Energy and security

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Published in:
Global Energy Assessment: Toward a Sustainable Future

2012

Citation for published version (APA):
Cherp, A., Adenikinju, A., Goldthau, A., Hernandez, F., Hughes, L., Jewell, J., Olshanskaya, M., Jansen, J., Soares, R., & Vakulenko, S. (2012). Energy and security. In T. B. Johansson, N. Nakicenovic, & A. Patwardan (Eds.), *Global Energy Assessment: Toward a Sustainable Future* (pp. 325-383). Cambridge University Press. http://www.globalenergyassessment.org/

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Energy and Security

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Executive Summary

Uninterrupted provision of vital energy services (see Chapter 1, Section 1.2.2) – energy security – is a high priority of every nation. Energy security concerns are a key driving force of energy policy. These concerns relate to the robustness (sufficiency of resources, reliability of infrastructure, and stable and affordable prices); sovereignty (protection from potential threats from external agents); and resilience (the ability to withstand diverse disruptions) of energy systems. Our analysis of energy security issues in over 130 countries shows that the absolute majority of them are vulnerable from at least one of these three perspectives. For most industrial countries, energy insecurity means import dependency and aging infrastructure, while many emerging economies have additional vulnerabilities such as insufficient capacity, high energy intensity, and rapid demand growth. In many low-income countries, multiple vulnerabilities overlap, making them especially insecure.

Oil and its products lack easily available substitutes in the transport sector, where they provide at least 90% of energy in almost all countries. Furthermore, the global demand for transport fuels is steadily rising, especially rapidly in Asian emerging economies. Disruptions of oil supplies may thus result in catastrophic effects on such vital functions of modern states as food production, medical care, and internal security. At the same time, the global production capacity of conventional oil is widely perceived as limited. These factors result in rising and volatile prices of oil affecting all economies, especially low-income countries, almost all of which import over 80% of their oil supplies. The costs of energy (primarily oil) imports exceed 20% of the export earnings in 35 countries with 2.5 billion people and exceed 10% of gross domestic product (GDP) in an additional 15 countries with 200 million people.

The remaining conventional oil resources are increasingly geographically concentrated in just a few countries and regions. This means that most countries must import an ever-higher share or even all of their oil. More than three billion people live in 83 countries that import more than 75% of the oil products they consume. This does not include China, where oil import dependency is projected to increase from the current 53% to 84% in 2035. The increasing concentration of conventional oil production and the rapidly shifting global demand patterns make some analysts and politicians fear a "scramble for energy" or even "resource wars."

Import dependency is also common in countries that rely on natural gas to provide heat and generate electricity. Almost 650 million people live in 32 Eurasian countries that import over 75% of their gas. Many of these countries are landlocked and import gas through a limited number of pipelines. The interregional trade in natural gas is projected to significantly increase, with yet more uncertain consequences for energy security. Developments in unconventional gas extraction and liquefied natural gas (LNG) technologies may have a defining influence in this regard.

Vulnerabilities of electricity systems are not limited to power plants relying on imported fossil fuels (which currently provide over 50% of electricity in some 39 countries with 600 million people). Hydroelectric power production, especially from major dams located on internationally shared rivers, is often perceived as insecure, particularly in light of climate change affecting seasonal water availability. Over 700 million people live in 31 countries that derive a significant proportion of their electricity from just one or two major dams and thus are vulnerable to failures of these dams.

Many countries using nuclear power are experiencing an aging of the reactor fleet and workforce, as well as difficulties in accessing capital and technologies to renew, expand, or launch new nuclear programs. Twenty of the 31 countries with nuclear power programs have not started building a new reactor in the last 20 years, and in 19 countries the average age of nuclear power plants is over 25 years. Large-scale enrichment, reactor manufacturing, and reprocessing technologies and capacities are currently concentrated in just a few countries. Transfer of these technologies and capacities to a larger number of countries is constrained by serious concerns over nuclear weapons proliferation, which is one of the main controversies and risks associated with nuclear energy. If nuclear energy can address energy security challenges, it will only happen in a few larger and more prosperous economies.

Various vulnerabilities in electricity supply are often made worse by demand-side pressures. Some 4.2 billion people live in 53 countries that will need to expand the capacity of their electricity systems massively in the near future because they have either less than 60% access to electricity or an average demand growth of over 6% over the last decade. Both fuels and infrastructure for such an expansion will need to be provided without further compromising the sovereignty or resilience of national electricity systems. The reliability of electricity supply is a serious concern, especially in developing countries. In almost three-quarters of low-income countries blackouts are on average for more than 24 hours per month, and in about one-sixth of low-income countries blackouts average over 144 hours (six days) a month. In over one-half of low-income countries blackouts occur at least 10 times a month.

The energy sector also provides vital export revenues for some 15–20 countries. In the majority of these oil- and gas-exporting countries the revenues are not expected to last for more than one generation, and in several cases they may cease in less than a decade. In addition, poor energy-exporting nations are at a high risk of the "resource curse": economic and political instability eventually affecting human development and security.

Almost all countries associate enhanced energy security with higher diversity of energy sources (especially in the transport sector), lower energy intensity of national economies, and reduced import dependency by relying on domestic energy sources. International regimes fostering cooperation between exporters and importers of energy and interacting with global governance arrangements for climate change and energy access are important for achieving these energy security goals. Energy security under sustainable energy transitions will be determined by the dynamics of phasing out fossil fuels and their substitution by new energy sources, as well as by new technologies in the end-use sector. A quantitative analysis of such developments is conducted in Chapter 17.

Table 5.1 | Summary of energy security issues in the world.

Energy sector and its significance	**Energy security concerns and the population affected**	
	Shorter term	**Longer term**
Oil (125 countries, 5.9 billion)*	>75% import dependency (**3 billion**) consumption growth >5%/year (**1.8 billion**)	Reserves/Consumption <15 years (**1.7 billion**)
Gas (78 countries, 2 billion)*	>75% import dependency (**650 million**)	Reserves/Consumption <16 years (**780 million**)
Coal (45 countries, 4.5 billion)*	>80% import dependency (**300 million**)	
Nuclear (21 countries, 1.3 billion)**		Average age of nuclear power plants >25 years (**1.9 billion**) Start of last plant construction >20 years (**1.4 billion**)
Hydro (58 countries, 1.5 billion)***	Low diversity (one or two major dams) (**730 million**)	
Electricity (all countries)	>50% dependency on imported fossil fuels (**600 million**) low diversity (one or two fuel sources) (**450 million**)	annual demand growth >6%/year and/or access rate <60% (**4.2 billion**)
Transport	>50% dependency on imported fuels (**4.9 billion**)	annual consumption growth >8% (**1.7 billion**)
Industry (>25% of GDP in 60 countries; 4.5 billion)	>50% dependency on imported fuels (**800 million**)	
Residential and commercial (all countries)	>50% dependency on imported fuels (**500 million**)	Reliance on traditional biofuels for >80% of the residential sector energy (**700 million**)
Cross-sectoral energy supply (all countries)	>50% overall import dependency (**700 million**) low diversity of PES (one or two dominant sources) (**1 billion**) cost of energy imports >20% of export earning (**2.5 billion**); cost of energy imports >10% of GDP (**200 million**)	energy intensity >50% of world average (**400million**) consumption growth >6% (**1.8 billion**) consumption per capita <30 GJ/year (**3 billion**)

Notes: PES – primary energy sources;

Numbers in brackets indicate the number of people who live in countries with the indicated energy security conditions;

* – more than 10% in total energy supply; ** – more than 10% in electricity generation; *** – more than 20% in electricity generation

5.1 Introduction

Energy systems are closely entangled with national and human security. Concerns over the reliability of vital energy services have shaped public opinions and political agendas, eventually affecting broader security issues ranging from risks of armed conflicts, to viability of national economies, and to integrity and stability of political systems. Policies developed in the quest for energy security have been – and are likely to remain – a key driving force in the transformations of energy systems.

Our analysis of energy security in the world is based on a rich tradition of addressing this topic in political, professional, and academic circles. Historically, the notion of energy security emerged in the first half of the 20th century as a concern over the secure supply of fuels (coal and oil) for naval fleets and armies. Political and military leaders sought to ensure security of fuel supplies through diversifying suppliers, substituting foreign imports with domestic production (e.g., synthetic aviation fuel in Germany), restricting non-essential uses of fuels (e.g., rationing of gasoline in the United States) and, finally, seeking military control over energy resources and infrastructure (military campaigns in Indonesia, Caucasus, and other theaters during World War II) (Yergin, 2006).

In the second half of the 20th century, oil became increasingly important not only for the military but also for sustaining such vital functions of industrialized societies as transport, mechanized agriculture, electricity generation, and the heating of buildings. At the same time, the global oil trade dramatically increased as major economies such as the United States became dependent on imported rather than domestic resources. The oil embargoes in the 1970s brought energy security to the forefront of political attention in industrialized countries. Energy security strategies prompted by these embargoes included establishing emergency stocks and joint response mechanisms in Organisation for Economic Co-operation and Development (OECD) countries, substituting oil by other energy sources (natural gas, nuclear, coal, etc.) in heating and electricity generation, investing in oil reserves outside the Organization of the Petroleum Exporting Countries (OPEC) – for example, in Alaska and the North Sea – and promoting energy efficiency to decrease oil intensities of economies.

By the end of the 20th century, many of these strategies bore fruit so that the fear of global oil supply disruptions subsided. At that time, other concerns at the interface of energy systems and national security emerged. One was the security of electricity transmission and generation systems. Vulnerability of nuclear power plants was exposed by the Three Mile Island, Chernobyl, and Fukushima accidents, with Chernobyl virtually halting the construction of new nuclear reactors in the world for two decades. Large-scale blackouts due to failures of generation and transmission exposed the vulnerability of modern societies to even short-term disruptions of electricity supply. At the same time, with the collapse of the Soviet Union, it became clear that the economies of many oil-exporting nations are not viable without steady energy export revenues. This prompted a shift in attention towards "demand security," another aspect of energy security.

Nowadays, the energy security debate is a mixture of many concerns, as "[i]n the background – but not too far back – is the anxiety over whether there will be sufficient resources to meet the world's energy requirements in the decades ahead" (Yergin, 2006). More immediate concerns include high and volatile oil prices, especially painful for lower-income countries; the predicted "plateau" of conventional oil production apparently falling short of the rising demand (see Chapter 7, Figure 7.4); the increasing geographic concentration of conventional oil and gas resources in just a few countries and regions; the shift of oil demand to India and China; and the fear of tensions and conflicts as new and old consumers "scramble" for the remaining, increasingly concentrated resources. The present energy security concerns also include the recent conflicts over deliveries of Russian natural gas to Eastern Europe, and fears over the excessive dependency of some European countries on a very limited number of energy supply options. In light of the September 2001 terrorist attacks and the disruption brought about by Hurricane Katrina, there are also serious worries over the vulnerability of critical energy infrastructure to terrorist attacks or extreme natural events. Moreover, energy security concerns are now closely entangled with other critical energy issues, most notably energy access and climate impacts of energy systems.

Throughout history, energy security has been viewed as protection from disruptions of essential energy systems. The notion of "essential energy systems" evolved from supplies of oil for military purposes to encompass various energy sources, infrastructure, and end-use sectors. The idea of "protection from disruptions" has also evolved from securing military or political control over energy resources to setting up complex policies and measures of strategically managing risks that affect all elements of energy systems.

Though it is possible to discuss energy security at household, community, and other levels, most political concerns and scholarly research are about energy security of individual countries. This is because nation-states have a historic responsibility for security, national energy systems provide appropriate units of analysis of key risks and vulnerabilities, and the majority of policy interventions to maintain energy security occur at the national level. Consequently, the analysis presented in this chapter primarily concentrates on the national level of energy security.

In line with the existing tradition, our analysis defines a nation's energy security as protection from disruptions of energy systems that can jeopardize nationally vital energy services. Numerous definitions of energy security (Box 5.1) are largely elaborations of this broader concept, particularly on the notions of "protection from disruptions" and "vital energy systems."

Box 5.1 | Defining Energy Security

The analysis of energy security in academic literature recognizes that its meaning varies from one country or one context to another. Thus, universal definitions of energy security are less frequently attempted than contextualized discussions of its various aspects or dimensions. One of the most frequently quoted definitions is the "availability of sufficient supplies at affordable prices" suggested by Yergin (2006). It is preceded by the European Commission's (2000) definition of energy security as the "uninterrupted physical availability on the market of energy products at a price which is affordable for all consumers." Energy insecurity is defined by (Bohi and Toman, 1996) as "the loss of economic welfare that may occur as a result of a change in the price or availability of energy."

These definitions contain notions of "availability," "sufficiency," "affordability," "welfare," "energy products" (or "supplies"), and "interruptions," which are open to wide interpretations. For example, Yergin (2006) discusses the different meaning of energy security – within his given definition – for several different countries. This concept of variability of the notion of energy security is also stressed by Müller-Kraenner (2008), Kruyt et al. (2009), and Chester (2010).

In its analysis of energy security, scholarly literature draws different boundaries for energy systems and subsystems. These boundaries differ between how many and which fuels are considered, as well as how far up- and downstream boundaries are drawn within that system. In terms of fuel-related boundaries, studies range from focusing on a specific fuel (generally oil) (Kendell, 1998; Gupta, 2008; Greene, 2010); looking at all fossil fuels (Le Coq and Paltseva, 2009); analyzing the security of an electricity system (Stirling, 1994) or critical energy infrastructure (Farrell et al., 2004) to evaluating the security of the whole primary energy system (Neff, 1997; Jansen et al., 2004; Jansen and Seebregts, 2010). Within each of these divisions, some studies focus only on the supply side, while others integrate supply and demand aspects and indicators.

With respect to the characteristics of energy systems that are associated with their security, various studies propose and discuss different dimensions of energy security. The simplest discussion uses two dimensions of energy security: the "physical" and "economic" dimensions (Kendell, 1998; Gupta, 2008). Another commonly used taxonomy is the 4 A's, or: "availability" (i.e., physical availability of resources), "accessibility" (geopolitical aspects associated with accessing resources), "affordability" (economic costs of energy), and "acceptability" (social and often environmental stewardship aspects of energy) (Kruyt et al., 2009). Other dimensional classifications include "economic, environmental, social, foreign policy, technical and security" (Alhajii, 2007) dimensions, as well as "energy supply, economic, technological, environmental, social-cultural, and military security" dimensions from von Hippel et al. (2009) and others.

Contemporary literature on energy security considers risks linked to natural (e.g., resource scarcity, extreme natural events), technical (e.g., aging of infrastructure, technological accidents), political (e.g., intentional restriction of supplies or technologies, sabotage and terrorism), and economic (e.g., high or volatile prices) factors. Correspondingly, "protection from risks" is defined by various authors as independence, reliability, resilience, availability, accessibility, affordability, or sustainability of energy systems.

This analysis considers three perspectives on energy security linked to distinct policy strategies and rooted in specific scholarly disciplines: robustness, sovereignty, and resilience (Cherp and Jewell, 2011) (see Box 5.2):

- **Robustness** is focused on protection from disruptions originating from predictable and "objective" natural, technical, and economic factors such as resource scarcity, rapid rise of demand, aging of infrastructure, or rising energy prices.
- **Sovereignty** is focused on protection from disruptions originating from intentional actions of various actors (such as unfriendly political powers and overly powerful market agents). Sovereignty implies the ability to control the behavior of energy systems and is often linked to much-discussed "energy independence."
- **Resilience** is focused on protection from disruptions originating from less predictable factors of any nature, such as political instability, game-changing innovations, or extreme weather events.

Box 5.2 | Three Perspectives on Energy Security

For assessing energy security, when it is defined as protection from disruptions of energy systems, it is necessary to understand the nature of such disruptions and adequate protection mechanisms. Energy security policies as well as scholarly literature present three distinct but complementary perspectives on this issue.

Historically, the oldest – "sovereignty" – perspective on energy security focuses on disruptions potentially arising from actions of "external" actors, be it hostile powers or terrorists, "unreliable" exporters, "foreign" energy companies, or overly powerful market agents. Protection from such disruptions is seen in increasing control over energy systems, be it by military, political, economic or technical means. In a broader sense, the sovereignty perspective focuses on interests, intentions, power, and the space for maneuver of various energy actors and institutions. In its most familiar and most simplistic form, a sovereignty strategy is the quest for energy independence.

The "robustness" perspective on energy security focuses on risks that arise from predictable and largely controlled characteristics of energy systems rather than from malevolent actions. Scarcity of energy resources, failures of infrastructure, or inadequate capacity to cope with the rising demand are examples of the issues addressed within this perspective. The main strategies for minimizing the risks of disruptions within this perspective are switching to more abundant and accessible energy sources, investment in infrastructure to minimize the risks of technical failures, and decreasing energy intensity to reduce vulnerability to high prices.

In contrast, the "resilience" perspective emphasizes unpredictable factors affecting energy security. Precisely due to the complexity and unpredictability of energy systems, this perspective focuses on diversity of energy options as the main strategy to cope with the potential threats.

Figure 5.1 shows the three perspectives on energy security in relation to fundamental assumptions about the nature of potential disruptions. The robustness strategies are most prominent when disruptions of energy systems are both controllable and predictable. Sovereignty strategies are focused on disruptions arising from forces outside of our control (these can be more or less predictable). Resilience strategies work in situations of unpredictability, independently of whether or not we have control over energy systems.

Figure 5.1 also shows that many widespread energy security strategies are defined by more than one perspective. For example, increasing diversity of energy suppliers or maintaining competitive energy markets addresses both resilience and sovereignty concerns, since it reduces the power of individual agents to disrupt energy systems and provides a diversity of options which may be useful in the face of unpredictable disruptions. Investing in redundant capacities responds to both robustness and resilience concerns, whereas maintaining emergency stocks and selecting "trusted" partners is an overlap of sovereignty and robustness strategies.

Source: Cherp and Jewell, 2011

"Vital energy systems" that should be protected to ensure energy security were historically interpreted as a supply of oil and subsequently included other fuels, energy infrastructure, and eventually energy services. The literature identified "vital" as linked to "national values and objectives" (Yergin, 1988), "affecting welfare" (Bohi and Toman, 1996), and, in some cases, not associated with unacceptable environmental and social impacts (Sovacool and Brown, 2010) of energy systems.

In this analysis, "vital energy services" mean those that are necessary for the stable functioning of modern societies. Inherent in this definition is the notion that governments and the public perceive the interruption of such services as a national security concern. Such services vary from one country to another but commonly include transportation and energy for buildings. Most countries also depend upon a supply of energy for industrial purposes, and for some countries uninterrupted energy exports provide vital revenues. Security of these vital services is linked to vulnerability of energy sources (such as oil, gas, coal, hydro, and nuclear energy) and infrastructure for energy conversion and transmission (such as power plants, fuel reservoirs, and pipelines). Thus, our analysis is not limited to energy supply but also extends to energy conversion and distribution infrastructure and to the demand aspects within the vital energy sectors. We also analyze the connections between supply, demand, and infrastructure to understand how vulnerabilities propagate within energy systems so that if one element is at risk, other connected elements may also be affected.

Table 5.2 | Summary of the three perspectives on energy security.

Perspective	Sovereignty	Robustness	Resilience
Historic roots	War-time oil supplies and the 1970s oil crises	Large technological accidents, electricity blackouts, concerns about resource scarcity	Liberalization of energy systems.
Key risks for energy systems	Intentional actions by malevolent agents	Predictable natural and technical factors	Diverse and partially unpredictable factors
Primary protection mechanisms	Control over energy systems. Institutional arrangements preventing disruptive actions	Upgrading infrastructure and switching to more abundant resources	Increasing the ability to withstand and recover from various disruptions

Source: Cherp and Jewell, 2011.

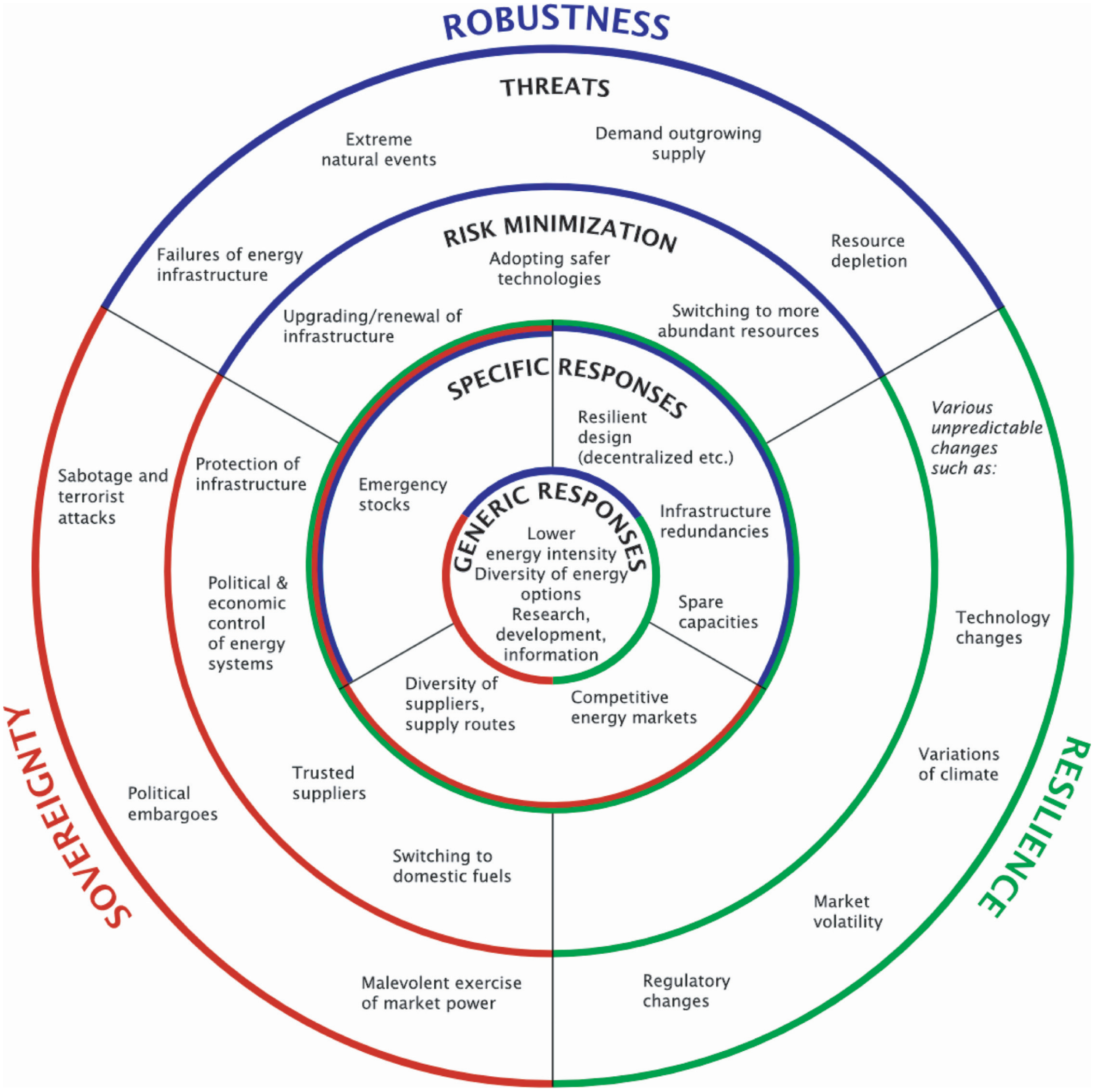


Figure 5.1 | Three perspectives on energy security. With their roots in political studies, natural science, engineering and economics, the three perspectives on energy security focus on different types of threats and risk minimization strategies. Source: Cherp and Jewell, 2011.

This chapter does not consider environmental and social impacts of energy systems as part of energy security, although such consideration is sometimes encountered in academic literature. For example, among 91 scholarly articles on energy security reviewed by Sovacool and Brown (2010), about one-quarter include environmental performance of energy systems in their definition of energy security. Our decision to separate the analysis of environmental and social impacts from the more conventional analysis of energy security is guided by two considerations. First, such impacts are analyzed in other chapters in this publication (Chapters 2, 3, and 4). Second, policies in the majority of countries consider energy security and climate change as distinct, although related, concerns. Thus, an analysis focused on energy security in a more narrow sense may be more policy relevant, as it appeals to a distinct policy community. Nevertheless, we acknowledge strong linkages between energy security and climate change, as explained in Box 5.3 and discussed throughout the chapter.

Box 5.3 | Energy Security and Other Energy-Related Concerns

Energy security concerns overlap with other concerns related to energy systems. This box briefly discusses this overlap with respect to climate and other environmental impacts, energy access and poverty, and energy affordability.

1. **Climate change and energy security.** Limiting the impacts of energy systems on climate change and ensuring energy security are clearly distinct policy concerns, as evidenced by many countries (especially in the developing world) that rigorously pursue energy security agendas without strong climate change agendas. Energy security and climate change concerns are associated with different policy communities, paradigms, and discourses. Yet there are strong links between the two policy areas. First, in some cases changes in climate present energy security risks affecting, for example, availability of water for hydro and thermal power generation or stability of permafrost in areas of oil and gas exploration. In some other cases, climate change results in new energy options such as hydropower from the melting glaciers of Greenland, or additional hydrocarbon resources available for exploration or marine transportation routes opened as a result of a retreat of Arctic sea ice. Second, climate and energy security policies may interact in a synergistic or conflicting manner. For example, reducing reliance on imported fossil fuels and promoting distributed generation from renewable energy sources has both climate change and energy security benefits. On the other hand, switching from imported natural gas to domestic coal advocated on energy security grounds is clearly disadvantageous from the climate change perspective. New technological dependencies, market arrangements, and international regimes associated with climate change governance may also have energy security implications. A similar argument also applies to other environmental impacts of energy systems and energy security.

2. **Energy access and energy security.** Whereas climate change is mostly a global concern, energy security is primarily a national concern, and energy access is often a local concern. Concerns over access to modern energy primarily focus on rural poor people, who are often not a high priority for statesmen dealing with national-level energy security, which concentrates on vital sectors often located in more prosperous urban centers. Likewise, poverty is often tolerated by national policymakers insofar as it does not affect the stability of national political or economic systems. Yet there are several strong links between energy security and energy access. First, enhancing access to modern energy services usually imposes a need to find additional resources and investments, which may exacerbate already existing energy security challenges. Second, lack of access to affordable energy *can* actually catalyze political or economic instability and thus become an energy-related security threat (for example, the uprising that resulted in the change of regime in Kyrgyzstan in April 2010 was allegedly initially triggered by high electricity prices and unreliable supply). Thus, our analysis considers lack of access an indicator of energy insecurity.

3. **Energy security and energy affordability.** Affordability of energy is often quoted as an important aspect of energy security. There is extensive literature analyzing and even defining energy security in purely economic terms. This is understandable, since some disruptions of energy systems are often nothing other than rapid increases in energy prices and can even, in other cases, be translated into economic losses. Yet, there is a clear distinction between "affordability" of energy and energy security. The former is a measure expressing the cost of energy relative to other economic parameters (GDP, income per capita, etc.). Thus energy affordability can be increased or decreased by changes outside energy systems, such as increases in income levels. Affordability also primarily addresses the relative cost of energy in the situation of economic equilibrium. In contrast, energy security deals with price disruptions that are outside economic equilibrium and induced by changes in energy systems (such as supply disruptions) rather than by general economic developments.

This chapter includes three main sections. The next section contains an assessment of energy security in over 130 countries carried out within a framework designed specifically for this purpose. The goal of this assessment is not to compare or rank the nations, but rather to identify common energy security concerns affecting significant parts of the world's population. The following section discusses energy security strategies pursued by individual countries and embodied in various international institutions. The last section provides an outlook for energy security in the future, connecting to Chapter 17 (Energy Pathways for Sustainable Development).

5.2 Energy Security Conditions in the World

This section presents a global overview of energy security in more than 130 countries using a National Energy Security Assessment Framework ("the Framework") specifically developed for this purpose. The Framework is presented in the first subsection and used in subsequent subsections to identify and map vulnerabilities of national energy systems globally.

5.2.1 National Energy Security Assessment Framework

There is extensive scholarly literature on measuring energy security. The methods and indicators used for this purpose vary depending upon the chosen definition of energy security, the intended use of the results of the analysis, the selection of boundaries of energy systems and time-horizons, the assumptions about the nature of potential risks, and the availability of data (Cherp and Jewell, 2010). Table 5.3 summarizes the key choices made in this study as compared to other quantitative evaluations of energy security.

The Framework used in this study proceeds from the definition of energy security as the protection from disruptions of nationally vital energy services. Our analysis aims to identify globally predominant national energy security concerns rather than to compare or rank countries as more or less secure.

This definition and the purpose of assessment leads to certain choices regarding the boundaries of energy systems analyzed within the Framework (see Figure 5.2). At the center of the analysis are national energy systems subdivided into subsystems of primary energy supply (oil, natural gas, hydro, nuclear energy, biomass, and "new renewables"); systems for the generation and transmission of electricity; and energy end-use sectors. This national-level analysis is supplemented by a global analysis of the vulnerabilities of internationally traded fossil fuels (oil, natural gas, and coal) electricity systems, and the nuclear fuel cycle.

The significance of energy end-use sectors analyzed in this chapter varies across countries. The first three of such sectors, discussed in Chapters 8, 9, and 10, are energy for (1) industry, (2) transport, and (3) commercial and residential buildings. The fourth important energy end-use sector is energy exports, which provide vital revenues to certain countries. By analyzing vulnerabilities of export revenues, we address "demand security," a serious concern of energy-exporting countries.

The Framework takes into account the propagation of vulnerabilities from energy sources to electricity systems and to energy end-uses. Electricity generated from less secure primary energy sources is considered more vulnerable. In turn, vulnerability of end-uses depends upon the vulnerabilities of primary energy sources and electricity used in a given sector. With respect to time-horizons we look into short- to medium-term concerns (up to 15–20 years), which are typically predominant in policy agendas.

The second set of choices concerns the nature of potential risks of disruptions of energy systems. The Framework assesses three dimensions of energy security: robustness (protection from disruptions due to predictable natural and technical factors), sovereignty (protection from disruptions originating from external actors), and resilience (the ability to withstand shocks and disruptions of various natures). We have chosen these three dimensions rather than other attributes of energy systems

Table 5.3 | Goals, choices and assumptions for measuring energy security made in this chapter as compared to other studies of energy security.

Choices and assumptions	Existing studies quantifying energy security	Chapter 5 of the Global Energy Assessment
Assessment goals	Rank groups of countries	Identify energy security concerns affecting a large number of countries and people globally
	Identify vulnerabilities of particular countries	
Definition of energy security	See Box 5.1	Low risk of disruptions of nationally vital energy systems
Energy security concerns	See Box 5.1	As reflected in sovereignty, robustness and resilience of energy systems, see Table 5.2. Exclude environmental and social issues
Energy systems and subsystems	Depending on the assessment purpose; often focused on energy supply, especially oil	Global systems for internationally traded fuels and nuclear fuel cycle; national energy systems including subsystems for energy sources, electricity generation and end-use sectors: transport; industry, residential and commercial energy, and energy export revenues
Aggregation of data	Compound or disaggregated energy security indicators	Aggregated for fuel systems, electricity and end-use sectors at the national and, where appropriate, the global level

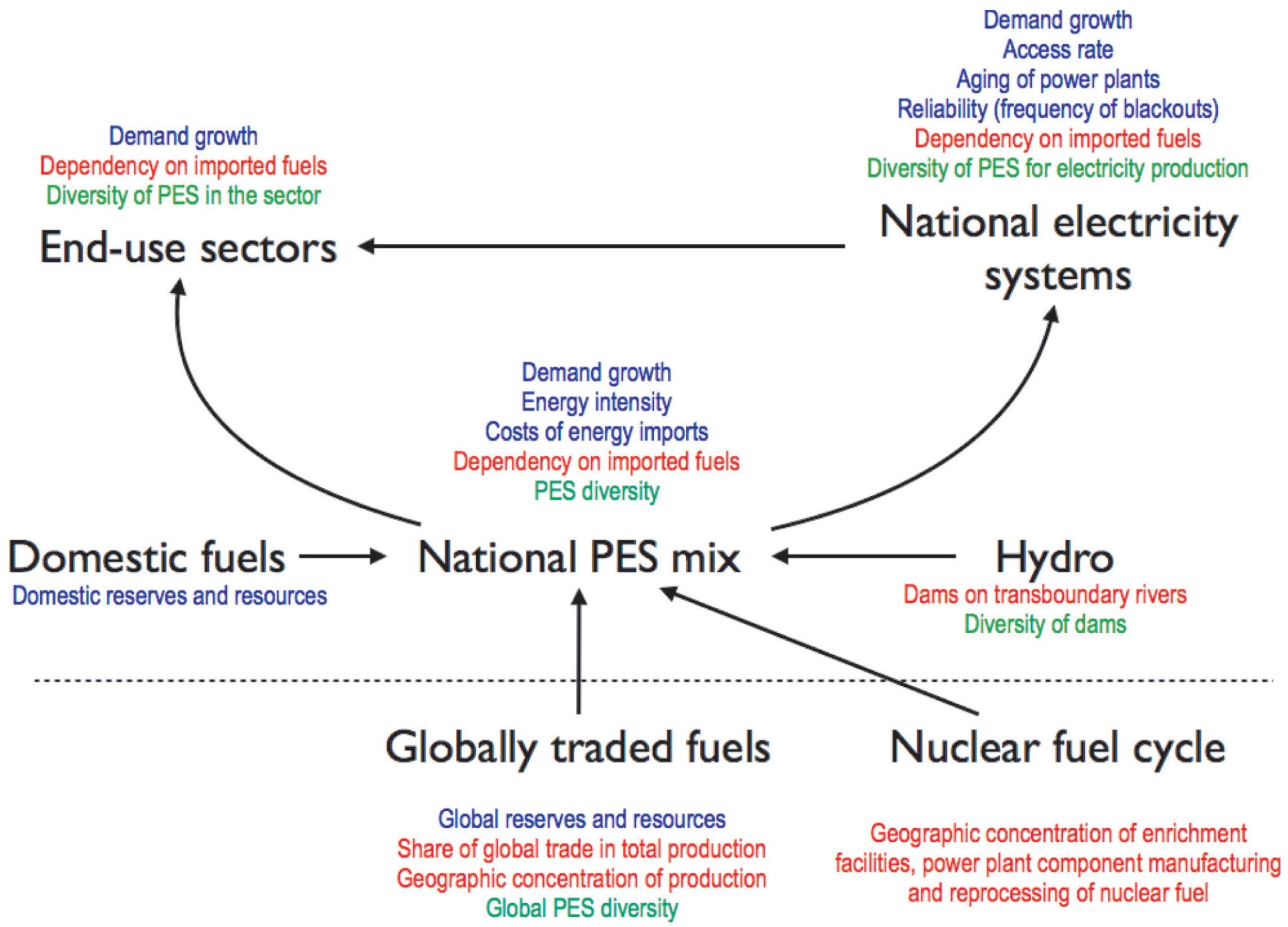


Figure 5.2 | Energy security assessment framework. The framework addresses the security of national energy systems with focus on energy sources, carriers and nationally vital energy services. The figure shows the elements of energy systems and their interconnections accounted for in the framework. The blue, red and green text indicates concerns related to the three perspectives on energy security (see Figure 5.1) – robustness, sovereignty and resilience respectively. The dotted line separates external and domestic factors.

proposed in the literature because they are linked to distinct policy mindsets and strategies, and thus we believe that the analysis along these dimensions will have the most policy relevance, as explained in Figure 5.1 and Box 5.2.

The four types of energy systems and the three dimensions of energy security are combined in a matrix defining key energy security concerns (Table 5.4).

The application of the Framework consists of several elements, as shown in Figure 5.1. This figure and the text below it provide only a brief description of the sample indicators. Further explanation of the choice of indicators and a qualitative analysis are given in the main text of the chapter.

The first element is the analysis of the global vulnerabilities of internationally traded fuels. The main robustness concerns regarding such fuels are available resources and reserves, as well as predicted supply-demand balances. Although these estimates are surrounded by large uncertainties, they nevertheless allow us to compare the major fuels and explain policy concerns about their vulnerabilities. The sovereignty concerns related to globally traded fuels are the share of international trade in total fuel production (which roughly indicates the degree of global dependency on imported fuels) and the geographic concentration of the fuel production (which indicates the market power of individual producing countries). Finally, the resilience concerns of the global primary energy sources system can be measured by the diversity of the global fuel mix.

The nuclear fuel cycle is also first evaluated at the global level, where we look at the concentration of capacities for uranium enrichment, manufacturing of nuclear power plant components, and nuclear fuel reprocessing.

The rest of the analysis is conducted at the national level for each of the 134 countries where the data are available in the IEA database (IEA, 2010b). With respect to the national primary energy supply, the Framework looks into such robustness indicators as domestic reserves and resources of non-renewable fuels, demand growth, and energy intensity. It uses import dependency (by fuel and for primary energy sources as a whole) as indicators of sovereignty concerns. Finally, the overall diversity of primary energy sources at the national level and the diversity of hydroelectric dams are used as an indicator of resilience of energy supply.

Table 5.4 | Energy security concerns analyzed in this chapter.

Energy subsystems	Energy security dimensions		
	Robustness	**Sovereignty**	**Resilience**
Global level			
Globally traded fuels: oil, coal, and gas	Availability of resources and reserves	Share of international trade in the overall production	Dominance (share) of a fuel in the total global PES mix
		Geographic concentration of fuel production	
Nuclear fuel cycle		Geographic concentration of uranium enrichment, manufacturing of nuclear power plant components, and reprocessing of nuclear fuel	
National level			
Energy sources			
Fossil fuels: oil, natural gas, and coal	Available domestic reserves (R/C ratio)		
	Demand growth for a particular fuel	Import dependency	Diversity of import routes
Hydro energy	Climate change effects on water availability and variation	Usage of transboundary water resources	Diversity of hydroelectric dams (see also electricity generation)
Electricity generation and transmission	Age of power plant fleet Growth in consumption of electricity Reliability (frequency of blackouts) Access rate	Reliance on imported fuels	Diversity of fuels used for electricity production Diversity of power plants
End-use sectors: industry, transport, residential and commercial, energy exports	Growth (decline*) in energy demand for the sector	Reliance on imported fuels within the sector	Diversity of energy sources used in the sector
National energy systems (cross-sectoral)	Energy intensity Growth in overall energy consumption Energy consumption per capita	Overall import dependency	Overall diversity of PES used in the national energy system

Notes: Concerns quantified by indicators are highlighted in bold. * – for energy exports

With respect to national electricity systems, the robustness indicators are the age of power plants, demand growth, and the reliability (blackout) statistics. The sovereignty indicator is the dependency of electricity systems on imported electricity and fuels. The resilience indicator is the diversity of primary energy sources used in electricity production.

With respect to end-use sectors, the Framework uses the rate of demand growth as the robustness indicator, the share of imported fuels in the sectoral primary energy sources mix as the sovereignty indicator, and the diversity of primary energy sources as the resilience indicator for a particular sector.

The final set of choices in evaluating national energy security concerns the aggregation of indicators and interpretation of results. This chapter recognizes that the nature of energy security risks varies among countries and in time, and thus a unified indicator is not plausible or relevant. The Framework seeks to identify, map, and explain the varying conditions of energy insecurity encountered around the world. It uses simplification and aggregation, necessary for mapping these concerns, rather than producing a single universal energy security index.

The Framework used in this analysis is naturally not capable of evaluating all important energy security concerns. Some of the issues that were intentionally left outside the analysis are discussed in Box 5.4. The method and some of the key indicators used in the Framework are subsequently deployed in analyzing energy security within the GEA Scenario in Chapter 17. The method of such analysis is explained both in Chapter 17 and in the last section of this chapter.

5.2.2 Security of Primary Energy Sources

This section considers the security of key primary energy sources. It starts by analyzing major internationally traded fuels: oil, natural gas, and coal. For each of these fuels, the analysis of their global vulnerabilities is followed by the analysis of national vulnerabilities in individual countries. The second subsection discusses vulnerabilities of nuclear energy: both at the global and the national level. The remaining three subsections discuss vulnerabilities of hydro energy, biomass, and "new renewables." The final subsection contains an analysis of the total primary energy supply of individual countries by aggregating the data on individual sources at the national level. The indicators used for the analysis in this section are summarized in Table 5.5; they cover the robustness, sovereignty, and resilience perspectives on each of the energy sources.

5.2.2.1 Globally Traded Fuels

The three major fuels traded on an international and global scale are oil and its products, natural gas, and coal. Global trade in these fuels means

Box 5.4 | Limitations of Current Analysis

The analysis presented in this chapter does not consider several issues that are occasionally addressed in energy security literature. These issues have been scoped out to maintain the focus of the assessment as well as due to time, space, and data limitations. The limitations relate to the types of energy systems considered in this assessment, time-horizons, and the nature of risks and disruptions analyzed.

First, the assessment is focused on key energy security issues that presently dominate policy concerns in a large number of countries. This means that only major traditional mainstream energy security systems are analyzed. For example, wind, solar, geothermal, and tidal energy at the moment do not make for a large share of energy supply in many countries and thus are not analyzed in detail. Yet, availability of alternative energy sources – to say nothing about technologies and finances – may be key factors in shaping national energy security in certain countries.

For largely the same reason, the analysis in this chapter is focused on short- to medium-term concerns (up to 15–20 years) that typically dominate policy agendas. We believe that energy security in a longer-term future will largely depend on policy choices and may unfold in the context of radical energy transitions. If these policy choices are guided by economic, environmental, and social sustainability goals, energy systems may evolve along pathways described in the GEA Scenario (Chapter 17). Energy security under such pathways is analyzed in Chapter 17 using the assumptions, methods, and indicators developed in this chapter.

Third, energy security is affected by a large number of complex and often intangible factors that are difficult to identify, quantify, or compare on the global scale. Some of these factors are subjective, such as trust between various actors in energy systems, consistency and predictability of policies, or reflexivity of market price-setting. Other factors are related to vulnerabilities of complex technical systems ranging from technological interdependencies (with respect to materials, equipment, expertise, and capacities related to energy systems) to cyber-security of critical energy infrastructure, especially electricity networks. Another critical group of factors relates to financing options, availability and effectiveness of investment, and capacities to develop various energy options. None of these factors could be extensively analyzed in this chapter, which does not make them less important in specific national contexts.

Despite these limitations, we believe that this chapter fulfills its goal of mapping the major energy security concerns of today's world and provides a methodological and factual basis for analyzing the potential evolution of these concerns under sustainable energy transitions.

that their vulnerabilities can be analyzed within the global and national systems using the three perspectives on energy security: robustness, sovereignty, and resilience.

Robustness of globally traded fuels means their physical availability, technological accessibility, and economic affordability (Kruyt et al., 2009). Although each of these characteristics is affected by a number of complex and often uncertain factors, for the purposes of this analysis they can be described by relatively simple proxy indicators such as the global reserves-to-production (R/P) ratio, supply and demand projections, and price dynamics.

At the national level, robustness of a particular fuel source can be characterized by national R/P ratios. Although such ratios are notoriously fluid (because the estimates of "resources" and "reserves" often change in time with economic and technological changes), they still signal important vulnerabilities to policymakers, especially if they are relatively short-term (under 10–20 years). A rapidly growing demand for a particular fuel signals a pressure on resources and infrastructure. Other national-level indicators of robustness of a particular fuel supply are the fuel intensity of a national economy (higher fuel intensity means that it is more difficult to adjust to potential disruptions of supply) and the proportion of national gross domestic product (GDP) or export revenues that is spent on imports of this fuel.

The main sovereignty concern related to internationally traded fuels at the global level is market power of dominant actors, which relates to their potential ability to disrupt prices or even physical supply of that fuel. Proxy indicators of this concern include the share of internationally traded fuel in the total fuel production and the geographic concentration of fuel production in particular countries or regions. These indicators are more informative where there is a single global market for the fuel (as in the case of oil and, partially, coal). In the case of gas, such indicators should be used in each of the separate regional markets.

The main sovereignty concern at the national level is import dependency on a particular fuel. This is probably the most widely used metric of energy security. Import dependency is important for policymakers because it makes their energy supply vulnerable to (a) global price volatility determined by factors beyond their control; (b) market power of major exporters, which may in extreme cases be manifested in direct physical supply disruptions; and (c) exposure to other disruption factors (including in transit countries) along import routes. In addition, many nations are concerned about the security of their energy imports if these originate in countries considered

Table 5.5 | Overview of concerns and indicators of national energy security addressed in this chapter.

Energy sector	Energy security concerns (indicators)*	
	Shorter term >	Longer term
Oil	**Exposure to the global oil market** (import dependency, cost of imports, **Demand-side vulnerabilities** (annual growth in oil consumption, *oil intensity*) **Domestic availability of oil** (R/C) Environmental acceptability of oil production and use	Global conventional oil scarcity ("peak oil")
Gas	**Exposure to the global and international gas markets** (import dependency, cost of imports **Demand-side vulnerabilities** (*gas intensity*)	
	Domestic availability of gas (R/C) Environmental acceptability of gas production and use	
Coal	**Exposure to the global coal market** (import dependency) **Domestic availability of coal** (R/C) Environmental and health acceptability of coal production and use	
Nuclear	Seasonal water availability **Aging infrastructure** (average age of nuclear power plants) **Capacity to replace existing fleet** (start of last plant construction) Access to capital, enrichment, reactor manufacturing, reprocessing Environmental, safety and security acceptability of nuclear power	
Hydro	Reliance on dams which are shared (*transboundary dams* or *dams on transboundary rivers*) Seasonal water availability Aging and silting of dams and other infrastructure **Exposure to risk of dam failure or sabotage** (diversity of dams)	Effects of climate change on water patterns and availability
Electricity	**Exposure to imported fuels** (dependency on imported fuels) **Exposure to a single fuel market** (low diversity of energy sources used for electricity production) **Adequate capacity** (annual demand growth rate, access rate) Underinvestment and aging infrastructure	
Transport	**Exposure to imported fuels** (dependence on imported fuels) **Demand-side vulnerabilities** (annual consumption growth rate)	
Industry	**Exposure to imported fuels** (dependence on imported fuels) **Demand-side vulnerabilities** (industrial energy intensity)	
Residential and commercial	**Exposure to imported fuels** (dependency on imported fuels) **Demand-side vulnerabilities** (annual consumption growth rate) **Adequacy of provision** (reliance on traditional biofuels in the residential sector)	
Energy for export	**Exposure to price fluctuations** (revenue from energy exports as share of GDP) "Security of demand" (diversity of export routes and destinations) "Dutch disease" and "resource curse"	
Cross-sectoral	**Exposure to imported fuels** (overall import dependency, cost of energy imports compared to GDP, cost of energy imports compared to export earnings) **Overall resilience of primary fuels** (diversity of PES) **Exposure to energy price volatility** (overall energy intensity) **Demand-side pressure** (annual growth rate in consumption, consumption per capita)	

Notes: R/C – reserves to consumption ratio; PES – primary energy sources

unfriendly, unstable, unreliable, politically unacceptable, or potentially exercising asymmetrical market power. In other situations, imports come from culturally and politically close and trusted partners and thus lead to few security concerns. In the global context, we do not systematically quantify these idiosyncrasies but comment on them in particularly relevant cases (e.g., in regional energy security discussions).

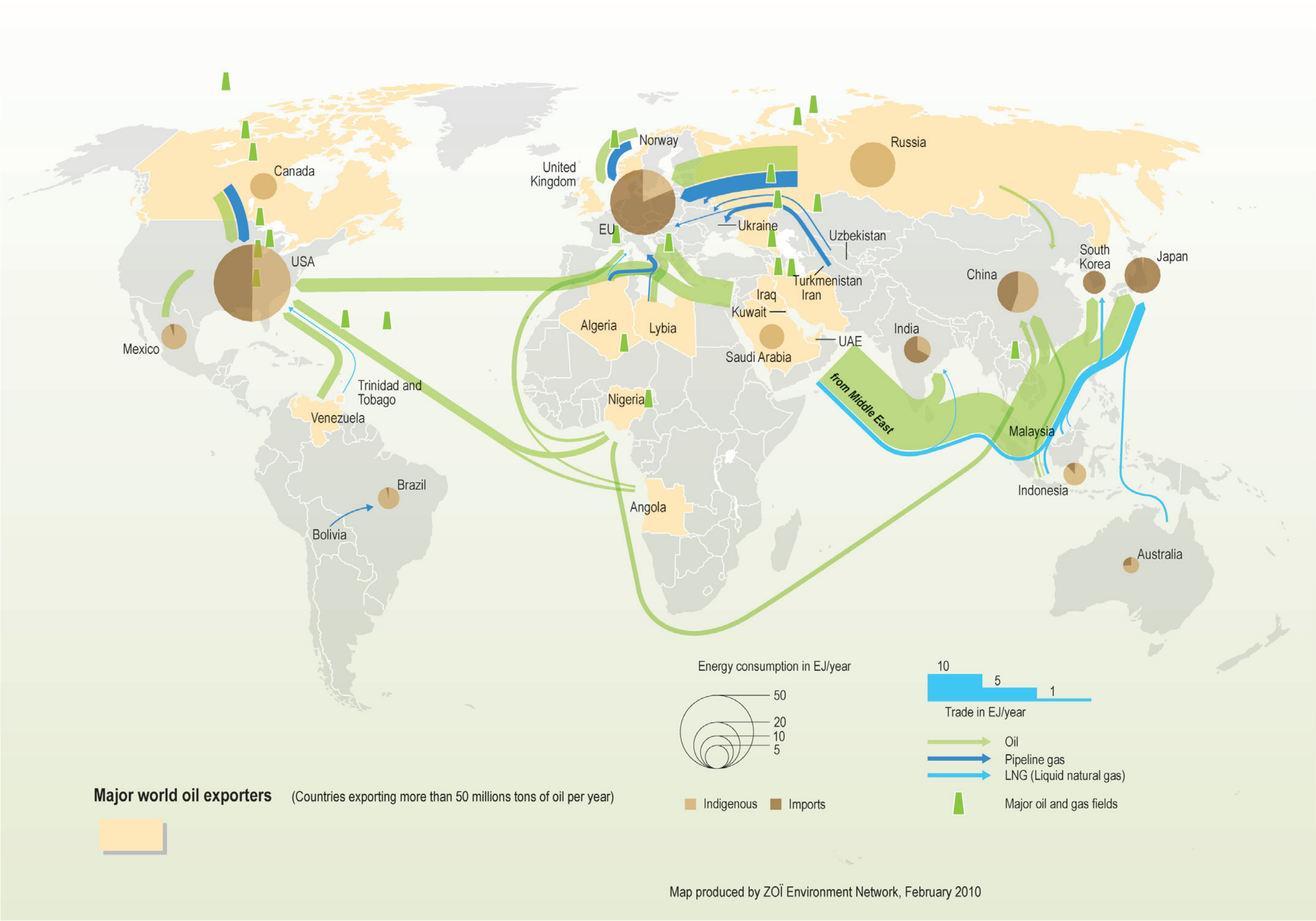
Finally, the main resilience metric with respect to energy supply is the diversity of primary energy sources, either nationally or globally. Strategic reserves of oil and, to a lesser extent, gas and coal support both resilience and robustness of energy supply, but their presence was not quantitatively analyzed in this chapter due to data limitations.

Global oil supply vulnerabilities

Oil is a non-renewable resource massively traded on the global scale. It is the largest single primary energy source worldwide and dominates the transport sector, where it lacks easily available substitutes. The global demand for oil is steadily rising, particularly as a result of increasing motor fuel consumption in emerging economies. Given limited new discoveries, the global production of conventional oil is predicted to "peak" or "plateau" in the first half of this century (see Chapter 7 for details) in spite of globally rising demand. This supply-demand imbalance will lead to higher oil prices in the medium to long term, as exploration and production will turn to progressively more demanding, and thus more expensive, sources (such as oil in deep-sea water or the Arctic). The costs are rising even in established production regions. The Kashagan oilfield in the Caspian Sea, one of the biggest discoveries in decades, was due to enter production in 2005. Now the target is 2012, and the costs could exceed US$100 billion.[1] The 2010 disaster at BP's well in the Gulf of Mexico may increase costs further as environmental regulations are tightened.

In addition to this expected medium- to long-term cost increase, global oil prices have been increasingly volatile in the last decade for several reasons. First, the global demand for oil has been growing faster than production capacity, and as a result the spare production capacity (the difference between what is possible to produce in the short term and what is actually produced to meet the demand) has significantly decreased. With the smaller spare capacity, even relatively minor disruptions of supply – whether they are due to natural, economic or political causes – may knock the demand and supply off balance, thus signaling rocketing prices or even a physical scarcity of fuel at least in the short term,[2] or the reverse.

Furthermore, the global oil price has been increasingly affected by highly volatile market expectations through speculation. Future contracts and other derivates have opened the oil market to speculative money, which is blamed as a contributing factor in oil price volatility. Due to the rapid increase in the number of actors and improvements in communication tools, the oil markets have become highly reflexive – i.e., driven by market sentiments and expectations. This reflexivity does not blend well with the decreasing and often uncertain spare capacity. A speculative market combined with low spare capacity and high uncertainty easily results in price bubbles and longer-term volatility.



Map produced by ZOÏ Environment Network, February 2010

Figure 5.3 | Global oil and gas production and trade. The figure shows the concentration of global oil and gas production in a limited number of regions and large volumes of trade in these fossil fuels. Source: BP, 2009; IEA, 2009a; b.

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[1] According to the Cambridge Energy Research Associates' (CERA) Upstream Capital Costs Index (UCCI), prices of drilling technology, skilled labor, and equipment have soared. Even in spite of recent economic recession, exploration and development costs in oil and gas have risen by 200% between 2000 and 2011 (IHS, 2011) adding a significant cost to crude supply.

[2] When BP had to shut down a single refinery in 2006, world crude prices jumped 2% (Sovacool, 2009).

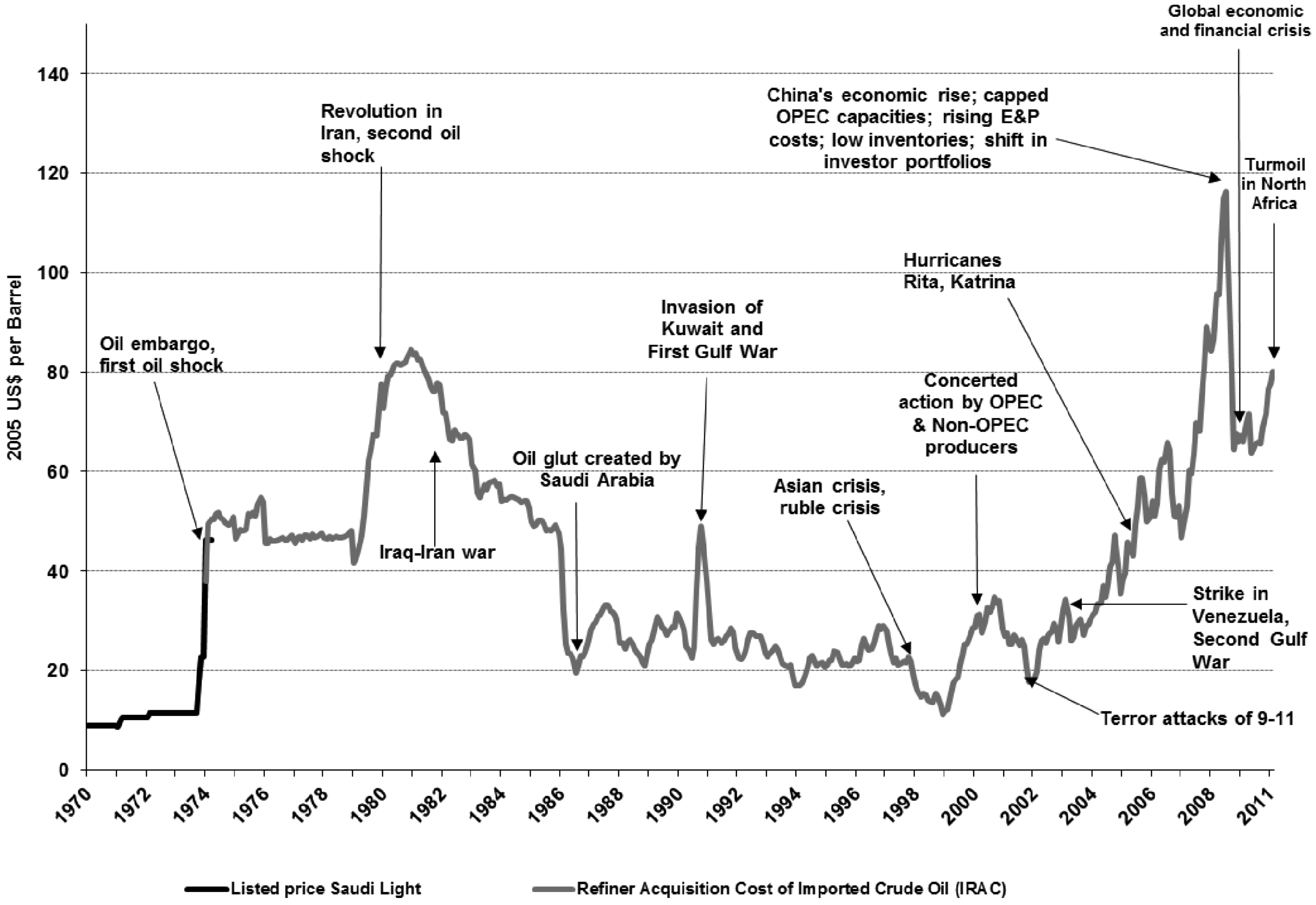

Figure 5.4 | Price of oil (in US$_{2005}$\$) and major political events 1970–2011. Source: modified from US EIA, 2011b. Note: Imported Refiner Acquisition Cost (IRAC) is the volume-weighted average price of all crude oil imported to the United States.

Moreover, the volatility of the global oil market is exacerbated by the fact that, whereas oil is traded globally, its production and reserves are heavily concentrated in just a few countries and regions (see Figures 5.3 and 5.4) away from the major consumption centers. In 2006 the Middle East accounted for 62% of the world's identifiable proved liquid reserves and 31% of the output. The world's top 10 producers represent approximately 62% of global output. Eight of the top 10 producers are net oil exporters that collectively supply 34% of global oil demand. On the other hand, seven of the world's 10 largest consuming countries lack sufficient oil production capacity to meet their internal consumption, importing more than 35% of the world's demand (Lehman Brothers, 2008). According to the IEA (2010a), the concentration of oil production and the market power of major producers are expected to increase by 2030, not only in the Reference Scenario but also in the presence of strong climate policies (the "450 scenario"). The interregional trade in oil will increase by over 30% and comprise almost one-half of the total volume of global production by 2035 (IEA, 2010a) in the New Policies Scenario.

This means that global oil supply is becoming increasingly more vulnerable to conditions in oil-producing countries and regions, as well as the demand dynamics and expectations of major consumers. There is an extensive record of political, economic, and natural events, military conflicts, and deliberate acts of sabotage that have either physically disrupted global oil flows or resulted in price hikes. According to (Jones et al., 2004), quoted in (Farrell et al., 2004), 24 oil supply shocks between 1950 and 2003 averaged eight months or 3.7% of the global supply. The 1990 Gulf War, for instance, resulted in production loses of 2.8 million barrels per day (mbd) of Iraqi and 1.4 mbd of Kuwaiti oil – some 7% of global supply (BP, 2007). The strike at Petróleos de Venezuela, SA during 2002/2003 brought to a halt the country's entire oil sector and temporarily reduced global oil supplies by 2.3 mbd, or 3% of total world supply (US Government Accountability Office, 2006). As it coincided with unrest in oil producer Nigeria and the looming US invasion of Iraq, the strike contributed to pushing the nominal price of oil to new highs (Shore and Hackworth, 2003). For an overview linking oil price developments and major political events since the early 1970s, see Figure 5.4.

Thus, countries relying on imported oil are at risk of facing medium- to long-term price increases combined with volatility of oil prices in the short term. Physical supply disruptions similar to the Arab OPEC oil embargo of the early 1970s are less likely nowadays because alternative suppliers can normally be found, given the "liquid" character of the global oil market, and strategic oil reserves present in most major economies can smooth out such impacts. However, infrastructural limitations (e.g., pipeline capacities or refineries "tuned up" to deal only with a particular kind of crude) can still make physical disruptions very painful for particular countries. For example, several landlocked countries in Central and Eastern Europe receive the majority of their oil supplies from Russia through the Druzhba pipeline and are, therefore, vulnerable to disruptions affecting this particular supplier and the transportation route. Globally, 64% of the global oil supply flows through just 10 supply chain "choke" points, with the top three accounting for 46% of supply (Lehman Brothers, 2008). In addition to the Druzhba pipeline, these include the Straits of Hormuz, Strait of Malacca, Abqaiq processing facility, Suez Canal, Bab el-Mandab, Bosporus/Turkish Straits, Mina al-Ahmadi terminal (Kuwait), Al Basrah oil terminal (Iraq), and LOOP (United States).

In summary, the global oil supply is vulnerable from robustness, sovereignty, and resilience perspectives. The main robustness concerns are the increasing demand in the face of limited conventional production capacities, rising costs of production, and high and volatile prices. The main sovereignty concerns are the increasing concentration of production away from major demand centers and the increasing market power of major producers. The resilience concerns include not only the dominance of oil in the world's energy use and the lack of easily available substitutes for oil in the transport sector (as we will be discussing further later in this chapter), but also the limited diversity of global oil supply routes and the vulnerability of the "choke" points.

National oil supply vulnerabilities

Oil is the only primary energy source that plays an important role in all of the national energy systems except in a few less-developed countries. Virtually every country (125 countries with 5.9 billion people)[3] has at least 10% of its primary energy derived from oil, while over 5.5 billion people live in 112 countries which rely on oil for more than 18% of their total primary energy supply. Moreover, some 370 million people live in 32 countries that use oil for more than half of their primary energy supply.

The majority of countries import most or even all of the oil and petroleum products they need. Over three billion people live in 83 countries that import more than 75% of the oil and petroleum products they consume, and 101 countries with 5.3 billion people import over 25% of the oil they consume.

The number of people living in countries significantly dependent on oil imports is likely to rise in the near future. At the moment there are 3.6 billion people in countries that import more than half of their oil, but a further 1.7 billion people live in countries (including Argentina, China, Indonesia, and the United Kingdom) where the ratio of domestic oil reserves to domestic annual oil consumption is under 15 years.[4] Even though some countries (e.g., Ghana) may become less dependent on imported oil due to new discoveries and developments, this is unlikely to reverse the overall trend of the rapid increase of oil import dependency in the world.

Several of the highly import-dependent countries have additional demand-side vulnerabilities. In 16 such countries (with 1.8 billion people), the demand for petroleum products grew at 5–10% per year on average from 1996–2006. In addition, five of these (including several African countries and Vietnam) have outstanding fuel intensities that make them highly vulnerable to market price disruptions.

China and India – which are together home to about 2.5 billion people – tell a story of their own. Oil consumption in China more than quadrupled between 1980 and 2009. It has grown at the annual rate of over 7% a year in the last 10–15 years. In the WEO (World Energy Outlook)'s New Policies Scenario, it is expected to almost double between 2009 and 2035, increasing on average by 2.4% per year. In this scenario, China accounts for 48% of the global rise in demand for oil. The majority of this increase will likely come from imports, as China already imports over 40% of its oil supply and its domestic reserves/consumption ratio is between seven and eight years. India already imports over 75% of its oil, and its domestic resource/supply ratio is under six years, with consumption growing on average 4.6% per year and projected to grow faster than in China at 3.6% between 2009 and 2035, accounting for a further 30% of the increase in the global demand for oil (IEA, 2010a).

It is worth commenting that all low-income countries (over 600 million people) except Uzbekistan,[5] Myanmar,[6] and Yemen import over 80% of their oil and petroleum products. In sub-Saharan Africa, apart from South Africa, Gabon, Nigeria, Angola, Sudan, Congo, Cameroon, and Côte d'Ivoire, all of the countries are completely dependent on the import of petroleum products!

Global natural gas supply vulnerabilities

Natural gas is the fastest growing fuel of choice for electricity generation in the Western hemisphere and has also gained an increasing importance in emerging economies. In addition, it is extensively used in the residential sector (for heating and cooking) and in many industrial applications. Similarly to oil, gas is a non-renewable resource with reserves and production concentrated in a few countries and regions, and most nations relying on imported supplies. There are, however,

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[3] According to IEA (2007), oil and its products represented less than 10% of total final energy use in only nine countries: Mozambique, Tanzania, Democratic People's Republic of Korea, Zimbabwe, Nepal, Ethiopia, Democratic Republic of Congo, and Nigeria.

[4] The concepts of reserve/production or reserve/consumption ratios are notoriously unreliable when used for projecting the date of "running out of oil." This is because the estimates of reserves are constantly updated and the rates of production/consumption also change. However, the very low (<10–15 years) ratio usually signals serious energy security concerns and the need to develop new reserves, imports, or other energy sources.

[5] Uzbekistan has the resource/supply ratio of about 16 years.

[6] Currently, Myanmar is a net crude oil exporter, but it imports more than 50% of its petroleum products and has the resource/supply ratio of just 3.75 years.

Table 5.6 | Vulnerabilities of primary energy sources.

Energy security perspectives	**Robustness**		**Sovereignty**		**Resilience**
			Globally traded fuels		
	Global R/P ratio	Projected demand growth 2008–2035*	Share of international trade in global production in 2009	Number of people (billions) in countries with import dependencies over 25/50/75%	Diversity of global producers by region, SWDI
Oil	30 yr.	15%	66%	5.3/3.6/3.1	1.63
Gas	80 yr.	44%	29%	2.2/0.75/0.65	1.84
Coal	150 yr.	19%	14%	1.3/1.1/0.70	1.92
			Other energy sources		
Nuclear	Aging of nuclear power plants; sensitivity to political interventions		Concentration of enriched uranium and reactor manufacturing technologies; nuclear fuel cycle controlled for non-proliferation reasons		Generally large facilities; difficult to substitute in case of failure
Hydro	Sensitivity to water availability; vulnerability to climate change in some regions.		Hydroelectric facilities located on internationally shared rivers		In certain cases extremely large facilities providing majority of electricity of certain countries
NRES	High initial costs; intermittency of supply		Technological dependencies; potential import dependencies for biofuels		Generally assumed to be higher than in the case of traditional sources due to distributed generation and more diverse energy mix

Source: see main text; *– New Policies Scenario (IEA, 2010a).

important differences between energy security concerns associated with oil and natural gas as globally traded energy sources.

With respect to globally available resources, the production of conventional gas is likely to peak (or plateau) several decades later than conventional oil in most scenarios. In addition, technological advances have recently added significant quantities of unconventional (primarily shale) gas to global reserve estimates (see Box 5.5). There are, generally speaking, fewer concerns about the risk of rapid increases in gas prices than in the case of oil (Söderbergh et al., 2009; Söderbergh et al., 2010). In other words, "peak gas" may not be as significant a concern as "peak oil."

Yet the global demand for natural gas is projected to increase faster than that for oil (by 44% in the WEO's New Policies Scenario, compared to 18% for oil). A quarter of this rise in global demand is set to come from China, where the consumption of natural gas is projected to increase on average by 6% per year up to 2035 (IEA, 2010a).

On the other hand, similarly to oil, a globally sufficient supply of natural gas depends upon adequate investments in exploration, production, and transportation. Such investment is all but granted, especially in connection with uncertainty over shale gas and other factors affecting gas prices (see Box 5.5). According to the IEA (2007), the total upstream and infrastructure investment needs in natural gas amount to US\$4.2 (US$_{2005}$\$ 4.0) trillion until 2030.

The difference between oil and natural gas is also in the volumes of international trade. Whereas about two-thirds of the globally produced oil is traded, this share is only about one-third for natural gas (see Table 5.6). However, interregional trade in natural gas is projected to increase very significantly (by 80% between 2008 and 2035 in the WEO's New Policies Scenario (IEA, 2010a) to account for over one-quarter of the total production). China's imports of natural gas are set to grow some 40-fold in this scenario, accounting for some 40% of the total growth in the interregional gas trade over this period (IEA, 2010b).

In contrast to oil, there is no unified global market for natural gas, primarily because the regional price differentials do not exceed the still high costs of interregional transportation (Stevens, 2010). Natural gas is transported via pipelines or between liquefied natural gas (LNG) installations tied with long-term contracts. Natural gas is traded on several largely independent regional markets, most notably the Eurasian, North American, and Asia-Pacific markets. While the North American natural gas market is liquid, regionally integrated, and deregulated, the Eurasian gas market is dominated by long-term bilateral contracts, entailing off-take agreements and destination clauses. Consequently, the Eurasian gas market, though considerably larger in volume than the North American one, is characterized by a comparably lower liquidity and a still marginal, although growing, role of spot markets. The emergence of a global gas market was widely predicted by experts and signaled by considerable investments in LNG infrastructure but delayed by the economic crisis and shale gas developments.

Natural gas is traded in regional markets by pipelines and globally as LNG. This has two major implications for energy security concerns associated with this fuel. On one hand, it prevents the emergence of globally powerful market actors, be it individual producers or cartels (like OPEC in the case of oil). On the other hand, it significantly increases the market power of regionally dominant market actors, such as Russia in Eurasia. Regional markets dominated by long-term contracts may also be more protected from price volatility, especially if the prices of gas are decoupled from those of oil, which has been a long-term trend and expectation (Stern, 2009; Stevens, 2010).

Box 5.5 | Shale Gas Revolution and Energy Security

Over the last several years the production of unconventional shale gas in the United States has dramatically increased (from 1% of total energy supply in 2000 to some 20% in 2009) and its share of total gas reserves increased by 50%. This has been heralded as the "shale gas revolution," with significant implications for energy security not only in the United States but also in the rest of the world, particularly in Western and Central Europe, which may become significantly less dependent on Russian gas imports.

At the same time, many uncertainties have been quoted with respect to shale gas developments. Even in the United States, cost estimates vary widely, and there are concerns over shorter life and low recovery rates of shale gas fields as well as environmental impacts of shale gas exploration. More uncertainties are associated with replication of North American success on other continents. Obstacles to shale gas development in Europe include different geology, lack of tax breaks, lack of technologies and expertise, more sensitive natural and cultural environment, potential opposition of local communities, and different land/natural resource structure than in the United States. Despite the potential shale gas revolution, the IEA New Policies Scenario predicts the overall decline in natural gas production in Western Europe, with the average rate of –1.5% per year up to 2035. Globally, the share of unconventional gas is predicted to increase from the current 12% to 15% in 2030, much of this increase being in North America.

In spite of these potentially positive (although less than certain) effects of the shale gas revolution, there may be some negative effects as well. So far, increasing shale gas production has resulted in decreasing gas prices and cancellation of investment projects in LNG and natural gas infrastructure. If the developments in shale gas do not follow the most optimistic forecasts, there may be a significant lack of capacity to meet the global demand. The shale gas revolution has also slowed down the development of spot trading and the emergence of a global gas market, leading to a temporary "glut" in LNG production and capacity. Investments in renewable energy alternatives to natural gas have also been slowed by this decrease in price.

Another concern associated with shale gas may be technological dependency. Chemicals, drilling technologies, and the expertise required for shale gas production are primarily available in the United States, where they have been developed over decades of trial and error. These will need to be exported, at least in the short term, to enable a similar increase in production in other countries.

Source: Stevens, 2010; IEA, 2010a. See also Chapter 7 for the discussion of technical issues related to shale and other unconventional natural gas.

Thus, sovereignty concerns related to natural gas are highly region-specific. They are most prominently highlighted by the recent gas disputes between Russia and the Ukraine (in 2006 and 2009) which led to interruptions in the supply of gas to members of the European Union (EU). This interruption most severely affected such countries as Slovakia, which is significantly dependent on Russian gas and lacks emergency gas stocks to cope with such short-term disruptions of supply. In another similar case, the Georgian gas supply in 2005/2006 was struck by a sabotaged Russian gas pipeline, causing severe energy shortages during that winter. Subsequently, the EU's energy security debate has become largely framed by the need to diversify the routes and origins of gas imports (as well as to substitute gas by other energy sources). The tense political relations between some Central and Eastern European countries and Russia played an important role in sustaining this debate. Outside Europe such deliberate disruptions of gas pipeline deliveries have been rarer, although not unknown.

Finally, in contrast to oil, which currently lacks readily available substitutes in the transport sector, natural gas can be more easily replaced by other sources such as oil, coal, nuclear power, or imported electricity (not to mention biogas and other renewable sources). Naturally, such a replacement might require substantial infrastructure investment.

In summary, the global vulnerabilities of the natural gas supply are largely similar to those of oil but with several important distinctions. With respect to robustness, it has larger conventional reserves and probably more optimistic expectations concerning non-conventional reserves, although it still remains a limited resource and upstream investment requirements are very high. In the case of natural gas, sovereignty concerns are strongly articulated on the regional level, particularly in Eurasia. With respect to resilience, the substitutability of natural gas is its major advantage, but for many markets the low diversity of origin of imports and supply routes presents a potential vulnerability to natural or political disruptions.

National natural gas supply vulnerabilities

Significantly fewer countries rely on natural gas than on oil. Fifty-seven countries with a population of almost two billion people use gas for 20% or more of their primary energy supply. Among those, 16 countries (with a combined population of over 350 million people) use natural gas for more than half of their energy needs. A further 850 million people in 21 countries rely on natural gas for between 10% and 20% of their energy. Further analysis in this section relates to these 78 countries (which notably exclude India and China, where the consumption of natural gas is still not very high, although it is projected to grow rapidly).

Most of the countries using natural gas have to rely on imports. Almost 650 million people live in 32 countries that import over 75% of all their gas needs. All of these countries are in Eurasia: most are in Europe, Turkey, and the former Soviet Union, but they also include Jordan, Singapore, Korea, and Japan. Remarkably, only seven of these highly import-dependent countries have LNG facilities. Of those, Korea and Japan only import natural gas through LNG facilities, and the remaining countries use pipeline imports as well. The remaining 25 highly import-dependent countries do not have LNG re-gasification terminals and rely exclusively on pipelines for gas imports. Eleven of those countries are landlocked and thus have no prospects of benefiting from LNG trade (Coutsoukis, 2008). At the same time, global LNG markets are rapidly expanding (IGU, 2010).

There are 35 countries, with a combined population of over 750 million people, which import more than 50% of their gas needs, while the number of people living in countries which import over 25% of their gas needs is almost 2.2 billion.

Among the countries that import less than 50% of their natural gas needs, including those relying on domestic reserves (such as the United Kingdom, the United States, Bangladesh, Mexico, Thailand, Brazil, and Argentina), 12 (780 million people) have a domestic reserves/supply ratio under 16 years, which signals the likely increase in import dependency in the near future.

Thus, over 1.5 billion people live in countries that are either seriously dependent on imported natural gas or are likely to experience such dependency soon. In addition, the majority of the 37 countries (with over 2.5 billion people) relying on natural gas for more than 10% of their supply experienced a growth rate of over 6% per year over the last decade, which is likely to put further pressures on their natural gas supply.

Global coal supply vulnerabilities

Coal is the world's fastest growing fossil fuel energy source, currently providing about one-third of the global primary energy supply. Similarly to oil and gas, coal is a non-renewable fuel that is traded on the global market. However, coal is different than oil and gas in several important aspects, which affect the vulnerability of coal supplies.

First of all, the worldwide reserves of coal are larger than those of conventional oil and gas, although they are subject to large uncertainties, as explained in detail in Chapter 7. The global R/P ratio of coal varies between different organizations and years in which estimates are provided but is generally believed to exceed 130 years.[7] Global coal production is expected to increase by some 14%, growing on average at 0.6% per year until 2035 in the WEO's New Policies Scenario. All of this growth is projected to come from non-OECD countries, with over 90% concentrated in China, India, and Indonesia (IEA, 2010a).

Global coal reserves are not as geographically concentrated as those of oil and natural gas. The United States, China, India, and the former Soviet Union together account for some 80% of global hard core reserves. Southern Africa and Australia account for 13% of the remaining 17% of reserves, with the remainder being split among the rest of the world. However, the existing coal reserves and production capacities are largely located in the same countries that consume or are expected to consume the majority of coal. For example, the WEO projects that China will account for half of global coal production in 2035 but will also consume all of this coal, being the largest world consumer and producer at the same time (IEA, 2010a). International trade in coal was only 16% of its total consumption in 2009 (compared to 66% of oil and 29% of natural gas). It may nevertheless increase in both the short and medium term. The main driver of this increase will be consumption and production of coal in China. In 2009, China's imports of coal tripled, but their growth in the future will be determined by the competitiveness of imported coal against the coal domestically produced and transported from China's western provinces. In the WEO's projections the share of globally traded coal will remain at approximately today's 16% of global demand, whereas the absolute volume of trade may grow some 15%. In this scenario the largest exporters will be Australia and Indonesia, and the largest importer, India.

The geographic distribution of coal reserves means that supplies of coal are less likely to be disrupted for such "geopolitical" reasons that are much feared in the cases of oil and gas. However, coal production may be slowed down because of its severe environmental and health costs. (Coal has the highest greenhouse gas emission factor of all fuels and also contributes significantly to local air pollution). Global climate change policies may also affect coal affordability (if carbon capture and storage becomes a requirement). If coal becomes a globally traded commodity, fluctuations of domestic currencies and a host of other factors can also affect its price.

As with other fuels, domestic availability of coal does not automatically mean that it is easily accessible to consumers. A case in point is China, whose reserves are mainly found in its western provinces, while consumption is concentrated on its east coast. Given China's rapidly rising consumption levels, its transport infrastructure faces heavy capacity challenges (see Box 5.6).

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[7] The BP *Statistical Review of World Energy 2007* gives a coal R/P ratio as 133 years at the end of 2007 (BP, 2007). The *World Energy Outlook 2010* (IEA, 2010a) notes a 1:150 R/P ratio.

Box 5.6 | Coal Use in China

China relies heavily on coal as a primary fuel for industrial use and electricity generation. Coal combustion provided 65% of national electricity in 1985 but ballooned to more than 80% in 2006 (though it shrank to 71% in 2008). From 2002 to 2007, demand for electricity in China grew by about 12%, and more than 70,000 MW of capacity were brought online to meet it. A majority of this capacity was coal-fired, and China is currently constructing the equivalent of two 500 MW coal-fired plants per week, or a capacity comparable to the entire power grid in the United Kingdom every year. During this time, every week to 10 days over the course of five years, a coal-fired power plant opens somewhere in China big enough to serve all of the households in Dallas or San Diego. More than half of China's total coal use is in the non-electricity sector. Coal provides 60% of Chinese chemical feed-stocks, 55% of industrial fuel, and about 45% of China's national railway capacity is devoted to the transport of coal. Coal is, therefore, China's most abundant and widely used fuel, and China is the world's largest coal producer (mining about 2.3 billion tons per year compared to just 1.1 billion tons in the United States). Put another way, coal production and consumption account for more than 65% of China's total energy supply and use. China already uses more coal than the European Union, Japan, and the United States combined.

In 2009, coal imports of China tripled, and for the first time it became a net coal importer. This import dependency may be reversed if coal production capacities of remote western provinces are utilized. For example, the province of Xinjiang holds about 40% of China's total coal resources. According to the expectations of its regional government reported by the IEA (2010a), the planned upgrade of the railway line linking Xinjiang to the east coast may help to increase coal production there by more than 10-fold so that its share of global coal production will be double the share of current oil production of the world's biggest oil field, Ghawar in Saudi Arabia.

Source: IEA, 2010a; Sovacool and Khuong, 2011.

National coal supply vulnerabilities

At present, 4.2 billion people live in 45 countries where coal represents more than 10% of the primary energy supply. About 3.4 billion people live in 28 countries (including China, India, Japan, and the United States) where coal represents more than 20% of the total primary energy supply. About 1.4 billion people live in seven countries (including China) where coal accounts for more than one-half of the total primary energy supply. In Mongolia, South Africa, and the Democratic People's Republic of Korea, more than 70% of the primary energy supply is derived from coal.

Only seven of these 28 countries (approximately 300 million people) import more than 80% of the coal they consume. These include Japan, which imports 100% of its coal. Some of these countries (e.g., Morocco, Slovakia, and the Republic of Korea) may be considered especially vulnerable, as either their coal consumption has been growing at over 5% per year or their economies have very high coal intensities. Despite its rapidly growing coal extraction, India is a net coal importer and is projected to increase its imports of coal more than five-fold between 2008 and 2035 (IEA, 2010a).

Most of the countries that significantly rely on domestic coal (net exporters and those that import less than 50% of their consumption) have a domestic resource/consumption ratio of over 30 years. The only exception is Vietnam, for which this ratio is 8.5 years. This makes the situation for coal very different than that for oil and gas, where import dependency is likely to significantly increase in a large number of countries even if the current levels of consumption do not notably grow.

5.2.2.2 Nuclear Power

Global nuclear energy supply vulnerabilities

Whereas the energy security concerns related to fossil fuels are primarily related to the supply and demand of resources, in case of nuclear power the primary concerns relate to nuclear energy infrastructure and technologies. Unlike fossil fuels, the fuel of nuclear energy (uranium) has a fairly high security of supply, offers protection from fuel price fluctuations, and is possible to stockpile. In comparison to oil and gas, uranium is abundant and more geographically distributed, with a third of proven reserves in OECD countries (NEA, 2008). Recent estimates indicate that even in the face of a large expansion of nuclear energy, proven uranium reserves would last at least a century (Macfarlane and Miller, 2007; NEA, 2008).[8] Furthermore, electricity produced from nuclear energy offers a greater protection from fluctuations in raw commodity prices; while doubling uranium prices leads to a 5–10% increase in generating cost for nuclear power, doubling the cost of coal and gas leads to a 35–45% and 70–80% increase, respectively (IAEA, 2008). Uranium is also a relatively easy fuel to stockpile. The refueling of a nuclear power plant generally provides fuel for two to three years of operation (Nelson and Sprecher, 2008), and it is possible to store up to a 10-year supply of

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[8] Chapter 7 contains a more extensive discussion of uranium resource availability.

nuclear fuel (IAEA, 2007b). In contrast, oil and gas emergency reserves, where they exist, are measured in days, weeks, or – in exceptional cases – months, not years.

At the same time, there are significant energy security risks associated with technological, economic, and institutional characteristics of nuclear power production. As the most capital-intensive electricity-generation technology, it is economically difficult for nuclear energy to compete in liberalized markets where the investor has to assume the financial risk of investment. As a result, strong government backing is necessary for the development of nuclear power (Finon and Roques, 2008). Such political backing depends on the public support of nuclear power, which has been very uneven. In particular, public opinion is swayed by nuclear accidents such as the ones at Three Mile Island in the United States in 1979, Chernobyl in the USSR in 1986, and Fukushima in Japan in 2011. Each such change of public opinion and the resulting change in the government policy may affect energy security both in the short term (e.g., as a result of shutting down nuclear power plants immediately affected by the accident[9] and those deemed unsafe) and in the longer term (through complicating the investment climate). Unlike other energy sources and electricity-generating technologies, for nuclear energy the risks associated with accidents extend beyond the plant level or national level to the entire nuclear power plant fleet. Thus, nuclear power globally faces the systemic risk of nuclear accidents.

Additionally, in most countries nuclear power plants are aging and often reaching the end of their licenses. The mean age of nuclear power plants worldwide is 26 years (calculated from IAEA, 2010). Since the standard lifespan of nuclear power plants is 30–40 years, many plants are nearing the end of their planned operational period. The IAEA has recently begun efforts to create a dialogue on effective management and safety enhancements to extend the lifespan of many of the world's nuclear power reactors (IAEA, 2007a). The power plants are not the only part of the industry that is old; in many countries the industry faces an aging workforce and a dearth of young workers to replace retiring nuclear engineers and plant operators (Sacchetti, 2008).

Nuclear power and other thermal plants are also subject to heat waves and water shortages. In 2006, France, Spain, and Germany had to shut down or scale back electricity production in several of their nuclear power plants due to low water levels. With growing concerns over water availability due to increasing pressure from uses and climate change, thermal power plants could face problems involving water supply more frequently. In addition to these robustness concerns, there are also sovereignty issues associated with nuclear power since capacities for fuel enrichment and nuclear reactor construction are concentrated in relatively few countries. Only six countries currently possess large-scale enrichment plants, and seven countries possess small-scale enrichment facilities (see Figure 5.5).[10] The fact that several countries (including Australia, Brazil, and South Africa) are considering constructing enrichment facilities indicates that even though countries can relatively easily stockpile nuclear fuel, national governments may feel too vulnerable if they rely solely on foreign suppliers. In addition to the concentration of nuclear fuel enrichment, construction capacity for new nuclear power plants is concentrated in just 12 companies in eight countries (see Figure 5.5). The number of countries holding the ability to forge the bottleneck component of large LWR pressure vessels is currently even more restricted.

National nuclear energy supply vulnerabilities

Currently, 29 countries with a total population of 4.4 billion people operate nuclear reactors. Nuclear power is located in middle- and high-income countries that are almost all relatively stable (see Figure 5.5). Nuclear energy comprises more than 10% of the electricity supply in 21 countries with a population of 1.3 billion people. Of these, only 200 million people live in 13 countries that rely on nuclear energy for at least 30% of their electricity generation, and about 80 million people live in three countries that rely on nuclear energy for more than 50% of their electricity production.

The most pressing energy security concerns for nuclear power in most countries are robustness concerns related to the age and obsolescence of their nuclear power programs combined with a lack of recent investment. Twenty-one out of the 29 countries with nuclear power (with a combined population of 1.3 billion people) have not started constructing a new nuclear power plant in the last 20 years. Without new nuclear power plants, the nuclear industry in these countries lacks the vitality of recent activity. This can, in turn, lead to a lack of dynamic capacity needs of the industry, from both a human resources and a manufacturing perspective.

There is also clear evidence that many of the countries with stagnating nuclear power programs face imminent human resources shortages. A nuclear industry institute in the United States reports that in the next five years as much as 35% of the nuclear workforce may reach retirement (NEI, 2010). The United Kingdom and Germany also face a dearth of young qualified workers: over 75% of nuclear employers in the United Kingdom report that they have trouble filling scientific and engineering positions, and in Germany in many recent years not a single person has graduated in a nuclear discipline (Sacchetti, 2008).

Nineteen of the 29 countries that use nuclear energy (with a combined population of 1.4 billion) have nuclear power plants with an average age greater than 25 years (see Table 5.7). While countries can extend the operating licenses of their existing nuclear power plants, this raises

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[9] For example, in the immediate aftermath of the March 2011 earthquake in Japan, 10.5 GW of nuclear power capacity was shut down (Nakano, 2011).

[10] There are conventional security concerns linked with uranium enrichment due to the link between civilian enrichment capabilities and nuclear weapons. This topic is beyond the scope of this chapter but is discussed in detail in Chapter 14 (Nuclear Energy).

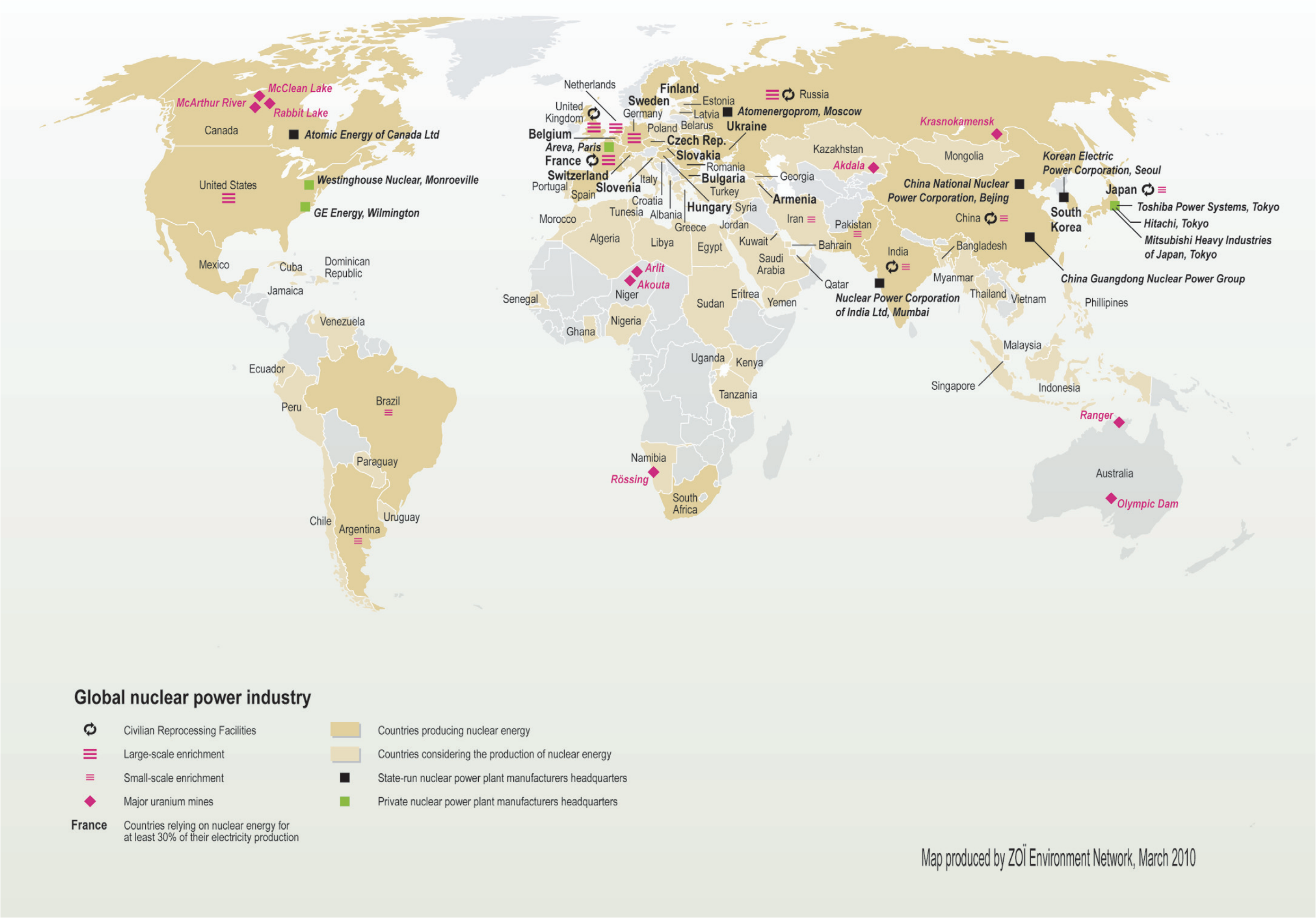

Figure 5.5 | Nuclear power worldwide. The figure shows the concentration of nuclear power and related capacities in a few industrialized countries in the Northern Hemisphere. It also indicates the aspirations of a large number of new countries, predominately in the developing world to deploy nuclear energy. Source: NEA, 2008; IAEA, 2011; Jewell, 2011; World Nuclear Association, 2011a; b; c.

Table 5.7 | The average age of nuclear power plants and the date of the start of the most recent construction.

Start of the most recent construction (years prior to 2010) Average age of NPPs (from the time of completion), years	Less than 22	22 or more
Less than 25	China, Brazil, India, Rep. of Korea	Czech Republic, Bulgaria, Ukraine, Slovakia, Romania, Mexico
More than 25	Russia, Japan, France, Pakistan, Finland	UK, USA, Canada, Germany, Argentina, Sweden, Belgium, Spain, Hungary, South Africa, Slovenia, the Netherlands, Switzerland, Armenia

safety concerns, especially in the wake of the Fukushima nuclear accident, which occurred at an older power plant. In Vermont, in the United States, the state legislature recently voted down extending the license of its nuclear power plant, which currently meets 73% of electricity demand, due to safety concerns over the 28-year-old plant.

Countries with aging plants will face the decision of whether to invest the required resources to jump-start a stale industry or redirect resources to fill the gap that aging nuclear power plants will open up. Such countries as the United States, the United Kingdom, and South Africa have recently expressed interest in restarting their nuclear power programs. However, the ability of these plans to get off the ground remains to be seen. This fact, combined with the lack of recent construction experience in all but eight countries (Table 5.7), indicates that nuclear power faces significant robustness challenges in almost three-quarters of the countries with nuclear power.

Due to safety concerns regarding the obsolescence of the operating technology, Bulgaria, Lithuania, and Slovakia were forced to close their early Soviet-designed plants as a precondition for accession to the EU. Since the Chernobyl-style nuclear power plant in Lithuania, the most recent EU Member State to close its nuclear reactor (at the end of 2009), met about 70% of its electricity demand, the government has had to seriously reconsider its energy strategy. The only remaining countries that operate Chernobyl-type reactors are Armenia and Russia. Although not an EU candidate country, Armenia has come under significant pressure from both the EU and neighboring Turkey to shut down its nuclear power plant. However, as the nuclear power plant currently meets almost 40% of its electricity generation, there is resistance.

In addition to the 29 countries currently operating nuclear power, an additional 52 countries, often citing growing energy security concerns and electricity demand, have expressed interest in starting a national nuclear power program (Rogner, 2009). While nuclear energy can affect energy security in both types of countries, in so-called "newcomer countries" the energy security risks pertain to the *potential of* and *capacity for* nuclear energy rather than risks to current generating capacity (Jewell, 2011). These newcomer countries will be discussed in Section 5.3.2, which explores the future of energy security.

5.2.2.3 Hydroelectric Power

Global hydropower supply vulnerabilities

Although hydropower is a renewable resource and hydroelectricity is not associated with massive global trade, as in the case of fossil and nuclear fuels, there are still related energy security concerns from the robustness, sovereignty, and resilience perspectives.

With respect to robustness, hydropower is vulnerable to seasonal and annual variability in hydrological regimes, as well as local weather conditions, temperature, and precipitation in the catchment area. These factors affect not only the availability of water for hydropower production, but also the amount of pressure on water resources in a region from competing uses.

The pressures on hydrological resources are likely to be exacerbated by climate change and shifting hydrological patterns. According to the Intergovernmental Panel on Climate Change (IPCC) (Bates et al., 2008), climate change is likely to alter river discharge, and thus water availability, for hydropower generation, although the exact extent of these effects is difficult to forecast. Furthermore, intensified glacial melting, while it initially has a positive impact on hydropower production, will eventually lead to reduced water flows and could seriously affect regions with glacier-fed rivers used for power production.[11] Additionally, an increase in the frequency of extreme weather events (both floods and droughts), which is predicted by the IPCC to accompany climate change (Bates et al., 2008), could alter the temporal availability of hydropower resources and place a greater stress on hydroelectric dam infrastructure.

In addition, changes in the available discharge of a river might have a direct influence on the economic and financial viability of a hydropower project, since hydropower plants have a life of more than 50 years. Even if a significant part of the changes takes place in the distant future, the impacts are inevitable. For instance, in North America, potential reductions in the outflow of the Great Lakes could result in significant economic losses as a result of reduced hydropower generation both at Niagara and on the St. Lawrence River. For a Coupled Global Climate Model (CGCM1) projection with 2°C global warming, Ontario's Niagara and St. Lawrence hydropower generation would decline by 25–35%, resulting in annual losses of C$240–350 million at 2002 prices (Buttle et al., 2004).

Changing hydrology, but also possible extreme events such as floods and droughts (which are expected to increase as a result of climate change), pose sediment risks. More sediment, along with other factors such as a changed composition of water, could raise the probability that a hydropower project suffers greater exposure to turbine erosion. When a major destruction actually occurs, the cost of recovery will be enormous. An unexpected amount of sediment will also lower turbine and generator efficiency, resulting in a decline in energy generated (Iimi, 2007).

In addition to these relatively gradual pressures that hydropower faces, there is the risk of sudden failure either from terrorism, faulty construction, or aging infrastructure. A report by the American Society of Civil Engineers (2009) recently highlighted the risk of dam failure as hydropower dams age.

From the sovereignty perspective, energy security risks associated with hydroelectricity primarily arise in situations where multiple countries share rivers feeding hydropower dams. In such cases, competing uses on different sides of a national border can be exacerbated by the fact that upstream countries can significantly affect the quantity and quality of hydrological resources that a downstream country receives. For example, China's plans to build a series of dams on the Mekong has raised significant concerns downstream in Vietnam, where scientists worry that the planned dams would significantly accelerate the disappearance of the Mekong Delta, thus decimating fisheries and livelihoods of locals in the region. Another example of water scarcity and conflicting uses of water between sectors is manifested in the ongoing tension in Central Asia, where downstream countries (Kazakhstan, Uzbekistan, and Turkmenistan) prefer to use water for irrigation in summer, while upstream countries (Tajikistan and Kyrgyzstan) need it for generating hydroelectricity in winter.

Finally, from the resilience perspective, energy security of hydropower may be considered to be under threat where a nation's electricity is supplied from just one or a few major hydroelectric facilities and thus is vulnerable to failures of these facilities.

National and regional hydropower supply vulnerabilities

Hydropower accounts for at least 20% of electricity generation in 58 countries with a combined population of 1.5 billion people and for at

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[11] Rain rather than snow in the winter will lead to less snow pack acting as a reservoir for the spring and summer months, leading to summer shortages. Higher temperatures can lead to more evaporation and less generation. Higher summer temperatures lead not only to water scarcity but also to higher electricity demand for air conditioning. This puts an additional pressure on electricity generation.

least 10% of electricity generation in 74 countries with a combined population of 4.6 billion people. About 800 million people live 35 countries that derive over half of their electricity from hydropower. The risks to hydroelectric production are highly contextualized and subject to local factors. This brief assessment considers the regional vulnerability of hydropower to climate change and the diversity of hydropower facilities in a particular country.

The IPCC's projections (Bates et al., 2008) for the impact of climate change on hydropower are available for the following regions:

In Europe, the IPCC's estimates state that the total European hydropower potential is projected to decrease by 7–12% by 2070s. The highest decreases of 20–50% are expected in Portugal, Spain, Ukraine, and Bulgaria. Some countries in Southern Europe are already vulnerable to water shortages. Albania, where 92% of power comes from hydro resources, has experienced severe shortages of power for a few consecutive summers. At the same time, in some parts of Europe, such as Scandinavia and northern Russia, the electricity production potential of hydropower plants is expected to increase by 15–30% by the end of the century.

In Africa, where little of the continent's hydropower potential has been developed, climate change simulations for the Batoka Gorge hydroelectric scheme on the Zambezi River projected a significant reduction in river flows and declining power production (a decrease in mean monthly production from 780 GWh to 613 GWh).

In Asia, changes in runoff could have a significant effect on the power output of hydropower-generating countries such as Tajikistan, which predominately relies on hydropower for its electricity needs and is among the larger hydroelectricity producers in the world. Climate change will also result in an increase in the frequency and duration of extreme climate events, i.e., floods and droughts. For instance, a hydrological model indicates a great risk of substantial increases in (mean) peak discharges in the three major rivers in Bangladesh: the Ganges, Brahmaputra, and Meghna (Iimi, 2007).

In Latin America, where hydropower is one of the main electrical energy sources, expected further glacier retreat is projected to negatively impact the generation of hydroelectricity over the long term in countries such as Colombia, Bolivia, and Peru (Bates et al., 2008). The consequences of droughts and increased energy demand caused a virtual breakdown of hydroelectricity in most of Brazil in 2001, which contributed to a GDP reduction of 1.5% (Kane, 2002). More recently, because of a shift in precipitation patterns due to El Niño, Venezuela experienced a water (and hydroelectricity production) shortage. President Chavez ordered a 20% reduction in electricity consumption in December 2009 (Cancel, 2009).

In 10 countries (with 100 million people), hydropower is derived from one dam; another 11 countries (with 290 million people) rely on one major dam and one to three significantly smaller dams (with a combined capacity less than half the size of the main dam). In another 10 countries, 330 million people rely on two major dams and one to four significantly smaller dams. Ten countries with 560 million people rely on at least three main dams for electricity supply, and 16 countries with 260 million people have four or more dams.

5.2.2.4 Traditional Biomass

There are several difficulties in assessing the vulnerabilities of biomass supply. First, biomass comes in a variety of very different forms ranging from dung, firewood, and charcoal to biodiesel, ethanol, palm oil, and specially grown plant species. Secondly, the flows of "traditional" biomass (which is not commercially produced, processed, and distributed) are often difficult to estimate. The available statistics often do not distinguish between "modern" and "traditional" *solid* biomass, especially when "modern" is used in a decentralized fashion. Yet different types of biomass are associated with different risks and vulnerabilities. We discuss traditional biomass in this subsection and further deal with modern *liquid* biomass (i.e., biofuels) in the next subsection.

Traditional biomass is primarily used for heating and cooking in residential buildings. It is estimated that 2.5 billion people rely on such energy in their daily lives. Over half of these people live in India, China, and Indonesia. In some countries, mainly in sub-Saharan Africa, these sources account for 90% of total household energy use. The main threats to traditional biomass availability are resource scarcity resulting from the growing demand (population growth, migration and other demographics, growth in consumption) and depletion of resources (change of land use, climate change). Though demand for wood-fuel is unlikely to deplete or remove forest cover on a large scale (Arnold et al., 2006), localized wood-fuel scarcities may indeed be projected to occur in parts of Southeast Asia and Africa.

Access to traditional energy resources may be further restricted for political or economic reasons. In many countries large portions of forest areas are controlled by the government, and access and use of firewood might therefore be limited. For example, in India in the mid-1990s about 55% of household needs for firewood were collected for free from common pool resources (CPRs). The share of CPRs has been shrinking at a five-yearly rate of 1.9%; coupled with decreased productivity of what remains, this has seriously restricted the CPRs' ability to meet the growing demand (Chopra and Dasgupta, 2000). Formal and informal privatization of land holdings in Africa have similarly reduced the areas available as CPRs, leading to local scarcity and shortages of firewood (Arnold et al., 2006). Seasonal variability is also an important factor that might undermine the availability of resources: bio-waste is abundant in the time of harvest; without appropriate storage capacity it is difficult to sustain the supply through the year.

Traditional biomass energy systems are typically inefficient, unreliable, and unsafe, with high environmental, social, and health externalities. They often fail to provide the level of services associated with modern energy systems (e.g., adequate heating in winter) and may not be equally available to vulnerable groups (elderly, disabled, landless, etc.). Therefore, residential energy sectors relying on traditional biomass are in most cases considered inadequate and need to be replaced by modern systems. We return to this issue in Section 5.3.3.

5.2.2.5 New Renewable Energy Sources

New renewable energy sources (NRES) include "modern" biomass (in solid, liquid, and gaseous forms), wind, solar photovoltaic, solar thermal, geothermal, tide, waves, and ocean current energy. NRES can provide most of the nationally vital energy services by generating electricity or heat, or providing liquid fuels for transportation. Despite being labeled together as "renewables," these are very different energy sources potentially associated with distinct energy security concerns. At present, these sources significantly contribute to energy supply in only a small number of countries, so there is much less empirical evidence on the nature and scale of their potential disruptions than for traditional energy sources summarized in the previous sections. Therefore, the discussion in this section is limited to general considerations and a brief overview of available quantitative data.

The main robustness concern related to fossil fuels – finite resources – is not applicable to NRES. Instead, the main concerns about the robustness of NRES are costs, intermittency, and sufficient availability in locations where they are needed. With respect to costs, vulnerabilities of NRES are different from vulnerabilities of fossil fuels because the running (fuel) costs account for a much smaller share in the total cost of energy (except solid and liquid biomass). This means that, although NRES are less vulnerable to price fluctuations, they may be more expensive in terms of total lifetime costs per unit of energy. Intermittency of NRES (with the exception of biomass and geothermal) is another concern: it is connected with daily, seasonal, or other variations in natural factors (sun, wind, tides). The impacts of intermittency can be reduced if NRES sources are integrated in larger networks where energy generated in one part of the system can compensate for the shortage of energy in another part. Developing technological solutions concerning electricity and heat storage may be another answer to the challenge of intermittency. More details on these solutions are provided in Chapter 11 (Renewable Energy).

Sovereignty concerns are in general less pronounced in the case of NRES. This is because most NRES are found locally and do not need to be imported as other fuels. The exception is liquid biofuels, which are already traded on a global scale, with Brazil and the United States accounting for over 90% of world production in 2007 (Balat and Balat, 2009). At the same time, most NRES require cutting-edge technologies that are not readily available for the majority of countries. There are signals that dependencies in renewable energy technologies may be perceived as energy security concerns by some countries (Burnett and Dwyer, 2011).

NRES also seem to be associated with better resilience than mainstream energy sources. This is because energy systems based on renewables are typically more diverse with respect to energy sources and more distributed in space. It has been argued (Lovins and Lovins, 1982) that such diversity means better protection from human or natural disruptions. Farrell et al. (2004) partially confirm this conclusion, but indicate that much more research needs to be done concerning the resilience of distributed energy generation.

Thus, NRES are widely perceived as providing better energy security, particularly from the sovereignty and resilience perspectives. That is why promotion of NRES figures prominently in almost all national energy security strategies. Although the number of countries where NRES comprise a significant share in energy supply remains small, some of these (notably the United States, Germany, Spain and China) have witnessed significant growth in NRES in recent years. Detailed information on the growth in the use of renewable energy resources in the world is provided in GEA Chapter 11.

In the residential sector, modern biomass (including waste residues) comprises over 10% of energy use in such high-income countries as Austria, Denmark, Finland, Estonia, France, Croatia, Slovenia, and Greece. Biofuels are used for transport in Brazil (15.4% of the overall transport energy use), Germany (7.2%), Cuba (6.3%), France (3.2%), and the United States (2.3%), as well as in insignificant amounts in smaller countries (IEA, 2010b).

As this discussion shows, energy security concerns associated with NRES are difficult to quantify empirically because the share of NRES in the total energy supply remains limited in the majority of countries. If large shares of renewables were to be used around the world, it might change the energy security landscape considerably and new energy security threats might emerge (e.g., demand for water and arable land). For example, it may turn out that trade in biofuels will acquire many characteristics of the current global oil market, which, as we argued, has many vulnerabilities. Answering these concerns about the security of future energy systems where NRES play a large role is beyond the scope of this chapter. Instead, they are systematically addressed in Chapter 17, which analyses energy security implications of major energy transformations.

5.2.2.6 Overall Energy Supply Security

The sectoral energy security analysis presented in the previous sections makes the most sense for identifying vulnerabilities to relatively minor disruptions unfolding in the short or medium term, when the elements and connections within energy systems remain largely fixed. Under such conditions we can make certain assumptions concerning the propagation of risks and vulnerabilities. For example, we assume that if the supply of petroleum products is disrupted, the transport system will be affected. However, over a longer term or under much stronger shocks, the energy system may become reconfigured. Liquid fuels may be produced from coal or biomass, or electrically-driven trains may take more cargo and passengers. System-wide, cross-sectoral indicators may reflect the more general vulnerabilities of national energy systems to systemic shocks and long-term threats.

We use both supply and demand indicators of cross-sectoral vulnerabilities of energy systems. On the supply side, we consider the overall import dependency, the diversity of primary energy sources, and the cost of imported fuels as a proportion of GDP or export earnings. On the demand side, we consider the total energy intensity, the overall rate of demand growth, and energy use per capita.

With regard to the supply side, 46 countries (700 million people) have a total energy import dependency higher than 50%. Fifty-eight countries (one billion people) have a low diversity (one or two dominant sources) of primary energy supply. For 15 countries (200 million people), the cost of imported fuels is higher than 10% of GDP, and for 35 countries (2.5 billion people), the cost of energy imports exceeds export earnings by 20% or more. In total, there are 102 countries (3.8 billion people) that are vulnerable in at least one of the abovementioned aspects.

In relation to the demand side, in 24 countries with 400 million people energy use per capita intensity exceeds the world average by more than 50%. In 18 countries (1.8 billion people), including China, the average annual growth in energy use has been higher than 6% over the last decade. There are 55 predominately low- and lower middle-income countries (three billion people) with energy use per capita of 30 GJ/year or lower. Such levels of energy use – at least three times less than even in the least energy-intensive developed countries such as Israel, Italy, or Japan – are likely to signal pressures on energy systems to rapidly and radically increase production to meet the future demand. There are 76 countries (4.7 billion people), primarily low- or lower middle-income, subject to at least one demand-side vulnerability mentioned above.

Cross-sectoral demand- and supply-side vulnerabilities overlap in 63 countries with 2.8 billion people, of which 47 are either low- or lower middle-income countries. Additionally, three billion people live in 52 countries that have either cross-sectoral demand or cross-sectoral supply vulnerabilities. Only 19 countries with 600 million people can be considered free from overall energy supply vulnerabilities.

5.2.3 Security of Electricity Systems

5.2.3.1 General Considerations

Due to the large and growing importance of electricity systems, the risks of their potential disruption are increasingly prominent on energy security agendas. The importance of secure delivery of electricity is growing in every country due to:

- the increasing dependency on electricity (for example, in the information and communications technology [ICT] sectors, and eventually in the transportation sector) of modern economies;
- the expansion in the coverage of electricity grids in developing nations;
- the increasing "electrification" of energy services in emerging economies where the entry into the middle class is often signaled with the arrival of domestic electrical appliances; and
- the advance of "new" energy systems relying on distributed generation, renewable energy sources, and possibly electric propulsion for vehicles.

In contrast to other energy carriers, electricity cannot at present be stored cheaply and easily and should in many critical cases be supplied without any interruption, closely matching the changing demand. This makes electricity systems vulnerable even to short-term disruptions and imposes particularly stringent requirements on electricity generation, conversion, and transmission. The vulnerability of electricity systems can be considered from robustness, sovereignty, and resilience perspectives.

In this analysis we use four indicators to estimate the robustness of electricity systems. Two of them relate to the supply side: the age of electric power plants and the frequency of blackouts. The two others relate to the demand side: the rate of access to electricity and the growth in demand for electricity. Rapid demand growth increases the pressure on existing electricity systems and stimulates countries to seek new sources of energy.[12] Another demand-side vulnerability is the inadequate provision of electricity, reflected in a low rate of access to electricity. The low access rate is untenable for most governments, and therefore results in pressures on the energy system to expand. Thus, all else being equal, a country with low access or higher growth will be less secure, as it will need to expand rather than merely maintain its electricity supply at the present level. Our analysis also considered the third demand-side vulnerability factor: the electricity intensity of the economy. In principle, more electricity-intensive economies should be more sensitive to energy price fluctuations and other disruptions of electricity systems. However, electricity intensity was not found to be a sufficiently discriminating factor in the final analysis.

The sovereignty perspective on the security of electricity systems is reflected in the reliance on imported fossil fuels for electricity generation and on imports of electricity. Finally, a proxy indicator for the resilience

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[12] Jewell (2011) demonstrates that the rapid growth in electricity demand has correlated with countries launching nuclear energy programs.

of national electricity systems used in this analysis is the diversity of fuels used for electricity generation.

In many industrialized countries, electricity subsystems are undergoing transformations. These include distributed decentralized generation, "smart grids," and possibly an increasing role of international interconnectedness and electricity imports. Energy security factors associated with these new developments will play increasingly important roles in the security of electricity generation, distribution, and transmission in the future. For example, it is often argued that distributed generation of electricity will result in higher reliability and resilience of energy provision (Lovins and Lovins, 1982). At the same time, the empirical evidence that distributed systems are more robust than centralized ones seems to be inconclusive (Farrell et al., 2004). Key technological and institutional developments that may affect the reliability of electricity systems are discussed in Chapter 15.

5.2.3.2 Vulnerability of National Electricity Systems

The primary energy security concerns from the perspective of robustness of electricity systems include the aging of power plants, rapid growth in demand and/or lack of adequate provision of electricity, and the reliability of electricity systems. The aging of power plants is particularly a problem for industrialized countries with established and stagnant fleets. Especially problematic is the aging of nuclear reactors because they typically provide large shares of national electricity and their replacement with other nuclear reactors may be problematic for economic and political reasons (see a more detailed discussion of this point, as well as statistics on the aging of nuclear reactors, in the previous section). Non-nuclear generating facilities are also aging in many countries. For example, in the United Kingdom, the aging of power stations is one of the three major national energy challenges (the other two being decarbonization and an increasing reliance on imported natural gas – see Figure 5.6).

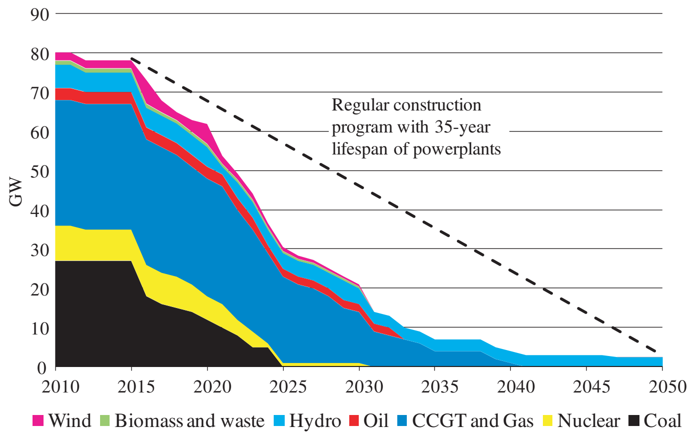

Figure 5.6 | Projected retirement of electricity-generating capacity in the United Kingdom. The figure shows the decline in capacity much faster than if the regular pace of construction was maintained in recent years (as shown by the dotted line). Source: Parsons Brinckerhoff, 2009.

The reliability of electricity infrastructure is addressed in Box 5.7. The scale of the problem is dramatically higher in low- and middle-income countries, although it is high on the political agenda of industrialized nations as well because their economies are increasingly sensitive to even minor disruptions of electricity supply.

There are energy security concerns from the robustness perspective related to the demand side of electricity systems. There are 32 countries with a total population of some 2.4 billion people that have less than 60% access to electricity. In 35 countries with some 2.6 billion people, the electricity demand has been growing at over 6%. The need to increase electricity-generation capacities is especially dramatic in larger low-income countries. For example, Ibitoye and Adenikinju (2007) estimate that under the assumption that Nigeria becomes a middle-income economy and meets its Millennium Development Goals by 2030, it will need to achieve a 25-fold increase in its electricity-generating capacities (from the current 6.5 GW to 164 GW). All in all, 53 countries with some 4.2 billion people experience either one or both of these demand-side vulnerabilities.

The importing of fuels for electricity production or the importing of electricity itself are considered an energy security concern in some countries. Almost 1.3 billion people live in 62 countries that rely on imported energy for more than 25% in their electricity, almost 600 million live in 39 countries importing over 50%, and almost 200 million live in 21 countries that import over 75% of energy for electricity production. Most of this energy is imported in the form of fuels for electricity production rather than directly as electricity imports.[13]

From the resilience perspective, the security of electricity systems may be measured as the diversity of fuels used for electricity generation. The Shannon-Weiner Diversity Index[14] of such fuels is less than 0.2 in 30 countries, which are home to some 360 million people. This means that virtually all of their electricity comes from a single source (often hydropower or natural gas-fired power plants). Even the diversity index of 0.4 (applicable to some 450 million people in 35 countries) can still be considered low.

All in all, some 990 million people live in 62 countries where electricity systems are vulnerable with respect to supply, because they are either significantly (over 40%) based on imported fossil fuels and/or have a low (<0.4) diversity of electricity generation.

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[13] There are only 12 relatively small countries (six in Europe and six in sub-Saharan Africa) that import more than 25% of the electricity they consume.

[14] The Shannon-Wiener Diversity Index (SWDI) is a most common measure of diversity of options or categories. It is based on the idea that the greater the variety and the more even the spread the greater is the diversity. The index is calculated as: SWDI = $-\sum_i p_i \ln p_i$, where pi represents the share of each category/option in the energy mix (Stirling, 1998; Jansen et al., 2004).

Box 5.7 | Reliability of Electricity Supply

Challenges for ensuring adequacy and reliability of electricity grids exist for both developed and developing countries. For developing countries, extending electricity networks and increasing generating capacity is the main challenge. Even for households connected to electricity grids, planned outages due to the lack of generating capacity are not uncommon. At the same time, an increasing number of emerging economies and all industrialized countries have sufficient network coverage and generating capacity. However, precisely because these societies rely heavily on permanent access to electricity, any disruptions of the systems are potentially very harmful. The increasing scale, complexity, age, and interconnectedness of modern electricity grids present a serious investment and energy security challenge worldwide.

Advanced electricity distribution systems are spatially distributed and technically complex. The spatial extent of electricity grids means that they face "distributed threats," which are difficult to predict and manage. Moreover, the scale and the degree of interconnectedness of modern grids mean that even a minor failure can have dramatic consequences throughout the system – the so-called "cascading failure." This is especially plausible when the system operates near its critical load. Paradoxically, some measures to control small-scale blackouts may actually increase the probability and severity of large-scale blackouts, since they increase the interconnectedness and thus the size of the system that may fail (Dobson et al., 2007).

There are no comparative international statistics on the number and intensity of disruptions of electricity supply also known as blackouts. However, detailed data that exist on some industrialized countries can be not only interpreted but also compared with analysis of the situation in developing countries.

Several comprehensive studies analyze blackouts in the United States. The analysis of the US data from 1984–2006 by Hines et al. (2008) indicates that the frequency of large blackouts was not decreasing with time despite the introduction of advanced data management, reliability standards, and many other measures. A particularly catastrophic blackout on August 14, 2003 affected approximately 50 million people in the northeastern United States and parts of Canada and resulted in US$3 billion in insurance claims alone. An assessment of major electricity blackouts conducted by the Institute of Electrical and Electronics Engineers estimates that no less than 17 major blackouts have affected more than 195 million residential, commercial, and industrial customers in the United States, with seven of these major blackouts occurring in the past 10 years. Sixty-six smaller blackouts (affecting between 50,000 and 600,000 customers) occurred from 1991 to 1995, and 76 occurred from 1996 to 2000. The costs of these blackouts are monumental: the US Department of Energy (DOE) estimates that power outages and power quality disturbances cost customers as much as US$206 billion annually, or more than the entire nation's electricity bill for 1990 (Hines et al., 2008).

According to Hines et al. (2008), the single most important reason for blackouts in the United States was technical failure (nearly 30% of all events), which together with operator failure, volunteer reduction, and weather conditions accounted for over 85% of all blackouts. Intentional attacks were responsible for some 1.6% of blackouts. Larger blackouts also resulted from earthquakes and hurricanes or tropical storms.

In the report on the reliability of the US electricity system presented to the Assistant Secretary of State for Energy Efficiency and Renewable Energy, Osborn and Kawann (2001) indicate that reserve capacity margins (for both transmission and generation) have been decreasing in most US regions for the past two decades and were projected to decrease until 2020, which may be the single most important factor explaining the lack of a downward trend in the number of blackouts in the United States. The decrease in this margin can be explained by both increasing demand and falling investment in transmission and electricity grid infrastructure. The report connects this fall in investment with institutional and market failures of the electric power system.

The frequency and severity of blackouts are reportedly less in Western Europe than in the United States. Nevertheless, severe blackouts in September 2003 affected some four million people in southern Sweden and eastern Denmark, and the nationwide blackout in Italy was the worst in the history of the nation (Andersson et al., 2005).

Despite concerns that electricity blackouts cause in developed countries, their intensity is dramatically less than in the developing world. The three largest blackouts in world history occurred in developing nations, including the 2005 Java-Bali blackout in Indonesia, which affected 100 millllion people (Donnan, 2005), the 1999 South Brazil blackout, which affected 75 million people (Yu and Pollitt, 2009), and the November 2009 Brazil-Paraguay blackout, which originated in the world's second largest hydroelectric plant and left tens of millions of people in Brazil and the whole of Paraguay without electricity (Reuters, 2009).

World Bank's Enterprise Survey data (World Bank, 2010) clearly show that both the number and severity of electricity blackouts are highest for low-income countries, lower for lower middle-income countries and the lowest for upper middle-income countries in the survey. For most lower-income countries, blackouts are not measured in hours per year (as in the United States and Europe), but rather in hours per *day*. In almost three-quarters of low-income countries, blackouts are on average for more than 24 hours per month, and in about one-sixth of low-income countries blackouts average over 144 hours (six days) a month. There are more than 10 blackouts every month in more than half of the surveyed low-income countries. Companies in Albania, Guinea, Kosovo, Nepal, Pakistan, and Yemen experienced 30 or more blackouts in a month, whereas firms in Bangladesh experienced, on average, 101 blackouts per month. The worst statistics of blackouts were shown in South Asia, followed by sub-Saharan Africa. The results of this analysis should be interpreted with an understanding that companies may, in fact, experience less frequent outages than private customers, as they tend to be located in urban areas with better infrastructure.

In 28 countries with over 500 million people, high supply- and demand-side vulnerabilities overlap. These electricity systems, pressed from both sides, can be considered especially insecure. The majority of the world's population (some 4.3 billion in 65 countries) lives in countries that are vulnerable in at least one of the supply or demand aspects. Finally, some 1.6 billion people live in about 38 countries with relatively secure energy systems, which rely primarily on diverse domestic resources and have high access to electricity and moderate rates of growth in demand.

5.2.4 Vulnerability of End-Use Sectors

A modern state cannot function without several vital services provided by national energy systems. For the purpose of this analysis, we distinguish between four such services. The first three are the "end-uses" discussed in Chapters 8, 9, and 10, i.e., energy in (1) transport, (2) industry, and (3) buildings. The last energy "service" is (4) revenue from energy exports. It is only relevant to a relatively small number of countries whose economies rely significantly on such revenues.

This subsection evaluates the vulnerabilities of each of the vital energy services: transportation, residential and commercial (R&C), industrial, and export-revenue generation. Such vulnerabilities are generally divided into those associated with the energy service itself (demand-side vulnerabilities) and those linked to the properties of the energy system in which a particular service is embedded, particularly the security of relevant energy sources.

5.2.4.1 Energy for Transport

Transportation is vital for almost every aspect of modern societies, ranging from personal mobility to food production and distribution, trade, availability of goods and services, and, not least of all, military security. Transport accounts for over 20% of energy use in virtually all developed countries. It is still under 15% in many developing countries, including China and India (where it is rapidly growing). Only in Least Developed Countries (LDCs) does transport account for under 10% of their total energy use. Modern transport systems rely on motorized vehicles that share fuels with agricultural, construction, and other machinery. Thus, this discussion of energy security for transportation is also applicable for the security of fuels for agricultural production and related sectors.

Among all nationally vital energy services, transport is beyond doubt the most vulnerable. This vulnerability is primarily a result of the reliance on imported oil as transport fuel. The absolute bulk of energy for transport is derived from oil and its products.

Only nine countries (Algeria, Argentina, Belarus, Brazil, Moldova, Russia, Slovakia, Ukraine, and Uzbekistan) rely on oil for less than 85% of their transport energy needs. In all these countries except Brazil, natural gas is the main alternative to oil products in transport. Whereas Algeria, Argentina, Russia, and Uzbekistan have their own natural gas reserves (with the R/S ratio of only 11 years in the case of Argentina), the other countries import most of their natural gas.

This means that the security of energy for transport largely reflects the security of oil supply discussed in Section 5.1.2.1. Around 3.2 billion people live in 85 countries that import[15] 70% or more, and 4.9 billion live in 93 countries (including China)[16] that import one-half or more of their transport fuels. Finally, 101 countries (5.3 billion people) import more than 25% of the fuel used for transport. Two other countries (Argentina and the United Kingdom), which currently import less than 25% of their transport fuels, may face import dependency in the near future, since their oil R/S ratio is under 15 years.

Transport energy systems are also subject to demand-side vulnerabilities. In particular, rapid growth in transport energy use signals a pressure on transport. About 1.7 billion people live in some 17 countries (including China) where transport energy use has grown faster than 8% annually over 1998–2007, and 29 countries with 1.9 billion people

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[15] Dependency on imported fuels for transport considers all fuels used in transport. In the case of oil, it includes petroleum products and crude oil imports.

[16] In 2007, China's dependency on imported fuels for transport was 47.4%. The resource/consumption ratio of domestic oil in China is 7.23 years, and the annual rate of growth of transport energy was 8.8% in 1998–2007.

have experienced a growth rate of over 6%. This is in contrast with some developed countries, notably the United States, where the car fleet shrank by four million vehicles in 2009 and the consumption of gasoline peaked in 2007 (NADA, 2009, quoted in Brown, 2010).

Supply- and demand-side vulnerabilities of transport energy systems overlap in some 15 countries (including China) with 1.7 billion people, which depend on imported fuels for one-half or more of their energy use and at the same time experience over 6% growth in demand. An additional 84 countries with 3.2 billion people experience either supply- or demand-side vulnerabilities. Only about 1.2 billion people live in 31 countries with relatively import-independent and slowly growing transport systems.

5.2.4.2 Energy for Industry

The industrial use of energy – mainly in the form of heat and electricity – varies between countries. Virtually all developed countries use at least 15% of their energy in the industrial sector. In 60 countries with 4.5 billion people, industry accounts for over 25% of their energy use, and in 12 countries with 1.7 billion people (which include Brazil, China, and Ukraine), it accounts for over 40% of their energy use. Many smaller developing and emerging economies are dominated by one or few industries relying on distinct energy systems, which are therefore critical for the energy security of those societies.

The industrial sector is less based on imported fuels than the transport sector. In 23 countries (400 million people) industry relies on fuels that are 75% or more imported, in 46 countries (800 million people) on fuels that are 50% or more imported, and in 77 countries (1.5 billion people) on fuels that are 25% or more imported.

Demand-side vulnerabilities should also be taken into account. Although many economies experience growth in industrial energy use, this cannot be considered as permanent and pressing, as in the case of the transport and residential sectors, because industrial growth may be reversed. Industrial energy intensity, on the other hand, is an important characteristic that can make the industrial sector relatively more or less vulnerable to price volatility and other energy supply disruptions. In 34 countries (including China, the Russian Federation, Brazil, Ukraine, and several other emerging economies) with 2.8 billion people, industrial energy intensity exceeds the world average by 25% or more (159% in Ukraine, 49% in China, 45% in Russia, 35% in Brazil). In the vast majority of these countries industrial products also account for a large portion of GDP (49% in China, 38% in Russia, 37% in Ukraine), which makes them even more vulnerable to industrial energy supply disruptions.

Supply- and demand-side vulnerabilities of industrial energy systems overlap in only two countries: Jordan and Moldova. About 80 countries in the world, with a combined population of some 3.6 billion people, experience either high import dependency of industrial fuels or high industrial energy intensity.

5.2.4.3 Energy in the Residential and Commercial Sector

The R&C sector in all countries vitally depends upon a supply of electricity that is used for lighting, cooking, heating, and other appliances. Other forms of energy are also used in this sector, particularly for heating, which is an important national priority in cold climates. In many countries, prevention of failures to provide adequate heating during cold seasons are rightly considered a matter of national priority.

Another key feature of the R&C sector is that it significantly relies on traditional biomass in many developing countries. Energy statistics typically designate this source as "renewables and combustibles" without making the distinction between "modern" (e.g., pellets, straw boilers, modern heaters) and "traditional" (e.g., firewood or dung used in open cooking stoves) uses of biomass. However, reliance on traditional biomass in the R&C sector represents a national energy security issue because such use is generally considered unacceptable on health, environmental, and developmental grounds. This means that the massive use of traditional biomass in the R&C sector, much like the low rate of access to electricity, is untenable for modern nation-states. When such use is widespread, the energy policy and the energy system are under pressure to find new sources of energy to replace traditional biomass, which can be combined with other pressures to exacerbate a nation's energy vulnerabilities.

The patterns of energy use in the R&C sector differ greatly between developing and industrialized countries. Lower-income countries typically have a higher proportion of R&C energy in the total energy use and a higher share of (mostly "traditional") biomass in R&C energy use.[17] In the following analysis we make a distinction between three groups of countries that differ in the degree to which they rely on traditional biomass in their R&C sector:

- 25 countries (700 million people) rely on combustibles and renewables for over 80% of their R&C energy, most of them low- or lower middle-income countries. These countries are not included in our analysis of import dependency of fuels for the R&C sector.[18]
- 22 countries (3.3 billion people) rely on combustibles and renewables for between 33% and 80% of their R&C energy, of these two-thirds are low- or lower middle-income countries and these rest are

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[17] All of the 27 countries with R&C energy representing more than 40% of total energy use are either low- or lower middle-income countries. The share of biomass in R&C energy use of those 27 countries is higher than 70%.

[18] The rationale for this approach is that the overarching vulnerability for those countries is an excessive reliance on traditional biomass in their R&C sectors rather than import dependency of the relatively insignificant remaining share of their R&C energy.

upper middle-income countries. This group also includes India and China. For these countries we analyze import dependency only for the share of their R&C energy, which does not include combustibles and renewables.[19]

- The remaining 86 countries (2.3 billion people) rely on combustibles and renewables for less than 30% in their R&C energy. About 75% of these countries are high- or higher middle-income. For these countries we analyze vulnerabilities of the R&C sector.

The R&C sector is generally less dependent on imported fuels than transport, but more dependent than the industrial sector. Twenty countries (400 million people) import more than 75% of their energy for R&C. In 39 countries (500 million people), the energy imported for this sector is higher than 50%. Finally, 52 countries (2.3 billion people) rely on more than 25% of imported energy for the R&C sector.

There are also demand-side pressures on R&C energy use. In 28 countries (400 million people), the growth rate of energy use in this sector exceeded 5% per year. In many low-income countries per capita energy use is far below the world average, which probably indicates an inadequate provision of energy services in this area and signals a potential vulnerability. This question will be explored further.

Only three small countries (Portugal, Cyprus, and Albania) have an import dependency on energy for R&C higher than 50% and annual demand growth higher than 6%. Forty-seven countries (1.1 billion people) have either dependency on energy higher than 50% or demand per capita for R&C higher than 6%. These vulnerabilities should be considered in addition to 25 countries (with 700 million people) that primarily rely on traditional biomass in their R&C sector.

5.2.4.4 Energy for Export and Resource Curse

Energy exports are central for several countries where export revenues provide core funding for the public sector and where energy export industries sustain employment and a large part of the economies. To articulate the role of energy exports, these countries sometimes formulate them as "demand security" to contrast with the "supply security" of energy-importing nations. We consider export revenues as another energy sector vital for the stability of economic, political, and social order in exporting countries.

Yet energy exports are as vulnerable to various disruptions as other energy services and can also be considered from the robustness, sovereignty, and resilience perspectives. First of all, energy exports are only possible when sufficient domestic energy resources are available. This presumes both physical availability and accessibility of resources, as well as a reasonably satisfied (or artificially constrained) national demand for such resources. Second, resources can only be exported if there are adequate extraction, conversion, and transportation technologies and infrastructure. Third, any export depends upon safe export routes and destinations. Thus, exports security depends upon the physical safety of export routes (from adverse natural events and deliberate disruptions) as well as upon functioning institutional arrangements (e.g., markets) to match energy supply and demand and ensure sufficient and predictable revenues.

Energy exports can be considered a vital national service for only a few of all energy-exporting countries. There are about 15 countries where energy exports constitute 20% or more of GDP. About half of these countries are LDCs; most of the rest are middle-income countries.

The first insecurity stems from the very fact that a particular national economy extensively relies on oil exports. Worldwide, such dependency is highly correlated with slower long-term rates of economic growth and political problems. The economic and political risks of significantly relying on oil exports are particularly pronounced for poor countries and are extensively analyzed in the literature on the so-called "resource curse" discussed in Box 5.8. Furthermore, domestic oil reserves in some exporting countries are quite limited and will not last longer at current rates of production unless new resources are found or put in production. For example, the R/P ratios for Angola, Cameroon, and Malaysia in 2007–2009 were estimated at 12–20 years and for Argentina at about 10 years (BP, 2007; 2009; US EIA, 2011b).

5.2.5 Energy Security in Selected Regions

The above analysis primarily concerns energy security in individual countries, as well as relevant global considerations. At the same time, energy security issues have a strong regional dimension because countries located in geographic proximity often experience similar conditions with respect to access to energy resources and the structure of energy use, and may be engaged in more intensive mutual trade and transit of energy carriers. This subsection outlines energy security issues from the robustness, sovereignty, and resilience perspectives in the major world sub-regions: Africa, Asia, Europe, and North and South America.

5.2.5.1 Energy Security in Africa[20]

Energy security is an important policy issue in Africa. A number of factors contribute to rising energy security challenges. The rising economic

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[19] The rationale for this approach is that such countries typically have two distinct residential sectors: one "modern," which can be subject to standard import vulnerability analysis, and the other "traditional," where the vulnerabilities associated with traditional fuels are most prominent.

[20] Source: Adenikinju, 2005; 2008; Anyanwu et al., 2010; US EIA, 2011a; Wohlgemuth, 2008.

Box 5.8 | Energy Exports and Resource Curse

Exports of energy resources – primarily oil and gas – have strongly influenced national economies and political systems in different historical periods in many countries. It has arguably supported economic development in such industrialized countries as Norway, the United Kingdom, Canada, and the United States. It has fueled economic development in Malaysia, Indonesia, the United Arab Emirates, and other emerging economies. Yet it has been blamed for slower economic growth, poor governance, political instability, and conflict in several low- and middle-income countries. This latter phenomenon has been termed the "resource curse" or "natural resource trap." There is an extensive body of scholarly literature that attempts to explain the resource curse and find appropriate remedies.

Poor economic performance of energy exporters, observed by many researchers, has been blamed on macroeconomic instability induced by the volatility of energy prices. More often than not, producers that face a season of windfalls spend extravagantly and have difficulty curbing this spending during lower price periods. In addition, some energy exporters tended to unsustainably borrow in times of high oil prices and were saddled with unbearably heavy debts in times of lower prices. Added to this, many low-income energy exporters are faced with money flows that far surpass their absorptive capacity, resulting in overheated economies and rampant inflation.

Another reason for slower economic growth of energy exporters is the so-called "Dutch disease," an economic phenomenon named after the negative impact on the Dutch economy of natural gas-related revenues in the 1970s resulting from over-valuation of the national currency and a set of other factors which inhibit the development of non-energy branches of an economy producing "tradable goods." The result of the Dutch disease is thus a steady decrease in non-oil productive activity and, in the face of the eclipse or lack of a non-oil fiscal base, the growing dependency of state coffers on petroleum rents.

The political consequences of oil wealth have been shown to be equally negative for many countries. Indeed, it is primarily at institutions, the mentalities of decision-makers, and the quality of governance rather than at macroeconomic trends that one must look to account for the predicament of the petro-state. An immediate consequence of oil revenues is the increase in state power and the absolute social, economic, and political centrality it acquires. The boom phase characteristically includes a growth in construction and proliferation of employment in the state sector and the services sector. As the key actor of the domestic economy and main supporter of the lingering private sector through handouts and public contracts, the state is everywhere and in constant expansion. The oil economy is meanwhile managed under a shroud of secrecy. Production levels and financial amounts transacted are matters of speculation; budgets are fictitious; and money flows are the object of unheard-of detours and misappropriations in a context of no public accountability (Ross, 2001). It is, therefore, unsurprising that of the top 15 oil exporters only one (Norway) is a well-functioning democracy and four others (Mexico, Venezuela, Russia, and Iraq) can be considered "imperfect democracies." This lack of accountability extends to the international level. More often than not, oil producers with questionable domestic records are nonetheless courted and protected by oil-consuming states in the industrial world, in a demonstration that oil, on account of its centrality for the functioning of modern economies, is a commodity like no other.

Easy oil money means that the state does not need to expand the domestic fiscal base. In fact, OPEC members' oil revenues represent an average of 42% of total government revenues. In cases where the building of state institutions runs parallel with the availability of oil wealth, no fiscal administrations are created at all. Oftentimes, the state does not seek to pursue this option anyway, for it faces articulate national constituencies that see themselves as legitimate beneficiaries of the national wealth rather than as net contributors to it. This fiscal aloofness strengthens the executive but also cuts its link with society as well as the minimal social contract the link might imply.

These arrangements, however, become unstable at times of low or decreasing oil prices. At such times, a petro-state becomes highly indebted, with a vast unemployed urban working class and a restive youth, a large and intermittently paid civil service, a neglected countryside, and an inequitable pattern of wealth distribution. Recent research shows that, faced with a powder keg of distorted economies and dissatisfied populations, oil states are far more likely than non-oil states to suffer from civil war or separatist bids from resource-rich regions. This political instability and poor governance can feed on each other, creating a vicious circle. In already unstable contexts such as West and Central Africa, for instance, oil is clearly a factor that exacerbates conflict and perpetuates the control of the state by self-seeking elites.

Researchers disagree on the root causes of the resource curse. The term itself tends to underplay two important factors. Regarding the first, it is becoming clear that poor institutions are largely responsible for economic under-performance, and vice versa: poor non-diversified economies are obstacles to improving governance. The second factor is the character of the economy, institutions, and political culture in oil-rich states prior to the arrival of oil rents. OECD oil-producing states had developed the institutions (strong and accountable governments, a free press, a robust political party system, etc.) that proved instrumental in steering oil revenues in a constructive direction decades before oil materialized. In much the same way, many of the problems found in oil-rich-but-poor states were everyday occurrences before oil: fragile economies, despotic rulers, and weak and inefficient institutions. In this context, oil accentuated pathologies that existed already.

More detailed recent analysis shows that endowment with national resources may be a curse or a blessing, depending on many other conditions. The larger the endowment of natural resources, the stronger are the institutions needed to overcome the risk of resource curse. However, under certain conditions – prevalent in many developing countries – the opposite occurs. The presence of natural resources actually weakens the institutions, which in turn are unable to manage the natural resource wealth; this leads to more resource-dependency, further weakening of the institutions, etc. Thus, suffering from resource curse or falling into a natural resource trap is not inevitable. However, it is a matter of very high risk and affects many developing oil-exporting nations. While analysts dispute what is at the root of the disappointing performance of most petroleum exporters – ranging from the single-minded determinism of a resource curse to more nuanced institutional and sociological analyses – there is a near consensus that few states have gone up the developmental ladder by virtue of their oil endowments.

As evidence that the resource curse does not always occur, one recent study looked at oil and gas production in Indonesia, Malaysia, Myanmar, and Thailand from 1987–2007. In each of these countries, including Myanmar, economies have become more diversified, per capita incomes have risen, and life expectancies and living standards have improved along with increased energy supply. Political transparency and accountability have remained constant in Indonesia, Malaysia, and Thailand, and oil and gas have contributed less to government revenues over time in Indonesia and Thailand. The situation in Southeast Asia suggests that extractive resources themselves are neither a curse nor a blessing. Instead, it is how they are used and the particular socio-political environment in which they evolve that determines whether they contribute to peace and prosperity or risk conflict and environmental degradation. The successful practice of managing energy export revenues in Chile included avoiding excessive spending in boom times, allowing deviations from a target surplus only in response to output gaps and long-lasting commodity price increases, as judged by independent panels of experts rather than politicians. Other measures to avoid the resource curse proposed by experts include hedging export proceeds in commodity futures markets, denominating debt in terms of commodity prices, allowing some nominal currency appreciation in response to an increase in world prices of the commodity, but also adding to foreign exchange reserves, especially at the early stages of the boom when it may prove to be transitory.

Source: Fardmanesh, 1991; Auty, 1993; 1994; Chaudhry, 1997; Karl, 1997; 1998; Leite and Weidmann, 1999; Fearon and Laitin, 2003; Katz et al., 2004; Karl, 2005; Soares de Oliveira, 2006; Collier, 2007; Soares de Oliveira, 2007; Brunnschweiler and Bulte, 2008; EIU, 2009; Sovacool, 2010.

prosperity of the continent after decades of economic underperformance has led to an increasing demand for modern energy. The rising costs of energy imports constitute a threat to economic resurgence of the continent. Weak investments in energy infrastructure, poor domestic policies that favor poorly targeted subsidies, and limited transportation connectivity across Africa also hamper the extent and pace at which trade in energy can occur between energy-surplus and energy-deficient parts of the continent. Most of the countries in the continent continue to depend on imports from outside the continent to meet the rising domestic demand.

Over the years, energy prices have risen rapidly and become highly volatile. While the upwards trend in global energy prices has led to a massive accumulation of reserves in many energy-rich African countries, net energy importers in the continent have borne the costs in terms of slower economic growth, rising trade deficit, faster depletion of foreign reserves, and rising inflation.

Affordability of and access to modern energy are very poor in Africa though in total, the continent produces more energy than it consumes. In 2009, extraction of crude oil, natural gas, and coal were 3.2, 2.2, and 1.34 times higher than their respective use, whereas the overall total primary energy supply was more than twice the amount of primary energy used. However, these aggregate figures mask a high degree of intra-African diversity in energy demand and supply, which largely reflects the diverging regional resource endowments.

The TPES in Africa grew by a mean of 4% between 2005 and 2009, mainly as a result of robust growth in crude oil production in North and West Africa. The share of biomass, while still significant in parts of Africa, especially in sub-Saharan Africa, decreased from 62% in 1971 to less than 45% in 2009. However, Africa's use of combustible renewable energy (mainly wood-fuel) still remains significantly higher than the world average. Total primary energy use in the same time period rose by an annual average of 3.7%.

Though the continent exports energy, it is unable to meet the energy needs of its population, especially in sub-Saharan Africa. The systemic energy problem in Africa is especially evident within its power sector. Africa is estimated to require 7000 MW of new power generation capacity each year, but has been installing only 1000 MW annually. Outside South Africa, power consumption averages 124 kWh (4.46 GJ) per person per year. Only one-fifth of the population of sub-Saharan Africa has access to electricity, compared with one-half in South Asia and four-fifths in Latin America. At the same time, the cost of electricity is higher in Africa. Frequent power outages force firms to rely on expensive back-up generators that cost up to US$0.40 per kWh. Many countries rely on inefficient, expensive, small-scale, oil-based power generation. Africa is well endowed with large-scale, cost-effective energy resources, but they tend to be located a long distance from the major demand centers and their development is often too expensive for the countries where they are found.

Energy resource ownership and use vary widely across Africa. For instance, three countries – South Africa, Egypt, and Algeria – account for two-thirds of total primary energy use. Algeria and Egypt account for 73.6% of total natural gas consumption. South Africa and Egypt jointly account for 61% of the continent's hydroelectricity consumption. South Africa alone accounts for 93% of total African coal consumption and 100% of its nuclear energy generation.

Nigeria, Algeria, Angola, and Libya are the major producers of oil, although oil is also produced in Cameroon, Chad, Congo, Côte d'Ivoire, Egypt, Equatorial Guinea, Gabon, Mauritania, Sudan, and Tunisia. Natural gas reserves are located in four major countries: Nigeria, Algeria, Egypt, and Libya.

There is a very limited amount of intra-Africa trade in energy. Only 1.8% of the continent's oil exports go to other African countries. LNG trade from Algeria, Egypt, Equatorial Guinea, Libya, and Nigeria go to countries in North America, Europe, and Asia/Pacific. Three countries – Egypt, Mozambique, and South Africa – are responsible for nearly all the coal exports in Africa. Most of the coal exports go to other African countries – Algeria, Congo Kinshasa, Kenya, Morocco, Mauritius, Namibia, and Senegal. There is also some electricity trading within the continent, especially within the various sub-regions. A good example is the West African Power Pool, designed to interconnect national grids across 5000 km of most West African countries. Another important initiative in West Africa is the West African Gas Pipeline. The US$635 million project was initially developed to utilize some of the gas currently being flared in Nigeria for power generation in Benin, Togo, and Ghana.

The presently low level of energy trade among countries has made it difficult to leverage the huge energy surplus produced in the continent to meet the needs of energy-poorer countries. Hence, significant scope exists for energy cooperation across sub-regions on the continent. Although there are a number of pan-African cooperative energy initiatives, the pace of implementation of these initiatives has been slow.

The diversity of energy resources in Africa is relatively low. Oil is the dominant fuel in most African countries. Four-fifths of the countries derive over 50% of their energy use from oil. Over one-third of the refined petroleum consumed in the region is imported. While the amount may vary, all the countries import some proportion of their product consumption. Over 63% of the countries import more than 90% of the refined products they consume. Paradoxically, Nigeria, the leading producer and exporter of crude oil in Africa, imports 69.8% of its product requirements and accounts for 17.7% of the continent's total imports. Dependency on imported energy is a risk to energy security and makes the country vulnerable to high and volatile world oil prices.

In some African countries, energy sources other than oil dominate consumption. Countries significantly dependent on coal are South Africa (76.4%), Zimbabwe (53.4%), Botswana (41%), and Swaziland (34.7%). Countries with high natural gas dependency are Equatorial Guinea (92.6%), Algeria (64.4%), Tunisia (50.5%), Egypt (49%), Côte d'Ivoire (44.5%), and Nigeria (41.7%). Countries heavily dependent on hydroelectric energy are Mozambique (82.1%), Zambia (75.2%), Congo Kinshasa (68.2%), Malawi (45.3%), and Cameroon (41.6%). Countries that depend almost exclusively on a single primary energy source are Benin, Chad, Djibouti, The Gambia, Seychelles, Sierra Leone, Somalia, and Togo.

The generally low energy diversity in Africa relates to low capacity and a weak technological base in most countries. Poverty and a lack of appropriate technologies have hampered diversification into renewables such as solar, wind, and small hydro.

Several options are open to African countries to address the huge energy gap in the region. These include the use of renewable energy to supplement the non-renewable energy sources that currently dominate the energy mix, the reduction of huge energy losses and wastages and adoption of energy efficiency technologies, increased investment in new technologies and energy supply infrastructure, and an enhanced level of intra-regional energy cooperation. The latter is required because many African countries are very small and may not be able to finance the huge investment costs needed to develop alternative energy sources. Africa must engage the private sector in addressing its energy supply inadequacies. While energy subsidies may not disappear for a while, such subsidies must be smart and better targeted to meet specific societal objectives.

5.2.5.2 Energy Security in Europe[21]

Europe[22] is among the world's largest energy-consuming regions. Oil, natural gas, and coal constitute the dominant fuels in Europe's energy mix. In 2009, coal accounted for 17% of Europe's total primary energy demand, oil accounted for 35%, and gas for 25%. That year, Europe represented around 18% of the global demand for oil, some 17% of the global demand for natural gas, and 9% for coal. Nuclear made up 14% and renewables 9% of primary energy use in Europe. Overall, Europe, representing 7% of the world's population, accounted for 15% of the world's primary energy demand.

Europe is also a key supplier of energy. In 2009, it produced 2.6% of global oil output, 5.7% of global gas output, 4.6% of global coal output and 11% of global renewable energy. Still, Europe is crucially relying on energy imports to satisfy its needs. In 2009, the EU imported more than half of its energy from non-EU countries. This number has increased in recent years, rising from less than 40% of gross energy use in 1980 to 55% at present. If the present trends continue, European import dependency is likely to steeply increase in the near future, a function of policies aimed at reducing carbon-intensive fuels such as coal with comparably less carbon-heavy fuels such as gas, but also due to declining domestic production, notably in the North Sea.

European energy imports are dominated by a few producers of energy. Some two-thirds of EU-27 imports of natural gas stem from only three countries: Norway, Algeria, and Russia. Russia is also Europe's dominant supplier of crude oil, accounting for some 30% of the bloc's imports in 2008. Even in hard coal, Russia plays an important role, supplying around 24% of European imports. High European import dependency is not a concern for all fuels. The coal market is relatively small in volume, and global reserves are relatively evenly distributed. The oil market is global, liquid, integrated, and therefore unlikely to give a dominant producer much political leverage over the consumer region supplied. Gas markets, however, still remain by and large regional and bilateralized in nature. Given the predominantly pipeline-bound infrastructure in natural gas, alternative suppliers are hard to find in the short to medium term. In light of this, concerns have been expressed over some European countries' heavy reliance on gas imports from Russia, reaching up to 100% of total demand in Central and Eastern Europe, especially the Baltic States. Recent disputes over gas transit between Russia and neighboring Ukraine, and also Belarus, have added to this concern and sparked political initiatives to reduce overall European import dependency on Russia. The degree to which Russian gas actually poses a security problem is, however, disputed. Russia's share of European natural gas imports has in fact declined steadily over the last two decades, from some 75% in 1990 to 31.5% today. Current developments in unconventional gas production (see Box 5.5), coupled with the increasing global capacity in LNG, may possibly also change existing market structures and contribute to a higher integration of regional markets and more gas-to-gas competition in the European market (IGU, 2010). The planned construction of the Nord Stream gas pipeline under the Baltic Sea, connecting Russia directly to Germany and Denmark, is intended to diversify gas trade routes and reduce dependency on transit countries.

Still, policy initiatives center on reducing gas import dependency on Russia by promoting diversification strategies, including pipelines in the "southern corridor" aimed at bringing Caspian gas to European households. A key European initiative in this context is the planned Nabucco pipeline, a 31 bcm per year interconnector for Azeri and possibly Turkmen or even Iraqi gas, via Turkey. Since available gas volumes remain uncertain, the pipeline has so far not left the planning stage. Recent Azeri pledges to commit parts of the gas output generated in the Shah-Deniz II field (planned to come on stream in the next years) may constitute a breakthrough for the project.

In addition to import dependency, European energy security challenges may, however, also be of domestic origin. In particular, they may stem from Europe's commitment to pursue low-carbon energy transition. Policy packages such as the EU's 20–20–20 initiative, aimed at reducing emissions of greenhouse gases by 20% by 2020 and flanked by reaching 20% of renewable energy in total energy use, will put demand-side pressure on European energy generation and systems. Replacing coal in power generation by bridge fuels (notably natural gas) before phasing them out to the benefit of renewables will pose unprecedented challenges with regards to finance, infrastructure, and technology. Adding to this challenge is a rapidly aging infrastructure in European nuclear energy, coupled with stiff public opposition to new nuclear power plants in most European countries.

5.2.5.3 Energy Security in North America

The North American continent has been endowed with immense energy wealth. The United States is among the world's top ten producers of coal, oil, natural gas, and electricity from nuclear and hydroelectricity, while Canada is in the top ten for oil, natural gas, and electricity from nuclear and hydroelectricity production, and Mexico ranks in the top ten for oil production (IEA, 2010a). Despite this, each country has its own set of energy security problems.

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[21] Sources: BP, 2010; IEA, 2010a; Eurostat, 2011.

[22] The term "Europe" is used here to designate European OECD member countries or the European Union Member States.

Probably the most dominant and well known of these problems is that being faced by the United States and its dependence on foreign supplies of crude oil. Every US president, from Nixon to Obama, has set targets, put forward proposals, commissioned reports, and signed legislation in an effort to stem crude oil imports and improve energy security (US DOE, 2010). Today, over 60% of US demand for crude oil is met from imports (US EIA, 2010).

Support for the US transportation system is the driving force behind all energy security legislation put forward in the United States. For example, the 2007 Energy Independence and Security Act (EISA) calls for, amongst other things, reducing vehicular fuel consumption through increased CAFE (Corporate Average Fuel Economy) standards, replacing gasoline with ethanol, and requiring auto manufacturers to develop a new generation of vehicles to operate on electricity (EISA, 2007).

EISA has had unintended consequences. The push for ethanol from cornstarch means that a significant percentage of US farmland is being diverted from food into fuel production; this has had an impact on world corn supplies, indirectly affecting food security in countries such as Mexico (Roig-Franzia, 2007).

The increasing demand for electricity in general, and the inevitable reliance on mains electricity to meet the energy needs of plug-in electric vehicles in particular, will have an impact on (electrical) energy security. At present, about 50% of the electricity in the United States is produced from domestic coal, followed by natural gas and nuclear (about 20% each), hydroelectricity (5%), and a mix of renewables (2.5%) (US EIA, 2011a). Demand pressures are forcing electricity suppliers to plan for new generation capacity and, if climate change is ever addressed seriously by the US Congress, it will be necessary to develop generation facilities that emit little or no carbon. However, the supply mix is only part of the problem – the US electrical grid is showing its age and must be refurbished if it is to meet the expected future reliance on electricity. The costs of new generation facilities (whether or not the United States addresses the issue of climate change) and grid upgrades are estimated in the trillions of dollars – the price of ensuring the availability of the electrical supply.

Until the middle of the last decade, it was assumed that domestic supplies of natural gas in the United States had peaked and, like crude oil before it, would make the United States increasingly reliant on imports of natural gas. To ensure (natural gas) energy security, plans were drawn up for dozens of liquefied natural gas (LNG) facilities around the continental United States (McAleb, 2005). Today, things look considerably different – the use of horizontal drilling fracking is making shale gas available as a replacement for declining stocks of conventional natural gas (Grape, 2006). Shale gas is rich in natural gas liquids (NGLs), meaning it can also improve US energy security by offsetting imports of crude oil (Sandrea, 2010). Optimistic reserve projections have industry analysts suggesting that the United States could soon start exporting LNG (PennEnergy, 2010); this would not appear to be in the long-term energy security interests of the United States. There are also concerns over the environmental impacts associated with the extraction of shale gas (Doggett, 2010); time will tell whether it is considered an acceptable source of natural gas that will improve the energy security of the United States.

Two of the countries on which the United States depends for its energy are its nearest neighbors, Mexico and Canada; both countries are exporters of crude oil and other refined petroleum products to the United States, while Canada also exports natural gas and electricity. The United States' reliance on Mexico and Canada for its energy has politicians and analysts in all three countries talking about North American, or continental, energy security (Angevine, 2010).

North America's energy security is governed by chapter six of NAFTA, the North America Free Trade Agreement, which outlines the rules and regulations regarding the trade of energy and petrochemicals. NAFTA requires a signatory to maintain its energy exports; short of war, any reduction in exports must be met by a proportional reduction in supply within the exporting nation. Mexico is exempt from this provision; Canada is not (NAFTA, 2002).

Mexico is facing energy security challenges of its own. Its most important oil field, Cantarell (in the Gulf of Mexico), is in decline and further exploration is hampered by the Mexican constitution that restricts oil and natural gas development to the state oil company, Pemex.

Canada, unlike Mexico, has few restrictions on international players exploiting its crude oil and natural gas. Despite the availability of these resources, not all Canadians have access to them; for example, although Canada is self-sufficient in crude oil, over 60% of it is exported to the United States, meaning that Canada meets almost 50% of its crude oil needs from imports (Hughes, 2010). Canada is also self-sufficient in natural gas, yet almost 60% is exported to the United States (US EIA, 2011a). Not only is Canada exporting energy that could improve its future energy security, but also it has compounded the problem by failing to develop the pipeline infrastructure to connect parts of eastern Canada with the oil and natural gas fields in western Canada (Hughes, 2010).

Although Canada's production of conventional crude oil and natural gas has peaked, the tar sands (euphemistically referred to as the "oil" sands in the United States) are seen as essential to continental energy security. Canada's current prime minister has gone so far as to call Canada an "energy superpower" with respect to the development of unconventional energy resources such as the tar sands, shale gas, and Arctic oil and natural gas for export to the United States (Hester and Welsh, 2009).

Canada is one of the few countries with the capacity to improve its energy security with its own energy resources. Despite this, Canada's trade and energy policies have evolved to the point where much of the energy that could be used for its own energy security is, instead, contributing to the improvement of energy security in the United States.

5.2.5.4 Energy Security in Asia[23]

Asia – meant here to encompass the big four energy consumers of China, India, Japan, and South Korea, as well as the developing economies including Southeast Asia and South Asia – faces a series of daunting energy security challenges that crisscross the three themes of robustness, sovereignty, and resilience.

Growth in energy use, both in terms of per capita use and total use in aggregate, is expected to rise dramatically in the next few decades. As a whole, Asia Pacific's per capita electricity demand was only about 1300 kWh in 2005, compared to the world average of more than 2500 kWh. Under a business-as-usual scenario, between 2005 and 2030 energy demand is expected to grow at 2.4%, whereas the world average during the same period will be 1.5%. Net imports of fossil fuels in Asia Pacific are expected to more than double. The region's oil dependency will increase from 57.5% to 66.4%. The region will also need between US$7 trillion and US$9.7 trillion of cumulative investment in the energy sector during this period, of which about two-thirds will be in electricity generation, transmission, and distribution. The 10 countries that comprise the Association of Southeast Asian Nations, for example, will likely experience an annual growth rate in energy demand of 2.5% between 2010 and 2030. If that projection holds true, regional demand for energy will equal the current combined total demand of Japan, Australia, South Korea, and New Zealand. Yet, although Southeast Asia is home to 8.5% of the world population (530 million people), the region possesses about 1% each of the world's oil and coal stocks and less than 4% of total natural gas reserves.

Security of supply has thus become a key economic and political concern. In China, Beijing had to ration its gas supply to shopping malls and supermarkets in January 2010 as a result of extreme winter weather. In 2008, India walked out of the deal to build an Iran-Pakistan-India (IPI) gas pipeline – on which discussions were conducted over 13 years – over security issues and the inability of Pakistan to agree to provide penalties for supply disruptions. Japan buys nearly 90% of its oil from the Middle East, making it vulnerable to disruptions of even a few days on the Strait of Hormuz or through shipping routes from the Middle East.

Threats need not be international or external. Laborers of India's public-sector petroleum company, Oil and Natural Gas Corporation Limited (ONGC), went on a three-day strike in early 2009, shutting down the Hazira plant that processes oil and gas from offshore operations and threatening to create shortages of compressed natural gas used for public transportation in Gujarat. Large parts of China also had to confront energy shortages in 2010 due to a combination of weather and infrastructure factors: the difficulty of transporting coal in the snow, less hydropower output due to freezing temperatures, and reduced coal supplies from Shanxi province due to mine closures. In 2008, shortages of gasoline and diesel occurred in Bali, Indonesia, when oil tankers had trouble accessing the island during a series of storms, and in Kalimantan long lines formed at petrol stations due to a shortfall of 10,000 liters of gasoline. In Jakarta and Java, as well, shortages of premium gasoline and LPG occurred after a refinery had maintenance problems, and disruptions of electricity hit every Indonesian province in both 2007 and 2008.

Trade in energy is another essential challenge. Apart from Indonesia, Malaysia, Vietnam, and Brunei, all other Asian countries are currently net energy importers. This means that the promotion of trade is instrumental to building energy markets so that countries can improve access to multiple sources of energy. Without such access, buyers must negotiate directly with producing nations such as those in the Middle East. Several "energy-poor" nations are relying on trade to overcome their energy shortages. The Bangladesh Power Development Board is currently holding a road show around the world to encourage foreign investors to help them erect about 3500 MW of new power plants and a terminal for LNG. The country suffers from an acute shortage of power, especially during the hot summer months. Pakistan is also facing severe energy shortages, and searching for private foreign investment by offering incentives related to upstream and downstream hydrocarbon development.

Some countries, such as China, India, and Japan, have begun aggressively investing overseas to then export energy fuels back to their mainland. The China National Offshore Oil Corporation (CNOC), after a well-publicized yet unsuccessful takeover bid for Unocal in the United States in 2005, took over Canadian-based PetroKazakhstan in 2006, and since then has won contracts in politically volatile places such as Angola and Nigeria and strengthened ties with Sudan, Cuba, Venezuela, Iran, Sudan, Kazakhstan, and Myanmar. India's government aimed to produce 20 million barrels of equity oil and gas abroad by 2010, and the overseas arm of ONGC has already acquired properties in Vietnam, Russia, and Sudan. Japan, in its quest to produce more "Hinomaru" oil (oil developed and imported through domestic producers), has integrated its key oil companies – Inpex and Teikoku Oil – under a joint holding company, to make them more competitive against foreign oil companies.

5.2.5.5 Energy Security in Latin America and the Caribbean

The Latin America and the Caribbean region (LAC) has considerable energy resources, including oil, natural gas, biomass, and hydro energy, and is a net energy exporter, producing about 8.4% of global energy and consuming about 6.3%. Venezuela and Mexico are among the top global oil exporters, whereas Brazil is the largest ethanol exporter, accounting for half of the world's bio-ethanol exports (US EIA, 2011a). However, these resources are unequally distributed. For example, more

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[23] Sources: Asian Development Bank, 2009; IEA, 2010a; Bambawale and Sovacool, 2011.

than 90% of proven oil reserves in LAC are concentrated in three countries: Venezuela (which also holds about two-thirds of the region's natural gas reserves), Brazil, and Mexico (BP, 2009).

Moreover, utilization of these resources requires considerable investment and capacities, which can often only be mobilized at the international level. For example, significant investment will be required to develop the giant Lula (Tupi) and other "pre-salt" oil and gas fields recently discovered in Brazil or to implement the ambitious plans for expanding production of hydroelectricity where only 22% of the regional potential is currently used (SESEM-CFT, 2005). The current underinvestment in energy infrastructure is sometimes explained by legal and political uncertainty and insecurity, including changing the rules and nationalization of energy assets in several countries (Iranzo and Carrasco, 2008).

The region is also diverse with respect to capacities of individual countries, some of which are both too small and poor to address their energy challenges. For example, Nicaragua, one of the Heavily Indebted Poor Countries, is dependent on imported oil for almost 40% of its primary energy supply, including electricity generation (IEA, 2010b). Ecuador, another low-income country, relies on oil exports for almost half of its total export earnings and one-third of all tax revenues. Despite its large oil production, Ecuador must still import refined petroleum products due to a lack of sufficient domestic refining capacity. As a result, the country cannot always benefit from high oil prices, which increase its export revenues but also increase its refined product import bill (US EIA, 2009). Almost all of the electricity in Paraguay relies on one hydroelectric plant (Itaipu).

Energy infrastructure in politically unstable LAC countries is often the target of sabotage. Only in 2001, 170 attacks were registered on one of the most important oil pipelines in Colombia, Cano Limón (CEPAL, 2007). The TransAndino pipeline connecting Colombia and Ecuador has also occasionally been the target of rebel forces in Colombia, and an attack in March 2008 shut the system down for several days. Similarly, another oil pipeline in Ecuador, Sistema Oleducto Trans-Ecuatoriano (SOTE), has suffered from natural disasters that severely disrupted Ecuador's oil production. In March 2008, landslides damaged SOTE, shutting operations for several days. In 1987, an earthquake destroyed a large section of SOTE, reducing Ecuador's oil production for that year by over 50% (US EIA, 2009).

In LAC, regional integration is often viewed as a means to both redistribute uneven resources and to pool forces for infrastructure development and needed investment. Several energy integration organizations were created in LAC as long ago as the 1960s and 1970s:

- OLADE (Latin America Energy Organization), formed in 1973 by 26 LAC countries as an umbrella organization promoting the political, institutional, and technical integration of energy systems as well as energy efficiency;
- ARPEL (Latin America and Caribbean Regional Association of Oil and Natural Gas Companies), created in 1976 by 27 public and private companies and organizations that account for 90% of total upstream and downstream operations in the region; and
- CIER (Commission for Regional Electricity Integration), created in 1964 and including all South American countries except Surinam and Guyana.

Energy security has received high-level political attention in the last decade. In the Caracas Declaration (made in 2005), energy ministries of South America agreed to seek energy integration and cooperation. In April 2007, the first Presidential Energy Summit in South America resulted in a common energy strategy known as the "Margarita Declaration" (CEPAL, 2007), which advocates for a stronger role of the state in energy issues and promotion of renewables, especially biofuels. In November 2008, the Energy Ministers of OLADE member countries issued the Buenos Aires Declaration, which stated that energy security (defined as "safe and reliable energy resources availability") is a priority of the region (OLADE, 2007a; 2007b).

Another regional energy integration effort is Venezuela-backed Petroamérica, which provides a framework of cooperation initiatives in the areas of oil and gas supply and infrastructure (PDVSA, 2009). Petroamérica is divided into sub-regional frameworks: Petrocaribe, Petroandina, and Petrosur.

Petrocaribe includes 14 Caribbean countries, as well as Venezuela and Surinam. Within Petrocaribe, Venezuela directly sells oil and products to these countries under favorable financing conditions (CEPAL, 2007; US EIA, 2008; PDVSA, 2009). In 2007, 10 Petrocaribe members signed an energy security agreement that promotes the expansion of refinery capacity, ethanol production, and LNG infrastructure, as well as energy efficiency measures (PDVSA, 2009). Many of the Caribbean countries import oil from Mexico and Venezuela under favorable terms. Under the San Jose Pact, Barbados, the Dominican Republic, Haiti, and Jamaica receive oil and refined products from those two countries.

Petroandia includes Bolivia, Colombia, Ecuador, Peru, and Venezuela. It is an alliance of state oil and energy organizations to promote electric and gas interconnection, mutual energy supply, and joint investments (PDVSA, 2009). As part of Petroandia, Venezuela operates joint ventures in oil exploration, production, and capacity with Bolivia and Ecuador (PDVSA, 2009). Petrosur is made up by Brazil, Argentina, Uruguay, and Venezuela. Activities within Petrosur include the construction of joint Venezuelan-Uruguayan and Venezuelan-Brazilian refineries and the creation of Petrosuramérica, a joint Venezuelan-Argentinean company (Comesaña, 2008).

One area of regional energy integration is jointly constructed infrastructure for transporting natural gas. An agreement on joint construction of "the southern gas pipeline" for transporting natural gas from Venezuela to Brazil and Argentina was signed in 2005. However, a later discovery of large oil and gas reserves in Brazil decreased that country's interest in the project. The needed investment (around US$25 billion) could not be secured, and the project was shelved in 2009 (Hidrocarburosbolivia.com, 2009). A more recent project, called the "Energy Ring," would connect three gas exporters (Ecuador, Bolivia, and Peru) to four (potential) importers (Brazil, Chile, Argentina, and Uruguay). However, the project was stopped due to the withdrawal of Bolivia and political differences between Chile and Peru. Instead, such countries as Chile have chosen to expand their LNG infrastructure to increase the diversity of gas import energy and routes.

There are also efforts to integrate electricity infrastructure such as a large integration initiative, the "Mesoamerican Integration and Development Project" (Proyecto Mesoamérica, 2009). The Electrical Interconnection System for Central America (SIEPAC), a 1,800 km power line that links six countries (Panama, Costa Rica, Honduras, Nicaragua, El Salvador, and Guatemala), was almost completed at the time of writing and a Regional Electrical Market was being put in place. This infrastructure is complemented by the existing electrical interconnection between Guatemala and Mexico, and a project to interconnect Panama and Colombia (IADB, 2010).

5.2.6 Summary: Energy Security in the World

This section explores energy security conditions in the world with respect to vulnerabilities of primary energy sources at the national and, where appropriate, global level, security of national electricity systems, and vulnerabilities of vital end-use sectors: transport, residential and commercial, industrial, and energy export revenues.

The results of the analysis of energy sources are summarized in Table 5.6. It shows that all primary energy sources have vulnerabilities from the robustness, sovereignty, and resilience perspectives. Globally, oil stands out as the most vulnerable in all three aspects among the internationally traded fuels, although natural gas may develop equally strong vulnerabilities in the near future. Rising demand plays as strong a role as supply limitations. Although the vulnerabilities of nuclear and hydro energy are not directly comparable to those of fossil fuels, they still affect hundreds of millions of people in dozens of countries.

Many countries using nuclear power experience aging of the reactor fleet and workforce as well as difficulties in accessing capital and technologies to renew, expand, or launch new nuclear programs. Of the 31 countries with nuclear power programs, 20 have not started constructing a new reactor in the last 20 years, and 19 countries have nuclear power plants with an average age of over 25 years. Large-scale enrichment, reactor manufacturing, and reprocessing technologies and capacities are currently concentrated in just a few countries. The transfer of these technologies and capacities to a larger number of countries is constrained by serious concerns over nuclear weapons, which is one of the main controversies and risks associated with nuclear energy.

Hydroelectric power production, especially from major dams located on internationally shared rivers, is often perceived as insecure, particularly in light of climate change affecting seasonal water availability. Over 700 million people live in 31 countries that derive a significant proportion of their electricity from just one or two major dams, and are thus vulnerable to failures of these dams.

The analysis also identifies vulnerabilities of national electricity systems. First of all, electricity systems inherit the vulnerabilities of energy sources used for electricity generation described above. For example, power plants relying on imported fossil fuels currently provide over 50% of electricity in some 39 countries with 600 million people. Some 450 million people in 35 countries primarily rely on just one source of energy for generating electricity, which is a concern from the resilience perspective.

In addition, electricity systems in developed countries often bear risks associated with aging power plants (especially pronounced in the case of nuclear reactors, which have not been renewed in most industrialized countries in the last 25 years) and other infrastructure. In developing and emerging economies, electricity systems are under strong demand-side pressures. The majority of the world population – some 4.2 billion people – lives in 53 countries that will need to massively expand the capacity of their electricity systems in the near future because they either have less than 60% access to electricity or demand growth averaging 6% or more over the last decade. Both fuels and infrastructure for such an expansion will need to be provided without further compromising the sovereignty or resilience of national electricity systems.

Finally, reliability of electricity supply is a serious concern, especially in developing countries. In almost three-quarters of low-income countries blackouts are on average for more than 24 hours per month, and in about one-sixth of low-income countries blackouts average over 144 hours (six days) a month. In over one-half of low-income countries blackouts occur at least 10 times a month.

With respect to nationally vital end-use energy services, transport is globally the most vulnerable. The absolute majority of countries rely on oil products for most of their transport energy and, as we have seen, in most of the world this oil has to be imported. Around 4.9 billion people live in 93 countries that import more than one-half of their transport energy requirements. This supply-side vulnerability is made worse by demand-side pressures: in some 17 developing countries with 1.7 billion people, transport energy use was growing faster than 8% annually from 1998 to 2007.

The energy sector also provides vital export revenues to some 15–20 countries. In the majority of these oil- and gas-exporting countries the revenues are not expected to last for more than one generation, and in several cases they may cease in less than a decade. In addition, poor energy-exporting nations are at a high risk of the resource curse: economic and political instability eventually affects human development and security.

If rapidly growing demand for energy and high risk of resource curse are considered vulnerabilities of energy systems, there will be very few, if any, countries in the world that do not experience significant energy security challenges. The next section considers how national governments and international institutions attempt to deal with such challenges.

5.3 Energy Security Actors and Institutions

The key to understanding energy security is not only in the quantitative analysis of energy systems, but also in examining perspectives and strategies of energy security actors, primarily nation-states. These perspectives and strategies shape energy security risks by posing or dissuading real and perceived threats and by determining responses to likely disruptions. The energy security perspectives and strategies reflect the objective conditions but are also influenced and limited by cognitive and political factors that shape the views of policymakers and by capacities to enact these views. In response to perceived energy security threats, nations initiate energy security strategies, as we describe in this section. We also discuss the interaction of national strategies at the international level through both conflict and cooperation, including within various international institutions.

5.3.1 National Perspectives and Strategies

National energy security strategies exist in an increasing number of countries and focus on minimizing the risks for the energy end-uses (transport, residential and commercial energy, industry or energy export revenues) most vital for a given country. Some strategies are rooted in specific energy security perspectives – robustness, sovereignty, or resilience – whereas other strategies present more generic responses to multiple threats (see Figure 5.1). This section first discusses the historically earlier and more prominent strategies and then reviews robustness and resilience strategies.

5.3.1.1 Sovereignty Strategies

The essence of sovereignty strategies is increasing control over energy systems vis-à-vis "foreign" or "external" agents. Such threats are often perceived as more imminent and more easily catching public attention. They have also historically been at the center of energy security concerns.

In many cases, sovereignty-driven strategies focus on attaining or increasing control over existing energy resources. One example is the so-called "resource nationalism" of energy exporters that has recently attracted significant attention following the re-nationalization of the energy sector in Venezuela in 2003; another example is the transfer of several major oil and gas projects from international oil companies (IOCs) to state companies in Russia in the last decade. Resource nationalism and the resulting dominance of national oil companies (NOCs) (see Table 5.8) is not exactly a new phenomenon (see Box 5.11). It is not uncommon for the states to seek sovereign control over technology and infrastructure, as well as natural resources. For example, there was significant resistance in the UK against Russian Gazprom acquiring Centrica, a gas distribution company, in 2006–2008, while the US blocked the attempt of the China National Offshore Oil Corporation (CNOOC) to buy a US oil company, Unocal, in 2005.

Resource nationalism is not only typical in energy-exporting countries. Most notably the emerging major importers, such as India and China, are supporting their NOCs in acquiring energy assets around the world. Even OECD countries such as Japan and Korea have shown a renewed interest in the idea of securing supply through a state-owned corporation. A plethora of existing bilateral energy deals, long-term contracts, and joint projects reflect the increasing interests of nation-states to enhance their influence over energy resources, if not to full control, then at least to management through a "trusted partner."

As a result of this trend towards state actors in the global energy market, NOCs have come to dominate the scene, as shown in Table 5.8. In fact, only two of the world's top 15 energy companies in terms of reserves are private, while only one is headquartered in an OECD country.

In fact, and contrary to widespread perception, the trend towards a greater role of NOCs in global energy does not fundamentally affect supply, although it increases the market power of certain states. A strong role of NOCs in global energy does not necessarily imply "less market." Producer NOCs supply the same global market as their private counterparts, while major consumer NOCs tend to sell significant volumes of their equity oil on global markets rather than shipping it back home (IEA, 2007).

Similarly to oil, and with the exception of North America, state companies also dominate the supply of natural gas. In Eurasia, these are, among others, Russia's Gazprom, Algeria's Sonatrach, Norway's Statoil and Azerbaijan's State Oil Company of Azerbaijan Republic (SOCAR).[24] State-owned companies also tend to dominate the downstream gas market in Asia (with Malaysia's Petronas, China's China National Petroleum Company [CNPC], and India's GAIL being prominent examples). At the same time, most European downstream markets have been privatized. Due to restricted access of gas producers to attractive European downstream markets, private retail companies – such as Germany's EoN

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[24] Where IOCs are admitted to exploration and production endeavors (as in the case of the Azerbaijan International Operating Company [AIOC] developing Azeri gas), state companies are at least party to all of the international consortia developing new gas projects.

Table 5.8 | Oil reserves of top 15 companies.

Rank	Company	Type	Proven reserves (bbl)	Percentage of world total (%)
1	Saudi Aramco	NOC	264.3	21.9
2	National Iranian Oil Co.	NOC	137.5	11.4
3	Iraq National Oil Co.	NOC	115.0	9.5
4	Kuwait Petroleum Corp.	NOC	101.5	8.4
5	Abu Dhabi National Oil Co.	NOC	92.2	7.6
6	Petróleos de Venezuala S.A.	NOC	80.0	6.6
7	National Oil Corp of Libya	NOC	41.5	3.4
8	Nigerian National Petroleum Corp.	NOC	36.2	3.0
9	Lukoil (Russian G8 Presidency)	IOC	16.1	1.3
10	Qatar Petroleum	NOC	15.2	1.3
11	Gazprom	NOC	13.8	1.1
12	Pemex (Mexico)	NOC	12.9	1.1
13	Petrobras (Brazil)	NOC	12.2	1.0
14	China National Petroleum Corp.	NOC	11.5	1.0
15	Chevron (USA)	IOC	8.0	0.7
	Total, top 15		957.9	79.3

Source: BP, 2007; Klare, 2008.

Ruhrgas, Spain's Gas Natural, or France's GDF Suez[25] – enjoy a generally powerful position vis-à-vis producers.

Other examples of moves to secure control over resources include an increasing number of deals that involve China, India, Russia, the United States, and other countries to secure access to uranium deposits in Mongolia, Kazakhstan, and other Central Asian countries (Pistilli, 2009).

It should also be noted that asserting full or partial control over fossil fuel resources is not an option for the majority of countries that both lack such resources domestically and do not have economic, political, or military power to project their influence internationally. Their primary sovereignty strategies are to increase their reliance on domestic resources. Among resources available to a majority of countries – and thus playing an increasingly important role in national energy security strategies – are renewables (hydro, wind, solar, and modern biomass) as well as, to a lesser extent, peat and coal. One of the most celebrated examples of increasing energy security by switching to indigenous fuels is the Brazilian ethanol program, which resulted in the replacement of a large share of imported oil as a transport fuel by domestically produced ethanol. Developing renewable energy resources is seen not only as addressing more pressing and immediate concerns with the volatilities and uncertainties of global fossil fuel markets, but also a more systemic and long-term pressure of the perceived scarcity of fossil fuels and in order to reduce climate impacts of energy systems.

Launching or expanding national nuclear energy programs may also be viewed as a sovereignty strategy. Although few states can build and manage a nuclear power plant and the related nuclear fuel cycle on their own, they typically feel that there are fewer uncertainties beyond their control once the facility is up and running. Nuclear power can also be considered a diversification strategy for states relying on fossil fuels. For example, several Gulf States are import-independent but excessively relying on oil and gas for their electricity generation (Jewell, 2010). Another example is Belarus, whose electricity sector almost entirely depends on imported Russian natural gas. Belarus' planned nuclear power plant will be manufactured from Russian parts and most likely use Russian fuel and expertise, thus not reducing the country's dependency on its neighbor. However, it will provide the much-needed diversity in terms of related technologies, markets, and institutions so that disruptions of natural gas supply will not necessarily be devastating for the country's electricity sector.

5.3.1.2 Robustness and Resilience Strategies

Robustness strategies focus on minimizing predictable and manageable risks within energy systems. For example, many industrialized countries have extensive standards concerning the reliability of electricity transmission and generation (European Parliament, 2006; North American Electric Reliability Corporation, 2010). Robustness strategies may also be focused on constraining demand. For example, following the oil crisis of the early 1970s, Japan, the United States, and eight Western European countries (including energy-exporting Norway) reduced their energy intensity by 30–34% (Geller et al., 2006). In its current energy strategy, Russia aims to reduce the energy intensity of its economy by 40% by 2020, as compared to 2007 (Ministry of Energy of the Russian Federation, 2010). However, no single country in modern times has been able to deliberately reduce or even stabilize its overall energy use over a long term, though demand could be reduced temporarily in response to short-term disruptions (Meier, 2005).

Resilience of an energy system is its ability to provide critical energy services in the face of disruptions. The concept of resilience has recently been brought into the public energy security debate, in particular in the United States, where an influential public figure commented in 2008:

> Our aim should not be total independence from foreign sources of petroleum. That is neither practical nor necessary in a world of interdependent economies. Instead, the objective should be developing a sufficient degree of resilience against disruptions in imports. Think of resilience as the ability to absorb a significant disruption, bigger than what could be managed by drawing down the strategic oil reserve (Grove, 2008).

Enhancing the ability to cope with short-term disruptions that do not alter the fundamental character of energy systems is often more prominent in national energy security strategies. For example, emergency fuel stocks, which are currently maintained by all developed and many

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[25] The French government holds a 37.5% stake in GDF Suez.

developing countries, address the risks of unexpected short-term interruptions of oil supply or price volatility. Some European countries now have emergency storage of natural gas, which serves the same purpose and proved instrumental in dealing with the shutdown of Russian gas deliveries to Europe in 2006 and 2009. Russia is exploring constructing its own gas storage facilities to deal with potential interruptions of delivery, be it for economic, political, or technical reasons.

Another resilience strategy is increasing diversity. Diversity can ensure that an energy system is able to adjust to more systemic disruptions. It is important to distinguish between various types of "diversity" that can relate to individual elements or aspects of energy systems.

Many energy security strategies contain elements of diversification. These range from increasing the number of import/export routes, origins, or destinations, to increasing the number of actors in the energy sector or the number and types of energy facilities and primary energy sources. Some of the diversity strategies only address relatively limited threats. For example, diversification of import and export routes does not address global price volatility or resource scarcity. In order to deal with more systemic and long-term risks to energy security, more profound diversity strategies are needed. For example, many energy-exporting states are aware of their long-term vulnerability to price fluctuations, eventual resource depletion, and the resource curse. Some of them, most notably the Gulf States and Russia, proclaim strategic focus on diversification of their economies away from reliance on energy exports.

Diversity can also be fostered by certain types of institutions. Although the key rationale for introducing energy markets is economic efficiency, markets may also foster diversity. The existence of the global oil market, where the ability of any single actor to significantly disrupt the supply is limited, is an example of enhancing security through diversity. Naturally, markets (and international trade in general) may also have negative effects on resilience and sovereignty, as further discussed below.

5.3.1.3 Limitations of National Strategies

The majority of countries in the world pursues or at least declares energy security strategies that have both resilience and sovereignty dimensions. These strategies, however, have generally not been effective, which is best evidenced by the presentation of the dire situation of energy security in the world. The reasons for this ineffectiveness are manifold. First of all, the strategies may be internally inconsistent or otherwise poorly designed.

It has proven to be very difficult to strategically reconcile various aspects of energy security. Some measures to boost short-term energy security have had negative impacts in the long term. Certain resilience strategies have adversely affected sovereignty, and vice versa. For example, liberalized markets may have increased the diversity of supply options but lead to increased price volatility and reduce the (real or perceived) control of critical resources by the government.

Similarly, some sovereignty strategies negatively affect resilience. Asserting control may increase confidence but also increase the objectively measured risks and vulnerabilities. For example, nationalization of oil and gas sectors has in some cases resulted in decreased government income from energy revenues due to increasing inefficiencies.[26] Squeezing foreign companies out of energy projects has also resulted in underinvestment and thus the deterioration of infrastructure, as national governments have not possesed the necessary capital, technology, and know-how.

The next reason for the mixed record of national sovereignty strategies lies in the fact that energy policies become too entangled with economic interests, foreign policy, and even conventional security imperatives. Foreign bids by Sinopec, PetroChina, and the CNOOC, for instance, tend to be accompanied by Chinese state aid projects; Gazprom's efforts to make the Ukraine pay "market prices" serves both Gazprom's economic and Russian state foreign policy interests. In addition, NOCs do not necessarily rely on financial markets when financing their exploration and production endeavors, and also enjoy a compelling lender of last resort: the state. Such "political" components of the NOCs' operation almost by definition compromise their energy security performance. What is worse, there is a dangerous trend of viewing energy security policies as an extension of conventional security policies, which leads to the discourse of geopolitics considered in more detail in the next section.

The other line of NOCs' evolution is perhaps more promising, even though it goes against the hope of asserting their parent states' control over energy resources. Observers note that maturing NOCs behave more and more like private companies, especially when operating in global or international markets. This is because they are subject to the same market rules and pressures. In particular, and ironically, some NOCs are affected by the same "resource nationalism" of host countries that resulted in their emergence in the first place. The case in point is Petrobras, a Brazilian semi-public NOC, having its assets nationalized in Bolivia. As any globally operating company, NOCs seek a stable and transparent regulatory environment, a level playing field, and well-protected property rights.[27]

The final reason for the lack of success may lie in the fundamental limitations to conceive and implement an energy security strategy by a single nation-state acting alone. It is quite obvious that small economies are rarely, if ever, able to implement energy system transformations on their own, since they simply do not possess the necessary financial,

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[26] A case in point here is Venezuela's PDVSA, which has experienced a strong downward trend both in output and overall efficiency after Chavez's re-nationalization of the energy sector in 2003.

[27] That is why Russian Gazprom is, for example, domestically championing corporate social responsibility and other "good business" causes and the CNOC is reportedly considering joining the Extractive Industries Transparency Initiative (EITI).

technological, and human resources. For example, a study shows that launching a national nuclear power program relying on their own resources may be out of reach for at least 28 of the 52 countries that expressed an interest in nuclear energy based on their energy security imperatives (Jewell, 2011).

Even larger countries face serious limitations in ensuring their own energy security. This is not only due to lack of capacity, but also to the natural reflexivity of energy security. If states start acting alone or in closed groups, other states may perceive their actions as threats to their own energy security. In no time, energy security becomes a "zero-sum game" dominated by "geopolitical" and other discourses drawn from the vocabulary of diplomacy and military security. We turn to such developments in the next section.

5.3.2 Energy, Geopolitics, and Confrontation: the Specter of Energy Wars

A comprehensive understanding of energy security includes perceptions and perspectives of nation-states alongside "objective" indicators. A peculiar aspect of such perceptions is reflexivity: their ability to dynamically influence each other. If the position or actions of a country are perceived as a "threat" to energy security, other countries may start responding in such a way that is also perceived as threatening, causing another round of threatening responses, etc. The situation may escalate into a zero-sum game, with the energy security of certain nations only being achieved at the expense of other nations. Eventually, such developments may result in a lack of much-needed confidence, disrupted cooperation, increased tensions, or even conflicts over energy resources or infrastructure.

The risk of conflicts over energy resources is a significant concern on the global security agenda. The extreme form of such confrontation is a much-feared "resource war" – an inter-state armed conflict aimed to secure access to energy resources. In 1980, the US President Jimmy Carter proclaimed that the United States would use military force in the Persian Gulf region to defend its national interests, specifically "the free movement of Middle Eastern oil" (Carter, 1980). The fear of resource wars has considerably grown in recent years, particularly prompted by the rise of the "new consumers" of globally tradable energy resources (India and China), concerns over inadequate capacity to meet the increasing demand for oil, rising oil prices, and a series of high-profile disputes involving Russian gas supply to Europe. An influential geopolitical school of thought (e.g., Klare, 2008) points to numerous factors increasing the risk of such a confrontation in the near future.

Other researchers (Jaffe et al., 2008) note that there have been very few – if any – resource wars in the recent past[28] (save the Iraq-Kuwait war of 1990) and downplay the risks of such conflicts in the future. The arguments about the future probability of oil conflicts are difficult to resolve. On the one hand, the risk of resource wars significantly depends upon non-energy factors such as the capacity of international and bilateral regimes and institutions; on the other hand, the configuration of global oil production, trade, and use are undoubtedly major factors determining such risks. Moreover, there are several forms of confrontations involving energy resources that are only marginally less worrisome than resource wars.

First, energy resources, particularly oil, have played an important role (sometimes as a weapon) in past inter-state confrontations, including armed conflicts. The "tanker war" linked to the Iran-Iraq conflict, the Arab oil embargo related to the Arab-Israeli war, and other modern examples are listed in Table 5.9. It may be argued that the presence of oil (or many other natural resources, for that matter) have made some armed conflicts more prolonged or destructive.

Second, energy resources and infrastructure have shaped inter-state relations, prompting either collaboration or confrontation or, more commonly, a mixture of both. The most prominent examples include:

- the dispute over borders in the potentially oil- and gas-rich Arctic (but also possible collaboration over the exploration of oil and gas in the Arctic); similar disputes have also been documented in other regions;[29]
- debates over gas and oil pipeline routes in Eurasia (such as the Nord Stream gas pipeline bringing Russian gas to Western Europe and the Baku-Tbilisi-Ceyhan (TBC) pipeline transporting Caspian oil to the Mediterranean); these were closely linked to several heated disputes over gas and oil supplies between Russia and former Soviet states in Eastern Europe (Belarus and Ukraine), as well as in the Caucasus;
- military and development support from major oil importers (notably the United States and China) to some oil-producing and transit countries in Africa (e.g., Sudan and Nigeria), the Gulf Region (e.g., Saudi Arabia), the Caucasus (Georgia and Azerbaijan), and Central Asia (e.g., Kazakhstan); which is often linked to:
- the struggle for influence in the remaining few oil-producing regions among major oil importers (the United States, Western Europe, China, and Japan).

Third, increasingly strained supplies of energy resources justify the growing deployment of military overseas to "protect" oil infrastructure (for example, terminals, tanker routes, etc.) against real and perceived threats and disruptions. The recent creation of the US Navy command

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[28] On the other hand, historically more wars can be linked to some resource issues. The very devastating Paraguay-Argentinean war (1932–1935) for Gran Chaco was for presumed oil reserves in that area (that never materialized). Many aspects of World War II (e.g., Japanese occupation of the Dutch East Indies or the German-Soviet battle over the Caucasus) also had an oil sub-text.

[29] The Spratly Islands are claimed by China, Taiwan, and Vietnam; parts of them are claimed by Malaysia, the Philippines, and Brunei (Klare, 2008). The Falkland Islands (Malvinas) are claimed by the United Kingdom and Argentina (Luft, 2010).

Table 5.9 | Major inter-state conflicts and tensions related to oil and gas systems (since the end of World War II).

Year	Resource/system in question	Security event or measure
1950	US and other oil exports to China	The Western bloc's Coordinating Committee for Multilateral Export Controls placed China under an oil embargo during the Korean War of 1950.
1956	Saudi oil reserves/production	Saudi oil embargo against France and the United Kingdom following the Suez crisis
1967	Middle Eastern oil embargo	Imposed by Arab nations on the USA, the UK or in relation to all oil exports after the beginning of the Six-Day War.
1973–1974	Oil production/reserves of Arab oil exporting countries	OPEC and Arab oil embargo, generating the first "oil price shock"
1979	Oil exports of Iran	Iranian revolution
1980	Crude oil exports of Iran/Iraq	"Tanker War" between Iraq and Iran
1981	Algerian gas supply	"Gas Battle" between Algeria, Italy, the United States and others
1990–1991	Kuwait oil reserves	Iraq invasion of Kuwait eventually repelled by the United States and allies
2003	Russian crude oil delivery/pipeline infrastructure	Cut-off in Russian oil supplies to Latvia
2003	Iraq and Middle East oil reserves	US invasion of Iraq
2005	Pricing mechanism of Russian gas	Gas dispute/cut-off in Russian gas supplies to Georgia
2006	Pricing mechanism of Russian gas	Cut-off in Russian gas supplies to Ukraine and Moldova
2006	Russian crude oil delivery/pipeline infrastructure	Cut-off in Russian oil supplies to Lithuania
2007	Pricing mechanism of Russian oil deliveries to Ukraine	Russian interruption of the Druzhba oil pipeline
2009	Pricing mechanism of Russian gas	Cut-off in gas supplies to Western Europe, causing side unclear (Ukraine or Russia)

for Africa (AFRICOM) and Russia's plans to increase its military presence in the Baltic to protect the Nord Stream gas pipeline (as well as the Swedish response of increasing its own forces in the Baltic) are quoted as some examples. US national security and oil imports, as well as the implications of various energy issues for the US Navy, have been the subject of two recent RAND reports (see Box 5.9).

Not only do energy resources (particularly oil and gas) shape inter-state relations, but they may also affect internal security issues, especially in poorer countries that face nation-building challenges. Current inter-ethnic conflicts in Iraq – largely related to oil – are most prominent, but energy resources shape and color internal tensions in many other countries. Civil wars in Angola, Colombia, the Republic of Congo, Indonesia (Aceh), Morocco, and Sudan, as well as a simmering conflict in the Niger Delta in Nigeria (see Box 5.10), have also been linked to oil. Whether the political challenges of allocating revenues from oil and gas production will lead to instability and conflict depends on the quality of governance and institutions as well as key international actors.

Finally, there have been concerns about the connection between energy resources and international terrorism, particularly the argument that oil revenues help to fund terrorist activities. However, very few, if any, facts have been found to support this assertion except circumstantial evidence that certain terrorist organizations and individuals come from the Arab-speaking countries which also happen to have significant oil reserves. On the contrary, many researchers point out that terrorism is a "low-cost activity" that does not depend on oil revenues. Moreover, the emergence of contemporary terrorist networks (such as al-Qaeda) occurred in the mid-1990s when oil revenues were at their lowest. On the other hand, the resource curse – i.e., economic and political problems in many poor oil-exporting countries, described earlier – has contributed to dissatisfaction and disenfranchisement of individuals and social groups that eventually support or engage in terrorist activities.[30]

Box 5.9 | Energy and US Defense Costs

Due to heavy dependency of the United States on imported oil, access to foreign oil remains a top priority driving the country's strategy and defense policy. US military forces have been present in the Persian Gulf since the 1970s to protect access to Middle Eastern oil. US efforts to ensure secure access to foreign oil also include, since the 1990s, deepened ties (economic, political, and military) with oil-producing states in Central Asia, South America, and West Africa.

The presence of US military forces to maintain the security of international oil flows for the global market undoubtedly incurs substantial costs. However, to date, there has been no comprehensive, accurate, publicly available US government study of the costs. Nevertheless, several attempts have been made to quantify them. In general, the analyses addressed the costs incurred by US Central Command (USCENTCOM)[31] in its mission to protect the maritime transit of oil supplies in the Persian Gulf and Indian Ocean, as well as to assist in

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[30] This hypothesis explains why terrorism often emerges during low rather than high oil prices when the level of popular dissatisfaction may be highest in those economies that primarily rely on oil revenues for their welfare programs.

[31] USCENTCOM is a military force created in 1979 to be available for worldwide contingencies. However, its focus quickly tilted heavily toward the Persian Gulf region.

the defense of United States-friendly oil-producing governments. Estimates in these studies have varied from as low as US_{2005}\$12 billion up to as high as US_{2005}\$130 billion of military spending per year, representing, respectively, 2.5% and 27% of the defense budget in 2006. This range in estimates reflects the complexity of how US forces are planned and operated and, thus, the difficulty of being very specific in allocating precise costs to this mission.

Recently, two RAND research teams estimated the incremental costs that the US government would likely avoid if it were to entirely drop the mission of ensuring the secure production and transit of oil from the Persian Gulf for the global market. Estimates of potential annual savings amounted to between US$67.5 billion and US$83 billion – respectively, 12% and 15% of the US defense budget. However, these estimates do not claim to be precise. Moreover, RAND's analysis does not argue that a partial reduction of the US dependency on imported oil would automatically lead to a proportional reduction in US spending that is focused on this mission (Crane et al., 2009). Another RAND study predicts that the defense budget is likely to decrease due to future increased social spending for the United States' growing numbers of elderly citizens, which, in turn, will likely affect the incremental amount available for protecting oil supply and transit (Gordon et al., 2008).

Two other academic assessments produce similarly startling figures. Researchers at the Oak Ridge National Laboratory in the United States estimated that from 1970 to 2004 American dependency on foreign supplies of oil has cost the country US$5.6–14.6 trillion in macroeconomic shocks and unnecessary transfers of wealth.[32] When the numbers are adjusted to 2007 dollars, the amount is greater than the costs of all wars fought by the country going back to the Revolutionary War, including both invasions of Iraq. Researchers from the University of California-Davis and University of Alaska-Anchorage calculated that US defense expenditures exclusively to protect oil in the Persian Gulf amount to about US_{2005}\$28 billion to US_{2005}\$75 billion per year (Delucchi and Murphy, 2008).

Box 5.10 | Resource Wealth, Civil Conflict and Disruption of Oil Supplied in Nigeria

The complex interplay between resource wealth, political and inter-ethnic conflict, and its impact on production facilities, infrastructure, and output is evident in the case of political conflict in the energy-rich Niger Delta. Nigeria is one of the world's top 10 oil exporters and produced around 3% of the world's total output in 2006 (BP, 2007). Yet traditional tension between different ethnic groups in the Niger Delta, one of the most densely populated areas in the world, turned into violent conflict as oil revenue started to pour into the country. The behavior of large oil corporations and poor capacities of the local government is largely regarded as having contributed to raising the degree of violence and to prolonging conflict. Violence has become a major cause of slowing production and causing interruptions in Nigerian crude deliveries. Attacking installations, kidnapping oil corporations' personnel, and siphoning off crude from pipelines have become common features. In 2006, militant attacks on oil facilities resulted in a shutdown of almost 500,000 barrels per day, or 20% of Nigeria's oil output. In addition, oil tankers have been stolen, with the crude being sold on foreign markets (Vesely, 2004).

5.3.3 Energy Alliances, Institutions, and Markets

Despite the rhetoric of geopolitics, the zero-sum game, and the resource wars, the actual international interaction in the field of energy security has so far been largely dominated not by conflict but by cooperation, albeit imperfect. This section examines the existing cooperation mechanisms as well as their successes and shortcomings.

At the moment there is no overarching global energy institution, but rather a plethora of alliances, multi- and bilateral deals, and arrangements. The most significant international energy alliances unite major exporters and importers of energy (primarily oil). First and foremost, these include OPEC, established in 1960 in Baghdad, with the aim of regulating global oil production. OPEC seeks to influence oil prices by adjusting production levels through the use of a quota system. At present, OPEC member states control around 80% of global oil reserves and almost half of global production. Gas-producing countries established the Gas Exporting Countries Forum (GECF) in 2001, which remains a rather loose gas club that might – depending on the development of the take-or-pay-dominated market – potentially become a future gas cartel similar to OPEC.

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[32] Source: Greene and Ahmad, 2005. Numbers have been adjusted to US_{2007}\$.

The International Energy Agency (IEA) is a watchdog for energy-importing members of the OECD. It has developed rules concerning strategic petroleum reserves and a supply shock emergency response mechanism. The IEA can draw on the International Energy Program (IEP, established in 1974) for larger supply interruptions, and on the coordinated emergency response mechanism (CERM), which applies for smaller emergencies.

Another type of energy alliance is formed on the basis of regional proximity. One example is the EU, whose prototype, the European Community for Coal and Steel, was created to govern access to coal resources, the then-dominant energy source. The EU aims to operate a single energy market. For that purpose, it fosters an integrated energy infrastructure (such as in electricity and natural gas) and liberalized cross-border trade of energy services governed by common rules and policy agenda. The EU has also sought to develop a common energy policy towards third parties, encompassing energy security and other energy-related goals as well as environmental and climate-related topics. Vis-à-vis main producers, the EU has initiated steps towards linking up with neighboring regions via energy partnerships within the realm of various agreements, including the Partnership and Cooperation Agreement with Russia, or via efforts targeting the Maghreb/Mashrek region. Project proposals also exist for the large scale import of renewably generated electricity from northern Africa (Komendantova et al., 2009).

Another regional club is the Shanghai Cooperation Organization (SCO) uniting Russia, Central Asian countries (all net energy exporters), and China (an energy importer). Whether the energy role of the SCO will extend beyond declarations is so far not clear. Regional "clubs" with energy agendas also exist in other regions. For example, in West Africa, common arrangements feature the West African Power Pool, West Africa Gas Pipeline projects, and the West Africa Regional Energy Access initiative, all designed to reduce energy insecurity in the region. Similar arrangements are being tried with the East African Power Pool and the Southern Africa Power Pool.

Some energy alliances have also been established based on nations' economic, rather than regional, characteristics. For example, the historically prominent G7, created in the aftermath of the first oil shock in 1973, gathered the largest economies of that time (Germany, Italy, Japan, the United Kingdom, the United States, France, and Canada) to coordinate its members' energy-related and macroeconomic policies. The G7 did not noticeably address energy issues during the almost two-decade-long low-price period on the oil market from the early 1980s to the early 2000s. It was joined by Russia in 2004, becoming the G8, and has recently sought to include other large economies including major consumers and producers of energy (China, India, Brazil, South Africa, and Mexico) to become the G20. However, the G8 and G20's energy activities so far have been limited to declarations rather than to establishing permanent effective institutions.

The relationships between various different alliances are sometimes portrayed as competition or confrontation.[33] In our view, a more accurate description would be that of "non-engagement." As already noted, there are very few global energy rules or institutions extending beyond specific alliances. The International Energy Forum (IEF), an organization that seeks to unite energy exporters and importers, has not yet resulted in any tangible institutions or arrangements. Perhaps the only widely applicable organizing principle is that of a free market for certain energy products, most importantly oil.

Establishing a global oil market was facilitated by the advances in transportation and communication technologies, as well as the end of the Cold War. As a result, many security concerns of the 1970s and the earlier era have subsided. The producer countries are no longer at the mercy of international oil corporations dictating their conditions (see also Box 5.11 on IOCs and NOCs). The consumer countries can seamlessly switch and mix suppliers and not worry about excessive dependency on a single supplier. The global oil trade system can assimilate minor shocks of disruptions in particular countries or regions.

However, the free market has its limitations. For example, it does not function well under conditions of imperfect information or monopoly, which often arise naturally in the case of grid based carriers (compare to Chapter 22). Also the global oil market has increasingly developed some of these features. Information about reserves and production capacities has been severely impeded by an explicit non-reporting policy of OPEC and other exporters. Moreover, due to the increasing geographic concentration of oil reserves and the lack of suitable substitutes, the global supply develops the characteristics of a monopoly. In addition, as discussed above in relation to national energy security, markets tend to under-provide such public goods as sufficient investment in production capacity and infrastructure.

This last feature has been empirically observed in the case of global oil markets. A prime example includes the current global shift from a "strategically planned," vertically integrated approach in the energy industry, practiced even in private companies, towards decision-making based on immediate economic objectives such as return on capital. This shift, partially encouraged by the financial investment community and seen especially in the low oil price environment of the 1990s, led to a decrease in spare capacity in production, storage, and transportation, thus increasing the effects of even small disruptions. Markets in their current shape tend not to reward players for maintaining spare capacity and do not have adequate mechanisms for charging for capacity on a pay-as-you-go basis, which tends to enhance booms and busts. Price hikes effectively allow some of those market players who did invest for extraordinary circumstances to obtain a return on their investments, albeit in a one-off fashion, as opposed to a constant stream of income.

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[33] For example, the SCO is sometimes considered a "geopolitical bloc" aimed at undermining the US presence in Central Asia. In the eyes of some pundits, such new geopolitical constellations will be increasingly framed by energy issues and will compete with each other (e.g., the SCO competing with the United States and Japan in the Western Pacific). See, among others, Klare, 2008.

To buffer these shortcomings, institutional arrangements need to be strengthened to provide for a greater degree of information, notably data collection and exchange. Here, the IEA's data-generating activities (though notoriously criticized on analytical fronts and short on information on producing countries) and institutions of producer-consumer cooperation such as the IEF in Riyadh become essential. The IEF's Joint Oil Data Initiative (JODI) is a particularly promising step.

Finally, there are vocal concerns that market arrangements might crumble in the face of rapidly unfolding scarcity or another severe energy security crisis. According to Klare (2008):

> Oil will cease to be primarily a trade commodity, to be bought and sold on the international market, becoming instead the preeminent strategic resource on the planet, whose acquisition, production, and distribution will increasingly absorb the time, effort, and focus of senior government and military officials.

While it is difficult to judge the validity of such concerns, history definitely provides many examples of when market arrangements were either heavily modified or entirely replaced by other rules in times of severe crisis. This leads many observers to believe that markets should not be viewed as the only or the most effective mechanism for providing energy security.

To summarize this brief overview of the most notable international institutions, the world governance of energy security has been ineffective for the following two reasons:

First, there has been little success in creating institutions that would serve and include key actors and stakeholders. There is no effective organization that would unite exporters and importers of energy. Some of the largest consumers, China and India, are not part of the "importers club," the IEA. The majority of countries are simply "too small" to qualify for various memberships, although their energy security concerns are no less significant than those of larger countries.

Second, the existing energy security institutions largely focus on oil and partially on naturally gas. This is understandable from the point of view of the present concerns, where these resources are at the front and center of energy security. However, this also shapes the expertise and the frame of reference of the existing institutions and largely predetermines their inability to govern seriously systemic energy transitions involving various supply, infrastructure, and demand elements.

Third, the international arena governing energy security should be more strongly connected to the international arenas governing climate change and supporting the provision of access to modern energy. These three arenas have historically developed in isolation from each other, but it is no longer possible for them to operate independently in the world where energy challenges are increasingly entangled (Cherp et al., 2011).

Potential pathways for the future evolution of global energy security institutions are touched upon in Section 5.3.

Box 5.11 | IOCs, NOCs and the Global Oil Market

The origins of the current global oil market date back to the 1930s. At that point, the industry became dominated by a small number of transnational corporations, controlling most of the sales of oil products. Most oil-rich nations lacked the domestic capacity to develop their reserves and were thus dependent on these large, integrated oil companies, also since the latter controlled the downstream assets in the main Western markets. The notions of the "Seven Sisters" or "Big Oil" still reflect the unprecedented power of the Western-dominated international oil companies (IOCs) in that era.[34] US policies supporting the "one base" or "Gulf plus freight" formula (later revised to the "two base" oil pricing formula) helped maintain a single price for all oil consumers outside the United States and secured enormous rents for this cartel. Until the 1960s, the United States was a major producer and a net exporter of oil. Thereafter, the decline of US mainland production, coinciding with the process of decolonialization and a growth in nationalism in producing countries shifted the balance of (market) power to the countries actually owning the resources. OPEC, initially established to enable producing countries to enhance their share in oil revenues vis-à-vis the dominating Western IOCs, is a result of this process, and profoundly changed the global oil market by introducing production quotas, a tool to influence oil prices. In response to OPEC's cartelization efforts in the 1970s, industrialized countries established the IEA, a consumers' club intended to strengthen the market power of importing nations; in addition, they pushed for energy efficiency improvements and the development of advanced offshore production techniques in the 1970s and the 1980s, leading to the opening up of new hydrocarbon provinces. As a result, the global oil market became more liquid and highly integrated, reducing the power of OPEC to set prices. OPEC defended the high price level established in 1980 by cutting production

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[34] The "Seven Sisters" consisted of Exxon (or Esso, Humble, Standard of NJ), Royal Dutch Shell, BP (originally British Petroleum, Burmah Oil + Anglo-Iranian), Gulf, Texaco, Mobil (Standard of NY or Socony-Vacuum), and Chevron (Standard of California).

every year until 1986, the long-term trends of world oil demand and non-OPEC supply eventually resulting in longer prices. However, in the new millennium, due to economic globalization and a steep rise in demand from "emerging consumers" (e.g., India and China), the pendulum has again swung back. In addition, financial market actors and mechanisms have entered the global oil market, which is now characterized by a variety of hedging instruments, swap and future contracts.

As this brief historical survey suggests, IOCs – i.e., private players – dominated the oil market for a long time. Historically, many of them (BP and the predecessors of Total, ENI) were fully or majority-owned by Western governments, and even private companies enjoyed a high level of support from their home states. In that respect, their role was somewhat comparable to the national oil companies (NOCs) from emerging importing nations such as India and China: a secure energy supply for their home nations abroad. With a more integrated global oil market, these companies have become fully fledged profit-driven enterprises. IOCs see their core competence in the ability to mobilize the large amounts of capital, equipment, and manpower required to develop and manage large projects; to use their technical expertise and know-how to reach even increasingly difficult reserves; and to live with price and resource market uncertainties and to manage political risks even in "frontier" environments through large investment portfolios. IOCs usually received a share in the upstream (equity oil) of the projects in which they were involved. More recently, and particularly against the backdrop of rising resource nationalism and market pressure to reduce costs, a second set of private players including integrated service providers (ISPs) such as Halliburton and Schlumberger have entered the scene. These companies bring in their specialized expertise and act as contractors to both IOCs and NOCs. In contrast to IOCs, they usually do not engage in exploration and production projects with their own capital.

5.4 The Future of Energy Security

This section considers possible future developments in energy security. It discusses the implications of projected or likely demographic, economic, natural resource, technological, and institutional developments. It also lays the foundation for a quantitative analysis of energy security under sustainable energy transition pathways modeled in GEA. This analysis is presented in Chapter 17.

5.4.1 Technology and Resource Developments

The role of oil on the global energy security scene will likely become even more important in the short- to medium-term future. Oil production will probably become more geographically concentrated, and demand for oil will continue to increase, primarily in Asia. Several present-day exporters (for example, the United Kingdom and Argentina) will likely become importers, and many countries will need to import more in both absolute and relative terms. The *World Energy Outlook 2010* (IEA, 2010a) predicts that both supply and demand of oil will become less responsive to prices, which will likely lead to long-term price increases for this fuel. At one point in the future, perhaps as soon as in one or two decades, the global production of conventional oil will likely "peak" or "plateau."

Many concerns have been expressed in connection with this imminent "peak oil." Some predictions paint a collapse of organized oil markets with catastrophic economic, and possibly political and military, consequences (Korowicz, 2010). It seems more likely that peak oil will have many more localized effects on those countries (mostly in the developing world) that lack the capacity to cope with steep increases in energy prices. Whether the international community will be able to mitigate the shock for these and other countries depends not only on other technological and resource developments but also upon the presence, focus, and effectiveness of global energy governance institutions in the future.

The production of natural gas is also likely to become more concentrated, but it is unlikely to peak in the nearest decades. The main developments affecting the situation with natural gas will most likely be advances in transportation technologies and infrastructure. A much more extended network of gas pipelines is likely to emerge in Eurasia, linking Russian and Central Asian producers not only to Europe but also to China and the rest of Asia. The development of LNG infrastructure will lead to the sharp increase in intercontinental trade. Growing LNG trade, while contributing to the emergence of a truly global natural gas market, may imply similar supply security patterns as the global oil market, including an increasing dependency on less reliable producer countries, transportation choke-points, and global supply-demand balances. Technological developments affecting the accessibility of shale and other unconventional gas may also alter the global gas market landscape, although the exact extent of this much-heralded "shale gas revolution" are difficult to predict.

A likely consequence of the dynamics of global oil and natural gas production will be a shift away from these energy sources, which is already vigorously pursued by many countries. It is unlikely that a new globally dominant source of energy, such as oil, will be found. Instead, there will be a shift to diverse sources, appropriate to national and regional contexts. One such source may be coal, especially if technologically and economically acceptable ways of low-carbon utilization of coal are found.

Nuclear energy will clearly be another alternative to fossil fuels considered by many countries. While the global scale of future nuclear expansion is not clear, it is likely that nuclear energy will be able to address energy security challenges only in a relatively limited number of countries. At the moment, the lion's share of the world's nuclear capacity is concentrated in the United States, whereas almost all short-term growth occurs in China, other Asian economies, France, and Russia. For most of the other countries with existing nuclear energy programs, such programs may become a liability rather than a solution to their energy security challenges.

There are over 50 "newcomer countries" that are interested in launching nuclear energy programs for the first time, by and large, to meet their energy security needs. According to Jewell (2011), safe deployment of nuclear power is likely in only 10 such countries under present conditions. Others will need very significant international help, including possibly forming energy partnerships among themselves, or dramatically altered nuclear energy markets and policies (see Figure 5.7).

Finally, oil, natural gas, coal, and nuclear power may be partially displaced by renewable energy sources. One such source is biomass. If the future biofuels or biomass systems assume production and transportation patterns similar to that of present-day fossil fuels (i.e., concentrated production regions away from consuming regions and large centralized refineries), they may also become subject to similar risks and vulnerabilities. Furthermore, the availability of biomass feedstocks may be disrupted by climate change as well as policies guided by conflicting uses (e.g., food production or ecosystems preservation). Given the emerging state of the present-day biofuels systems, the scale of these risks is difficult to estimate.

Replacing with other renewables (such as wind and solar) will require technological innovation and creation of new infrastructure, including (as penetrations rise significantly) new systems for the storage and distribution of energy and for possible new propulsion systems for vehicles (e.g., electricity or hydrogen). There are possibilities that the storage requirements associated with large-scale electricity system transitions towards distributed renewable resources may be offset by synergies between parallel emerging smart management procedures for distributed energy storage in electric vehicles. Relatively simple co-ordination systems enabling the remote control of certain consumer products also offer an important resource in cost-effective management of intermittency and other electricity security challenges. Specific technologies for carbon capture at centralized fossil fuel plants may also present opportunities for improving capacity to manage intermittency. These developments introduce a potentially significant level of effective aggregate electricity system storage capacity as a side effect. However, the task of

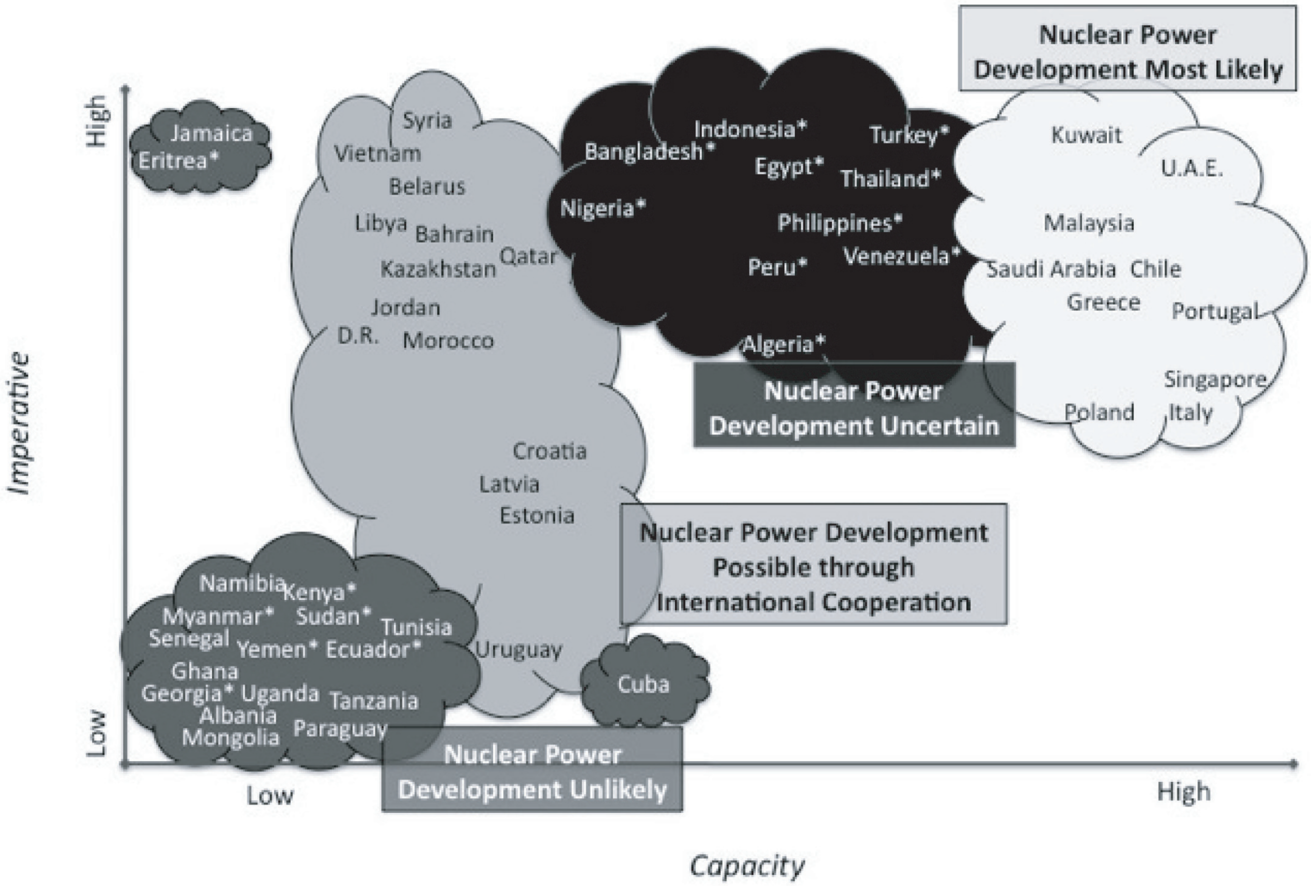

Figure 5.7 | Feasibility and uncertainty of nuclear power adoption by new countries. Source: Jewell, 2011.

Table 5.10 | Factors in future energy scenarios related to national energy security strategies and international institutions.

Focus of national strategies International institutions	Sovereignty	Robustness and Resilience
Less effective	Fragile markets and geopolitics; national state-driven transitions to centralized solutions	Self-organizing markets; decentralized and diverse transitions
More effective	Strong rules and powerful alliances; regulated markets	More uniform transitions at several levels

realizing the positive synergies of these technological innovations raises many challenges for associated infrastructural, organizational, contractual, and regulatory innovation. Wind, solar, and hydro energy are more likely to be produced domestically and thus not invoke traditional sovereignty concerns. However, there are also plans (such as Desertec) to generate solar energy for intercontinental trade.

Another imminent development affecting energy security in the future is the increasing role of electricity in energy systems. Electricity will play a more important role due to the likely advent of plug-in electric propulsion vehicles and the continuing spread of ICTs and other consumer technologies requiring electricity, as well as to the increasing use of electricity by the rising middle class in emerging economies.

An increasing reliance on electricity will mean that reliability of its production and distribution is likely to come to the forefront of energy security concerns in the future. The complexity of future electricity systems is likely to increase to incorporate:

- technologies for storage of electricity;
- "smart grids" including "active load" devices;
- "super grids" for transferring large quantities of electricity over long distances with minimal losses (e.g., through high-voltage direct current lines) when localized distributed systems are not feasible or sufficient; and
- hybrid systems,[35] to increase reliability of power generation and distributed generation such as modular small-scale systems with improved or increased energy storage capacity.

Some of these approaches may reduce the risk of "cascading failures" inherent in modern complex centralized grids. It is possible that other approaches to increasing reliability will evolve as a result of a combination of electric and information technologies. As the role of electricity in energy systems increases, the factors affecting energy security will have increasingly more to do with institutional structures and capacities than with more traditional issues of access to natural resources.

5.4.2 Institutional Uncertainties in Future Energy Security

Energy security perspectives and strategies are both a key driving force of and a central strategic uncertainty in future energy transformations. Security has been a main driver of past technological and political transformations, and it is also a prominent consideration in most, if not all, of the global long-term scenarios. It is not certain which of the perspectives on energy security will prevail in national energy agendas and discourses. Another, separate uncertainty is whether new international energy institutions will emerge and be able to function effectively (see Table 5.10).

If the resilience and robustness perspectives gain more prominence at the national level, countries are likely to promote diverse energy solutions. The focus of national policies may become decentralized and distributed energy generation, improvement of electricity grids, and demand-side measures such as energy efficiency. Regulated but generally liberalized markets may become more common national energy arrangements. Many such measures will also improve sovereignty – i.e., reduce import dependency – although nations driven by these two perspectives may remain open to international trade and investments.

An additional uncertainty in this case may arise at the international level. If effective international energy institutions are created, they will be able to help countries with technology transfer, ensuring investments and well-functioning markets to enhance energy resilience. These global energy institutions may be able to oversee new patterns of intensive international energy trade (e.g., in electricity, hydrogen, or biofuels). This will be a more favorable scenario.

It will be more difficult for most countries to pursue resilience and robustness strategies in the absence of effective international institutions. The pace of transformation to diverse and more robust energy systems may be significantly slowed down, especially in smaller and poorer economies. More disparity in energy security may emerge as a result. In fact, the absence of functioning international institutions may push many countries towards the sovereignty perspective.

If the sovereignty perspective in national energy security policies prevails, countries may view international trade, foreign capital, and even domestic private actors with a degree of suspicion. Energy solutions are likely to be less diverse, more centralized, and relying on state support (e.g., nuclear power, or coal with carbon capture and storage). If international energy institutions continue to be weak, the global energy markets may start failing, especially in the case of increasingly scarce "strategic"

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[35] For example, hybrid systems using wind or solar photovoltaics to provide emergency back-up to conventionally distributed electricity.

commodities such as oil and natural gas. Geopolitics may become the rule of the day, with stronger and larger countries gaining better "access" to scarce resources. This may, in turn, push national governments towards surprisingly rapid transformations of energy systems. There is naturally no guarantee that such transformations will always be safe or successful.

Finally, one can imagine strong international institutions in the world where most countries pursue sovereignty strategies. The role of such institutions will be more limited than in the resilience scenario, but they will still be able to set the rules of the game (such as market institutions) to prevent geopolitical manipulations from exploding into open confrontation. Regionally or ideologically based "energy clubs" based on "mutual trust" may also become increasingly prominent.

5.4.3 Energy Security under Sustainable Energy Transitions

The GEA argues that energy systems can support such global goals as poverty reduction and the stability of Earth's climate only if they are radically and rapidly transformed. Chapter 17 (Energy Pathways for Sustainable Development) defines multiple pathways for such sustainable energy transitions.

The question is: what are the energy security implications of these pathways? Due to the radical transformations of energy systems, the energy security concerns identified in this chapter cannot be simply projected into the future. While some of these concerns may disappear or become irrelevant, new vulnerabilities may emerge. For example, oil, an energy source that is at the heart and center of most energy security concerns today, may be phased out and replaced by other fuels. But will using these new fuels on the global scale result in similar energy security concerns? Will they be produced in just a few countries and regions that will set terms for the global market? Will they dominate end-use sectors and lack easily available substitutes so that any disruption may be catastrophic? Will poorer countries and regions spend a significant portion of their revenues to procure these new fuels?

This section summarizes generic energy security considerations that form the basis of assessing energy security under sustainable energy transitions. We presume that, although energy security concerns might change in the future, the perspectives on energy security will remain the same. This means that nations will still be concerned about the robustness (i.e., the protection from certain known risks), the sovereignty (i.e., the protection from actions by external actors), and the resilience (i.e., the ability to withstand various disruptions, both known and unknown) of their energy systems.

Applying these three perspectives to energy sources, carriers, end-use services, and regions[36] of the future will answer the following questions:

- With respect to *energy sources*: what will be the energy sources of the future? Will any of them dominate the global energy supply to the same degree that oil, gas, and coal dominate the present-day energy landscape? Will they be based on non-renewable and hence limited resources or utilize renewable energy? Which of these sources will be traded on the global scale? Will their global trade be equally as intensive as it is currently for oil? Will their production be concentrated in only a few regions or be more evenly spread around the world?

- With respect to *energy carriers* and *end-use sectors*: will they be based on diverse energy sources or dominated by one fuel, like the transport sector today? Will they primarily rely on imported or domestic energy sources? Will they experience very rapid and destabilizing growth or decline during any periods of the transition?

- With respect to *countries and regions*: will any of them be significantly dependent on imported energy? Will any of them rely on just a small number of energy sources? Will energy intensity and hence vulnerability to changing energy prices increase or decline?

The above questions are answered in Chapter 17 with the help of a quantitative projection of selected energy security indicators. The overall conclusion of this analysis is that in most pathways of the GEA Scenario, energy systems become more secure from all perspectives and in most of the regions. At the same time, certain vulnerabilities may emerge in particular regions or globally, and these need to be taken into account and mitigated while managing sustainable energy transitions.

5.5 Conclusions

Adequate protection from disruptions of vital energy systems – "energy security" – is one of the most politically prominent energy-related concerns. Disruptions of energy systems may result from both short-term shocks, such as natural events, technical failures, malfunctioning markets, or deliberate sabotage, and slowly unfolding but more permanent threats, such as resource scarcity, aging of infrastructure, and unsustainable demand growth. Such disruptions may affect broader security issues ranging from the viability of national economies and stability of political systems to the danger of armed conflicts. This means that policies developed in the quest for higher energy security have been, and are likely to remain, a key driving force in the transformations of energy systems.

Although energy security concerns differ from one country to another, they typically relate to the robustness, sovereignty, and resilience of energy systems. Robustness means minimizing risks arising from well-defined natural, technical, and economic factors. It is associated with sufficient energy resources, reliable infrastructure, energy efficiency, and managed demand. Sovereignty means the protection from disruptions to energy systems by external agents. Reliance on domestic

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[36] The GEA model cannot forecast energy developments in individual nations, and the analysis is, therefore, concentrated on the regional level. The caveats of such an analysis of energy security are explained in the relevant section of Chapter 17.

resources and technologies, stable prices, control over infrastructure, and trusted institutions are typically associated with sovereignty. Resilience means the ability of energy systems to withstand diverse and uncertain threats. Resilience is linked to diversity of supply and infrastructure options, redundancies and spare capacities, and institutions capable of adequately adjusting to disruptions, as well as flexibility in demand.

This chapter examines robustness, sovereignty, and resilience concerns with respect to energy sources, electricity systems, and the primary enduses of energy in over 130 countries. Its main conclusion is that significant energy security concerns from at least one of these perspectives affect the absolute majority of countries and are likely to become more serious in the short- to medium-term if the present trends are allowed to continue. Whereas the primary energy security concern of most industrialized countries is import dependency and aging infrastructure, many emerging economies have additional vulnerabilities such as insufficient capacity, high energy intensity, and rapid demand growth. In many low-income countries supply and demand vulnerabilities overlap, making them especially insecure.

Most globally prominent energy security concerns relate to the oil sector. Oil is a significant source of energy in almost every nation, whereas the majority of countries must import most or even all of the oil and petroleum products they need. Over three billion people live in 83 countries that import more than 75% of the oil and petroleum products they consume. This number does not yet include China, with its 1.3 billion people, where oil consumption has been rising on average by 7% per year over the last decade, and the current oil import dependency of 53% is projected to reach 84% by 2035 (IEA, 2010a). Virtually all of the world's low-income countries import over 80% of their oil supplies. Those that do not have another type of dependency: on oil export revenues to sustain their economies.

Furthermore, the recent rise in the global demand for oil has not been matched by an increase in the supply capacity, which – together with concerns over eventual scarcity – has made markets more volatile. A longer-term issue, the much-discussed "peak oil" – a rapid forced decline in production and consumption – also cannot be dismissed, although it is likely to be initially experienced as painful disruptions of vital energy services in low-income countries rather than as a global energy crisis. Peak oil is covered in more detail in Chapter 7 (Energy Resources and Potentials).

Oil is the main, but not the only, energy source causing widespread energy security concerns. Natural gas accounts for over 10% of primary energy supply in 78 countries with a combined population of some 2.9 billion people. Among those, almost 650 million people live in 32 Eurasian countries that import over 75% of their gas needs. In addition, 12 countries with some 780 million people have a domestic reserves/consumption ratio of natural gas under 16 years and are thus likely to experience significant import dependency in the future.

For many countries, coal is a potential solution to the energy sovereignty problem, since its resources are more abundant and more evenly geographically distributed. Only a small number of countries (12) currently significantly depend on coal imports, and this number is not likely to significantly increase in the near future. However, the use of coal may be subject to environmental and health constraints, as discussed in other parts of this publication.

These vulnerabilities of energy sources affect the security of national electricity systems. For example, almost 600 million people live in 39 countries where over 50% of electricity production is based on imported fossil fuels. In many developing and transition countries these sovereignty concerns are aggravated by low robustness and resilience: inadequate generation capacity, as well as low diversity of electricity generation options. For example, in 35 countries with a population of 450 million people, the absolute majority of electricity production comes from just one or two major power plants. In addition, both developing and industrialized countries suffer from disruptions of electricity systems due to natural and technical failures exacerbated by increasing complexity, poor maintenance, aging infrastructure, and insufficient investment.

In addition to fossil fuels, many countries rely on nuclear power for significant parts of their electricity supply. The sovereignty aspects of nuclear power are access to enrichment, reactor manufacturing, and reprocessing technologies and capacities, which are currently concentrated in just a few countries. For example, large-scale uranium enrichment plants exist in only six countries, and commercial reprocessing facilities in only five. One of the main problems with currently operating nuclear power programs is the aging of reactors and workforce. There are 21 countries with 1.3 billion people with existing nuclear power programs that have not started constructing a new reactor in the last 20 years, and 19 countries (1.4 billion people) have nuclear power plants with an average age of over 25 years. The nuclear power programs in these countries would need to be either "re-launched" or phased out. Access to capital and technology will be critically important for nuclear power expansion and renewal.

An additional 52 countries have expressed their intention to start nuclear power programs for the first time. However, only about one-quarter of them are likely to be able to securely deploy nuclear power with their own resources. In the remaining "newcomers," access to capital and creating necessary institutional arrangements for secure deployment of nuclear power will present serious challenges. For the same reasons, nuclear power will remain beyond the reach of the majority of less-developed countries.

Another significant source of electricity supply in many countries is hydropower. In many regions of the world, notably in Southern Europe, Africa, and South Asia, its long-term security may be affected by shifting patterns of water availability due to climate change. Many existing hydroelectric plants are located on internationally shared rivers, with divergent water use interests of the riparian states in some cases threatening the secure supply of hydroelectricity. Finally, over 700 million people live in 31 countries that derive a significant proportion of their electricity from just one or two major dams and thus are vulnerable to a variety of natural and technical factors affecting these dams.

Reliability of electricity systems is a source of concern for both industrialized and developing countries. The economies of the former are increasingly sensitive to even minor disruptions of electricity supply, so even relatively short blackouts (typically not exceeding a few hours per year) translate into major economic costs. The scale and frequency of blackouts in most developing countries is at least one to two orders of magnitude higher. Companies in the majority of low-income countries experience 10 or more blackouts averaging 24 hours or more every month, and in some cases the number of blackouts exceeds 100 a month and their total duration approaches 100 hours.

In addition to these supply-side vulnerabilities, electricity systems in developing countries are also under strong demand-side pressures. The majority of the world's population – some 4.2 billion people – live in 53 countries that will need to massively expand the capacity of their electricity systems in the near future because they either have less than 60% access to electricity or average annual demand growth of over 6% over the last decade. Both fuels and infrastructure for such an expansion will need to be provided without further compromising the sovereignty or resilience of national electricity systems.

Insecurities of energy sources and electricity systems affect vulnerabilities of vital energy services: transport, industry, the residential and commercial sector, and providing energy for export.

Insecurities of oil supply affect first and foremost the transport sector, where petroleum products provide at least 90% of energy in the majority of countries. Almost five billion people live in countries that import over 50% of fuels for their transport sector. The situation could get especially serious in 17 countries (with 1.7 billion people) where transport energy use has grown on average more than 8% per year over the last decade.

In the industrial sector, 46 countries with some 800 million people, and in the residential and commercial sector, 39 countries with some 500 million people rely on imported fuels for over 50% of energy use. This does not include 25 countries with some 700 million people that use traditional biomass for over 80% of their residential energy use.

Some 15–20 national economies significantly rely on revenues from energy (primarily oil) exports. In the majority of these oil-exporting countries the revenues are not expected to last for more than one generation, and in several cases they are likely to cease in less than a decade. In addition, poor energy-exporting nations are at a high risk of the resource curse: economic and political instability eventually affecting human development and security.

National energy security strategies throughout the world seek to address those of the above-listed issues that are most prominent in a particular national context. Such strategies generally seek to increase the robustness, sovereignty, or resilience of national energy systems. With respect to robustness, the main strategies are to switch to more abundant and affordable energy sources, stimulate investments in infrastructure, and manage energy demand. With respect to resilience, many states maintain emergency stocks of critical fuels and seek to increase reliability of energy infrastructure by securing necessary investment. Energy exporters seek to achieve resilience by establishing Sovereign Welfare Funds and promoting diversification of their economies. One generic resilience strategy is to increase the diversity of various elements in energy systems: import or export transportation routes, production options and facilities, primary energy sources, or actors on the energy market.

In addition, most nation-states pursue sovereignty strategies that range from switching to domestic energy resources and entering long-term contractual arrangements with trusted partners to nationalizing energy-related assets ("resource nationalism"), establishing nationally controlled energy companies to secure energy resources abroad, and in some cases projecting economic, political, or military power to secure access to energy resources. Domestically, sovereignty strategies may mean increasing state control over the supply and use of energy.

Many nation-states lack the capacity to implement coherent and effective energy security strategies. One reason is that they often focus on shorter-term issues and solutions such as potential disruptions of supply, especially by "hostile" actions of "foreign" actors. Thus, politically it is often challenging to strike the right balance between short-term sovereignty and longer-term resilience strategies. Moreover, energy security strategies need to be reconciled with broader foreign policy and economic strategies that do not necessarily favor the most secure energy solutions. Finally, many countries simply lack financial and other resources to implement the required energy security measures.

Resource nationalism and some other sovereignty strategies may be beneficial when they mobilize additional resources and capacities to energy systems but may turn self-defeating in the international context, where the pursuit of energy security may become a zero-sum game, where states seek to achieve their own energy security at the expense of each other. Thus, in some situations concerns over energy security – especially in relation to oil and to a lesser extent natural gas – translate into broader geopolitical concerns. Although all-out "resource wars" are highly unlikely in the foreseeable future, the "energy security factor" already plays a significant role in US defense outlooks and may increase the tensions between states and make existing confrontations more protracted.

However, the present international interaction in the field of energy is largely dominated by cooperation rather than conflict. Unfortunately, the plethora of existing energy institutions and alliances have not always been successful in reducing national energy security concerns. This may be largely due to their narrow focus (on a particular energy sector, region, or a group of countries) not reflecting the systemic nature of the energy security risks and their connection with other energy issues such as access and climate change.

The future of energy security will be affected by a variety of technological, economic, and natural factors. It is likely that the production of conventional oil will reach its maximum in the next few decades, whereas the resources of both oil and natural gas may become more geographically concentrated as the center of consumption will shift towards Asia, especially China and India. New nuclear energy programs – despite their large costs – may be able to alleviate energy security concerns in some of the larger and more prosperous economies. At the same time, the inevitable phasing-out of some of the existing nuclear programs will result in new energy security issues. Many countries are likely to expand energy supply from domestic resources such as coal and renewables (including biofuels). The prominence of energy security concerns related to electricity will undoubtedly increase. Whereas the overall demand for energy, and especially for electricity, will grow dramatically, especially in developing countries, there may also be significant gains in energy efficiency, reducing this demand to more manageable levels.

The energy security landscape of the future will depend critically on both the direction of national strategies and the nature of international energy institutions. In the scenario where national strategies focus on sovereignty concerns and international institutions are weak, one can expect centralized but not internationally integrated energy infrastructure and fragile markets subordinated by resource nationalism and geopolitics. In the opposite scenario, when the national strategies focus on resilience under strong international institutions, it may be possible to support transitions to more secure energy systems even in those countries that lack the capacity to do it on their own.

Under sustainable energy transitions modeled in the GEA Scenario in Chapter 17, the energy security landscape will change so significantly that many of the current energy security threats may disappear and new ones may emerge. To assess energy security in the future, it is important to know how diverse and geographically concentrated the future global energy supply will be, what the diversity of fuels used in key end-use sectors will be, and whether some regions will continue to be seriously dependent on imported energy sources.

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