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8. Energy security assessment framework and three case studies

Aleh Cherp and Jessica Jewell

INTRODUCTION

The interest in measuring energy security results not only from its rising prominence but also from its increasing complexity. In the past, energy security concerns were no less acute than they are today. Consider, for example, the importance of access to oil for nations engaged in major wars of the 20th century. Yet, to strive for energy security in such cases did not require complex measures because policy makers were directly engaged and closely familiar with these immediate and pressing issues. In contrast, today's energy security problems often overlap national, institutional and sectoral boundaries stretching the cognitive abilities of experts and policy makers to deal with diverse situations and challenges which may not be directly familiar or predictable. One approach to cutting through this complexity is relating energy security to a common yardstick that would allow comparing it across different countries, at different points in time or to other policy priorities, in other words quantitatively *measuring* energy security.

The challenge of measuring energy security is not only to see through natural, technological, and economic complexities and uncertainties, but also to address the fact that it has different meanings for different groups (Chester, 2009). No single set of metrics is suitable for assessing energy security for all purposes in all situations. Instead energy security should be measured through application of an assessment framework sufficiently systematic to ensure scientific rigor and sufficiently flexible to account for specific circumstances and perspectives (Cherp and Jewell, 2011a). This chapter outlines such a framework and illustrates its application in the following three cases:

- The **International Energy Agency's Model of Short-term Energy Security (MOSES)** (Jewell, 2011). The purpose of MOSES was to depict the energy security landscape of the 28 IEA member countries by characterizing their energy security profiles and grouping together countries with similar energy profiles.

- The **Global Energy Assessment** (GEA) (GEA, 2012), a major international effort to evaluate energy challenges and construct long-term scenarios for meeting these challenges. The purpose of GEA's energy security assessment (GEA Chapter 5, Cherp et al., 2012) was to "identify common energy security concerns (in over 130 countries) affecting significant parts of the world's population".
- A set of recent studies of **energy security in future scenarios** based on the methodology originally proposed by (Jewell, 2010) and subsequently used in Chapter 17 of GEA (Riahi et al., 2012) as well as in Jewell et al. (2012) and Cherp et al. (2013). The purpose of these studies has been to analyze energy security in long-term (up to the year 2010) scenarios of transformation of global energy systems.

METHODOLOGICAL CHOICES

Any quantification of energy security requires certain methodological choices. Making such choices is a difficult task because of the multitude of interpretations of energy security (see overviews in Cherp and Jewell, 2011b; Sovacool, 2011; Chester, 2009; Winzer, 2012). The two most fundamental methodological choices in energy security assessments are (1) the choice between perceptions and facts in deciding what constitutes a significant energy security concern and (2) the choice between the specific and generic in deciding on what is the appropriate level of detail of the assessment. As we explain in the next section these choices need to be made with respect to vital energy systems, their vulnerabilities, and selection and interpretation of indicators.

The first choice in deciding what constitutes an energy security concern and whether such a concern is significant is between facts and perceptions. Focusing on facts means conceptualizing energy security as an objective property of energy systems which makes it easier to quantify and compare (e.g. by Le Coq and Paltseva, 2009 and Gupta, 2008). This approach, however, sometimes fails to explain the actual energy security policy priorities influenced by such hard-to-quantify factors as history, culture, politics and psychology.

On the other end of the epistemological spectrum are perceptions. For example, Sovacool and Mukherjee (2011) solicit views of various stakeholders to arrive at a set of "dimensions" and indicators of energy security. However, stakeholders can be biased, manipulative or poorly informed. They may either use security rhetoric or ignore obvious concerns to advance their own interests. As a result, an assessment guided

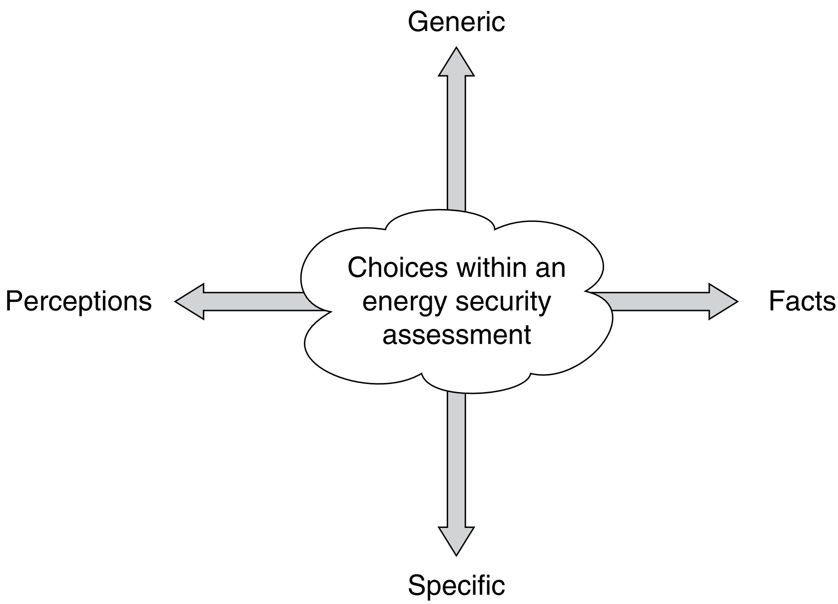


Figure 8.1 Major methodological choices in measuring energy security and the energy systems approach

by such a survey would risk not being policy relevant. Thus, an energy security analyst should be aware of biases and try to reduce them while still remaining policy relevant. Cherp (2012) argues that perceptions can be useful in framing energy security assessments only if they are solicited from a relevant group of stakeholders and in such a way that forces prioritization of various concerns.

The three case studies discussed in this chapter strive to combine analyses of energy systems and insights from energy security policies to arrive at findings that are both scientifically rigorous and reflective of policy concerns. MOSES was conducted under the oversight of IEA member countries and in direct and continuous dialogue with policy-makers. The GEA analysis frames its quantitative findings with an analysis of energy security policies. Finally, the analysis of future energy scenarios derives its approach from the careful study of the evolution of energy security policy paradigms over last century to distill generic concerns which can be plausibly valid for the next 100 years.

The second choice is between the generic and the specific in choosing the scope, focus and tools for an assessment. The three case-studies discussed in this chapter feature various degree of specificity. MOSES uses approaches specific to energy supply of developed market economies. GEA's approach is more generic as it needs to be applicable to over 130 countries. Finally, the analysis of energy security of future scenarios needs to deal with energy systems which are widely different from those of today and thus uses the most generic approach of the three cases.

In summary, an effective energy security assessment is specific enough to reflect context-specific issues and yet generic enough to enable sufficiently wide comparison. Likewise, it is based on hard facts, not opinions while still responding to perceptions and policy priorities. Finding such trade-offs is the science and art of energy security assessments. There is no blueprint for achieving this balance, but in all the three cases it has been guided by an energy systems approach. This approach proceeds from the premise that the term "energy" in "energy security" designates not a black box with amorphous content, but rather a set of interlinked systems each consisting of elements connected to each other and to the outside world and each with their own sets of vulnerabilities.

Thinking in such systems terms can support methodological choices within energy security assessments. For example, perceptions of energy stakeholders, especially policy makers, can be structured in accordance with three fundamental security questions: What to protect? From which risks? And by which means? Answers to these questions reflect the way policy makers perceive energy systems which can be related to objective facts about them.

The energy systems approach can also support the choice between the specific and the generic in energy security assessments. Specific approaches developed for particular situations work better when the assessment compares similar energy systems (e.g. the change in energy security of a particular country from one year to another). However, the wider the difference in energy systems that require comparison is (for example involving many diverse countries or addressing the situation in a distant future), the more generic the energy security assessment methodology should be. The range of addressed concerns may need to be wider, the indicators more universal and their interpretation involve stronger qualitative elements.

The methodological choices in an energy security assessment should be systematic rational and transparent. They should reflect the configuration of energy systems (real and perceived), justified based on the purpose on the assessment and clearly explained for the intended audience. The proposed energy security assessment framework presents an approach for guiding such choices through several stages as explained in the following section.

ENERGY SECURITY ASSESSMENT FRAMEWORK

The energy security assessment framework includes five stages:

1. defining energy security for the purpose of the assessment;
2. delineating vital energy systems;
3. identifying vulnerabilities of vital energy systems;
4. selecting and calculating indicators for these vulnerabilities;
5. interpreting the indicators to answer the questions posed by the assessment.

Defining Energy Security

Because there is no universal definition of energy security (Chester, 2009; Winzer, 2012), any energy security assessment should start with choosing or operationalizing an appropriate definition. For example, the analysis of energy security in future energy scenarios uses the most generic definition of energy security as *low vulnerability of vital energy systems*. It covers a wide variety of situations and at the same time provides a clear direction of operationalizing it for a specific context by narrowing down the concepts of "vulnerability" and "vital energy systems". The GEA defines energy security as *uninterrupted provision of vital energy services*. The focus on energy services reflects GEA's emphasis on energy's role in human welfare and sustainable development. As we shall see later, the GEA's actual approach to measuring energy security covers not only energy end-uses but also sources and carriers linked to those services. MOSES proceeds from the IEA definition of energy security as *the uninterrupted physical availability at a price which is affordable, while respecting environmental concerns*. MOSES focuses only on the short-term physical availability of energy referred to in the first part of the definition.

Vital Energy Systems

As already mentioned, energy security is fundamentally a systemic notion. What is secure for a particular system may not be secure for its sub-system(s) and vice-versa. Thus, evaluating energy security entails clearly and explicitly defining the boundaries of the energy systems, which are being evaluated. The choice of these systems is not arbitrary. In addressing the *What to protect?* question, energy security policies are focused not on some abstract "energy" but rather on protecting energy systems which are critical for societies, in other words, vital energy systems.

An early example of a vital energy system can be traced to the time when the British Navy switched from coal to oil on the eve of the First World War (Yergin, 1991). The first vital energy system critical for the survival of the British Empire consisted of a fleet of navy ships and oil wells connected by transportation lines. It formed a true system: shortfalls of oil supplies could be replaced by oil from another source but not, for example, by coal or wood. This explains why even though oil was a tiny proportion of the overall energy consumed at that time it was still at the center of its energy security concerns.

Thus, the notion of a vital energy system combines two aspects. The term "vital" means that it is critical for the functioning and stability of a society.[1] The term "system" means that it consists of resources, materials, infrastructure, technologies, markets and other elements connected to each other stronger than they are connected to the outside world. From the energy security angle, the meaning of such connections is that in the case of a disruption the elements within a system can replace each other, but the elements from outside the system – can't.

Energy systems can be delineated along geographic or sectoral boundaries. Various combinations of geographic and sectoral choices define a potentially large number of energy systems (see Figure 8.2 for an illustration). Only some of these combinations making up vital energy systems will be relevant for a particular energy security assessment.

With respect to geographic boundaries, energy security concerns are primarily articulated at the national level.[2] This is because historically it has always been the responsibility of the nation state to protect security. Even such supra-national entities as the IEA and the European Union respect national boundaries by focusing on energy security of their individual member states. Thus, MOSES focuses on national energy systems of the IEA member countries and GEA focuses on energy security of over 130 countries.

Regional and global energy systems can also be viewed as vital by energy security policies. An historic example is the US Carter doctrine which called for the protection of global oil-producing regions and transportation routes because they are linked to US "vital interests" (Carter, 1980). More recent UK and EU energy security strategies address Eurasian and global gas markets. The Australian National Energy Security Assessment (NESA) analyzes the global markets in liquid fuels and natural gas (Department of Resources, 2011). State-supported Chinese investments in overseas oil assets have been driven by concerns over the security of the global oil market (Zhang, 2012). Bridge et al. (2012) develop an elegant notion of the "global production networks" for the energy system encompassing natural gas production and trade. The GEA discusses energy security in individual regions and analyzes the global market for international traded fuels and the global nuclear fuel cycle.

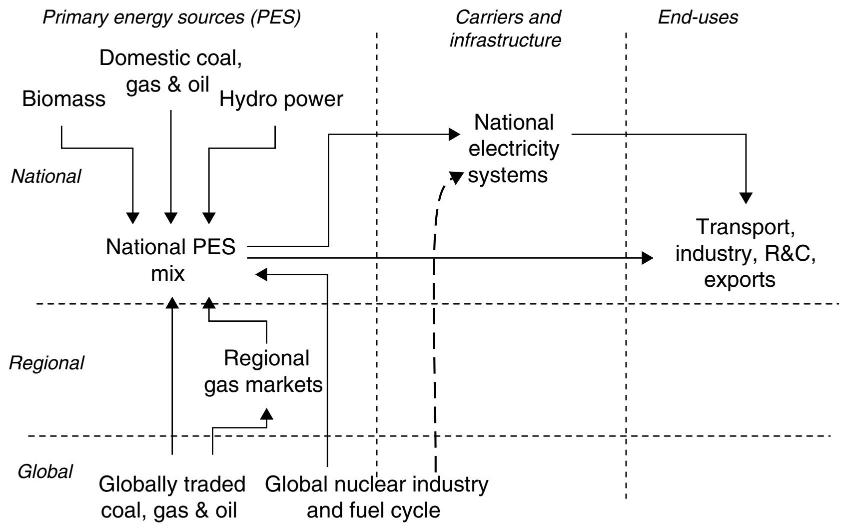
The analysis of energy security in future scenarios (as well as earlier studies of future energy security such as Turton and Barreto (2006) and Costantini et al. (2007)) faces the limitation that global long-term energy models do not have national-level resolution, instead they generate scenarios for a dozen or so "global regions" (for example the Middle East and North Africa). Based on the assumption that intra-regional energy integration and trade will likely be stronger than at present, these assessments analyze energy security at the regional (as well as the global) level.[3]

With respect to sectoral boundaries of vital energy systems, some academic literature refers to "security of supply" drawing the systems boundaries around all primary energy sources. The supply-focused approach is implicit in such generic concepts of energy security as the "4 As" (availability, accessibility, affordability and acceptability) (proposed in APERC (2007)). Such an approach is based on the assumption that various primary energy sources can substitute one another, which is often not the case. In reality, different primary energy sources often have distinct vulnerabilities which need to be analyzed separately. That is why for example Le Coq and Paltseva (2009) analyze vulnerabilities of oil, gas and coal separately.

We already mentioned the historic focus of energy security analysis on oil. This focus has persisted starting from early 20th century and been fueled by such events as the two world wars[4] and the oil embargoes of the 1970s. Security of oil supply clearly remains on the global energy security agenda, however, other sources have entered the picture as well. The IEA's "comprehensive view of energy security" is reflected in MOSES' analysis of seven primary energy sources (oil, natural gas, coal, biomass and waste, nuclear energy, hydropower and geothermal energy). The vital energy systems addressed in the GEA are shown in Figure 8.2. They include biomass particularly important for developing nations.

An example of a vital global energy system examined in the GEA is the nuclear fuel cycle. The GEA analysis shows that while nuclear power plants are constructed and maintained nationally they depend upon supply of nuclear fuel, parts of nuclear reactors and nuclear fuel reprocessing organized globally. Such global systems are another example of "global production networks" (Bridge et al., 2012).

Vital energy systems may also be structured around energy carriers such as electricity analyzed in the GEA (Figure 8.4) and the future energy studies. National electricity grids and power plants represent a truly unified energy system (often backed up by international interconnections). Electricity generation usually relies on a mix of sources so that disruptions in one fuel can be compensated by increased input from another fuel.



Note: The dotted arrow represents vulnerabilities associated with the concentration of nuclear reactor parts, nuclear fuel reprocessing and long-term nuclear waste storage.

Source: Adopted from Cherp et al. (2012).

Figure 8.2 Vital energy systems covered in the GEA

That is why many energy security policies and studies (e.g. Stirling, 1994; Awerbuch, 2006 and Grubb et al., 2006) address security of electricity. Other energy carriers include oil products (diesel, gasoline and others) and biofuels (both categories are analyzed in MOSES) or liquids fuels in general (Department of Resources, 2011; Cherp et al., 2013).

The assessment of energy security in future scenarios faces a major challenge to delineate vital energy systems of the future which might be significantly different from those of today. Thus, this energy security assessment looked into primary energy sources and energy carriers which will play a significant role in future energy systems. With respect to energy sources, it considers tradable fuels: oil, gas, coal and biofuels. With respect to energy carriers, it included synthetic fuels and hydrogen in addition to electricity and liquid fuels.

Finally, end-use sectors (sometimes called "energy services") can also be considered as vital energy systems (an example of an analysis focused on end-use services is Jansen and Seebregts, 2009). For example, one energy end-use vital for all countries is transportation. In the same way as the British Empire could not defend itself without a fleet of navy ships, a modern society cannot function without a fleet of motor vehicles. Other end-uses analyzed in both the GEA and the assessment of future scenarios include the residential and commercial sector and the industrial sector. In addition, the GEA assessment also addresses energy exports as a vital energy system for energy exporting nations, sometimes referred to as "demand security".

In summary, delineation of vital energy systems for an energy security assessment can be supported by the following checklist:

☑ Is this a true system? Are the elements within this system mutually substitutable? Can it be divided into sub-systems or merged with a larger system without making the assessment less meaningful?
☑ Is this a sufficiently significant system in terms of its size or the population using it or the economy it supports? Does this system support truly vital functions of a society?
☑ Is there a history or plausible scenario of disruption of this system or similar systems?
☑ Is this system consistently delineated and meaningful for all situations covered by the assessment?
☑ Are there energy security policies or discourses that address this system?

Vulnerabilities

Vulnerabilities of an energy system are a combination of its exposure to risks and resilience, i.e. its capacity to respond to disruptions. Some authors only look at risks (e.g. APERC, 2007; Winzer, 2012) others focus primarily on resilience (Stirling, 1994; 1998) whereas others (e.g. Kendell, 1998; Gupta, 2008) look at both risks and resilience. Energy security risks differ with respect to their time-profile (shocks or stresses) and the nature of disruptions (physical or economic). Resilience can relate to specific risks (e.g. the presence of alternative pipelines may help to reroute gas imports in case of problems in transit countries) or to more general risks categories (e.g. strategic storage can protect from shocks of supply caused by political, economic or technical factors). The distinction between risk and resilience capacities is not always observed in reality: sometimes these two can only be analyzed in combination.

Disruptions of vital energy systems come in the form of shocks (rapidly unfolding short-term disruptions) and stresses (slowly approaching and longer-lasting phenomena) (Stirling, 2010). Historically the energy security agenda was primarily shaped by shocks such as the oil crises of the 1970s, the coal miners' strikes of the 1980s, and the disruptions of natural gas supply and electricity blackouts of the 2000s. Stresses include unrelenting demand growth, resource depletion and aging of infrastructure.

The second distinction between physical and economic risks is drawn in a classic definition of energy security "sufficient supplies at affordable prices" (Yergin, 2006). Whereas "sufficient supplies" is an intuitively clear concept referring to physical risks, "affordable prices" is more of a widely debated political construct. Policy rhetoric on this issue uses such colorful but unhelpful terms as "reasonable", "true", "fair", "affordable", "cost-effective" and "competitive". A wide body of literature (among which Keppler (2007), Greene (2010) and Helm (2002) can be especially recommended) explores the economic aspects of energy security. An analysis of the policy measures from the UK, Sweden and the EU shows that despite the rhetoric their real focus (compatible with the overall idea of energy security) is on *stable* and *competitive* prices that do not threaten the operation of vitally important industries. Whatever the case, the exact meaning of economic risks to energy systems should be clarified at this stage of the assessment.

The literature proposes multiple ways to classify vulnerabilities often dividing them into economic, political, natural, technical, military, etc. (see e.g. Alhajji, 2008). However, in order to be useful for energy security assessments such classifications need to be more fundamental. Indeed, gaining insight into the causes of potential vulnerabilities of vital energy systems requires detailed understanding of how these systems function. This understanding needs to go beyond common sense and be rooted in a disciplined epistemological community and armed with an effective tool kit. Cherp and Jewell (2011b) identify three such perspectives on energy security rooted in their own historic experience and different disciplines as summarized in Table 8.1.

Historically, the energy security discourse emerged in the context of military hostilities and therefore focused on risks associated with hostile actions such as attacks on supply lines or oil fields. The risk that an adversary would attack or otherwise disrupt vital energy systems has remained high on the political agenda for the last 100 years (be it in the discourse of the "Arab oil weapon" (Paust and Blaustein, 2008), "the Russian gas weapon" (Baran, 2007), or in discussing possible "resource wars" between the US and China (Klare, 2008). The notion of targeted and intentional embargoes is now broadened and more nuanced: it includes concerns over political extortion, political stability of suppliers or collateral damage due to unrelated energy disputes. Nevertheless, all these concerns focus on risks arising from foreign control over vital energy systems. As an influential UK energy security policy document puts it: "[energy security would allow the UK to] retain independence in its foreign policy through avoiding dependence on particular nations" (Wicks, 2009:8). This *sovereignty perspective* on energy security analyzes risks in terms of interests, alliances, power balances and space for maneuver as the sovereignty perspective.

The second perspective on energy security sees the origin of risks in

Table 8.1 Three perspectives on energy security

Perspective	Sovereignty	Robustness	Resilience
Historic roots	War-time oil supplies and the 1970s oil crises	Large accidents, electricity blackouts, resource scarcity	Liberalization of energy systems
Parent discipline	Security studies, international relations, political science	Engineering, natural science	Economics, complex system analysis
Key risks	Intentional actions by malevolent agents including politically motivated disruptions, political extortion and price manipulations	Probabilistically predictable natural, technical and economic factors. Infrastructure failures and aging, extreme natural events, depletion of resources, demand growth	Diverse and partially unpredictable factors: political instability, labor actions, terrorism, climate, economic volatility etc.
Resilience capacities	Competitive market arrangements, diversity of actors, trusted suppliers and reliable regimes	Emergency stocks and redundancies, spare capacities, infrastructure diversity	Diversity of energy technologies, low energy intensity, emergency preparedeness, investent in research and development, etc.
Primary protection mechanisms	Control over energy systems and institutional arrangements preventing disruptive actions	Upgrading infrastructure, constraining demand, switching to more abundant resources	Increasing the ability to withstand and recover from various disruptions

Source: Modified from Cherp and Jewell (2011b).

natural and technical factors rather than in hostile or intentional human actions. It puts at the center concerns such as aging of infrastructure, depletion of resources, and vulnerability of energy systems to extreme natural events. This *robustness perspective* has its roots in natural science and engineering and relies on forecasts and estimation of probabilities for risk evaluation.

The third, *resilience perspective* sees the origin of risks in increasing complexity and uncertainty of technological, social and economic factors affecting energy systems. It recognizes that many disruptions and risks cannot be accurately predicted. It shifts attention from identifying and managing risks to building resilient energy systems that are able to respond to diverse disruptions.

Among the three assessments, MOSES has the narrowest focus on short-term physical disruptions whereas the GEA and the analysis of future energy scenarios cover both shocks and stresses with both a physical and economic nature. All of the assessments seek to integrate the three perspectives on energy security though MOSES predominately focuses on sovereignty and robustness concerns (which it classifies in external and domestic risk and resilience factors, see Table 8.2) whereas the future analysis in its current form only covers sovereignty and resilience concerns. The list of potential future vulnerabilities (see Table 8.4) is largely derived from the prioritization of the *current* vulnerabilities as identified in the GEA (Table 8.3 and Figure 8.4) and interpreted in more generic terms to be applicable to future vital energy systems.

As with vital energy systems, it is important to make systematic and transparent choices of which vulnerabilities (either listed in Table 8.1 or additional ones) to include in (and which to exclude from) the energy security assessments. The following checklist may aid identification of vulnerabilities of vital energy systems in an energy security assessment:

☑ Does a particular vulnerability characterize one of the vital energy systems identified at the previous stage of the assessment?
☑ Is the vulnerability likely to cause a significant disruption to one of the vital energy systems?
☑ Is the vulnerability addressed in energy security policies or rhetoric?

Selecting Indicators

Energy security indicators should reflect the vulnerabilities of vital energy systems identified at the earlier stages of the assessment. They can be selected from those suggested in the abundant literature or designed specifically for the purpose of a particular assessment. Selection of indicators should be guided by how well they represent a particular risk or vulnerability of a vital energy system. However, an indicator is rarely a direct measure of a risk or a resilience capacity. Rather it is a quantitative proxy, a signal of a state of a complex and dynamic energy system. A good analogy here is body temperature as an indicator of human health. As a proxy it does not exactly point to the causes, nature or extent of illness but it is still widely used and relatively reliable, especially when used in conjunction with other observations. So are energy security indicators. One indicator may signal the presence of several risks. For example, import dependency may reflect the exposure to deliberate supply cuts, disputes with transit countries, failures or sabotage of transportation lines, or price volatility. Similarly, one vulnerability can be reflected in several indicators. For example, the risk of blackouts may be reflected by their historic frequency, the age of the power plants, the spare capacity, and the diversity of electricity generation.

Some indicators can be directly found in existing statistical information and other data sources. In most cases, however, the indicators will need to be calculated based on available data. For example, MOSES used data from the IEA, the World Bank and the IAEA; the GEA used publicly available IEA and BP energy statistics as well as Platts energy database, the World Bank, and the IAEA. The analysis of energy security in future energy scenarios derived its data from the variables calculated from Integrated Assessment Models such as MESSAGE and REMIND. Calculation of indicators may use relatively simple formulas such as the reserves-to-production (R/P) ratios or a diversity index such as the Shannon-Weiner Diversity Index or the Herfindahl Hirschmann index. An example of a more complex formula is the calculation of the diversity of energy sources used in transport in future energy scenarios which reflects dozens of links inside the energy system (Jewell et al., 2012).

MOSES uses 35 indicators (see Table 8.2 for a sample, the full list is available in Jewell (2011:11) grouped into four dimensions of vulnerability for each of the primary sources and secondary fuels.

GEA uses some 30 indicators most of which are listed in Table 8.3. In contrast to MOSES, GEA addresses a wider range of energy systems and vulnerabilities and thus uses less detailed but more diverse indicators. The more general nature of the GEA indicators is also explained by the fact that the GEA analysts did not have access to as detailed information for all 134 countries as MOSES had for the IEA members.

The analysis of energy security in future energy scenarios used 20 global and five regional indicators summarized in Table 8.4 (some of these are proposed for future studies).

Table 8.2 Indicators of crude oil supply security used in MOSES

	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: ● Domestic storage level

Source: Jewell (2011).

Selection of energy security indicators may be guided by the following checklist of questions:

☑ Is the indicator a characteristic of one of the vital energy systems?
☑ Does the indicator reflect one or more significant vulnerabilities (risks and/or resilience capacities) identified earlier?
☑ Does the indicator provide useful information about this risk or vulnerability in addition to that provided by other indicators?
☑ Are there reliable data and tools (models, etc.) available for calculating the indicator at all time points or for all situations covered by the assessment purposes?

Making Sense of Indicators

After the indicators have been calculated, the complex journey from the initial assessment questions to a set of numbers needs to be traced backwards: from those numbers to meaningful answers. The final task is to process, interpret and communicate the indicators in such a way that they convey accurate and relevant information cognitively accessible to the intended audiences of the assessment. There are three interrelated strategies for achieving this objective:

- interpreting individual indicators;
- reducing the number of indicators by combining them into aggregated metrics;
- presenting the indicators (individually or jointly) in a format that facilitates the assessment.

First, well-selected indicators can sometimes directly provide the answers. For example, policy makers often use indicators such as import dependency, R/P ratios, demand growth rates, blackout frequencies and

Table 8.3 Indicators used in the GEA energy security assessment

Energy system	Energy security indicators	
	Shocks	Stresses
Globally traded fuels: oil, gas and coal	Import dependency, cost of imports	Global R/P Domestic R/C Growth in oil consumption
	Fuel intensity of GDP	
Nuclear		Average age of nuclear power plants Start of last plant construction (reflecting the capacity to replace existing fleet)
Hydro	Diversity of hydro power dams	
Electricity	Dependency on imported fuels	Electricity demand growth rate Rate of access to electricity
	Diversity of energy sources used in production of electricity	
End-use sectors: transport, industry, residential and commercial	Dependence on imported fuels	Demand growth rate in the sector
	Diversity of sources and carriers used in the sector	
Energy exports	Revenue from energy exports as share of GDP (reflecting exposure to price fluctuations)	R/P ratios of exported fuel
National Energy Systems	Overall energy import dependency Cost of energy imports compared to GDP Cost of energy imports compared to export earnings	Energy demand growth
	Diversity of PES; Energy intensity	

Source: Adopted from Cherp et al. (2012).

Table 8.4 Vulnerabilities of future energy systems and related indicators

<table>
<tr><th colspan="2" rowspan="2">Energy systems</th><th colspan="2">Perspectives:</th></tr>
<tr><th>Sovereignty</th><th>Resilience</th></tr>
<tr><td rowspan="3">Primary energy sources</td><td>Total Primary Energy Supply (TPES)</td><td>Global energy trade (absolute and relative to the total TPES)
Net import dependency*</td><td>Diversity of TPES
Energy intensity</td></tr>
<tr><td rowspan="2">Oil, gas, coal, biofuels</td><td>Global fuel trade
Fuel import dependency*</td><td></td></tr>
<tr><td colspan="2">Regional diversity of fuel production</td></tr>
<tr><td>Carriers</td><td>Hydrogen, electricity</td><td>Global trade in carrier
Regional diversity of carrier production
Reliance on imported fuels in carrier production*</td><td>Diversity of PES used in carrier production</td></tr>
<tr><td>End-use sectors</td><td>Transport, industry, residential and commercial</td><td>Reliance on imported fuels in end-use sector*</td><td>Diversity of PES used in the end-use sector
Energy intensity of end-use sector</td></tr>
</table>

Notes: *Regional level indicator.

Source: Jewell et al. (2012).

the age of power plants. Interpretation of individual indicators may involve comparison between countries or different points in time or relating them to some reference values such as the baseline. For example, the ranking of indicators for crude oil supply used in MOSES is shown in Table 8.5. Each indicator is assigned to a band of low, medium or high vulnerability on the basis of the indicator's values for IEA countries.

The GEA uses simple indicators to demonstrate that oil is the most vulnerable among the globally traded fuels because it has the lowest global R/P ratio, the highest proportion of international trade in global production, the largest number of people living in countries with major oil import dependency and the highest concentration of global production. The assessment reaches these conclusions by comparing indicators for global and national oil vulnerability with those for coal and natural gas.

Interpretation of individual indicators of future energy security is based on their comparison to the present situation and other scenarios (including business as usual development). For example, in most low-carbon scenar-

Table 8.5 Ranges of indicators for crude oil supply in MOSES

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

Source: Simplified from Jewell (2011:16).

ios the global energy trade decreases in comparison to the present situation and the diversity of fuels used in the most vulnerable transport sector increases. At the same time in the business-as-usual scenarios the levels of global energy trade significantly rise and the diversity of transport fuels rises much slower. This leads to a conclusion that most low-carbon energy transition scenarios are beneficial to energy security at the global level.

In many cases, however, direct interpretation of individual indicators is not sufficient. Policy makers often need to see an integrated picture of energy security as reflected in several indicators. However, the more indicators that come into the picture the more difficult it is to make sense of them, especially if each tells a different story. Thus, the second strategy is aggregating indicators into energy security "indices" using one of the many methods proposed in the academic literature (Gupta, 2008; Scheepers et al., 2007). The rationale for such indices is that they can reduce the amount of information and thus make the results of an assessment more understandable.

However, policy-maker's enthusiasm for compound indices has been varied. The problem is not that they have an aversion to aggregation as such: in fact even the most simple, straightforward and much used energy security indicators are already to some extent aggregated. For example, the most widely used indicator of import dependence aggregates imports at different periods of time (usually across a year) from different suppliers, at different prices, by different routes and for different purposes. There is even more aggregation involved when import dependence is calculated not for an individual fuel or a carrier (such as LNG or gasoline) but for "oil products", "fossil fuels" or total "energy".

In systematic energy security assessments energy security indicators should be aggregated at the level of vital energy systems and their vulnerabilities (e.g. Le Coq and Paltseva (2009) aggregate vulnerabilities of individual fuels). If the initial identification of systems and vulnerabilities correctly accounts for policy perspectives, policy makers are comfortable with such aggregation, because it corresponds to their familiar boundaries of energy systems and their ideas of vulnerabilities. If, on the other hand, the methods of aggregation (or calculation of complex indicators in the first place) produce a disconnect between the intuitively familiar systems and vulnerabilities and the numbers resulting from the assessment, policy-makers are likely to feel much less comfortable. In this latter case, the aggregated metrics designed to make the results more understandable achieve exactly the opposite: they complicate and obscure the message of the assessment.

Thus, any aggregation must strike a very delicate balance between on the one hand reducing the amount of data and on the other hand staying true to the systems and vulnerabilities which were identified as important at earlier stages. In line with the energy systems approach, the aggregation of indicators should to the extent possible correspond to how energy systems function. Aggregation makes more sense when the indicators relate to the same vital energy systems and/or to vulnerabilities which can potentially interact. For example, it may take into account how particular risks may exacerbate one another and how particular resilience capacities may mitigate specific risks. Such aggregation preserves the focus of the assessment on key energy systems and their vulnerabilities and thus facilitates achieving the purpose of the assessment. In contrast, aggregating indicators which relate to different and disconnected energy systems or to vulnerabilities which reflect different perspectives on energy security or different types of risks and resilience capacities is usually counterproductive.

The first step of aggregation is closely connected to interpretation of individual indicators that we discussed above. As a result of such interpretation, indicators may be normalized or related to a non-dimensional scale (e.g. ranking) making them comparable. Once indicators are normalized, the methods of aggregation can be based on simple semi-quantitative matrices as shown in Table 8.6 illustrating semi-quantitative aggregation of two external resilience indicators for crude oil in MOSES. The aggregation in MOSES proceeds through several similar stages until arriving at the final results (illustrated in Table 8.7). MOSES does not aggregate results across fuels and carriers because energy officials guiding this process perceived that important information might be lost as a result of such aggregation.

The energy systems approach used in MOSES and GEA allows aggregating not only vulnerabilities related to one and the same energy system, but also indicates the proliferation of vulnerabilities from one energy

Table 8.6 Aggregating indicators for external resilience of crude oil supply in MOSES

		Import infrastructure		
		Low	Medium	High
Diversity of suppliers	Low	Slovakia	Finland	
	Medium	Ireland	Sweden	
	High	Austria	Turkey	Japan

Note: As a result of combining these two indicators, the countries are divided into four groups indicated by different shades, the lighter shades indicating more resilience. One country is listed for every group as an example.

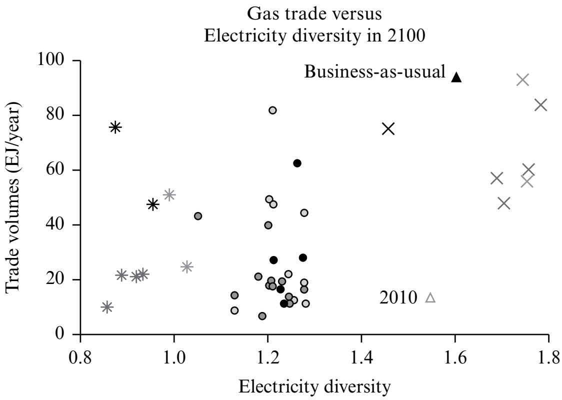
Source: simplified from Jewell (2011:17).

system to another. For example, MOSES accounts for the aggregate security of crude oil supply in calculating the vulnerability of oil products. The GEA takes into account for concerns associated with individual primary energy sources in calculating vulnerability of electricity systems and end-uses that rely on those sources.

In the quest for an "objective" evaluation of energy security, many studies use mathematical operations to aggregate indicators into a combined index. Scheepers et al. (2007) use relatively arbitrary (but transparently defined and explained) weights to aggregate indicators throughout the energy system into the "S/D index" for EU countries (Scheepers et al. 2007, 31). Gupta (2008) analyzes oil security by using principal component analysis to remove correlation between indicators to avoid double-counting vulnerabilities.

Aiming for a strictly objective evaluation of energy security is futile. All methods for interpreting and aggregating indicators require some form of human judgment, implicit or explicit, on the relative importance of energy systems or their vulnerabilities. For example, in MOSES expert judgments are used to determine the "safe" levels of risks or "adequate" resilience capacities (see Table 8.5). Some of the aggregation methods solicit such judgment in a more formal and sophisticated way. Badea et al. (2011) use the idea of risk aversion to prioritize energy security concerns in cases a country ends up at the bottom of the list with respect to a particular indicator.

Though complex manipulations of indicators can be very thoughtful and elegant they always involve a lot of assumptions and a risk that they might conceal rather than highlight truly important information. Therefore if the main reason for aggregating indicators is to reduce their number, two alternative approaches may be tried. Firstly, it is important



Note: Different shapes and shades of the data points represent different scenarios. Scenarios represented by lightly shaded crosses imply high energy efficiency and constraints on renewable energy penetration.

Source: Adopted from Jewell et al. (2012).

Figure 8.3 Aggregate analysis of energy security in future energy scenarios using a two-dimensional plotting

to ask whether all of the indicators are necessary in the first place. Do they all tell meaningful stories? Perhaps some of them looked promising at the stage of selecting indicators but turned out to not be sufficiently reliable or differentiating. Perhaps the focus of the assessment was initially defined too widely and it is necessary to exclude some systems or vulnerabilities for the purposes of communication.

Secondly, it may be possible to present disaggregated indicators in such a way that they are more understandable without aggregating them. For example, instead of combining two independent indicators they can be presented on a two-dimensional scatterplot as shown in Figure 8.3, giving an example of analysis of future energy scenarios. The analysis does not combine two unrelated indicators of electricity diversity and the gas trade into a single index but instead presents the two most prominent vulnerabilities identified in the assessment in a two-dimensional plot. It clearly shows that low trade and high diversity (the optimal conditions for energy security) are only possible in certain scenarios.

There are other techniques for visualizing multiple numerical data which can be successfully used in communicating assessment results. Since energy security is very much about context and perceptions it is useful to consider methods of communication which have a clear qualitative aspect such as narratives or visuals. For example MOSES summarizes

Table 8.7 Results of the crude oil analysis for MOSES

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

Source: Jewell (2011:18).

its results in terms of "profiles" of energy security of individual countries which together form a "landscape" of energy security in the IEA Member Countries. The terms "profile" and "landscape" convey clear qualitative images. The results of MOSES convey holistic stories about countries (divided into groups according to their vulnerability profiles) as shown in Table 7 for the case of crude oil.

The GEA messages are also expressed in a narrative and qualitative form. Thus GEA summarizes one of its main messages as follows (note how quantitative indicators and depiction of energy systems which span end-uses and primary energy sources are woven into the narratives):

> Oil is at the center of contemporary energy-security concerns for most nations, regions, and communities. Oil products provide over 90% of transport energy in almost all countries. Thus, disruptions of oil supplies may have catastrophic effects, not only on personal mobility, but also on food production and distribution, medical care, national security, manufacturing, and other vital functions of modern societies. At the same time, conventional oil resources are increasingly concentrated in just a few regions. The concerns over political stability affecting resource extraction and transport add to uncertainty. Moreover, the global production capacity of conventional oil is widely perceived as limited. Furthermore, the demand for transport fuels is steadily rising, especially rapidly in emerging Asian economies. Thus, for most countries, an ever higher share of their oil, or even all of it, must be imported. More than three billion people live in countries that import more than 75% of the oil and petroleum products they use. An additional 1.7 billion people live in countries with limited domestic oil resources (including China) which are likely to experience similarly high levels of import dependence in the coming decades.

In summary, interpretation of indicators can use the following approaches:

☑ Individual indicators may be interpreted by comparing them across the systems (or points in time) covered by the assessment or with meaningful reference values;

☑ Several indicators may be aggregated into a compound index. Such aggregation makes sense if it:

- Combines indicators related to systems or vulnerabilities that potentially interact with or affect each other;
- Uses techniques which reflect such interaction;
- Does not obscure or conceal important choices and trade-offs that are meant to be highlighted by the assessment.

☑ Other methods for making sense of a large number of indicators and data points include various visual techniques and qualitative narratives;

☑ Subjective judgments are an inevitable part of interpreting indicators and should be made in a transparent way consistent with the overall purpose of the assessment.

CONCLUSIONS

This final section recaps the main messages of the chapter and outlines the agenda for further development and application of the energy security assessment framework. In contrast to the mainstream tradition the framework does not place indicators at the center of measuring energy security. Instead it focuses on how to make transparent and informed choices at five distinct stages of an energy security assessment as schematically shown at Figure 8.4.

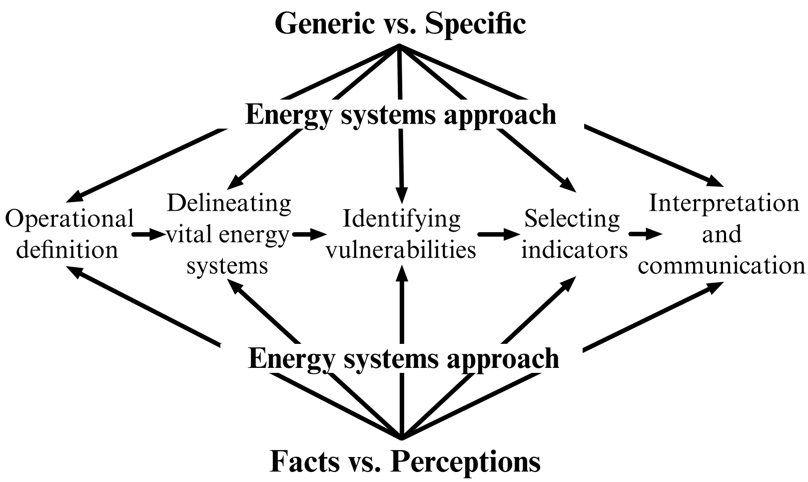


Figure 8.4 Energy security assessment framework

The first set of choices reflects the idea that energy security is as much about perceptions as it is about the hard realities of energy systems. The second set of choices reflects the fact that energy security is a highly contextualized characteristic of energy systems which nevertheless should be rendered generic for the purpose of comparison. A good assessment strikes the right balance between these major choices at each of its five stages:

- At the first stage, it selects a definition of energy security acceptable to the audience of the assessment and sufficiently operational with respect to all energy systems analyzed.
- At the second stage it delineates vital energy systems, in a manner that is meaningful and consistent for all points of comparison, with reference to both policy concerns and the realities of energy flows.
- At the third stage, it identifies the vulnerabilities of these vital energy systems. Existing policy concerns are a good starting point, however, human perception of risks can be severely biased towards higher-profile, particularly dreaded events, especially resulting from actions of hated adversaries rather than "Acts of God". This bias may need to be adjusted by an objective analysis.
- At the fourth stage, it selects energy security indicators that reflect (but not necessarily measure!) the identified vulnerabilities. It is usually easier to start with the metrics already used in policy-making because (a) they will be more familiar and easier to interpret

and communicate; and (b) there will usually be data available for such metrics. More complicated calculation and data mining may be required to obtain indicators for vulnerabilities which for one reason or another are not on the political agenda. Such complex indicators will also require more efforts to interpret and communicate. While indicators should be relevant for a particular situation, they should also be comparable across all situations covered by the assessment.

- At the fifth and final stage, the indicators are interpreted and presented in a form that facilitates answering the original questions posed by the assessment. This may require aggregating indicators quantitatively into compound indices or qualitatively into narratives. Perspectives of the audiences of the assessment need to be taken into account in this process. They should, however, not distort the rigor of the assessment or obscure its main messages.

As indicated in Figure 8.4, the energy systems approach helps making informed choices at each stage of the assessment. It means that at every stage analysts should work not with a black box of amorphous "energy" but with actual energy systems. Vital energy systems should be delineated based on an understanding of energy flows and their significance for societies. Vulnerabilities should be identified based on how energy systems might respond to disruptions. Indicators are selected based on their abilities to serve as proxies for such complex system behavior. Finally, indicators should be interpreted, processed and presented to reflect the way actual energy systems function.

This chapter illustrates the application of the proposed framework in three case studies summarized in Table 8.8. Despite the fact that all the studies make different choices about the definition of energy security, vital energy systems, key vulnerabilities, indicators and approach to their interpretation they all systematically move through the five stages and apply the principles of the energy systems approach.

There are several ways in which the proposed framework can be further developed and used. This research agenda can also be structured in line with the key stages of the assessment, as follows. There should be better understanding of different types of vital energy systems; for example, more research is needed to understand the vulnerabilities of nuclear energy, renewable energy sources and traditional biomass. There should be better methods to explore vulnerabilities of vital energy systems, for example through researching their reaction to possible disturbances in dedicated modelling exercises. Based on this understanding new indicators of energy security may be developed, e.g. based on indicators used to characterize

Table 8.8 Cases of energy security assessments presented in this chapter

Energy security assessment	**IEA model of short-term energy security (MOSES)**	**Global Energy Assessment (*Energy and security chapter*)**	**Future energy security**
Scope and purpose	Develop energy security profiles of 28 IEA countries	Identify the most prominent energy security challenges at present and in the near future affecting the world as a whole (134 countries)	Examine energy security implications of long-term energy transition scenarios
Vital energy systems			
Geographic and political boundaries	National	Global and national, qualitative regional discussions	Global and regional
Sectoral boundaries	Seven primary energy sources and secondary fuels	Primary energy sources, electricity, key end-uses	Globally traded fuels and carriers, electricity, selected end-uses
Vulnerabilities	Short-term physical disruptions	Stresses and shocks both physical and economic	Primarily physical shocks and stresses, sovereignty risks and resilience factors
Indicators	35 indicators	34 indicators	20 global and five regional indicators
Interpretation and aggregation method	Comparative ranking between IEA countries, then semi-quantitative aggregation to characterize their "energy security profiles" and the IEA "energy security landscape"	Narratives to describe the most significant vulnerabilities	Narratives to describe the dynamics of future energy security

resilience of ecological systems and social networks. In order to make sense of the new and existing indicators, large and consistent data sets will need to be created spanning a range of energy systems and time points for monitoring and comparison. Energy security assessments should go hand in hand with developing a toolkit for energy security policy analysis, in which policies and vulnerabilities of energy systems are understood as interacting and co-evolving.

NOTES

1. This is in line with the classic definition of the objective of energy security by Daniel Yergin (1988:112): 'The objective of energy security is to assure adequate, reliable supplies of energy at reasonable prices and in ways that *do not jeopardize major national values and objectives.*' (emphasis added)
2. It is also not uncommon, especially for larger countries, to address energy security of sub-national regions (e.g. regional electricity grids in Sweden or the US or regional gas markets in Australia).
3. In the case of some regions this approach is a good proxy of assessing national energy security. This concerns highly integrated and homogenous regions (e.g. the European Union) and those that are dominated by a single major country (e.g. North America by the US, South Asia by India and Centrally Planned Asia by China). In other cases such as Africa, Latin America and the former Soviet Union the results of the assessment using this method are likely to be very different from an assessment from national perspectives which unfortunately cannot be conducted when dealing with long-term radical energy transformation scenarios.
4. We have already mentioned the importance of crude oil for the British Navy in World War I. The importance of oil products for the USSR during the World War II is vividly described by (Matvejchuk, 2012).

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