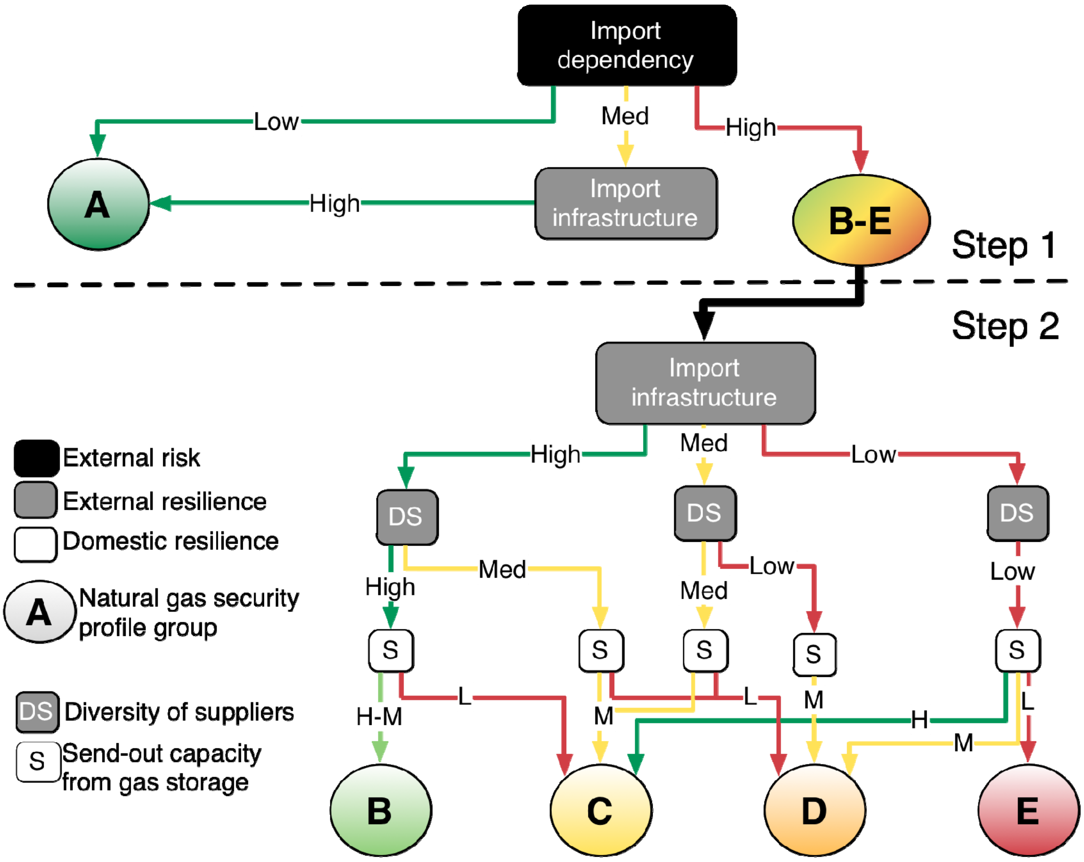
Dimension	Indicator		Low	Medium	High
External risk	Import dependency		≤10%	30%-40%	≥70%
	Political stability of suppliers		<1.0	1.0-4.0	≥4.0
Domestic risk	Share of offshore production		≤30%	≥80%	
External resilience	Diversity of suppliers		>0.6	0.30-0.6	≤0.30
	Entry points	Ports	0	1-2	≥3
		Pipelines	1-2	3-4	≥5
Domestic resilience	Send-out capacity		<50%	50%-100%	>100%
	Natural gas intensity, bcm/$1000 USD		<20	20-60	>60

Assessment process: natural gas

Natural gas security is evaluated in a step-by-step process (Figure 5). At each step, countries are compared with respect to one indicator and then sorted into different categories (Table 16). They are then grouped according to their overall risk exposure and resilience capacity (Table 20).

The first step in assessing natural gas security is to group countries by net import dependency. Seven countries with low import dependency (≤10%) and net exporters are assigned to Group A. External resilience factors are less relevant for the countries in this group because they do not rely heavily on imported natural gas. The United Kingdom is also assigned to Group A; it imports 40% of its gas from politically stable countries and has a highly developed import infrastructure.

Figure 5 Natural gas: steps for assessing security of supply



Countries with high import dependency are then sorted, based on their external and internal resilience factors (Figure 5). Countries are first sorted based on their external resilience capacity: importing infrastructure (Table 17) and diversity of suppliers (Table 18).

Table 17 Natural gas: import infrastructure rating

		Number of LNG ports		
		0	1-2	≥3
Number of Pipelines	0			JP, KR
	1-2	HU, FI, IE, SE	GR, PT	
	3-4	AT, LU, SK, CZ, CH, PL		
	≥5	DE	BE, IT, TK	ES, FR, UK, US

Table 18 Natural gas: external resilience for highly import-dependent countries

		Infrastructure rating		
		Low	Medium	High
Diversity rating	Low	FI, HU, IE, SE	PL, SK	
	Med		AT, CZ, GR, LU, PT, CH	DE, TK,
	High			BE, FR, IT, JP, KR, ES

Finally, importing countries are sorted for domestic resilience according to their send-out capacity for natural gas (Table 19).

Table 19 Natural gas: send-out capacity and external resilience

		External resilience rating (Import infrastructure and diversity)		
		Low	Medium	High
Send-out capacity	Low	FI, IE, SE	LU, CH	BE,
	Med	PL, SK	CZ, DE, TK	FR, IT
	High	HU	AT, GR, PT	JP, KR, ES

The countries with the highest external resilience and high or medium send-out capacity are assigned to Group B. The countries with the lowest external resilience and low send-out capacity are assigned to Group E. The remaining countries are assigned to Group D if either external resilience or send-out capacity is low. Countries with moderate resilience capacities are assigned to Group C.

MOSES further refines this evaluation by considering group-specific factors such as:

- offshore production for net exporters in Group A;
- political stability of suppliers for countries in Groups B, C, D and E; and
- send-out capacity and gas intensity for all countries.

Results: natural gas

Table 20 Natural gas: security profiles

Group	Countries that:	No. of countries
A	**Export natural gas** or **Import ≤10%** of their natural gas supply or **Import 10%-40%** with ≥5 pipelines, ≥3 LNG ports, and a high supplier diversity.	8
B	**Import ≥70%** of their natural gas supply and have • ≥5 pipelines and/or ≥3 LNG ports, a high supplier diversity, and maximum send-out capacity from gas storage ≥50% peak-daily demand.	4
C	**Import ≥70%** of their natural gas supply and have • ≥5 pipelines and/or ≥3 LNG ports, a high supplier diversity, and maximum send-out capacity from gas storage <50% of peak-daily demand or • 3-4 pipelines and/or 1-2 LNG ports, a medium to high supplier diversity, and maximum gas storage send-out capacity ≥50% peak-daily demand or • ≤4 pipelines or ≤2 LNG ports, low to medium supplier diversity, and maximum send-out capacity ≥100% of peak-daily demand.	8
D	**Import ≥70%** of their natural gas supply with 3-5 pipelines and/or 1-2 LNG ports and • medium to high supplier diversity and maximum send-out capacity from gas storage <50% of peak-daily demand or • low to medium supplier diversity and maximum send-out capacity ≥50% of peak-daily demand.	5
E	**Import ≥70%** of their natural gas supply and have • 3-4 pipelines and/or 1-2 LNG ports with low supplier diversity and maximum send-out capacity <50% of peak-daily demand.	3

Coal

Security of coal supply is analysed by considering total coal flow without differentiating among different coal qualities. With a few exceptions, different types of coal are substitutable or can be blended, and most boilers can handle different types of coal or coal blends.[8]

Indicators: coal

The analysis of coal security is based on four indicators related to three dimensions of energy security (Table 21).

Table 21 Coal: dimensions of energy security and indicators

	Risks	Resilience
External	**External risks:** • import dependency	**External resilience:** • entry points • diversity of suppliers
Domestic	**Domestic risks:** • proportion of underground mining	**Domestic resilience:** • n/a

The most important indicator for coal is **import dependency**. While not nearly as risky as oil and natural gas, imported coal is still considered riskier than domestically produced coal. Political stability of suppliers is not taken into account because there is no historical evidence that this factor disrupts coal exports.

The risk of import dependency is considered in combination with external resilience factors that include the number and type of **entry points** and the **diversity of suppliers**. As with crude oil, oil products and natural gas, these factors are seen as counteracting the risk of imports.

MOSES uses the **proportion of underground mining** as a domestic risk indicator, because underground mining is more exposed to disruptions than above-ground mining. Underground mining faces risks such as gas explosions and cavern collapses, and is more vulnerable to workers' strikes, since underground miners are more skilled and harder to replace than above-ground miners. In addition, production from open-pit mining is easier to expand in the case of a shortage.

The three ranges of values for each indicator of coal supply security are used (Table 22).

Table 22 Coal: ranges for indicators

Dimension	Indicator		Low	Medium	High
External risk	Import dependency		0%	30%-70%	>70%
Domestic risk	Share of underground mining		<40%	40%-60%	No countries have more than 60% of their domestic coal from underground sources
External resilience	Diversity of suppliers		>0.6	0.3-0.6	<0.3
	Import Infrastructure (entry points)	Sea or river ports	1-2	3-4	>5
		Railways	2-3	No countries have >3 railway entry points and <3 sea or river ports.	

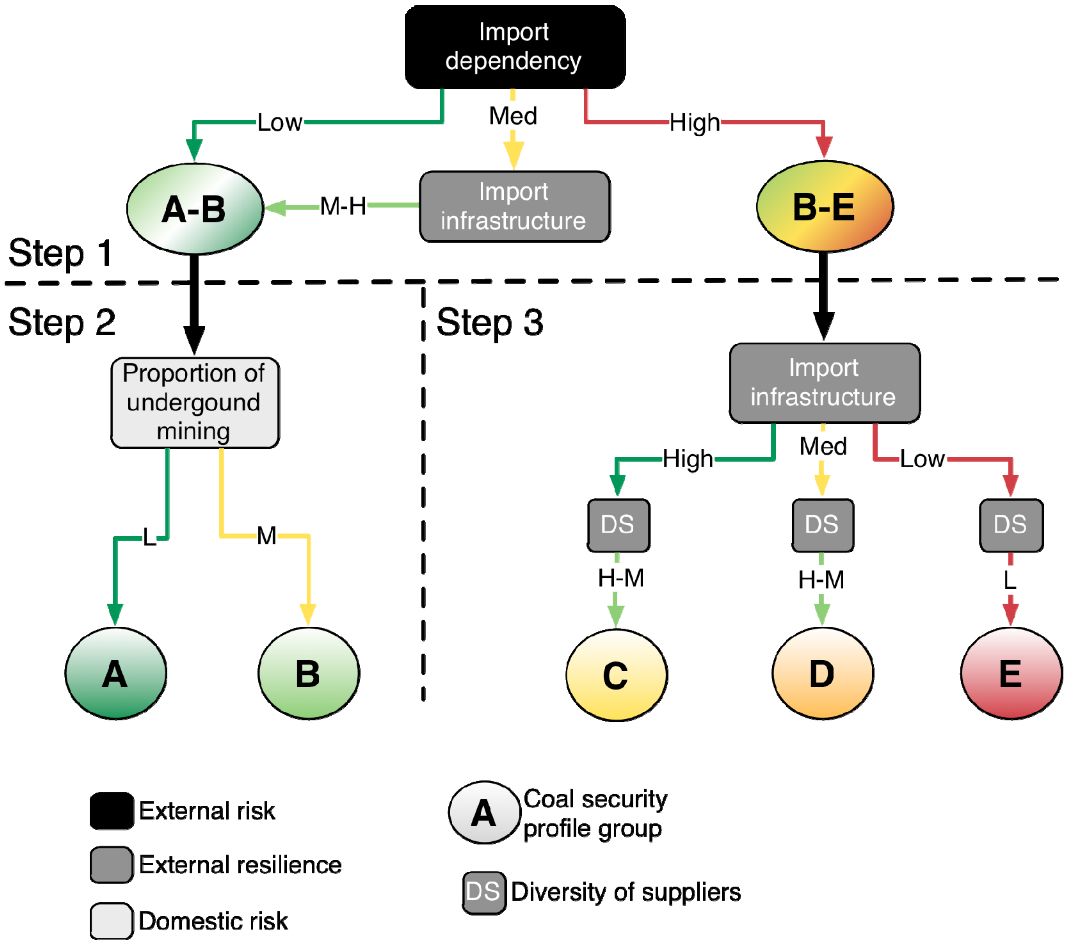
[8] The main exception is coking coal, which globally accounts for just over 10% of coal consumption. Coking coal is primarily used in steel production both as an input to the manufacturing process and for electricity production.

Assessment process: coal

The first step in assessing security of coal supply involves evaluating the exposure to external risks by sorting countries based on import dependency (Figure 6). Low and moderate import-dependent countries are assigned to Groups A and B, depending on the proportion of their domestic production that comes from underground mining. Countries with high import dependency are sorted into Groups C, D and E based on their external resilience.

The second step is to evaluate domestic risk based on the proportion of domestic mining that comes from underground mines. Countries where less than 40% of coal comes from underground mines are assigned to Group A. Countries where more than 40% of coal comes from underground mines are assigned to Group B.

Figure 6 Coal: steps for assessing security of supply



The third step is to sort countries with high import dependency based on their external resilience capacities (Table 23). Countries fall into three categories in terms of entry points: those with a strong importing infrastructure (more than five coal-receiving ports); those with a moderate importing infrastructure (two to four river or marine ports, and up to three land entry points); and one country with only one port and two land entry points. All countries have medium to high diversity of suppliers of coal, except Switzerland and Finland.

Table 23 Coal: external resilience of supply

		Infrastructure rating		
		High (≥5 ports)	**Medium (2-4 ports)**	**Low (1 port & 0-3 railways)**
Diversity of suppliers	**High**	BE, DE, DK, ES, FR, IT, KR, NL, UK	HU, PT, SK, SE, TK	
	Med	IE, JP	AT, LU	
	Low	FI		CH

Results: coal

IEA countries fall into five groups according to the security of their coal supply (Table 24).

Table 24 Coal: summary of findings on security of supply

Group	Countries that:	No. of countries
A	**Export coal** or **Import 30%-60%** of coal with • the share of underground mining ≤40%.	12
B	**Import 30%-60%** of coal with • the share of underground mining >40%.	2
C	**Import ≥70%** of coal with • medium to high supplier diversity and ≥5 river or sea ports for coal import.	8
D	**Import ≥70%** of coal with • medium to high supplier diversity and 3-4 river or sea ports for coal import.	5
E	**Import ≥70%** of coal with • low supplier diversity and ≤2 sea or river ports.	1

Biomass and waste

Biomass and waste encompass a large array of energy sources, including industrial and municipal waste; solid biomass (wood, wood wastes, agricultural wastes, etc.); and landfill, sludge and biogases. Liquid biofuels destined for the transportation sector are dealt with separately at the end of the section since they are mostly used for blending into oil products and follow production and transformation routes whose risks differ from those for solid biomass and waste used in power generation, industry and the residential sector.

Indicators: biomass and waste

The analysis for **biomass and waste** security is based on two indicators (Table 25). External resilience is not considered because only solid biomass is imported and such imports are easy to deliver by sea to commercial ports or by land on a special goods train.

Table 25 Biomass and waste: dimensions of energy security and indicators

	Risks	Resilience
External	**External risks:** • import dependence	**External resilience:** • n/a
Domestic	**Domestic risks:** • n/a	**Domestic resilience:** • diversity of sources

External risks are evaluated by measuring the **import dependency** of solid biomass, the only energy source in this category traded in IEA countries.

Biomass and waste generally face little risk of disruption. Wood can be subject to forest fires; agricultural and wood waste can be disrupted by lower production levels or by upstream plants closing. The more the biomass and waste group depends on a single source, however, the more exposed it is to disruption, so the domestic resilience of the group is measured by the **diversity of sources** (Table 26).

Table 26 Biomass and waste: ranges for indicators

Dimension	Indicator	Low		Medium	High
External risk	Import dependence	<15%	15%-25%	No country imports more than 25% of this source	
Domestic resilience	Source diversity	>0.5		0.3-0.5	<0.3

The analysis of **biofuels** is based on three indicators (Table 27) and separates countries into low, medium and high risk or resilience capacity (Table 28).

Table 27 Biofuels: dimensions of energy security and indicators

	Risks	Resilience
External	**External risks:** • import dependence	**External resilience:** • entry points
Domestic	**Domestic risks:** • volatility of agricultural output	**Domestic resilience:** • n/a

Import dependency, an external risk indicator for biofuels, is considered independently for biodiesel and bioethanol (just as gasoline, middle distillates and other oil products are evaluated independently). This external risk is measured against the number and nature of **entry points** as an indicator of external resilience. (The number of entry points is based on data for oil products, as biofuel-specific entry point data were not available.)

Domestic risks are evaluated using the **volatility of agricultural output** as measured by the OECD agricultural output index (OECD 2008). Since biofuels are primarily produced from agricultural output and increasingly from agricultural wastes, disruptions in agricultural production can disrupt biofuels production.

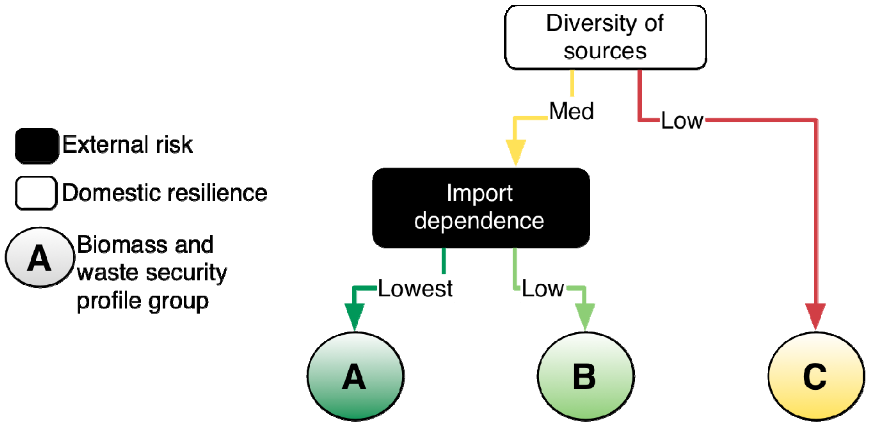
Table 28 Biofuels: ranges for indicators

Dimensions	Indicator		Low	Medium	High
External risk	Import dependence		<20%	40%-70%	>80%
External resilience	Import infrastructure (entry points)	Sea ports	0	2-4	≥5
		River ports	1-2	No countries have more than 2 river entry points without at least 5 maritime ports	
Domestic risk	Volatility of agricultural output		0%-5%	5%-10%	>10%

Assessment process: biomass and waste

Biomass and waste security does not vary greatly between IEA countries; the range and natural groupings for the two indicators are far smaller than for any other fuel. Import dependency ranges from 0% to 24% (with only three countries importing more than 15%) and the diversity of sources ranges from 0.3 to 1.0. Thus no country has high exposure to external risks. As a result of this homogeneity, countries are grouped into three categories rather than five (Table 32). In this module, unlike other MOSES modules, the diversity of sources is the most important indicator, rather than import dependency, because no member country imports more than 25% of the energy it derives from these sources (Figure 7).

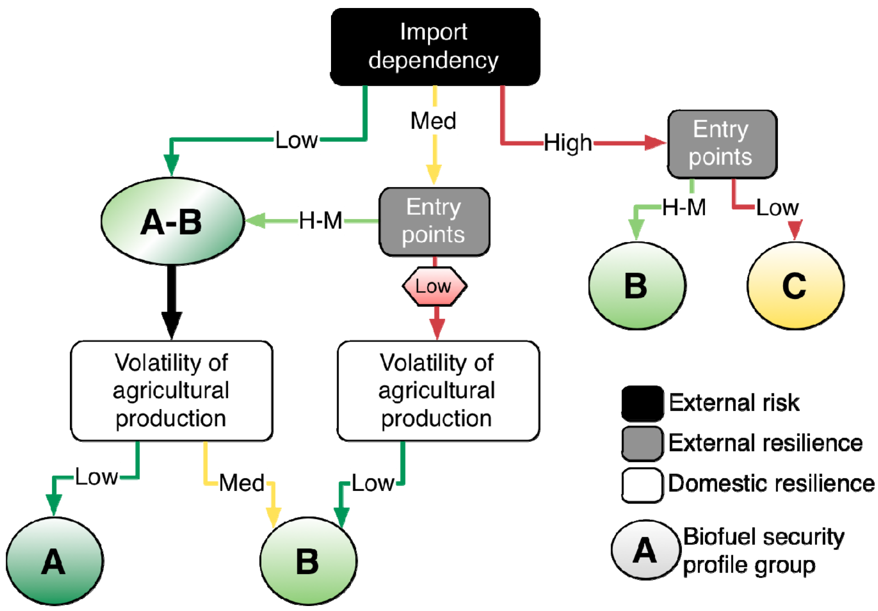
Figure 7 Biomass and waste: steps for assessing security of supply



Assessment process: biofuels

Like oil products, biofuels are evaluated independently for different end-use products (bioethanol and biodiesel). Other biofuels are not evaluated as they account for less than 5% of biofuel demand in IEA countries. The assessment process is similar to that for oil products: step 1 evaluates the security of externally sourced bioethanol and biodiesel (based on import dependence and the nature of entry points); step 2 evaluates the security of domestically produced biofuels based on the volatility of agricultural output; and step 3 evaluates the overall security of both bioethanol and biodiesel by combining the externally and domestically produced flows of both bioethanol and biodiesel (Figure 8).

Figure 8 Biofuels: steps for assessing security of supply



Vulnerability of externally sourced bioethanol and biodiesel

This step evaluates countries both on their exposure to external disruptions and their external resilience capacity. The rating for external resilience is solely based on infrastructure, since the diversity of suppliers is not available for biofuels. The infrastructure ratings from the oil products module are used to evaluate the external resilience with respect to biofuels imports (Table 29).

Table 29 Biofuels: external resilience for imports

	Infrastructure rating
High (>5 ports)	AU, CA, IE, DE, DK, ES, FI, FR, IT, KR, NO, NZ, PT, SE, TK, UK, US
Medium (2 maritime and 2 river ports)	PL
Low (1-2 river ports)	AT, CH, CZ, HU, LU, NO, SK

Note: We only evaluate external resilience for countries with a net import dependence of bioethanol and/or biodiesel.

The external resilience rating is then combined with the import dependency for both biodiesel and bioethanol to evaluate the overall security of externally sourced biofuels.

Table 30a Bioethanol: exposure to disruptions of external supply

Import dependence			
<20%	AU, AT, BE, CA, CH, CZ, DE, ES, FR, HU, IT, NZ, SK, SE, TK, US		
	External resilience		
	High	Medium	Low
Medium (40%-70%)	UK	PL	
High (>70%)	DK, FI, IE, NL		LU

Note: We only evaluate external supply for countries that consume bioethanol.

Table 30b Biodiesel: exposure to disruptions of external supply

Import dependence			
<20%	CA, LU, NO		
	External resilience		
	High	Medium	Low
Medium (40%-70%)	IE, IT, UK		AT
High (>70%)	AU, BE, DE, ES, FI, FR, GR, KR, NL, NZ, PT, SE, TK, US	PL	CH, CZ, HU, SK

Note: We only evaluate external supply for countries that consume biodiesel.

Vulnerability of domestically produced biofuels

This step sorts countries based on the volatility of agricultural output. Countries fall into three groups: those with very low volatility of agricultural production, those with low volatility of agricultural production, and one country with medium volatility of agricultural production.

Table 31 Biofuels: security of domestic production

	Volatility of agricultural production
Very low	AT, BE, CZ, CH DE, DK, ES, FI, FR, GR, IE, IT, KR, LU, NL, NO, PL, PT, SE, TK, UK, US
Low	AU, CA, HU, NZ
Medium	SK

Combining external and domestic factors for biodiesel and bioethanol

The final step combines the external and domestic vulnerability factors for an overall evaluation of both biodiesel and bioethanol, separating IEA countries into groups with similar risk and resilience profiles. The range and diversity of indicators is smaller than for other fuels, so we present only four groups for bioethanol (Table 33a) and three for biodiesel security (Table 33b).

Results: biomass and waste

Table 32 Biomass and waste: summary of findings on security of supply

Group	Countries that have:	No. of Countries
A	**High diversity of sources** (with concentration <0.3) and **very low import dependency** (≤8%).	7
B	**High diversity of sources** (with concentration <0.3) and **low import dependency** (16%-24%).	18
C	**Low diversity of sources** (with high concentration of sources >0.5 which means at least 75% of their biomass and waste comes from a single source) and **low import dependency** (16%-24%).	3

Table 33a Bioethanol: summary of findings on security of supply

Group	Countries that have:	No. of countries
A	**Low or medium import dependency** (<70%), combined with ≥5 sea ports and low volatility of agricultural production (<5%).	18
B_1	**High import dependency** (>80%) and ≥5 sea ports.	4
B_2	**No import dependency** combined with medium volatility of agricultural production (5%-10%).	1
C	**High import dependency** (>80%) combined with 1-2 river ports.	1

Table 33b Biodiesel: summary of findings on security of supply

Group	Countries that have:	No. of countries
A	**Low or medium import dependency** (<70%), combined with ≥5 sea ports and low volatility of agricultural production (<5%).	5
B	**High import dependency** (>80%) combined with ≥2 sea ports or **Medium import dependency** (40%-70%) combined with 1-2 river ports and low volatility of agricultural production (<5%).	18
C	**High import dependency** (>80%) combined with 1-2 river ports.	4

Geothermal, hydropower, solar, wind and ocean energy

Geothermal, hydropower, solar, wind and ocean energy are primarily used to produce electricity, so the security of their supply is closely linked to the vulnerability of electricity systems. However, the present version of MOSES focuses on security of supply rather than on risks associated with production, transmission and use of electricity. As a result, its potential to evaluate security of these sources is limited.

Geothermal, hydropower, solar, wind, and ocean energy are harnessed domestically and are widely viewed as increasing overall security of energy supply by reducing import dependency and increasing diversity of total primary energy supply (TPES). Electricity produced from these renewable sources currently accounts for only a small proportion of TPES in most IEA countries. Only six IEA countries (Austria, Canada, New Zealand, Norway, Sweden and Switzerland) meet more than 10% of their TPES with electricity produced from these renewables. For five of these countries, this electricity is produced almost exclusively from hydropower; in New Zealand, about 20% of TPES comes from hydropower and geothermal sources.

Most renewable sources are exposed to specific security risks related to their natural availability. Variability in these energy sources is specifically planned for in electricity system design and management. Hydropower, solar, wind and ocean energy vary over time and can be limited either by the intrinsic nature of the source (*e.g.* solar energy is only available during daytime) or by climatic conditions. However, while hydropower can vary on a yearly, monthly and/or weekly basis, wind, solar and ocean energy can vary hourly or even by the minute and are more difficult to forecast and balance.[9] In contrast, geothermal resources are much like fossil resources and do not experience large variation over the short-term.[10]

This section provides a quantitative evaluation of hydropower and qualitatively discusses the issues related to security of other renewable energy sources used for electricity production.

Indicators: hydropower

Since hydropower is produced domestically,[11] only domestic risks and resilience factors are relevant (Table 34).

Table 34 Hydropower: indicators for evaluating vulnerability

	Risks	Resilience
External	**External risks:** • n/a	**External resilience:** • n/a
Domestic	**Domestic risks:** • variability of hydropower (as measured by annual volatility of production)	**Domestic resilience:** • variability of hydropower (as measured by annual volatility of production)

Note: The variability of hydropower is considered to be a measure of both risk and resilience (see text).

Variability of hydropower production is determined by monthly- and annual- (rather than hourly) variations of weather conditions. The indicator used to evaluate hydropower is the average annual volatility of hydropower production (1990-2009), which is calculated by the standard deviation of full load hours over the average of full load hours. This indicator measures both risk and resilience aspects of hydropower production. In terms of risks, the average annual volatility of production is a proxy for weather variability: a high volatility is assumed to indicate a high

[9] Although tidal energy is variable, it is completely predictable. Solar power can also be predicted to a certain extent.

[10] Solid biomass for power generation is also dispatchable. It is treated in detail in another section on biomass and waste.

[11] Imports of electricity generated from renewable (and other) sources will be considered in another section of MOSES.

variability in the weather. In terms of resilience capacities, a low volatility is assumed to indicate a high resilience capacity of the hydropower system, for instance large hydro reservoirs (stocks) compared with annual production. Thus, this indicator reflects not only weather variability but also the load and storage capacity and is considered both a risk and resilience indicator.

In an ideal evaluation, additional risks and resilience capacities would be measured. For risks, an ideal indicator would be drought frequency, severity and duration. For resilience, spare capacity, water storage reservoirs and the geographic spread of hydro power plants could be used. However, comparable data are not available for all IEA countries for these ideal indicators.

Annual volatility of hydropower production for all IEA countries varies from 4% to 30%. The six IEA countries with the largest proportion of TPES from hydropower have the lowest observed annual volatility of production (all ≤11%), probably because they have the best systems for managing variations of hydropower availability.

Results: hydropower

Table 35 Hydropower: security profiles

Group	Countries with:	No. of countries
A	Volatility of hydropower production ≤11%.	12
B	Volatility of hydropower production 12%-21%.	12
C	Volatility of hydropower production ≥22%.	4

Other non-combustible electricity-producing renewables

In addition to hydropower there are three other variable non-combustible sources (wind, solar, and ocean energy) and geothermal energy. Geothermal energy is considered to be most secure because its supply is less variable over the short term. At this stage, IEA countries are not differentiated according to the security of their geothermal energy supply.

The other non-combustible renewables are not dealt with quantitatively in this version of MOSES. Intermittency of wind and solar energy constitutes an inherent part of electricity security, whereas this version of MOSES is focused on security of supply.

The IEA is actively researching electricity security and intermittent resources. A recent IEA publication discusses in detail the technological, geographical, institutional and market factors affecting variable renewable deployment and integration in grids (*Harnessing Variable Renewables*, IEA 2011). The study concludes that reliable penetration (and consequent high security) of variable renewable power sources depends on the flexibility of the whole electric system they are embedded in.

Nuclear power

In evaluating the security of nuclear energy supply, MOSES assesses the likelihood of disruption in the supply of electricity produced from nuclear power plants. This assessment is the first step in a comprehensive evaluation of the security of nuclear energy supply; later steps will integrate this evaluation into an assessment of electricity security. It is important to note that the evaluation does not assess the safety of nuclear power plants.

Neither the supply security of the primary source (uranium) nor the supply security of secondary fuels (nuclear fuel) is relevant to an evaluation of short-term energy security. When refuelled, nuclear power plants typically receive two to three years of nuclear fuel stocks and some plants can stockpile up to ten years of nuclear fuel. This resilience, which is unique to nuclear energy, is a major advantage for the energy security of countries that have nuclear power plants.

Indicators: nuclear power

The analysis is based on four indicators that relate to two dimensions of energy security (Table 36). External risks are not considered because, as discussed, they are not relevant to short-term nuclear energy security. The analysis presented here will be integrated into the analysis of electricity security, which the IEA is currently developing (see Overview). The results presented below are therefore not representative of the security of overall electricity supply. The nuclear energy indicators and assessment process may also be reviewed to ensure the consistency of the analysis between electricity generation technologies.

Table 36 Nuclear power: dimensions of energy security and indicators

	Risks	Resilience
External	**External risks:** • n/a	**External resilience:** • n/a
Domestic	**Domestic risks:** • unplanned outage rate • average age of nuclear power plants	**Domestic resilience:** • diversity of reactor models • number of nuclear power plants

The most important indicator is the **unplanned outage rate**. This indicator is reported by the International Atomic Energy Agency (IAEA) and is the measurement of unplanned energy losses for a given period divided by the reference energy generation for that period. It measures the proportion of unplanned time that a nuclear power plant is offline. For this indicator, the average value for the period 1999-2009 is used.

The second risk indicator is the **average age of nuclear power plants**. As nuclear power plants age, the likelihood that they will experience an outage increases. This has been signalled as an energy security concern in several member countries. This is a judgement not of the safety of these plants, but of the likelihood they will be available for energy production.

To measure resilience, the **diversity of reactor models** and the **number of nuclear power reactors** are used as indicators. The first indicator is calculated using the total generation capacity of each type of reactor model from IAEA data with a Herfindahl-Hirschman index. The fewer models a reactor fleet has, the more vulnerable it is to a systematic design flaw. In France this is known as the "risque générique", which is the risk that the discovery of a technical flaw in one reactor would lead to shutdown of the entire fleet or a large portion of it. The second resilience indicator, the number of nuclear power plants, measures how concentrated the fleet is and how exposed it is to malfunction or shutdown (*e.g.* because of extreme natural events or accidents) of a single reactor.

Each indicator is broken into different ranges for low, medium and high risk or resilience capacity (Table 37).

Table 37 Nuclear power: ranges for indicators

Indicator		Low	Medium	High	
Domestic risk	Unplanned capability loss factor	<3%	3%-6%	6%-9%	>15%
	Average age of NPPs	<20	20-30	>30	
Domestic resilience	Nuclear power reactors	1	4-10	≥15	
	Diversity of reactor models	>0.6	0.3-0.6	<0.3	

Assessment process: nuclear power

As with other fuels, aggregation of nuclear power indicators is a step-by-step process to separate IEA countries into five groups based on their risk and resilience profiles (Figure 9).

The first step involves evaluating the exposure to risks. Countries are sorted based on their unplanned capability loss factor and the average age of their NPPs. These two indicators are combined to present low, medium and high risk exposure ratings (Table 38).

Table 38 Nuclear power: evaluating risk exposure for security of supply

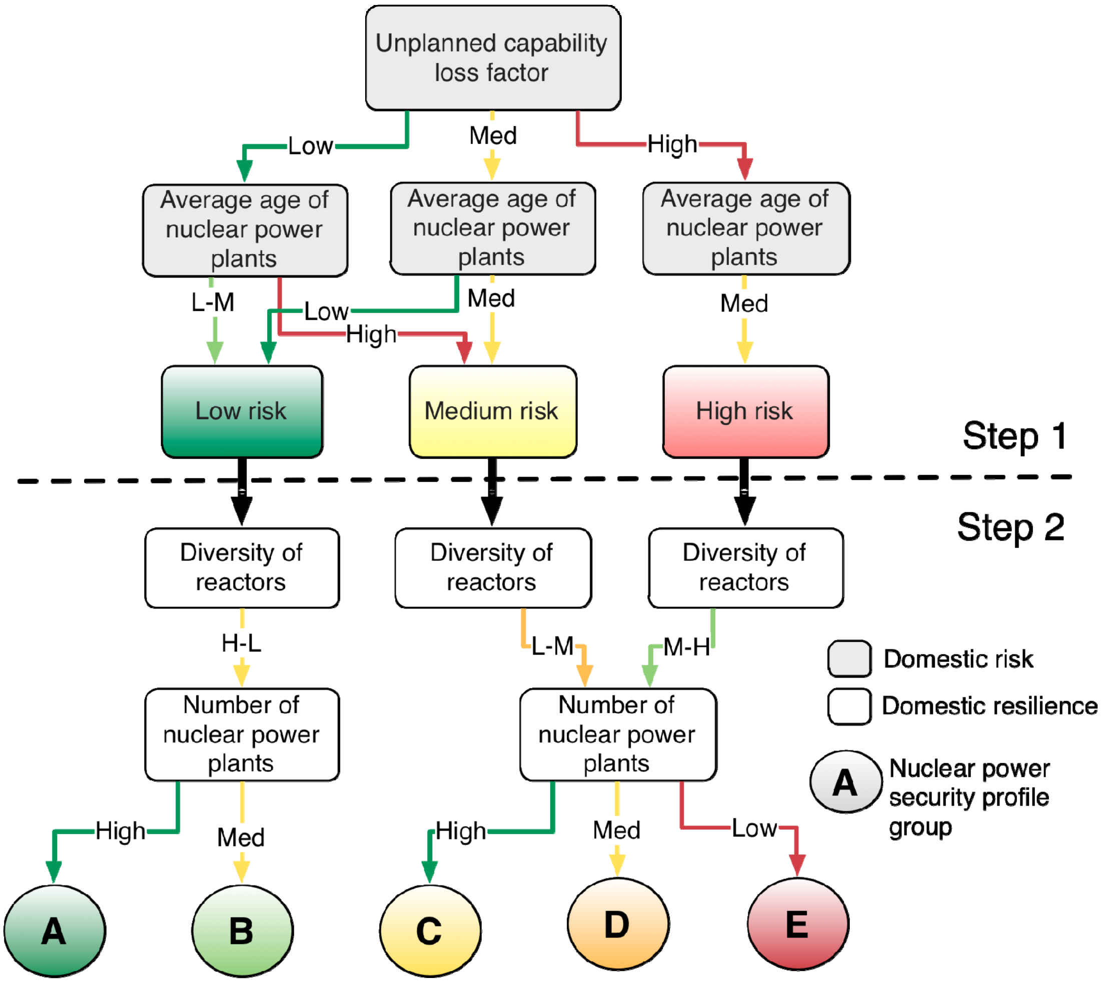
		Unplanned outage rate		
		Low (<3%)	Medium (3%-6%)	High (>6%)
Average age of NPPs	Low	KR, SK	CZ	
	Med	BE, FI, US	DE, ES, HU	CA, FR, JP, SE, UK
	High	CH, NL		

The second step is to evaluate countries based on their resilience capacity. Countries are evaluated for both the number of NPP reactors and the diversity of reactor models (Table 39).

Table 39 Nuclear power: evaluating resilience capacity for security of supply

		Number of NPP reactors		
		High (>15)	Medium (4-10)	Low (1)
Diversity of reactor models	High	CA, FR, JP, US	SE	
	Med	KR, UK	BE, CH, CZ, DE, ES, FI	
	Low		HU, SK	NL

Figure 9 Nuclear power: steps for assessing security of supply



The final step of the analysis separates countries into five groups based on their risk and resilience level for nuclear power production (Table 40).

Results: nuclear power

Table 40 Nuclear power: summary of findings on security of supply

Group	Countries that have:	No. of countries
A	An unplanned outage rate ≤3% with • ≥15 nuclear power plants and a moderate to high diversity of reactor models.	2
B	An unplanned outage rate ≤3% with • 4-10 nuclear power plants and a moderate to high diversity of reactor models..	4
C	An unplanned outage rate >3% with • ≥ 15 nuclear power plants and a moderate to high diversity of reactor models.	5
D	An unplanned outage rate >3% with • 4-10 nuclear power plants and a moderate diversity of reactor models.	4
E	An unplanned outage rate ≤3% with • 1 relatively old nuclear power plant.	1

Conclusions

This paper presents a systematic framework and a set of indicators to analyse short-term security of supply for primary energy sources and secondary fuels in IEA countries. Focusing on national energy systems, the paper examines external and domestic sources of risk as well as resilience to short-term disruptions. This work is framed by a comprehensive view of energy security that looks beyond the vulnerability of a country's oil supplies.

MOSES is a step towards developing a toolbox for understanding and measuring comprehensive energy security. This version of MOSES covers short-term security of supply for seven primary energy sources and two sets of secondary fuels. It provides a foundation for an energy systems approach to energy security in which the vulnerability of primary energy sources is connected to vulnerabilities of related secondary fuels.

MOSES can be used to track a country's energy security over time or analyse the effect that a particular policy would have on a nation's energy security situation. By grouping countries with similar energy security profiles, it depicts the energy security landscape of IEA countries. It can also be used to facilitate a dialogue between policy makers in different countries to identify common priorities and strategies. On the national level, MOSES can be a starting point for energy security assessments and can be supplemented by additional nationally relevant indicators.

The next step in developing a comprehensive energy systems approach to energy security will be to analyse the vulnerability of electricity and energy end-uses such as the transportation, industrial and residential sectors. While security of energy supply is important, consumers and policy makers are ultimately concerned with the security of energy services for end-users. By extending the MOSES methodology to energy services, the IEA aims to develop a comprehensive policy-relevant perspective on global energy security.

Country abbreviations

Austria	AT
Australia	AU
Belgium	BE
Canada	CA
Czech Republic	CZ
Denmark	DK
Finland	FI
France	FR
Germany	DE
Greece	GR
Hungary	HU
Ireland	IE
Italy	IT
Japan	JP
Korea	KR
Luxembourg	LU
Netherlands	NL
New Zealand	NZ
Norway	NO
Poland	PL
Portugal	PT
Slovak Republic	SK
Spain	ES
Sweden	SE
Switzerland	CH
Turkey	TK
United Kingdom	UK
United States	US

References

APERC (2007). A quest for energy security in the 21st century: Resources and constraints. Asia Pacific Research Centre: Tokyo.

Bohi, D.R. and M.A. Toman (1996). *The economics of energy security*. Kluwer Academic Publishers: Norwell, Massachusetts.

Cherp, A. and J. Jewell. (2010). Measuring energy security: From universal indicators to contextualised frameworks. In B. Sovacool (Ed.), *The Routledge handbook to energy security.* Routledge: London.

Cherp, A. and J. Jewell. (2011). The three perspectives on energy security: intellectual history, disciplinary roots and the potential for integration. *Current Opinion in Environmental Sustainability,* 3(4), pp.202-212.

Cherp A. *et al*. (In Press). Energy and security in *Global Energy Assessment: Toward a More Sustainable Future*. IIASA and Cambridge University Press: Cambridge, U.K./New York, U.S.A. and Laxenburg, Austria.

Gupta, E. (2008). Oil vulnerability index of oil-importing countries. *Energy Policy*, 36(3), pp.1195-1211.

Jansen, J. C., W.G. van Arkel and M.G. Boots. (2004, January). *Designing indicators of long-term energy supply security*. Energy research Centre of the Netherlands: Petten, Netherlands.

Jansen, J.C. and A.J. Seebregts (2010), Long-term energy services security: What is it and how can it be measured and valued? *Energy Policy*, 38(4), pp.1654-64.

Kendell, J. M. (1998, July). *Measures of oil import dependence*. U.S. Energy Information Agency: Washington, DC.

Keppler, J.H. (2007). International relations and security of energy supply: Risks to continuity and geopolitical risks. Brussels: Directorate General External Policies of the Union. European Parliament.

Kruyt, B., D. P. van Vuuren, H.J.M. de Vries, and H. Groenenberg. (2009). Indicators for energy security. *Energy Policy*, *37*(6), pp.2166-2181.

OECD, 2008. *OECD Environmental Data Compendium: Agriculture*. Table 9: Agricultural Production. OECD: Paris.

Scheepers, M., A. Seebregts, J. de Jong, and H. Maters. (2007). EU standards for energy security of supply. *EU standards for energy security of supply*. ECN/Clingendael International Energy Programme: Petten & the Hague.

Sovacool, B. and M.A. Brown (2010). Competing dimensions of energy security: An international perspective. *Annual Review of Environment and Resources*, 35(1), pp.77-108.

Stirling, A. (1994). Diversity and ignorance in electricity supply investment: Addressing the solution rather than the problem. *Energy Policy*, 22(3), pp.195-216.

Stirling, A. (2010). Multicriteria diversity analysis: A novel heuristic framework for appraising energy portfolios. *Energy Policy*, 38(4), pp.1622 - 1634.

US Chamber of Commerce (2010). *Index of U.S. Energy security risk: Assessing America's vulnerabilities in a global energy market*. U.S. Chamber of Commerce: Washington D.C.

International Energy Agency

Online bookshop

Buy IEA publications online:

www.iea.org/books

PDF versions available at 20% discount

Books published before January 2010
- except statistics publications -
are freely available in pdf

International Energy Agency • 9 rue de la Fédération • 75739 Paris Cedex 15, France

iea
Tel: +33 (0)1 40 57 66 90
E-mail:
books@iea.org

International Energy Agency

9 rue de la Fédération
75739 Paris Cedex 15

www.iea.org